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Société franco-japonaise d'Océanographie, Tokyo

日仏海洋学会創設 60 周年記念
第 18 回日仏海洋学シンポジウムに寄せて

日仏海洋学会会長
小松輝久

日仏海洋学会（Société franco-japonaise d'Océanographie）は，海洋学や水産学の分野で活動している日本とフランスの科学者や団体の学術交流を促進することを目的として，1960 年 4 月に東京のお茶の水にあった日仏会館で創立されました。この日仏海洋学会創立の背景として，当時の最新鋭の深海探査のための有人潜水艇（バチスカーフ）FNRS III 号の来日と，その調査による科学的成果があげられます。FNRS III の来日は，東京水産大学教授故佐々木忠義博士を中心とする研究者らの熱心かつ周到な準備と日本政府，関連学会，日本学術会議，朝日新聞社の協力・後援およびフランスの協力により，1958 年に実現しました。FNRS III は，日本海溝およびその周辺において日本人とフランス人の研究者を乗せて潜水調査を行い，深海に関する多くの科学的成果を得ました。フランスの先進的技術により得られた科学的成果を受けて，佐々木忠義博士の呼びかけで，日本とフランスの海洋学と水産学の分野における学術交流を促進するために，本学会が創立されました。初代会長の佐々木博士に宛てて，当時のパリ大学理学部教授でフランス学士院会員のルイ・ファージュ博士や，当時のモナコ海洋博物館長のジャック＝イヴ・クストー氏などから本学会の創立に賛意が寄せられています。その 2 年後の 1962 年には新しいバチスカーフのアルシメード号が来日し，日仏海洋学会会員を乗せて日本海溝周辺で潜降を行い，初代会長の佐々木博士は千島海溝で 9,545 m深の海底に達しました。

1963 年には学会機関誌「うみ」の発行を始めました。欧文名は「La mer」で，現在は年 4 回発行しています。2023 年で第 61 巻を数えます。例年 6 月に学術研究発表会と総会を開催しています。日仏海洋学会の会員は現在約 130 人です。1966 年には学会賞を，2002 年には論文賞を設けました。

1960 年中頃にフランスでカキの病気による大量斃死が起こり，カキ養殖業が危機に陥りました。この病気に強い日本のマガキの稚貝をフランスに送って欲しいという要請がフランス人研究者から本会会員の東北大学教授故今井丈夫博士に寄せられました。今井博士が中心となり，マガキのシングルシード稚貝を送る準備と検疫を行い，1960 年代末から 70 年代初めにかけてフランスにこれらの三陸産マガキ稚貝を輸出しました。その結果，フランスのカキ養殖は，元通りの生産量を回復し，現在に至っています。この三陸産マガキ稚貝の輸出を契機として，日本とフランスの間のカキ養殖業者と研究者の強い絆が生まれました。

1984 年に，当時のフランス国立高等研究院教授ユベール=ジャン・セッカルディ博士の呼びかけで，フランスにも日仏海洋学会（日本の日仏海洋学会と区別するため仏日海洋学会と記す場合がある）が設立されました。日本とフランスの両日仏海洋学会は，共同して 1983 年以来，ほぼ 2 年から 3 年に 1 回，日本とフランスで交互に「日仏海洋学シンポジウム」を開催しています。

2011 年 3 月 11 日の東日本大震災の津波により三陸沿岸のカキ養殖施設は壊滅しました。その直後に，フランスのカキ養殖業者や仏日海洋学会か

らカキ養殖の復興を手伝うために, 本会を通じて, あるいは直接, 三陸の漁業者に多くの機材が送られました。このように, 海洋学だけでなくカキ養殖という水産分野においても日仏間の草の根交流は深化しています。

日仏海洋学会は2020年に学会創立60周年を迎えました。その記念事業として, 2020年に第18回日仏海洋学シンポジウムを, 学会創立60周年記念シンポジウムとして開催することを企画しました。しかし, 2019年に始まったCOVID-19の蔓延により, このシンポジウムは, 順延となりました。対面での開催できない状況が続く中, それに対処するためのWebを用いた会議システムの設置が各機関で行われ, Webでの開催が可能となってきました。そこで, 第18回日仏海洋学シンポジウムを, Webにより, 2021年10月18日から2021年10月23日の期間に開催しました。

第18回日仏海洋学シンポジウムは, 次に述べる考えをもとに, テーマを決め, 組織しました。2012年にブラジルのリオデジャネイロで開催された国連地球サミットは, 持続可能な開発への国連のコミットメントを新たにし, 私たちの地球と現在および将来の世代のために, 経済的, 社会的, 環境的に持続可能な未来の促進を確保することを目的としていました。このサミットの宣言は, "Future we want"と題されています。海は, 気候を支配する決定的な要素であり, 人類が生活する地球を支配しています。人類社会は, 海洋環境と生態系から多くの財とサービスを得てきました。2012年に国連地球サミットの宣言がなされましたが, 温室効果ガスの排出による海水温の上昇, 陸上・沿岸・海洋活動による富栄養化, 破壊的漁業, 海洋生物多様性の減少など, 人間活動は依然として海洋に影響を与え, 今なお海洋生態系を脅かしています。

このようなことから, 陸と海の接点である海岸を含む海について理解を深め, 海や生態系に及ぼす人為的・自然的な影響を測定し, 地球システムの不可逆的な変化への対策を講じる必要があります。自然科学, 技術科学だけでなく, 人文科学, 社会科学も含めた総合的な海の理解を得ることで, 将来の海の状態を健全に保つためのより良いアイディアが生まれるはずです。そこで, 日仏海洋学会創立60周年記念事業として, 第18回日仏海洋シンポジウム「Oceanography for future we want: transformation of our society for sustainable development under the changing sea」を開催することにしました。本シンポジウムは, 持続可能な発展に向けた人類社会の変革や, 海洋・海域・沿岸環境の変化に対応するために, 先進的な海洋研究によって得られた新しい知見を日仏の参加者で共有することを目的としていました。

このコンセプトとタイトルのもと, 2021年10月21日のオンラインにより双方向で質問時間を含む10月18日（月）から10月21日（木）までのWebでのポスター発表, 10月19日（火）の日仏の研究者それぞれ4名によるWebでのオンラインのミニシンポジウム, 10月20日（水）にWebでのオンラインの学会創立記念シンポジウム, 10月23日（土）にWebでのオンラインによる市民向けの講演会が行われました。

記念シンポジウムは, 日仏会館・フランス国立日本研究所の協力により, フランスの研究者を含むほぼ100名もの参加を得てWebオンラインで盛大に開催されました。その詳細については, この記念号の「日仏海洋学会創立60周年記念行事」と「創立60周年記念第18回日仏海洋学シンポジウム」をご覧下さい。なお, この記念号の発行では, 笹川日仏財団（東京事務局長：伊藤朋子氏）から格別のご支援をいただきました。

日仏海洋学会はこれからも日本とフランスの間の海洋学や水産学の学術交流を中心として活動を続けて参ります。今後とも, ご支援・ご鞭撻をお願いいたします。

A l'occasion du 18ème Colloque franco-japonais d'Océanographie, commémorant le 60ème anniversaire de la création de la Société franco-japonaise d'Océanographie du Japon

Teruhisa KOMATSU
Président de la Société franco-japonaise d'Océanographie du Japon

La Société franco-japonaise d'Océanographie (SFJO) a été fondée en avril 1960 à la Maison franco-japonaise d'Ochanomizu à Tokyo, afin de promouvoir les échanges académiques entre les scientifiques et les organisations japonaises et françaises actives dans les domaines de l'océanographie et des sciences halieutiques. La fondation de la SFJO a été motivée par l'arrivée au Japon du FNRS III, le submersible habité (appelé bathyscaphe) le plus avancé de l'époque pour l'exploration des fonds marins, et par les résultats scientifiques de ses recherches. Le FNRS III, le submersible, est arrivé au Japon en 1958, grâce à l'enthousiasme et aux préparatifs minutieux de feu le Dr Tadayoshi Sasaki, professeur à l'Université des pêches de Tokyo (*Tokyo Suisan Daigaku*), et avec la coopération et le soutien du gouvernement japonais, des sociétés apparentées, du Conseil scientifique du Japon et du journal Asahi. Suite aux résultats scientifiques obtenus grâce à la technologie française de pointe, la Société a été fondée à l'instigation du Pr Tadayoshi Sasaki pour promouvoir les échanges académiques entre le Japon et la France dans les domaines de l'océanographie et des sciences halieutiques. Louis Fage, alors professeur de sciences à l'Université de Paris et membre de l'Académie française, et Jacques-Yves Cousteau, alors directeur du Musée océanographique de Monaco, ont écrit au Pr Sasaki, le premier président, pour lui faire part de leur soutien à la fondation de la Société. Deux ans plus tard, en 1962, un nouveau bathyscaphe, l'Archimède, est venu au Japon et a transporté des membres de la Société franco-japonaise d'Océanographie dont le premier président, le Pr Sasaki, pour des plongées autour de la fosse du Japon, atteignant une profondeur de 9,545 m dans la fosse des îles Kouriles.

En 1963, la société a commencé à publier son journal, *La mer*, qui est actuellement publié quatre fois par an, son 61ème volume est sorti en 2023. Les présentations de recherches scientifiques et l'assemblée générale de la société se tiennent généralement au mois de juin de chaque année. La Société franco-japonaise d'Océanographie compte aujourd'hui environ 130 membres et a créé, en 1966, le Prix de la Société et, en 2002, le Prix du meilleur article.

Au milieu des années 60, une mortalité massive d'huîtres en France, causée par une maladie, a plongé l'industrie ostréicole dans la crise. Un chercheur français a demandé à Dr Takeo Imai, professeur à l'Université de Tohoku et membre de la Société, d'envoyer en France des naissains d'huîtres japonaises résistants à la maladie. Pr Imai a pris l'initiative de préparer des naissains d'huîtres, de les mettre en quarantaine et de les exporter de Sanriku vers la France entre la fin des années 1960 et le début des années 1970. L'ostréiculture française a ainsi retrouvé son niveau de production antérieur. Cette exportation de naissains d'huîtres japonaises a permis de créer des liens étroits entre les ostréiculteurs et les chercheurs japonais et français.

En 1984, à l'instigation du Dr Hubert-Jean Ceccaldi, alors professeur à l'Ecole pratique des Hautes Etudes, une Société franco-japonaise d'Océanographie France a également été créée en France. Depuis 1983, les sociétés française et japonaise organisent conjointement le « Colloque franco-japonais d'Océanographie » environ tous les deux ou trois ans, alternativement au Japon et en France.

Le tsunami du 11 mars 2011 provoqué par le Grand séisme de l'Est du Japon a détruit les installations ostréicoles le long de la côte de Sanriku. Immédiatement après, les ostréiculteurs français et les Sociétés franco-japonaise d'Océanographie du Japon et de France ont envoyé de nombreux équipements aux pêcheurs du Sanriku, soit par l'intermédiaire des Société, soit directement, afin d'aider l'industrie ostréicole à se reconstruire à Sanriku. Ainsi, les échanges de proximité entre la France et le Japon s'intensifient, non seulement dans le domaine de l'océanographie, mais aussi dans celui des sciences halieutiques, y compris l'ostréiculture.

En 2020, la Société franco-japonaise d'Océanographie du Japon célèbre son 60ème anniversaire. En tant qu'événement commémoratif, le 18ème Colloque franco-japonais d'Océanographie devait se tenir en 2020 comme colloque commémoratif. Cependant, en raison de la prévalence de COVID-19, qui a débuté en 2019, ce colloque a été reporté. Bien qu'il n'ait pas été possible d'organiser le colloque en face à face, des systèmes de conférence basés sur le web ont été mis en place par diverses organisations pour faire face à cette situation, ce qui a permis d'organiser le colloque via le Web. Le 18ème Colloque franco-japonais d'Océanographie a donc été organisé par le web du 18 au 23 octobre 2021.

Le 18ème Colloque franco-japonais d'Océanographie a été thématisé et organisé autour des idées suivantes. Le Sommet de la Terre des Nations Unies s'est tenu à Rio de Janeiro (Brésil) en 2012 pour renouveler l'engagement des Nations Unies en faveur du développement durable et pour assurer la promotion d'un avenir économiquement, socialement et écologiquement durable pour notre planète et pour les générations actuelles et futures. La déclaration du sommet était intitulée « L'avenir que nous voulons ». La mer est l'élément déterminant qui contrôle le climat et le système planétaire sur lequel vit l'être humain. La société humaine a tiré de nombreux biens et services des environnements et écosystèmes marins. Bien que la déclaration du Sommet de la Terre des Nations Unies ait été faite en 2012, les activités humaines ont toujours un impact sur les océans et menacent les écosystèmes marins en raison des émissions de gaz à effet de serre qui entraînent entre autres une augmentation de la température de l'eau de mer. Les activités terrestres, côtières et marines entraînent une eutrophisation, une pêche destructrice et donc une diminution de la biodiversité marine.

Compte tenu de ces faits, nous devons renforcer notre compréhension des océans, en particulier des côtes en tant qu'interface entre la terre et la mer, afin de mieux préparer des mesures contre les changements irréversibles du système planétaire, en mesurant les effets des impacts humains et naturels sur la mer et ses écosystèmes. Grâce à une compréhension globale de la mer basée non seulement sur les sciences naturelles et technologiques, mais aussi sur les sciences humaines et sociales, nous aurons de meilleures idées pour maintenir l'état de la mer en bonne santé. Ainsi, le 18ème Colloque franco-japonais d'Océanographie intitulé « Oceanography for future we want:

transformation of our society for sustainable development under the changing sea » a été préparé pour commémorer le 60ème anniversaire de la SFJO du Japon. Le colloque vise à partager les nouvelles découvertes obtenues par des recherches océanographiques de pointe, entre les participants du Japon et de la France, pour servir à mieux transformer la société humaine pour le développement durable et mieux l'adapter aux changements actuels de l'océan, des environnements marins et côtiers.

Sous ce concept et ce titre, du lundi 18 au samedi 23 octobre 2021, se sont tenus plusieurs événements : le lundi 18 au jeudi 21 octobre, la présentation de posters par le web, y compris un temps interactif et de questions le jeudi 21 octobre, le mardi 19 octobre, un mini-symposium par le web avec quatre chercheurs, chacun de France et du Japon, le mercredi 20 octobre, un colloque sur l'anniversaire de la société en ligne, et le samedi 23 octobre, une conférence pour le public en ligne.

Le symposium commémoratif a été organisé en coopération avec l'Institut français de Recherche sur le Japon à la Maison franco-japonaise et a réuni près de 100 participants, dont des chercheurs français, en ligne. Pour plus de détails, veuillez vous référer aux articles sur « Evénements commémorant le 60ème anniversaire de la fondation de la Société franco-japonaise d'Océanographie du Japon » et « Le 18ème Colloque franco-japonais d'Océanographie à l'occasion du 60ème anniversaire de la fondation de la SFJO du Japon » dans ce numéro commémoratif. La Fondation franco-japonaise Sasakawa (Directrice du bureau de Tokyo : Mme Tomoko Ito) a apporté un soutien exceptionnel à la publication de ce numéro commémoratif.

La Société franco-japonaise d'Océanographie du Japon continuera à se concentrer sur les échanges académiques dans le domaine de l'océanographie et des sciences halieutiques entre le Japon et la France. Nous espérons pouvoir compter sur votre soutien et vos encouragements.

Message de Conseiller pour la Science et la Technologie, Ambassade de France au Japon à la Société franco-japonaise d'Océanographie

Professeur Didier MARTY-DESSUS
Conseiller pour la Science et la Technologie, Ambassade de France au Japon

Cher Pr Teruhisa Komatsu, Président, de la Société franco-japonaise d'Océanographie,
Cher Pr Yasuyuki Koike, Conseiller de la Société franco-japonaise d'Océanographie du Japon,
Cher Dr Patrick Prouzet, Président de la Société franco-japonaise d'Océanographie France
Cher Pr Hubert Jean Ceccaldi, Président honoraire de la Société Franco Japonaise d'Océanographie France
Cher Pr Bernard Thomann, Directeur de l'Institut français de recherches sur le Japon à la Maison franco-japonaise,
Chers collègues et participants en ligne et présents,
Mesdames et Messieurs,

Je suis très heureux de voir s'ouvrir ce 18ème colloque franco-japonais d'océanographie, qui aborde non seulement les défis futurs des sciences océaniques pour une société plus durable, mais qui marque également le 60ème anniversaire de la Société franco-japonaise d'Océanographie du Japon.

Les discussions qui suivront permettront ainsi de se replonger dans l'histoire de ces 60 ans de coopération scientifique entre nos deux pays, coopération ayant débuté en 1960 au sein de cette même Maison franco-japonaise où se retrouveront, très symboliquement, les participants, ayant la chance de prendre part en personne au dernier jour de ce colloque.

Le rôle majeur des sciences océaniques dans la bonne compréhension de notre monde et dans l'identification de réponses à apporter aux enjeux environnementaux et climatiques du 21 ème siècle, n'est plus à démontrer.

Le Japon, en tant qu'archipel, et la France qui bénéficie de la plus grande Zone Economique Exclusive au monde, ont tous deux compris cette importance depuis longtemps.

Je tiens ainsi à rappeler l'engagement de la France, et de l'Ambassade de France au Japon, en faveur des sciences océaniques, qui participent pleinement à animer le dialogue maritime franco-japonais et qui font partie intégrante des axes d'action prioritaires du Service pour la science et la technologie que je représente. Je profite ainsi de cette occasion pour réaffirmer notre soutien continu à l'organisation régulière de ce colloque.

Cet engagement a notamment été réaffirmé au travers de la nouvelle Stratégie nationale française pour les grands fonds marins, qui encadrera pour les 10 années à venir l'action publique et les opérateurs français en la matière. Cette grande stratégie vise à renforcer la connaissance des écosystèmes des grands fonds et des ressources minérales sous-marines, tout en assurant la protection de ces milieux, et l'implication des acteurs locaux, en s'appuyant notamment sur la mise en place d'une mission de coordination interministérielle, ainsi que par le renforcement de nos partenariats à l'international.

J'ai découvert avec grand enthousiasme la thématique de ce 60ème colloque, qui associe très pertinemment océan et avenir. C'est également un objectif français que de faire des sciences de l'océan un sujet d'avenir au travers de son Programme d'Investissements d'Avenir qui allouera 40 millions d'euros au Programme Prioritaire de Recherche « Océan et climat ». Ce dernier financera des projets de recherche interdisciplinaires ambitieux et en phase avec les objectifs de la Décennie des Nations-Unies pour les sciences océaniques au service du développement durable.

J'en profite pour mentionner le lancement, ce 25 octobre, du tour du monde digital des sciences océaniques et climatiques OneOceanScience, organisé par l'IFREMER avec le soutien du CNRS et de l'IRD. Cette campagne inédite de communication scientifique permettra d'illustrer la mobilisation des chercheurs, qui, à travers le monde permettent de mieux décrire et comprendre les interactions entre l'océan et le climat. Je tiens d'ailleurs à remercier très chaleureusement la JAMSTEC d'avoir rejoint cette initiative.

Ce colloque est également une excellente occasion de rappeler et de renforcer le fort lien qui unit nos deux pays en matière de sciences marines. La collaboration qui existe de longue date entre la JAMSTEC et l'IFREMER en est un parfait exemple.

Je me réjouis d'écouter les discussions de ces prochains jours, qui permettront aux équipes françaises et japonaises de partager leurs expertises respectives, ainsi que de voir émerger, je l'espère, des pistes futures de collaboration franco-japonaise.

Tout en espérant que la situation sanitaire vous permette de vous retrouver à Caen ainsi que prévu en 2023, je vous souhaite d'excellents et fructueux échanges et vous remercie de votre attention.

日仏海洋学会への在日フランス大使館科学技術参事官からのメッセージ

在日フランス大使館　科学技術参事官
ディディエ・マルティ=ドシュ

日仏海洋学会 小松輝久会長
日仏海洋学会 小池康之幹事
仏日海洋学会 パトリック・プルーゼ会長
仏日海洋学会 ユベール=ジャン・セッカルディ名誉会長
日仏会館・フランス国立日本研究所 ベルナール・トマン所長
オンライン参加者の皆様，並びに会場にお集まりの皆様

この第18回日仏海洋学シンポジウムが，より持続可能な社会に向けた海洋科学の将来の課題を取り上げるだけでなく，日仏海洋学会の60周年を記念して開幕することを大変喜ばしく思います。

これから行われるさまざまな議論を通して，1960年に日仏会館で始まった両国の科学協力60年を振り返ることができるわけですが，このシンポジウムの最終日に幸運にも直接参加できる方々は，非常に象徴的な形でまさにその日仏会館に集うことになります。

私たちの世界を理解し，21世紀の環境と気候の課題に対する解決策を見出す上で，海洋科学が果たす重要な役割は，十分に理解されていると言えるでしょう。

列島である日本も，世界最大の排他的経済水域を持つフランスも，海洋科学の重要性を以前から理解していました。

ここで私から，フランスと在日フランス大使館の海洋科学に対するコミットメントを改めてお伝えします。海洋科学は日仏海洋対話において重要な役割を担い，私が代表を務める科学技術部の優先的行動の不可欠な柱でもあります。そうした理由からも，この日仏海洋学シンポジウムの定期的な開催に対する私どもの絶え間ない支援を，この機会に改めて明確に示したいと思います。

このコミットメントは，とりわけ海洋科学分野における今後10年間のフランスの公的活動，および事業者のための枠組みとなる，新たな「深海底のためのフランス国家戦略」を通して，改めて明確にされました。この戦略の目的は，深海の生態系や海底鉱物資源に関する知識を深めるとともに，深海環境の保護と地域アクターの関与を保障することにあり，とりわけ省庁間の調整をする機関を設置し，国際的なパートナーシップを強化することで実現を目指します。

私は，第60回シンポジウムのテーマが，「海」と「未来」を見事に結びつけていることを知り，大変喜ばしく思いました。海洋科学を未来のテーマとすることは，フランスの「将来投資計画（Programme d'Investissements d'Avenir）」の目的でもあり，優先研究プログラム「海洋と気候」には4千万ユーロが割り当てられることになっています。このプログラムでは，「持続可能な開発のための国連海洋科学の10年」の目標に沿った，野心的な学際的研究プロジェクトへの資金提供が行われる予定です。

フランス海洋開発研究所（Ifremer）が，フランス国立科学研究センター（CNRS）とフランスの開発研究所（IRD）の支援を受けて，海洋・気候科学のデジタルワールドツアー「OneOcean-Science」を10月25日に開催したことについても，この機会に触れておきたいと思います。前例のないこの科学コミュニケーション活動は，海洋と気候の相互作用をよりよく説明し理解するために，世界中の研究者が動員されていることを示すものです。この取り組みに参加してくださった海洋研究開発機構（JAMSTEC）に，心から感謝申し上げます。

また，このシンポジウムは，海洋科学における日仏両国の絆を改めて強調し，さらに強化する絶好の機会でもあります。JAMSTEC と Ifremer の長年にわたる協力関係は，その好例と言えるでしょう。

両国のチームがそれぞれの専門知識を共有し，将来の日仏協力の新たな道筋が開かれることに期待を寄せながら，これから行われる数日間の議論を拝聴させていただきます。

コロナ禍が終息し，予定通り2023年にフランスのカーンにて皆様が一堂に会せるよう，お祈り申し上げるとともに，実り多き交流が行われることを心から願っています。ご清聴ありがとうございました。

Discours d'introduction pour le 60ème anniversaire de la Société franco-japonaise d'Océanographie du Japon

Patrick PROUZET
Président de la Société franco-japonaise d'Océanographie France

En tant qu'actuel président de la Société franco-japonaise d'Océanographie (SFJO) France, je suis particulièrement honoré de participer à ce 60ème anniversaire de la SFJO Japon et désolé de ne pouvoir pour des raisons sanitaires être physiquement présent. 60 ans c'est un bel âge, celui de la raison et de la plénitude, mais aussi le signe que cette Société a su conserver, au cours de cette longue période, les aspirations de ses fondateurs, le Professeur T. Sasaki et ses collègues, en les faisant évoluer vers des sujets scientifiques et sociétaux, comme l'adaptation de nos sociétés et de nos écosystèmes au changement climatique, et plus largement au changement global.

Je voudrais ici rendre hommage aux présidents successifs de la SFJO Japon et, bien évidemment à son président actuel, le professeur Teruhisa Komatsu, qui ont su pérenniser la dynamique de cette société savante qui nous permet, à l'heure actuelle, d'avoir un rayonnement important dans le monde scientifique : près de 150 000 téléchargements des communications présentées lors des 4 derniers colloques ont été effectués.

La SFJO France s'est associée depuis 1984 à cette dynamique qui permet aux deux sociétés savantes d'occuper une place de choix dans la coopération océanographique franco-japonaise, mais aussi dans le développement d'une coopération étroite avec le monde de la pêche et de l'ostréiculture, tant en France qu'au Japon, comme en atteste le projet « Nature et Culture » lancé par les deux Sociétés.

Je ne voudrais pas terminer mon exposé sans rendre hommage au Professeur Hubert-Jean Ceccaldi qui a fondé, avec quelques autres collègues, Y. Hénocque, C. Mariojouls et D. Bailly, la SFJO France. Sa grande compétence, son rayonnement tant en France qu'au Japon, ont fait de la SFJO France une structure reconnue internationalement et qui peut apporter à sa grande sœur une aide efficace et complémentaire.

Longue vie donc à la SFJO Japon et bon anniversaire.

日仏海洋学会創立 60 周年記念挨拶

仏日海洋学会会長
パトリック・プルーゼ

仏日海洋学会会長として，この日仏海洋学会 60 周年記念式典に参加できることを特に光栄に思う

とともに，衛生上の理由で物理的に出席できないことを残念に思います。60 歳という年齢は，理性的で充実した年齢であると同時に，この長い期間，本会が，創設者である佐々木教授とその同僚たちの志を守り，気候変動，より広くは地球変動に対する我々の社会と生態系の適応といった科学的，社会的テーマに向けて発展させてきた証です。

この場をお借りして，日仏海洋学会の歴代会長，そしてもちろん現会長の小松輝久教授に敬意を表します。この学会の勢いは，過去 4 回のシンポジウムで発表された論文のダウンロード件数が合計で約 15 万件に達するなど，科学界に大きなインパクトを与えることに成功しています。

1984 年以来，SFJO フランスは，このダイナミックな活動によって，日仏海洋学協力において重要な役割を果たすとともに，両学会が立ち上げた「自然と文化」プロジェクトに見られるように，日仏両国の漁業やカキ養殖業との密接な協力関係を発展させることができました。

同僚のイヴ・エノック博士，カトリーヌ・マリオジュールス教授，デゥニー・バイー教授とともに仏日海洋学会を創設したユベール＝ジャン・セッカルディ教授に敬意を表さずには，私のこの講演を終えることはできません。フランスと日本の両国におけるセッカルディ教授の専門知識と影響力により，仏日海洋学会は，その大きな姉妹に効果的かつ補完的なサポートを提供できる国際的に認められた組織となりました。

日仏海洋学会万歳，そして創立記念日おめでとうございます。

（日仏海洋学会の責任においてフランス語のテキストを和訳しました）

国立研究開発法人海洋研究開発機構理事長祝辞

国立研究開発法人海洋研究開発機構理事長
松永　是

祝　辞

日仏海洋学会が創立六十周年を迎えられたとのこと心よりご祝福申し上げます。

本日ここに，多くの関係者の皆様のご参加を得て，日仏会館・フランス国立日本研究所共催シンポジウム「海洋学における日仏協力 60 周年の歴史」が盛大に開催されますことに心からお祝いを申し上げます。依然として世界中で新型コロナウイルス感染症が猛威をふるうなか，本シンポジウムのオンライン開催にあたりご尽力されました日仏海洋学会会長及び事務局の皆様に深く敬意を表します。

さて，当機構とフランスとの関係を振り返らせていただきますと，日仏科学技術協力協定の枠組みの下での様々な研究協力の交流を経て，1998 年に締結したフランス海洋開発研究所（IFREMER）との研究協力の覚書（MOU）等を通じた協力など，現在にいたるまで IFREMER をはじめフランスの海洋科学関係者とは良好な協力関係を構築，維持していところであり，これからも重要なパートナーの一つです。

最近では 2019 年に，日仏の複数機関の共催により，日仏の様々な機関の研究者を含むステークホルダーの参加の下で，ニューカレドニア周辺海域における海洋観測についてのワークショップを仏領ニューカレドニア・ヌメアにて開催し，このワークショップには仏日海洋学会　副会長の Yves Hénocque 様及び日仏海洋学会　会長の小松輝久様にもご参加を賜りました。また，日仏海洋学会　会長の小松輝久様には，当機構が事務局

を務める政府間海洋学会委員会（IOC）協力推進委員会 WESTPAC 国内専門部会におきまして，海洋科学の国際協力の推進等に関して，大所高所，かつ，専門的な観点からご知見を提供いただいているところです。改めまして感謝申し上げます。

最後に，皆様ご承知のとおり，2021 年は国連による「持続可能な開発のための国連海洋科学の 10 年」が開始する節目の年となります。海洋科学を通じた持続可能な開発の推進・達成に向け，日仏は更に緊密な連携及び協力が必要となります。当機構といたしましては，今後とも貴学会とともに，海洋科学を通じて世界の諸課題解決等に尽力してまいります。

結びに，お集まりの皆様の益々のご健勝をお祈り申し上げ，お祝いの言葉と結ばせていただきます。本日は誠におめでとうございます。

Message de félicitations du président de Japan Agency for Marine-Earth Science and Technology

Discours de félicitations

Tadashi MATSUNAGA
Président de Japan Agency for Marine-Earth Science and Technology

Je tiens à féliciter la Société franco-japonaise d'Océanographie du Japon à l'occasion du 60ème anniversaire de sa création.

Je vous félicite pour le succès du colloques « 60 ans de Coopération franco-japonaise en Océanographie »", organisé conjointement par l'Institut français de recherche sur le Japon à la Maison franco-japonaise avec la participation de nombreuses parties intéressées. Je tiens à exprimer mon profond respect au président et au secrétariat de la Société franco-japonaise d'Océanographie pour les efforts qu'ils ont déployés afin d'organiser ce colloques en ligne, à un moment où le Covid fait encore rage dans le monde.

En ce qui concerne les relations entre notre organisation et la France, nous avons eu plusieurs échanges de coopération en matière de recherche, dans le cadre de l'accord franco-japonais de coopération scientifique et technologique, et nous avons coopéré avec l'Institut français de recherche pour l'exploitation de la mer (Ifremer), par le biais d'un protocole d'accord sur la coopération en matière de recherche, signé en 1998. Nous avons établi et maintenu une bonne coopération avec l'Ifremer et d'autres acteurs français des sciences de la mer, qui resteront nos partenaires les plus importants.

Récemment, en 2019, un atelier sur les observations océanographiques dans les eaux autour de la Nouvelle-Calédonie a été organisé à Nouméa, en Nouvelle-Calédonie française, conjointement par plusieurs organisations françaises et japonaises, avec la participation de parties prenantes, y compris des chercheurs de diverses organisations françaises et japonaises. L'atelier s'est déroulé en présence de M. Yves Hénocque, vice-président de la Société franco-japonaise d'Océanographie de France, et de M. Teruhisa Komatsu, président de la Société franco-japonaise d'Océanographie du Japon. En outre, M. Teruhisa Komatsu, président de la Société franco-japonaise d'Océanographie, nous a fait bénéficier de ses connaissances sur la promotion de la coopération internationale dans le domaine des sciences de la mer, d'un point de vue large et professionnel au sein du groupe d'experts nationaux WESTPAC du comité de promotion de la coopération de la Commission océanographique intergouvernementale (COI), dont notre organisation assure le secrétariat. Je tiens à vous remercier une fois de plus.

Enfin, comme vous le savez tous, l'année 2021 marque le début de la Décennie des Nations Unies pour les sciences océaniques au service du développement durable. La France et le Japon devront travailler et coopérer encore plus étroitement pour promouvoir et réaliser le développement durable grâce aux sciences marines. Notre organisation continuera à travailler avec vos sociétés pour aider à résoudre les problèmes mondiaux grâce aux sciences marines.

En conclusion, je voudrais vous souhaiter le meilleur et terminer mes félicitations. Je tiens à vous féliciter pour l'occasion qui nous est donnée aujourd'hui.

(Ce texte a été traduit du japonais en français sous la responsabilité de la Société franco-japonaise d'Océanographie du Japon.)

Discours de félicitations du Professeur Hubert-Jean Ceccaldi, Président d'honneur de la Société franco-japonaise d'Océanographie France au 18ème Colloque franco-japonais d'Océanographie du Japon à l'occasion du 60ème anniversaire de sa création

Hubert-Jean Ceccaldi
Président d'honneur de la Société franco-japonaise d'Océanographie France

C'est avec un immense plaisir que je participe au 18ème Colloque franco-japonais d'Océanographie et à la célébration, avec nos collègues et amis japonais, du 60ème anniversaire de la Société franco-japonaise d'Océanographie du Japon. J'en suis d'autant plus heureux que ce colloque se déroule à la Maison franco-japonaise de Tokyo, dont j'ai été le Directeur français pendant quatre années, qui comptent parmi les plus passionnantes de ma vie.

La Maison franco-japonaise dispose d'un immense potentiel : la présence de 26 sociétés savantes, qui donne la possibilité de multiples travaux pluridisciplinaires et de fructueux échanges entre spécialistes des deux pays. Ainsi, au sein des deux Sociétés franco-japonaises d'Océanographie, nous avons, depuis les domaines de la physique, de la chimie, de la biologie, lentement évolué vers des aspects sociaux et culturels, qui sont essentiels dans l'exploitation des ressources marines.

Permettez-moi d'exprimer ma reconnaissance à nos collègues et amis japonais qui, depuis le Professeur Tadayoshi Sasaki et ses successeurs, ont maintenu et enrichi nos échanges pendant tant d'années, et, aujourd'hui, aux Professeurs Teruhisa Komatsu et Yasuyuki Koike, ainsi qu'aux membres de la Société franco-japonaise d'Océanographie du Japon, sans oublier les éditeurs du journal « La Mer », qui publient d'excellents articles depuis 60 ans.

Ma profonde reconnaissance va aussi aux membres du Bureau japonais de la Maison franco-japonaise et à leurs nombreux soutiens, sans lesquels cette aventure scientifique et amicale serait très différente.

Je salue également la présence et les très intéressantes activités de mon collègue Bernard Thomann et de son équipe, qui permettent d'accroître nos connaissances d'un pays aussi particulier que remarquable, auquel je suis très attaché. Nous pouvons ainsi aborder avec confiance le futur des échanges avec nos homologues japonais : c'est une garantie d'enrichissements mutuels.

創立 60 周年記念第 18 回日仏海洋学シンポジウムへの仏日海洋学会名誉会長ユベール=ジャン・セッカルディ教授祝辞

仏日海洋学会名誉会長
ユベール=ジャン・セッカルディ

このたび，第 18 回日仏海洋学シンポジウムに参加させていただくとともに，日仏海洋学会の創立 60 周年を日本の仲間や友人とともに祝うことができ，大変嬉しく思います。このシンポジウムが東京の日仏会館で開催されることを特に嬉しく思います。この日仏会館は，私が 4 年間フランス館長を務め，私の人生の中でも最も刺激的な場所でした。

日仏会館には，26 の学協会があり，両国の専門家による幅広い学際的な研究や実りある交流の機会が提供されるという，計り知れない可能性があります。このように，日仏海洋学会では，物理学，化学，生物学の分野から，海洋資源の開発に不可欠な社会的，文化的な側面へとゆっくりと移行してきました。

佐々木忠義教授とその後継者たち以来，長年にわたって私たちの交流を維持し，豊かにしてくれた日本の同僚や友人たち，そして今日，小松輝久教授と小池康之教授，さらに日仏海洋学会の会員，そして 60 年にわたって優れた論文を発表し続けている雑誌「La Mer」の編集者たちに感謝の意を表することをお許しください。

また，日仏会館の日本事務局メンバーや，多くの後援者の方々にも深く感謝します。彼らがいなければ，この科学的で友好的な冒険はまったく違ったものになっていたでしょう。

また，私の同僚であるベルナール・トマン所長と彼のチームの存在と非常に興味深い活動にも敬意を表したいと思います。彼らのおかげで，私たちは，注目すべき国であると同時に特別な国であり，私が非常に愛着を持っているこの国について知識を深めることができました。私たちは，日本の皆さんとの今後の交流に自信を持って臨むことができます。それは，お互いを豊かにする保証でもあります。

（日仏海洋学会の責任においてフランス語のテキストを和訳しました）

日本海洋学会会長祝辞
日仏海洋学会設立 60 周年を記念して

日本海洋学会会長
神田　穣太

第 18 回日仏海洋学シンポジウムの開催ならびに日仏海洋学会創立 60 周年，誠におめでとうございます。日本海洋学会を代表して一言お祝い申し上げます。

あらゆる学術分野において共通ではありますが，しかしとりわけ海洋学の分野においては，国際的な連携や協力は大きな意味を持ちます。海洋は，全人類の共有財産であり，地球環境維持のため極めて重要な役割を果たすのみならず，その恵みは人類社会が持続可能な発展を続けていくための依って立つべき基盤でもあるからです。

貴学会において長年にわたって培われてきたフランスとの学術交流は，海洋学の発展に貢献したことはもちろん，海洋を通して人類が共有する未来のためにも大きく資するものであると考えます。

皆様ご承知のとおり，今年から「持続可能な開発のための国連海洋科学の 10 年」がスタートしました。人類社会の持続可能な発展のために海洋がいかに大切であるかを国際社会が理解し，その上で特に海洋科学の進展を目指した国際的な取り組みを重視して，国連総会において決議いただいたものであり，海洋学分野における国際的な連携・協力の重要性を明瞭に示しているものです。

このような記念すべき年に開催されるシンポジウムのご成功と，貴学会のますますのご発展を祈念致しまして，私からの祝辞とさせていただきます。

Message de félicitations du Président au Président de la Société océanographique du Japon
A l’occasion du 60ème anniversaire de la création de la Société franco-japonaise d’Océanographie du Japon

Jota KANDA
Président de la Société océanographique du Japon

Félicitations pour le 18ème Colloque franco-japonais d’Océanographie et pour le 60ème anniversaire de la fondation de la Société franco-japonaise d’Océanographie du Japon. Au nom de la Société océanographique du Japon, je tiens à vous adresser mes félicitations.

Comme dans toutes les disciplines académiques, mais particulièrement dans le domaine de l’océanographie, la collaboration et la coopération internationales sont d’une grande importance. En effet, l’océan est la propriété commune de toute l’humanité et joue non seulement un rôle extrêmement important dans la préservation de l'environnement mondial, mais sa générosité est également le fondement sur lequel la société humaine doit s'appuyer pour poursuivre son développement durable.

Les échanges académiques avec la France que votre société a encouragés au fil des ans, ont non seulement contribué au développement de l'océanographie, mais ont également apporté une contribution significative à l'avenir commun de l'humanité à travers les océans.

Comme vous le savez tous, cette année marque le début de la Décennie des Nations Unies pour les sciences océaniques au service du développement durable. La résolution a été adoptée par l'Assemblée générale des Nations unies afin de promouvoir la compréhension par la communauté internationale de l'importance des océans pour le développement durable de la société humaine, et de mettre l'accent sur les efforts internationaux visant à faire progresser les sciences marines en particulier.

Je tiens à vous adresser mes félicitations et mes meilleurs vœux pour le succès du colloque, qui se tient en cette année mémorable, et pour la poursuite du développement de votre société.

（Ce texte a été traduit du japonais en français sous la responsabilité de la Société franco-japonaise d'Océanographie du Japon.）

日本水産学会会長祝辞

公益社団法人日本水産学会会長
金子　豊二

祝 辞

日仏海洋学会が創立60周年を迎えられましたことを，心からお祝い申し上げます。

日仏海洋学会は，海洋学や水産学に関連する分野で活動する日本とフランスの科学者や団体が連絡を密にし，日本・フランス両国のこの科学分野における協力を促進することを目指して1960年に発足したと伺っております。それまで個人的な交流に留まっていた日本・フランス両国の海洋学・水産学の分野における学問的交流が，日仏海洋学会の発足により組織化された意義は極めて大きいものであります。

また日仏海洋学会は，海洋学と水産学に軸足を置きつつ，日本・フランス両国の架け橋としての国際的役割も担うという点で唯一無二の存在です。日仏海洋学会の活動は，海洋学や水産学に関する基礎から応用まで幅広く，学会誌 La Mer の刊行，研究発表会やシンポジウムの開催，学会賞・論文賞の顕彰事業，さらには東北復興支援等，極めて多岐にわたります。当然ながら，日本水産学会との関わりも深く，日本人会員で日本水産学会にも所属されている方は少なくありません。

フランスの方には馴染みがないかと思いますが，日本には古くから60年を人生の一周期とする還暦という考え方があります。日仏海洋学会が創立60周年つまり還暦を迎えられたことは，この上なく喜ばしいことです。なぜなら，還暦を迎えることは，この間に学会が果たした役割が社会から高く評価されてきた証でもあるからです。またそれは同時に，次の60年間に向けての再出発でもあります。日仏海洋学会が，さらなる高みを目指して新たな一歩を踏み出したことを，重ねてお祝い申し上げます。

Discours de félicitations du Président de la Société japonaise des Sciences halieutiques

Toyoji KANEKO
Président de la Société japonaise des Sciences halieutiques

Je tiens à féliciter la Société franco-japonaise d'Océanographie à l'occasion de son 60ème anniversaire.

Je crois savoir que la Société franco-japonaise d'Océanographie du Japon a été fondée en 1960 dans le but de promouvoir des contacts étroits entre les scientifiques et les organisations japonaises et françaises travaillant dans les domaines liés à l'océanographie et aux sciences halieutiques, et de promouvoir la coopération entre les deux pays dans ce domaine scientifique, qui était restée jusqu'alors limitée à des échanges personnels.

La Société franco-japonaise d'Océanographie est unique en ce sens qu'elle joue un rôle international de pont entre le Japon et la France, tout en restant centrée sur l'océanographie et la science halieutique. Les activités de la Société franco-japonaise d'Océanographie couvrent un large éventail de l'océanographie fondamentale et appliquée et des sciences halieutiques, y compris la publication de la revue *La Mer*, l'organisation de présentations de recherche et de colloques, l'attribution de prix de la Société et de prix de communication, et le soutien à la reconstruction de la région de Tohoku. Naturellement, elle est également très impliquée dans la Société japonaise des Sciences halieutiques, et de nombreux membres japonais sont également membres de la Société japonaise des Sciences halieutiques.

Bien qu'il ne soit pas familier aux Français, au Japon, le concept de *kanréki* (60ème anniversaire de la vie) qui considère les 60 ans comme un cycle de vie, est bien ancré dans les mentalités. C'est avec grand plaisir que la Société franco-japonaise d'Océanographie célèbre son *kanréki*, c'est-à-dire sa 60ème année d'existence. En effet, le 60ème anniversaire est la preuve que le rôle joué par la Société au cours de cette période a été hautement apprécié par la société.

En même temps, c'est un nouveau départ pour les 60 prochaines années. Je tiens à féliciter la Société franco-japonaise d'Océanographie d'avoir franchi une nouvelle étape dans sa quête pour atteindre des sommets encore plus élevés.

(Ce texte a été traduit du japonais en français sous la responsabilité de la Société franco-japonaise d'Océanographie du Japon.)

日本水産海洋学会会長祝辞

水産海洋学会会長
木村　伸吾

日仏海洋学会設立60周年を心よりお慶び申し上げます。

貴学会は，日本における海洋や水産に関わる主要な学会の一つとして，日本とフランスの研究者・関係者が協力し合いながら学問の進歩のために貢献するという他の学会には例を見ない特徴的な活動をされてきています。海洋の謎や神秘を学問の観点からだけではなく芸術の分野からも古くから挑戦的に探求してきたフランスとの活動は，とても刺激的であり，日本の海洋学や水産学の発展に大きく貢献されてきたものと拝察します。そして，日本がようやく海洋の探求に目を向け始めた1960年前後に，いち早く国際的な視野を持って活動を展開した先進性は，特筆すべきことと感じ入っています。

水産海洋学会は漁業の現場と密着した研究を探求してきており，当学会も来年には設立60周年を迎えます。これからも貴学会との友好な関係を築きながら学問の進歩のために協力し合えることを切にお願い申し上げる次第です。

末筆ながら，日仏海洋学会のますますのご発展をお祈り致します。

Message de félicitations du Président de la Société japonaise d'Océanographie de la Pêcherie

Shingo KIMURA
Président de la Société japonaise d'Océanographie de la Pêcherie

Je tiens à vous féliciter à l'occasion du 60ème anniversaire de la création de la Société franco-japonaise d'Océanographie du Japon.

En tant que l'une des principales sociétés académiques liées à l'océan et à la pêche au Japon, votre société a été particulièrement active en contribuant à l'avancement de la discipline grâce à la coopération de chercheurs et de personnes concernées japonais et français. Les activités avec la France qui a depuis longtemps relevé le défi d'explorer les mystères et les merveilles des océans non seulement d'un point de vue académique, mais aussi dans le domaine de l'art, ont été très stimulantes et ont grandement contribué au développement de l'océanographie japonaise et des sciences halieutiques. Je pense également qu'il est remarquable que la Société ait été l'une des premières sociétés académiques à développer des activités dans une perspective internationale vers 1960, lorsque le Japon commençait enfin à s'intéresser à l'exploration des océans.

La Société japonaise d'océanographie de la Pêcherie a poursuivi des recherches étroitement liées à l'industrie de la pêche et l'année prochaine marquera le 60ème anniversaire de la fondation de la société. J'espère sincèrement que nous pourrons continuer à construire une relation amicale avec votre société et à coopérer ensemble pour faire avancer la discipline.

Enfin, je souhaite à la Société franco-japonaise d'Océanographie du Japon de poursuivre ses efforts avec succès.

(Ce texte a été traduit du japonais en français sous la responsabilité de la Société franco-japonaise d'Océanographie du Japon.)

日仏海洋学会功労賞賞状の贈呈

日仏海洋学会は，創立 60 周年を記念して，海洋科学・水産学の分野における日仏交流の促進に貢献された方々を表彰することにしました。これらの方々の貢献がなければ，日仏間の海洋学・水産学における学問的および人的な交流を 60 年間も持続させ，また，深めることはできませんでした。これらの方々の厚意と努力に対して，日仏海洋学会は，心より感謝し，表彰状を贈呈することにいたしました。それぞれの方のお名前と，貢献について感謝状の文面で紹介させていただきます。

Remise du Certificat de Mérite de la Société franco-japonaise Océanographie du Japon

A l’occasion de son 60ème anniversaire, la Société franco-japonaise d’Océanographie du Japon a décidé d’honorer ceux qui ont contribué à la promotion des échanges entre la France et le Japon dans les domaines des sciences de l’océanographie et des sciences halieutiques. Sans les contributions de ces personnes, il n’aurait pas été possible de soutenir et d’approfondir les échanges académiques et personnels en océanographie et en sciences halieutiques entre la France et le Japon depuis 60 ans. Pour leur générosité et leurs efforts, la Société franco-japonaise d’océanographie a le plaisir de leur remettre un certificat de reconnaissance. Les noms de chaque personne et leurs contributions sont présentés dans le texte de la lettre d’appréciation.

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感謝状

Certificat de Mérite de la Société franco-japonaise d’Océanographie du Japon


感 謝 状

ﾕﾍﾞｰﾙ=ｼﾞｬﾝ・ｾｯｶﾙﾃﾞｨ殿

貴殿は海洋・水産分野における日仏交流に貢献しその深化に寄与されました　創立 60 周年記念を迎えるにあたりその功労に深謝の意を表します

令和 3 年 10 月 20 日

日仏海洋学会
会長　小松輝久

Lettre d’ appréciation

Prof. Hubert-Jean CECCALDI

Vous avez contribué et approfondi les échanges franco-japonais dans le domaine de l'océanographie et des sciences halieutiques et de l'aquaculture.
À l'occasion de notre 60e anniversaire, je tiens à vous exprimer notre profonde gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu

Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

仏日海洋学会名誉会長　ユベール=ジャン・セッカルディ 殿

貴殿は海洋・水産分野における日仏交流に貢献し，その深化に寄与されました。創立 60 周年記念を迎えるにあたりその功労に深謝の意を表します。

2021 年 10 月 20 日
日仏海洋学会　会長　小松輝久

Cher Hubert-Jean CECCALDI, Président d'honneur de la Société franco-japonaise d'Océanographie France,

Vous avez contribué et approfondi les échanges franco-japonais dans le domaine de l'océanographie et des sciences halieutiques. A l'occasion du 60ème anniversaire de votre fondation, nous tenons à vous exprimer notre profonde gratitude pour les services rendus.

Le 20 octobre 2021
Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

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感謝状

小池康之殿

貴殿は貝類養殖技術と三陸カキ養殖復興支援において日仏交流に貢献し本学会の発展のために尽力されました　創立 60 周年を迎えるにあたりその功労に深謝の意を表します

令和 3 年 10 月 20 日
日仏海洋学会
会長　小松輝久

Lettre d' appréciation

Prof. Yasuyuki Koike

Vous avez contribué et vous contribuez encore aux échanges franco-japonais dans le domaine de la technologie conchylicole et du soutien à la reprise de l'ostréiculture à Sanriku, et vous avez joué un rôle déterminant dans le développement de la Société. À l'occasion de notre 60e anniversaire, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu
Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

日仏海洋学会幹事　小池　康之 殿
貴殿は貝類養殖技術と三陸カキ養殖復興支援において日仏間の橋渡しを担い，本学会発展のために尽力されました。創立 60 周年を迎えるにあたりその功労に深謝の意を表します。

2021 年 10 月 20 日
日仏海洋学会　会長　小松輝久

Cher Professeur Yasuyuki Koike, Secrétaire de la Société franco-japonaise d'Océanographie du Japon,

Vous avez été un pont entre la France et le Japon dans le domaine de la technologie de la conchyliculture et du soutien à la reconstruction de l'ostréiculture du Sanriku, et vous avez fait de grands efforts pour le développement de notre société. A l'occasion du 60ème anniversaire de notre fondation, nous tenons à vous exprimer notre profonde gratitude pour les services rendus.

Le 20 octobre 2021

Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

感謝状

ﾊﾟﾄﾘｯｸ･ﾌﾟﾙｰｾﾞ殿

貴殿は日仏海洋学シンポジウム
プロシーデングスの編集と日仏交
流の新企画「Nature et Culture」
を通じて海洋・水産学分野における
日仏交流に貢献されました
創立60周年記念を迎えるにあた
りその功労に深謝の意を表します

令和3年10月20日

日仏海洋学会
会長　小松輝久

Lettre d' appréciation

Dr. Patrick PROUZET

Vous avez contribué aux échanges franco-japonais dans le domaine de l'océanographie et de la pêche et de l'aquaculture en éditant les actes du colloque océanographique franco-japonais et le nouveau projet d'échange franco-japonais "Nature et Culture". À l'occasion de notre 60e anniversaire, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu

Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

仏日海洋学会会長　パトリック・プルーゼ 殿

貴殿は日仏海洋学シンポジウムプロシーデングスの編集と日仏交流の新企画「Nature et Culture」を通じて，海洋･水産学分野における日仏交流に貢献されました。創立60周年記念を迎えるにあたりその功労に深謝の意を表します。

2021年10月20日

日仏海洋学会　会長　小松輝久

Cher Patrick PROUZET, Président de la Société franco-japonaise d'Océanographie France,

Vous avez contribué et approfondi les échanges franco-japonais dans le domaine de l'océanographie et des sciences halieutiques à travers l'édition des Actes du colloque franco-japonais d'océanographie et le nouveau projet Nature et Culture pour les échanges franco-japonais. A l'occasion du 60ème anniversaire de sa fondation, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

Le 20 octobre 2021

Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

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感 謝 状

伊藤朋子殿

貴殿は海洋・水産学分野における日仏交流と本学会の発展のために多大な貢献をされました
創立 60 周年を迎えるにあたりその功労に深謝の意を表します

2021 年 10 月 20 日

日仏海洋学会
会長　小松輝久

Lettre d' appréciation

Ms. Tomoko ito

Vous avez apporté une contribution exceptionnelle à notre Société et au développement des échanges franco-japonais dans le domaine de l'océanographie, des sciences des pêcheries et de l'aquaculture. À l'occasion de notre 60e anniversaire, nous tenons à vous exprimer notre sincère gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu
Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

笹川日仏財団東京事務局長　伊藤 朋子 殿
貴殿は海洋・水産学分野における日仏交流と本学会の発展のために多大な貢献をされました。創立 60 周年を迎えるにあたりその功労に深謝の意を表します。

2021 年 10 月 20 日
日仏海洋学会　会長　小松輝久

Chère Tomoko Ito, Secrétaire général de la Fondation franco-japonaise Sasakawa,

Vous avez grandement contribué et approfondi les échanges franco-japonais dans le domaine de l'océanographie et des sciences halieutiques et au développement de notre société. A l'occasion de notre 60ème anniversaire, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

Le 20 octobre 2021
Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

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感謝状

カトリーヌ・マリオジュールス殿

貴殿は三陸カキ養殖復興支援において日仏間の橋渡しを担い日仏交流の発展に尽力されました創立 60 周年記念を迎えるにあたりその功労に深謝の意を表します

令和３年10月20日

日仏海洋学会
会長　小松輝久

Lettre d' appréciation

Prof. Catherine MARIOJOULS

Vous avez été un pont entre le Japon et la France dans la reconstruction de l'ostréiculture à Sanriku, et vous avez contribué au développement des échanges franco-japonais. À l'occasion de notre 60e anniversaire, nous tenons à vous exprimer notre profonde gratitude pour vos services.

LE 20 OCTOBRE 2021

Teruhisa Komatsu

Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

仏日海洋学会副会長　カトリーヌ・マリオジュールス 殿
貴殿は三陸カキ養殖復興支援において日仏間の橋渡しを担い，日仏交流の発展に尽力されました。創立60周年記念を迎えるにあたりその功労に深謝の意を表します。

2021年10月20日
日仏海洋学会　会長　小松輝久

Chère Professeur Catherine MARIOJOULS, Vice-présidente de la Société franco-japonaise d'Océanographie France,

Vous avez été un pont entre la France et le Japon en soutenant le rétablissement de l'ostréiculture du Sanriku, et vous avez grandement contribué au développement des relations franco-japonaises. A l'occasion du 60ème anniversaire de notre fondation, nous tenons à vous exprimer notre profonde gratitude pour votre service.

Le 20 octobre 2021
Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

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感謝状

佐々木　良殿

貴殿は三陸カキ養殖復興支援において日仏間の橋渡しを担い日仏交流の発展と本学会の活動のために尽力されました

創立 60 周年を迎えるにあたりその功労に深謝の意を表します

令和３年10月20日

日仏海洋学会

会長　小松輝久

Lettre d' appréciation

Mr. Ryo Sasaki

Vous avez joué le rôle de pont entre le Japon et la France en soutenant la reprise de l'ostréiculture à Sanriku et vous avez joué un rôle déterminant dans le développement des échanges franco-japonais et de la Société. À l'occasion de notre 60e anniversaire, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu

Prof. Teruhisa Komatsu
Président de la Société franco-japonaise d'Océanographie

元・宮城県気仙沼水産試験場長　佐々木 良 殿
貴殿は三陸カキ養殖復興支援において日仏間の橋渡しを担い，日仏交流の発展と本学会の活動のために尽力されました。創立 60 周年を迎えるにあたりその功労に深謝の意を表します。

2021 年 10 月 20 日
日仏海洋学会　会長　小松輝久

Cher Monsieur Ryo Sasaki, Ancien Directeur de la Station expérimentale de Pêcheries de Kesennuma du Miyagi,

Pour votre rôle de pont entre la France et le Japon dans le soutien à la relance de l'ostréiculture du Sanriku, pour vos efforts dans le développement des échanges entre la France et le Japon et pour les activités de notre société. A l'occasion du 60ème anniversaire de notre fondation, nous tenons à vous exprimer notre plus profonde gratitude pour votre service.

Le 20 octobre 2021
Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

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感謝状

イヴ・エノック殿

貴殿は海洋・水産分野における
日仏交流に貢献しその深化に寄
与されました 創立60周年記
念を迎えるにあたりその功労に
深謝の意を表します

令和3年10月20日

日仏海洋学会
会長 小松輝久

Lettre d' appréciation

Dr. Yves HENOCQUE

Vous avez contribué et approfond
les échanges franco-japonais dans le
domaine de l'océanographie et des
sciences halieutiques et de l'aquaculture.
À l'occasion de notre 60e anniversaire,
je tiens à vous exprimer notre profonde
gratitude pour votre contribution.

LE 20 OCTOBRE 2021

Teruhisa Komatsu

Prof. Teruhisa Komatsu
Président de la Société franco-japonaise
d'Océanographie

仏日海洋学会副会長　イヴ・エノック 殿

貴殿は海洋・水産分野における日仏交流に貢献し，その深化に寄与されました。創立60周年記念を迎えるにあたりその功労に深謝の意を表します。

2021年10月20日

日仏海洋学会　会長　小松輝久

Cher Monsieur Yves Hénocque, Vice-président, Société franco-japonaise d'Océanographie France,

Vous avez contribué à l'approfondissement des relations franco-japonaises dans le domaine de l'océanographie et des sciences des pêcheries. A l'occasion du 60ème anniversaire de votre fondation, nous tenons à vous exprimer notre profonde gratitude pour votre contribution.

Le 20 octobre 2021

Teruhisa Komatsu, Président de la Société franco-japonaise d'Océanographie du Japon

仏日海洋学会からの日仏海洋学会創立 60 周年を記念するメダルの贈呈

2021 年 10 月 20 日，日仏会館・フランス国立日本研究所において，フランス国立日本研究所長ベルナール・トマン教授臨席のもと，仏日海洋学会イヴ・エノック副会長は日仏海洋学会創立 60 周年への祝辞を述べました。仏日海洋学会の依頼により，フランスにおける最優秀職人の称号を与えられたメダル彫刻家 Nicolas SALAGNA 氏が制作した日仏海洋学会創立 60 周年記念メダルを，仏日海洋学会イヴ・エノック副会長は，小松輝久日仏海洋学会会長に直接手渡しました（Fig. 1）。日仏海洋学会は，日仏海洋学会と仏日海洋学会の友好の証としてこの記念メダル（Fig. 2）を大切に保存しています。

Remise d’une médaille pour commémorer le 60ème anniversaire de la fondation de la Société franco-japonaise d’Océanographie du Japon par la Société franco-japonaise d’Océanographie France

Le 20 octobre 2021, Docteur Yves Hénocque, Vice-président de la Société franco-japonaise d’Océanographie France, a félicité la Société franco-japonaise d’Océanographie du Japon pour son 60ème anniversaire en présence du Professeur Bernard Thomann, Directeur de l’Institut français de Recherche sur le Japon à la Maison franco-japonaise. Il a remis directement au Président Teruhisa Komatsu de la Société franco-japonaise d’Océanographie du Japon, une médaille commandée au graveur médailleur, Nicolas Salagnac, Meilleur Ouvrier de France par la Société franco-japonaise d’Océanographie France, pour commémorer le 60ème anniversaire de la fondation de la Société franco-japonaise d’Océanographie du Japon（Fig. 1）. La Société franco-japonaise d’Océanographie du Japon a conservé précieusement cette médaille commémorative（Fig. 2）comme preuve de l’amitié entre la Société franco-japonaise d’Océanographie du Japon et la Société franco-japonaise d’Océanographie France.

Fig. 1 Dr Yves Hénocque, Vice-President of the Société franco-japonaise d'Océanographie France, handed over directly to the President Teruhisa Komatsu of the Société franco-japonaise d'Océanographie du Japon the medal that the engraver Nicolas Salagnac, Meilleur Ouvrier de France, had made on behalf of the Société franco-japonaise d'Océanographie France to commemorate the 60th anniversary of the creation of the Société franco-japonaise d'Océanographie du Japon.

Fig. 2 Photographs of the medal engraved by Nicolas Salagnac, Meilleur Ouvrier de France, commissioned by the Société franco-japonaise d'Océanographie France to commemorate the 60th anniversary of the foundation of the Société franco-japonaise d'Océanographie du Japon: the front of the medal on the left and the back on the right.

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Symposium Commemorating the 60th Anniversary of the Japanese-French Oceanographic Society of Japan: "60 years of Japanese-French cooperation in oceanography"

Teruhisa KOMATSU[1, 2)]*

Abstract: This article introduces the symposium commemorating the 60th anniversary of the Japanese-French Oceanographic Society of Japan (SFJO Japan), founded in 1960. Due to the COVID-19 pandemic, the symposium celebrating the 60th anniversary was postponed to 2021 and held virtually through the web. The symposium reviewed the historical exchanges between France and Japan in the field of oceanography and fisheries science and looked to the future. The first part highlighted significant moments in the exchange of sciences and technologies and collaboration between the two countries, such as the visit of the French deep-sea research submersible FNRS III to Japan in 1958 and the export of Japanese oyster spats to France in the 1960s and the establishment and activities of the French-Japanese Ocean Development Sub-Committee. Future cooperative plans were also presented: A research cooperation for studying seamounts around New Caledonia decided by the maritime dialogue between Japan and France and the Nature and Culture Project for exchanging knowledge and know-how between France and Japan. The second part introduced congratulation messages from academic societies and organisations related to the oceanography and fisheries science for celebrating 60th anniversary of SFJO of Japan. The SFJO of Japan acknowledged the persons who have contributed to the exchanges of oceanography and fisheries science between France and Japan. Vice-President of SFJO France delivered the message of congratulations and the commemorative medal from the SFJO France to the SFJO of Japan.

Keywords : *Société franco-japonaise d'Océanographie, Japanese-French Oceanographic Society, 60th Anniversary of the Japanese-French Oceanographic Society, Japanese-French cooperation in oceanography*

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1. Introduction

The Japanese-French Oceanographic Society of Japan, founded in 1960, celebrates its 60th anniversary in 2020. To mark this milestone, we wanted to look back at the kind of exchanges that have taken place between France and Japan, and to consider future exchanges in the field of oceanography and fisheries science including aquaculture/shellfish farming issues.

In the first part, we reviewed the history of exchanges between Japan and France in the field of oceanography. The pioneering moment in post-war French-Japanese exchanges in the field of marine science was the visit to Japan in 1958 of the French deep-sea research submersible FNRS Ⅲ called the bathyscaphe), on board of which was the Japanese scientist Professor Tadayoshi Sasaki of Tokyo University of Fisheries (Komatsu and Ceccaldi, 2023). In the mid-1960s, after a large number of oysters died in France, Professor Takeo Imai of Tohoku University, a member of the Japanese-French Oceanographic Society of Japan (*Société franco-japonaise d'Océanographie*: SFJO), and others worked on quarantining for export of Sanriku oyster spats to France (Koike and Komatsu, 2023). Thus, the export of Japanese oyster spats saved the French oyster industry, which was in great danger at the time. In July 1974, the Japanese and French governments signed an agreement on science and technology, under which "the French-Japanese Ocean Development Sub-Committee" for cooperation was established (Totani, 2023). The French and Japanese governments take turns convening the group every two years or so, and it continues to promote research in the field of marine science and fisheries science between Japan and France. The minutes of this meeting are used to review the exchanges in the field of marine science and fisheries science between the two countries. In addition, a maritime dialogue has been initiated between the French and Japanese governments, and the first Japan-France Comprehensive Maritime Dialogue was held in Noumea on 20 September 2019. Thanks to the efforts of Yves Hénocque, a Vice-President of the Japanese-French Oceanographic Society of France and others, it was decided to carry out a study of the seamounts around New Caledonia, based on a memorandum of understanding between the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the *Institut Français de Recherche pour l'Exploitation de la Mer* (Ifremer). In addition, the two Japanese-French Oceanographic Societies are preparing a "Nature and Culture" project which aims to bring together the traditional and academic knowledge of both countries to achieve sustainable exploitation of the sea (Prouzet, 2023). In the first part, we will reflect on these issues and discuss future cooperation.

The second part aims to reflect on the contribution of the Japanese-French Oceanographic Society of Japan to the French-Japanese exchanges in oceanography summarised in the first part. We would like to present the messages of the academic organisations concerned about the 60 years of work of the Japanese-French Oceanographic Society of Japan and to thank those who have contributed to the French-Japanese cooperation in the field of oceanography and fisheries science.

The symposium was originally scheduled to take place in October 2020, but was postponed to 2021 due to the restrictions on the travel of people between France and Japan following the COVID-19 pandemic disaster. In this situation, we decided to organize this symposium, although it is the 60th anniversary plus one year, using the Internet, as we now have a system in place at the *Maison franco-japonaise* that allows French researchers to participate in the symposium.

2. Structure of the symposium

This symposium was organised by the Japanese-French Oceanographic Society of Japan and the French Institute of Research on Japan at Maison franco-japonaise（*Institut français de Recherche sur le Japon à la Maison franco-japonaise*: IFRJ）. It was supported by the Ministry of Education, Culture, Sports, Science and Technology, the Service for Science and Technology, French Embassy in Japan, the Japanese-French Oceanographic Society of France, the Japan Agency for Marine-Earth Science and Technology of Japan, the Japanese Society of Fisheries Science, the Japanese Society of Fisheries Oceanography, the Oceanographic Society of Japan, the *Fondation Sasakawa franco-japonaise*, the Japanese National Committee of the UN Decade of Ocean Science for Sustainable Development. It consisted of Part 1 "History of Japanese-French exchanges in oceanography" and Part 2 "Celebration of the 60th anniversary of the Japanese-French Oceanographic Society of Japan". The latter part is introduced in the biggening of this special issue.

3. Programme

Time（JST）	Titre of the presentation	Affiliation	Speaker
13：00 ～13：10	Congratulatory speech at the conference	French Institute for Research on Japan	Professor Bernard Thomann
	Explanation of the objective of this conference	President of the Japanese-French Oceanographic Society（SFJO）of Japan	Professor Teruhisa Komatsu
		President of the SFJO France	Dr Patrick Prouzet
Part 1 : History of Japanese-French exchanges in oceanography			
13：10 ～13：40	Why did the FNRS III bathyscaphe come to Japan? A major step in Japanese-French cooperation in the field of oceanography	Honorary President of the SFJO France President of the SFJO Japan	Professor Hubert-Jean Ceccaldi and Professor Teruhisa Komatsu
13：40 ～14：10	Japanese-French exchanges in the field of fisheries science: Mass die-off of oysters in France and export of Sanriku oyster spats	Advisor of the SFJO Japan	Professor Yasuyuki Koike
14：10 ～14：40	Creation of the French-Japanese Ocean Development Sub-Committee and its subsequent activities	Ministry of Education, Culture, Sports, Science and Technology of Japan	Mr Gen Totani
14：40 ～15：10	French-Japanese dialogue on the marine environment and marine research: seamount research in New Caledonia	Vise-President of the SFJO France	Dr Yves Henocque
15：10 ～15：40	Nature and Culture Project: Exchange of knowledge and know-how between France and Japan - Around the 5 pillars of sustainable development and the 5 senses	President of the SFJO France	Dr Patrick Prouzet

15：40 ～15：55	General discussion	Moderator Professor Yuji Tanaka（Vice-President of the SFJO of Japan）
15：55 ～16：05	Break	

Part 2: Celebration of the 60th anniversary of the Japanese-French Oceanographic Society of Japan			
16：05 ～16：25	Creation of the Japanese-French Oceanographic Society in 1960 and its contribution to the development of cooperation in the field of oceanography between France and Japan	President of the SFJO of Japan	Professor Teruhisa Komatsu
16：25 ～16：45	Congratulations from French Embassy in Japan	Scientific Counsellor	Professor Didier Marty-Dessus
	Introduction of congratulatory speeches from the scientific community read on behalf	Vise-President of the SFJO of Japan	Dr Kazufumi Takayanagi
16：45 ～16：55	Message of congratulations and presentation of a commemorative medal from the Japanese-French Oceanographic Society of France to the Japanese-French Oceanographic Society of Japan	Vise-President of the SFJO France	Dr Yves Hénocque
16：55 ～17：05	Presentation of a certificate of appreciation to those who contributed to the oceanography exchange between France and Japan		
17：05 ～17：15	19th Japanese-French Oceanography Symposium - Caen, France - October- 2023	Professor at the University of Caen Normandy/the SFJO France	Professor Jean-Claude Dauvin
17：15 ～17：20	Closing remarks	Vice-President of the SFJO of Japan	Dr Kazufumi Takayanagi

4. Abstracts of Part 1

4.1 Why did the FNRS III bathyscaphe come to Japan? A major step in French-Japanese cooperation in the field of oceanography

Hubert-Jean CECCALDI[1)] and Teruhisa KOMATSU[2)]
1) Japanese-French Oceanographic Society France
2) Japanese-French Oceanographic Society of Japan

On 19 May 1958, the French bathyscaphe FNRS III arrived in the port of Yokohama from the French port of Toulon, transported by a cargo ship, the Atsuta Maru of the NYK Line. The most advanced manned submersible in the world at the time, capable of studying the deep sea, arrived from France to conduct research in the Japan Trenches. Several Japanese oceanographers participated in these dives and obtained excellent results. These joint operations led to the creation of the Japanese-French Oceanographic Society in 1960. In the context of this symposium, where we have the task of reviewing the exchanges between Japan and France in the field of oceanography and fisheries science, we would like to reveal some little-known aspects of the visit of the FNRS III bathyscaphe to Japan.

The visit of the bathyscaphe FNRS III to Japan started with the encounter of a Japanese oceanographer, Professor Tadayoshi Sasaki of the Tokyo University of Fisheries (Tokyo Suisan Daigaku), and a French oceanographer, Professor Louis Fage of the *Muséum National d'Histoire Naturelle* and Director of the *Institut Océanographique de Paris*. In 1951, Tadayoshi Sasaki, a specialist in physical oceanography, was working as a researcher at the Research Institute of Physics and Chemistry, RIKEN (Rikagaku Kenkyūjo), in Japan, where he studied the ocean floor down to about 200 m in a cable-suspended submersible called Kuroshio.

In 1953, he became a professor at the Tokyo University of Fisheries, and from January to August 1956, he was sent abroad as a researcher by the Japanese Ministry of Education to the *Institut Océanographique de Paris*. In January 1958, Professor Tadayoshi Sasaki, who had a passion for deep-sea research, and Professor Louis Fage, Director of the *Institut océanographique*, met in Paris to discuss their research. In January 1958, after long discussions, the two specialists decided to bring the FNRS III Bathyscaphe to Japan.

On his return to Japan in August 1958, Professor Tadayoshi Sasaki, with the support of the leading newspaper Asahi Shimbun, set up a Japanese committee to coordinate the use of the bathyscaphe and, at the end of December 1956, he informed Professor Fage that the FNRS III bathyscaphe was ready to be received. It was decided to send it to Japan from May to the end of August 1958.

In this presentation, we also give an overview of how the French-Japanese co-operation in the field of oceanography and fisheries science developed after the departure of the FNRS III bathyscaphe from Japan at the end of August 1958.

We would like to recall here that the very existence and current activities of the Japanese-French Oceanographic Society of Japan are the result of these encounters, exchanges and events in 1958.

4.2 French-Japanese exchanges in the field of fisheries science: Mass die-off of oysters in France and export of Sanriku oyster spats

Yasuyuki Koike
Japanese-French Oceanographic Society of Japan

The Japanese-French Oceanographic Society (SFJO) was founded in 1960 by Professor Tadayoshi Sasaki of the former Tokyo University of Fisheries, who had been impressed by the advanced technology of French oceanography when the deep-sea exploration bathyscaphe FNRS III made a deep dive off the coast of Sanriku in Japan in the late 1950s. This led to a flourishing scientific and technical exchange, both in oceanography and fisheries. In the 1970s, researchers from Japan and France alternated visits to transfer or study the aquaculture techniques. In particular, France learned a lot from Japan, which had a long lead in the production of fish and shellfish (yellowtail, sea bream, abalone, scallops, shrimp, seaweed, etc.) cultures and in aquaculture techniques. However, in the case of oyster farming, France also has developed its own cultivation techniques adapted to the French marine environment.

In the late 1960s, an oyster disease spread in France, causing massive mortality of French oysters.

The response was to transplant Portuguese oysters, but a few years later this species was also severely damaged by another disease. At that time, the Scientific and Technical Institute of Marine Fisheries of France (*l'Institut Scientifique et Technique des Pêches Maritimes*) asked the member of SFJO Professor Takeo Imai of Tohoku University, with whom it had a close relationship, to send the oyster spats from Japan to France. In response to this request, a research group of Professors Takeo Imai and Tadashi Nomura, Akimitsu Koganezawa of the Tohoku Regional Fisheries Research Laboratory and Kunio Goto of the Miyagi Prefectural Fisheries Experimental Station, developed techniques to prevent exported Japanese oysters from carrying parasites and diseases to France and to grow the single-seed oysters requested by France. As a result, a large quantity of oyster spats was exported from Sanriku to France in early 1970, and the spats were delivered to oyster farmers throughout France to revive oyster farming.

Forty years later, on 11 March 2011, the Sanriku Coast of Japan was hit by a devastating tsunami caused by the earthquake, which brought extensive damage to aquaculture facilities. In response, the French oyster farming industry launched the "*Okaeshi*" (meaning "return gift" in English) project, providing aquaculture materials such as ropes and buoys for oyster farmers in Sanriku Coast. Apart from the *Okaeshi* project, a group of researchers belonging to the SFJO of Japan and France voluntarily pooled donation in each society. The total of the donations from two societies pooling the donation from volunteer members, the Association for the Development of Aquaculture, the Air Liquide Foundation, the Rotary Club of Marseille-Saint-Jean was 3,300,000 yen for recovering Sanriku Coastal fisheries. We consulted prefectural fisheries research centres of Iwate and Miyagi prefectures, with which France has had close relations since export of Sanriku oyster spats to France, about what aquaculture equipment Sanriku oyster farmers need now. According to the responses, we purchased seven sets of plankton nets and microscopes needed to collect oyster larvae, with the help of equipment manufacturers Olympus Medical Science and Rigosha, who offered discounts, and donated them to research institutions in both prefectures in summer 2011, when the oysters were spawning. In the summer of the year of the disaster, this equipment, along with those French oyster farmers sent to Sanriku, played a role in making the collection of oyster spats possible.

The following year, in the autumn of 2012, the SFJOs of Japan and France organised a seminar in Shiogama to exchange information between researchers and oyster farmers of Japan and France. Two months later, Dr Tetsuo Seki (former director of the Tohoku Regional Fisheries Research Laboratory) and I were invited as speakers to the World Oyster Congress organized by the oyster farmers in Arcachon, France, together with Dr Kunio Goto and two other oyster farmers. Dr Goto was welcomed as a contributor to the rescue of the French oyster crisis 40 years ago. We discussed the continuation of technical exchanges of oyster farming in the future.

The great bond created by the export of oyster spats from Sanriku to France has since been nurtured and carried on to a large extent by the SFJOs which regularly organise symposia and technical exchanges on oceanography and fisheries science in Japan and France.

4.3 Establishment of the French-Japanese Ocean Development Sub-Committee and its subsequent activities

Gen TOTANI
Ocean and Earth Division, Research and Development Bureau,
Ministry of Education, Culture, Sports, Science and Technology

The French-Japanese Ocean Development Sub-Committee has its origin in the Agreement on Scientific and Technological Cooperation between the Government of Japan and the Government of the French Republic signed on 2 July 1974. Article 3 of the agreement provides for the establishment of a joint Japan-France Committee for Scientific and Technological Cooperation and the creation of specialised groups within this committee. It was quickly agreed to set up a French-Japanese Ocean Development Sub-Committee to promote cooperation between the two countries. This reflected a great interest in marine development in both countries at the time, and it was on this basis that the Japanese-French Oceanographic Society was established in 1960, following the visit of the FNRS III bathyscaphe to Japan in 1958 and the Archimedes in 1962. Since then, understanding in the field of oceanography has been deepened and the basis for cooperation between the two countries has been developed. In both countries, fisheries research institutes were established in the 19th century to support the then flourishing fisheries sector, and both countries have set up institutions to promote the development of marine technology, such as the *Centre National pour l'Exploitation des Océans* (CNEXO) in France established in January 1967 and the Japan Marine Science and Technology Center (JAMSTEC) in October 1971. At the first meeting of the French-Japanese Ocean Development Sub-Committee, held in Tokyo in April 1975, in addition to the proposals made by the French side, the Japanese side proposed specific areas of interest, namely (1) diving technology, (2) coastal development and marine structures, and (3) marine observation devices. Since then, the subcommittee has been one of the most active and long-standing organisations of its kind. The two parts of the group meet approximately every 18 months, alternately in Japan and France. Currently, the Chair of the Japanese side is the Director of Deep Sea Exploration, Ocean and Earth Division, Office of Research and Development, MEXT, and the Chair of the French side is the Director of European and International Affairs, *Institut français de recherche pour l'exploitation de la mer* (Ifremer), the successor organisation to CNEXO.

More recently, the 27th meeting was held in Tokyo in May 2018, and the next edition was planned to be held in France in 2020, but the new COVID-19 pandemic has made international travel difficult, and the meeting has not taken place to date.

This symposium will be an opportunity to look back at the establishment of the French-Japanese Ocean Development Sub-Committee, the evolution of its focus and the results obtained so far. This event will also be an opportunity to discuss the activities and cooperation between our two countries in the framework of the United Nations Decade of Marine Science for Sustainable Development (2021–2030) launched this year.

4.4 About the France-Japan deep observatory project in New Caledonia: political context, preparation process, and perspectives

Yves Hénocque
Japanese-French Oceanographic Society France

This summary uses large excerpts from the 2019 workshop that was held between all the scientific parties in Noumea, New Caledonia

Political and institutional context

The French State and the New Caledonian government representatives support the observatory project as a tangible action for regional cooperation on the preservation of biodiversity, fisheries management, and climate change. New Caledonian lagoons are registered as UNESCO World Heritage and its entire EEZ has been adopted as a multi-use natural park with a management plan 2018–2022[1) including (i) Research development, (ii) Innovation more particularly for shipping surveillance, (iii) Economic development and (iv) Regional cooperation with neighboring countries. It is about the preservation and development of the natural heritage with the participation and for the well-being of local communities.

The Pacific Community (SPC)[2), an intergovernmental organization with 26 Member States and territories, has a mission "to work for the well-being of Pacific people through the effective and innovative application of science and knowledge" with a vision to 'assist the Pacific Community in achieving SDGs and contributing to the Blue Pacific vision.'

The Consortium for Cooperation in Research, Higher Education and Innovation in the New Caledonia (CRESICA[3)) federates university and research institutes in order to optimise resources and equipment, as well as reinforcing the cooperation in the Pacific area. The University of New Caledonia is also a member to the Pacific Islands Universities Research Network (PIURN)[4).

Ifremer and JAMSTEC, long term partners in ocean research, spearhead the organization of this workshop to define the scientific and technological objectives whilst bearing in mind the social issues through local participation.

New Caledonia: protection and sustainable development

The area: Natural Park of the Coral Sea

Created in 2014, the Natural Park of the Coral Sea cover the entire EEZ of New Caledonia of 1.3 million km^2. It has a rich biodiversity with many deep water habitats like seamounts, submarine volcanoes in the South and deep trenches in the eastern part. The first concern is to develop a better understanding of the deep-sea ecosystem functioning which is poorly known. There is a need for an integrated scientific monitoring system to better assess the impacts of anthropogenic activity and the effectiveness of ecosystem-based management plan.

New Caledonia maritime activities

Labeled as one of the 'Innovation territory', more specifically in relation with the ocean, New

Caledonia is considered as a 'demonstration area' for ocean observation in the Pacific. Among others, there are four important innovation projects: (1) SMART cable initiative, using the opportunity of telecom cable laying between New Caledonia and Vanuatu, to create two observation nodes on each side of the trench in between the two countries; (2) ABYSSA, consisting in the development of a fleet of underwater submarine vehicles; (3) REMORA, utilizing wave gliders as surface and subsurface platforms for measuring contaminants, and (4) a geospatial marine data hub.

New Caledonia: underwater geological characteristics

98% of the New Caledonia territory is underwater. The bottom of its marine area is made of diverse features from east to west: the oceanic domain with crusts and volcanic arc, the submarine continent, and the Tasman basin. From what is known but also largely unknown, some ideas of what could be an observatory contribute to are given as:

- Volcanism and hydrothermal vents
- Subduction/collision seismicity (earthquakes)
- Sea-level rise and land motions (e.g.subsidence)
- Coastal dynamics (sediments) and source to sink sediment transfers
- Abrupt margins and slope instabilities
- Climate change and short to long term changes in the deep

Which technology from what has been already developed?

Ifremer and JAMSTEC have respectively about 10-year experience of running deep-sea observatory systems but for different purposes and with different technological concepts.

The IFREMER EMSO-Azores deep sea observatory is located offshore the Azores on the mid-Atlantic ridge. It is a fix point observatory with two nodes (seismic activity and environmental parameters) and a buoy at surface for transmission of data. Several tools are linked to the nodes and in addition there are unconnected components for measuring temperature and many other physical parameters. Data management is done in real time and periodically (images). More recently, the ocean dynamic close to the bottom has been studied, more particularly regarding possible larval dispersion (connectivity). The perspectives include the deployment of an observatory in a protected area in the Bay of Biscay (West of metropolitan France) where deep coral habitats will be monitored. The challenges are about multidisciplinary observation, the dynamics and functioning of the ecosystem, and environmental monitoring for management. Ifremer has also a know-how in developing and running in situ instrumentation for chemistry, from surface to deep sea, including in specific environments such as hydrothermal vents.

In Japan, JAMSTEC has deployed the Dense Ocean floor Network for Earthquake and Tsunamis (DONET) with a high reliability and flexibility. Each node has 8 laboratory modules that can be connected to the network. The system may be complemented with the use of subsurface floating buoys (MERMAID) with different type of sensors for seismic, acoustic (cetaceans), pressure data application (meteorology, sea level change). Long-term sediment trap moorings in deep water are also being run.

Sharing knowledge and information with local stakeholders

Developing such a project requires attracting local stakeholders including decision makers at regional and local level in related science and technology fields. This can be achieved by engaging them with deep-sea research challenges, raising awareness of deep-sea exploration and discoveries, an-demphasizing the need to fill gaps in ocean/climate interaction processes, seafloor geological processes, and deep-ecosystem functions and dynamics. Citizen Science is increasingly viewed as a way to empower communities by involving them in research that can be used to drive forward policy changes.

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4.5 Nature and Culture Project: Exchange of knowledge and know-how between France and Japan: Around the 5 pillars of Sustainable Development and the 5 senses

Patrick Prouzet
President of the Japanese-French Oceanographic Society France

The objective of Sustainable Development as defined by the World Commission on Environment and Development in 1988 is: "to promote a state of harmony between human beings and between Human and Nature". The Brundtland Report in 1987 defined Sustainable Development as the convergence of three spheres of equivalent interest: social, economic and environmental.

It is clear not only from the assessment of the state of our environment within structures such as the IPCC (Intergovernmental Panel on Climate Change) or the IPBES (International Panel for Biodiversity and Ecosystem Services), but also from the observations made by many local players that the implementation of a sustainable development policy associated with genuine environmental governance does not correspond to the initial objectives announced (Millennium Assessment or Conferences of the Parties).

The implementation of a sustainable development policy is decided within a set of actors of varying strength and influence. Within this framework, economic and social imperatives have largely taken precedence over environmental interests and the actors whose future depends directly on the exploitation of environmental resources, particularly aquatic resources, are not sufficiently listened to. Hence the need to consider environmental governance as one of the pillars of sustainable development in order to put environmental protection at the top of managers' concerns and to minimise the ecological footprint of all uses.

To avoid future generations being left behind in these negotiations and to put intergenerational solidarity at the heart of the negotiations, it is important to take culture into account as the 5th pillar of this development and to link "Nature and Culture" in order to ensure the transmission of knowledge and know-how between generations.

This is the philosophy of the "Nature and Culture" project, which integrates the different expertises, knowledge and know-how for the development of territorial projects between French and Japanese actors: restoration of sea grass beds（Seto Sea and Arcachon Basin）; enhancement of fisheries and shellfish production（eel, oyster farming networks）, promotion of local products and regional cultures（implementation of Franco-Japanese projects within a slow-food framework） and education on the environment It is also for this reason that the 5 pillars of sustainable development are associated with the 5 senses: hearing, smell, sight, taste and touch in order to highlight the culture and productions of the fishing and aquaculture/shellfish farming communities within a framework of sustainable development.

5. Conclusion

Although the symposium was conducted with a web-based system, it was attended by 100 participants from France as well as Japan. The success of the symposium can be attributed to the long history of exchanges between Japan and France in the fields of oceanography and fisheries science, which began in 1958. Collaboration in these fields between Japan and France may contribute to the future generations and realising sustainable development goals through its activities.

Acknowledgements

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Why did the bathyscaphe FNRS III come to Japan in 1958 ? The beginning of French-Japanese cooperation in the field of oceanography

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Abstract: This paper provides an overview of why the bathyscaphe FNRS III came to Japan in May 1958 and how it explored Japan Trench with Japanese and French scientists. Launched in Toulon in 1953, the FNRS III was the most advanced submersible in the world at the time. Professor Tadayoshi Sasaki of Tokyo University of Fisheries who had been conducting deep-sea research in Japan, spent seven months at the *Institut océanographique* of Paris from January 1956. Then, he met Professor Louis Fage of the *Museum National d'Histoire naturelle* and the *Institut océanographique* who was President of *Comité de Direction du Bathyscaphecf et de la Calypso*. After some persuasion by Professor Sasaki, Professor Fage promised to send the bathyscaphe to Japan. Professor Sasaki with another Japanese organisations prepared to accept FNRS III in Japan. The bathyscaphe arrived in Japan in May 1958 and descended into the Japan Trench and surrounds to achieve valuable findings. Based on them, the Japanese-French Oceanographic Society (SFJO) was established in Japan in April 1960 to develop and deepen French-Japanese cooperation in oceanography and fisheries science. The SFJO has been promoting and contributing to cooperations between the two countries in the fields of oceanography and fisheries science since then.

Keywords : *bathyscaphe FNRS III, Japanese-French Oceanographic Society, Japan Trench, French-Japanese cooperation in oceanography*

1. What is a bathyscaphe?

A bathyscaphe is an underwater device for exploring the deep sea. Its name, derived from the Greek words 'bathus' (deep) and 'skaphos' (ship) (ASAHI SHIMBUN, 1958). It was invented by Swiss Auguste Piccard, a professor at the Free

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Fig. 1 Swiss Auguste Piccard (left: https://en.wikipedia.org/wiki/Auguste_Piccard), professor at the Free University of Brussels, who invented the bathyscaphe, Professor Beaker (centre: https://comicvine.gamespot.com/professor-calculus/4005-67717/images/), modelled on Professor Piccard in the Belgian cartoon "The Adventures of Tintin" and cover of "Red Rackham's Treasure" issue of "Adventures of Tintin" designed by Hergé, featuring Professor Calculus and the bathyscaphe (right: https://ec.tintin.sc/shopdetail/003006000012/)

University of Brussels, and perfected by his son Jacques Piccard. It descends to great depths using two principles:

a) a spherical pressurised cabin built in thick steel, in which the air is renewed, where scientists or observers take place with a captain, the bathysphere,

b) a reservoir filled with petroleum, supporting the bathysphere, all floating at the surface according to the principle of Archimedes. The 2-3-seater bathyscaphe descends by gravity and rises by releasing ballast.

Incidentally, Professor Auguste Piccard was the model for the Belgian cartoon "Professor Calculus (Tournesol in French and Beaker in Japanese)" in the Belgian cartoon "The Adventures of Tintin". In "Red Rackham's Treasure", one of "Adventures of Tintin" designed by the designer Hergé, there is a bathyscaphe (Fig. 1) (https://en.wikipedia.org/wiki/Professor_Calculus accessed on 1 June 2021).

FNRS III (Fig. 2) was the second bathyscaphe developed for deep-sea exploration after FNRS II. It was a French-Belgian collaboration since 1950, completed and launched in June 1953 at the naval shipyard in Toulon, France (SASAKI, 1958b). She was commanded by *Capitaine de Corvette* Georges Houot, with the assistance of marine Engineer in Chief Pierre Willm (Fig. 2).

At the sea surface, the water is fed into the air pipe through the seawater inlet shown in Fig. 3 and sinks due to gravity on the lead and steel ballast, the wire rope and the seawater in the air pipe (SASAKI, 1958b). The buoyancy of the petroleum in the float allows the boat to dive slowly. The FNRS III has one electrically driven propeller each to starboard and port, and can

Fig. 2 Picture of bathyscaphe FNRS III arrived at the Port of Yokohama in May 1958 (SASAKI, 1958b).

move forwards and backwards, left and right, at speeds of 2–3 km s^{-1}. When the FNRS III discards the iron ballast, its buoyancy exceeds the force of gravity and the FNRS III rises from the seabed.

2. Encounter between the great French and Japanese oceanographers in Paris

Why did a French bathyscaphe come to Japan? The key to the success of this great undertaking of bathyscaphe's visit to Japan was the encounter between the great French and Japanese oceanographers at *Institut océanographique* of Paris in January 1956. One was Professor Tadayoshi Sasaki of Tokyo University of Fisheries and the other was Professor Louis Fage, *Muséum national d'Histoire naturelle* (National Museum of Natural History) and *Institut océanographique* in Paris (Fig. 4) (SASAKI, 1958b).

Professor Sasaki graduated from the Faculty of Science at Hokkaido Imperial University. After working as a preparatory professor at Keijo Imperial University, he became a researcher at the Nishina Laboratory of RIKEN in 1944, and obtained his Doctor of Science degree from Hokkaido University in 1949 (https://ja.wikipedia.org/wiki/佐々木忠義 accessed on 1 June 2021). At this time, he conducted deep-sea research using a suspended submersible called the Kuroshio (SASAKI, 1958a). In 1951, the Kuroshio, which recorded a depth of 208 m in Sagami Bay, was investigating the seabed shallower than around 200 m. In 1953, he became a professor at Tokyo University of Fisheries and a senior researcher at Ocean Physics Laboratory of RIKEN. From January 1956, he was an overseas researcher of the Ministry of Education, staying at *Institut océanographique* of Paris until August 1956.

Professor Louis Fage studied biology at Sorbonne University, where he obtained his PhD in 1906 (FOREST, 1964). He then spent 14 years working on Mediterranean fish research at the Marine Biology Laboratory in Banyuls-sur-Mer. From 1920 he worked in the zoological department of the *Muséum national d'Histoire naturelle*, where he was appointed professor of zoology in 1938.

A committee was set up in Paris to establish a coherent programme for the scientific exploitation of bathyscaphe from 1954. Professor Louis Fage, the most eminent French marine scientist of his time chaired the *Comité de Direction du Bathyscaphe et de la Calypso* (Bathyscaphe and Calypso Steering Committee). *La Calypso* is

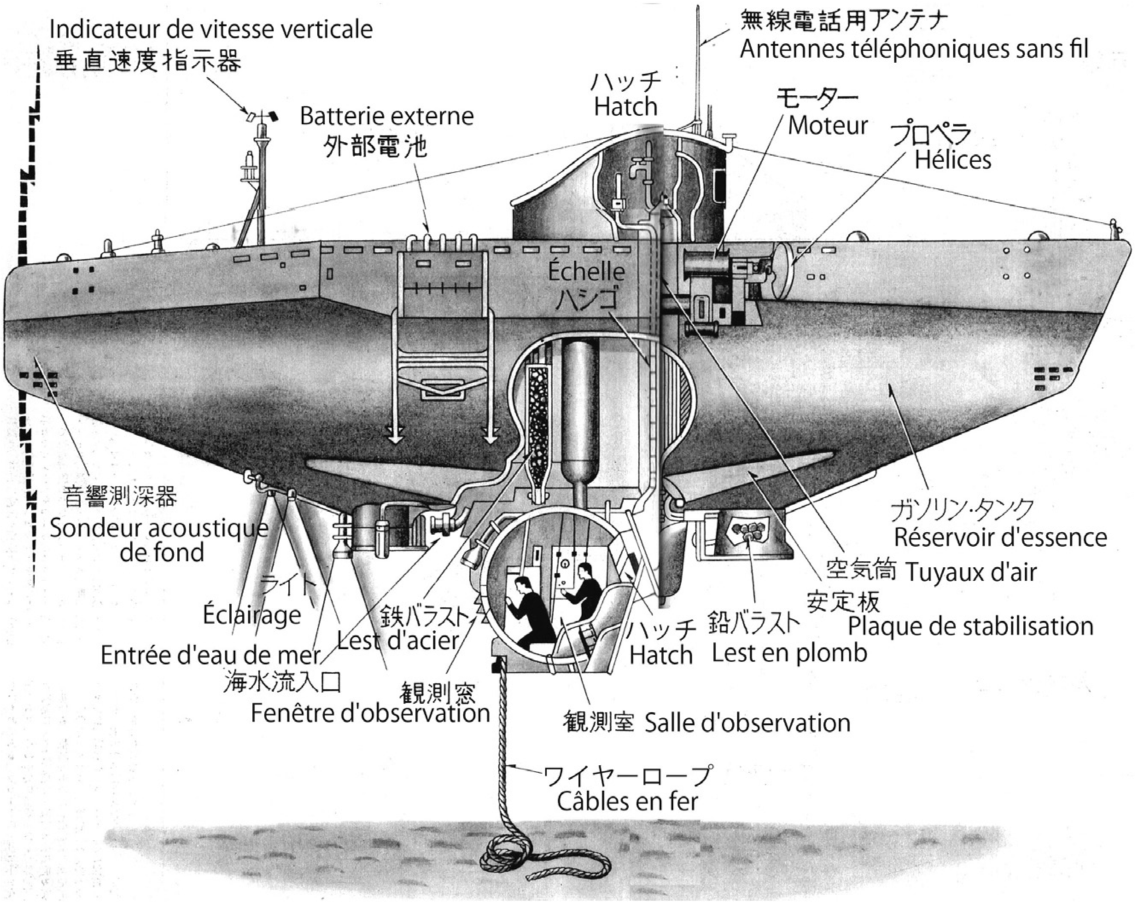


Fig. 3 Schematic diagram showing details of the bathyscaphe FNRS III (Source: Asahi Shimbun, 1958).

Fig. 4 Tadayoshi Sasaki, Professor at Tokyo University of Fisheries (left: Asahi Shimbun, 1958) and Louis Fage, Professor at the National Museum of Natural History and Oceanographic Institute (right: Forest, 1964).

RV *Calypso* which is a former British Royal Navy minesweeper converted into a research vessel for the oceanographic researcher Jacques Cousteau, equipped with a mobile laboratory for underwater field research during 1950 to 1997 (https://en.wikipedia.org/wiki/RV_Calypso accessed on 1 June 2021).

3. Professor Sasaki's approach to Professor Fage

During Professor Sasaki's stay at *Institut océanographique* from January 1956 as an overseas researcher of the Ministry of Education, Professor Sasaki became acquainted with the

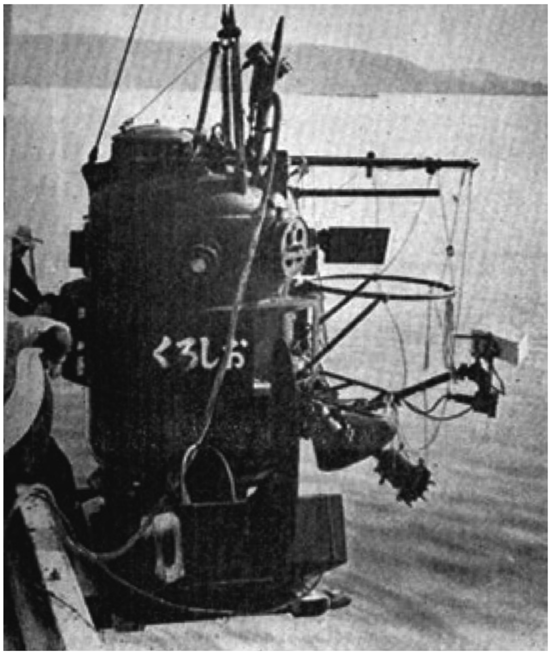


Fig. 5 Hokkaido University's suspended submersible Kuroshio (SASAKI, 1958a).

Director, Professor Louis Fage. It was then that he learnt that Professor Fage was President of the Bathyscaphe and Calypso Steering Committee. Two years earlier, on 15 February 1954, bathyscaphe FNRS III had successfully dived to a bottom depth of 4,050 m in Senegalese waters. Professor Sasaki then strongly wanted to bring bathyscaphe FNRS III to Japan to explore the Japan Trench at any cost.

Let us reproduce a conversation between Professor Fage and Professor Sasaki that took place at *Institut Oceanographique* in January 1956, based on Professor Sasaki's book (SASAKI, 1958b). According to his book, the discussions at the institute were lengthy.

Professor Sasaki: I would like to invite bathyscaphe to Japan and do deep-sea research in Japan.

Professor Fage: There is a bathyscaphe in Japan, isn't there?

Professor Fage considered the small submersible Kuroshio to be Japan's bathyscaphe. The Kuroshio is a suspended type and can only dive to a depth of 200 m (Fig. 5). The French bathyscaphe FNRS III, on the other hand, had dived to a depth of 4,050 m in 1954. Professor Sasaki explained this to Professor Fage.

Professor Fage: Why don't you make one bathyscaphe in Japan?

Professor Sasaki: In Japan today, we cannot make an excellent bathyscaphe like in France. Due to the high cost and technical problems, the building of the bathyscaphe FNRS III is not feasible.

Professor Fage: There are rumours that the Soviet Union is going to make a bathyscaphe, so they are going to explore the seas around Japan. If such rumours spread, the Japanese Government will be motivated to make a bathyscaphe.

Professor Sasaki: I am well aware that the Soviet Union has been studying Japan's surroundings in great detail, with their magnificent ships and a wide range of highly sophisticated observation equipment. I also know that they are particularly focused on the Japan Trench.

Professor Fage: The Emperor is a great biologist, so if you ask him, you will get funding.

Professor Sasaki: No, no, it is not easy for me to talk to His Majesty the Emperor, and even if I do talk to His Majesty the Emperor, it is not easy for the Government to fund my research.

After a long discussion.

Professor Fage: I understand well. Agreed. As I am the chairperson of the French bathyscaphe and Calypso Steering Committee, it is safe to send the bathyscaphe to Japan as long as I agree. When you return to Japan, you should be in high spirits and be well prepared to accept the bathyscaphe in Japan.

In Professor Sasaki's retrospect (SASAKI, 1958b), at first Professor Fage was very reluctant to send the bathyscaphe FNRS III to Japan. However, Professor Sasaki's passion convinced him.

4. Preparations for the reception of the bathyscaphe FNRS III in Japan

The Japanese side was to pay for the transport and research costs of the bathyscaphe FRNS III, the petrol to be put into the float of FNRS III and the accommodation of the French crew and scientist. For this reason, Professor Sasaki immediately looked for companies willing to fund the project after his return from France to Japan in August 1956. He approached film companies, fisheries companies and others, all to no avail (SASAKI, 1958b).

Finally, Professor Sasaki went to the Asahi Shimbun to ask for help. It was decided two days later after Professor Sasaki's visit that the Asahi Shimbun, one of the biggest newspaper companies in Japan, would bear the cost of inviting bathyscaphe FNRS III to Japan to explore the Japan Trench, because the Asahi Shimbun judged the expedition of bathyscaphe FNRS III in the Japan Trench as a very worthy task. The total amount of support, as a result of the estimates, came to 18 million yen, which the Asahi Shimbun would provide (SASAKI, 1958b).

The Japan Bathyscaphe Steering Committee was formed, chaired by Yoshikatsu Matsuike, President of Tokyo University of Fisheries including the heads of divisions and departments of the Ministry of Foreign Affairs, Ministry of Education, Fisheries Agency and Japan Coast Guard, President of the Science Council of Japan, Director of Tohoku Regional Fisheries Research Laboratory, Director of the Asahi Shimbun, President of Scientific Research Institute Ltd. (formerly RIKEN) and professors from the University of Tokyo, Tokyo University of Fisheries, Nagoya University and Tohoku University (ASAHI SHIMBUN, 1958) (Table 1; Fig 6). The purpose of this committee was to consider where, who and what kind of studies should be carried out using the bathyscaphe FNRS III. Note that the Japanese Government was represented at this time by the Ministry of Foreign Affairs, the Ministry of Education, the Japan Fisheries Agency and the Japan Coast Guard, as well as the President of the Science Council of Japan. The list of members of this committee shows how high Japan's expectations were.

At the end of December 1956, Professor Sasaki informed Professor Fage that it would be possible to receive the bathyscaphe in Japan. However, plans for the 1957 bathyscaphe operation had already been decided, so the bathyscaphe was to come to Japan the following year, in May 1958.

Professor Sasaki attended international conferences in Germany and Norway in September-October 1957. Taking advantage of the opportunity, he went to France after the international conferences. He returned to Japan from France in February 1958, having agreed the terms of the contract to accept the bathyscaphe belonging to French Navy from France to Japan e.g. that it would be transported by Japanese cargo ship and that the costs of transporting it would be borne by the Japan Bathyscaphe Steering Committee.

Table 1. Members of Japan Bathyscaphe Steering Committee.

President	President, Tokyo University of Fisheries	Yoshikatsu Matsuike
Committee Member	President, Tokyo University of Fisheries	Jyunichi Anbara
	Dean, Faculty of Agriculture, Tohoku University	Takeo Imai
	Professor, Tokyo University of Fisheries	Michitaka Uda
	Director, Academic Affairs Division, University Academic Affairs Bureau, Ministry of Education	Sumi Okada
	President, The University of Tokyo	Seiji Kaya
	Director, Tohoku Regional Fisheries Research Laboratory, Fisheries Agency	Kinosuke Kimura
	Professor, Tokyo University of Fisheries	Itsuo Kubo
	Professor, Tokyo University of Fisheries	Takeharu Kumagori
	Professor, Tokyo University of Fisheries	Tadayoshi Sasaki
	Professor and Head of Department of Fisheries, Tokyo University of Fisheries	Takejiro Sasayama
	Director of Hydrographic Department, Japan Coast Guard	Kanji Suda
	Professor, The University of Tokyo	Takao Suehiro
	Professor, Nagoya University	Ken Sugawara
	Director, First Division, Research Department, Fisheries Agency	Toru Sone
	Director, First Division, European and Asian Affairs Bureau, Ministry of Foreign Affairs	Kenjiro Rikiishi
	Professor, Tokyo University of Fisheries	Hiroshi Niino
	Professor, The University of Tokyo, President of the Oceanographic Society of Japan	Kouji Hidaka
	Chief Editor, Asahi Shimbun Tokyo Head Office	Tomoo Hirooka
	Professor, The University of Tokyo	Yoshiyuki Matsusue
	Professor, Tokyo University of Education	Yasuo Miyake
	President, Scientific Research Institute Ltd.	Takeshi Murayama

In order to borrow the bathyscaphe FNRS III from France, the Japan Bathyscaphe Steering Committee signed an agreement with the French Bathyscaphe and Calypso Steering Committee (President: Professor Louis Fage) for the "FNRS III bathyscaphe Study Mission in Japan". The important points of the contract are as follows:

a) The number of dives to be carried out is eleven. The allocation is eight dives with a crew nominated by the Japanese committee and three dives with French biologists;

b) The duration is three months;

c) The scientific results, as well as the photographic and film documentation, shall be the property of the French and Japanese organisations. The Asahi Shimbun shall have the exclusive right to publish all reportage, articles, photographs and films of dives made during the bathyscaphe's voyage and stay in Japan, except those in France and its overseas territories.

The Japan Bathyscaphe Steering Committee has often met to decide on studies, plans and other matters. It defined the research items as follows:

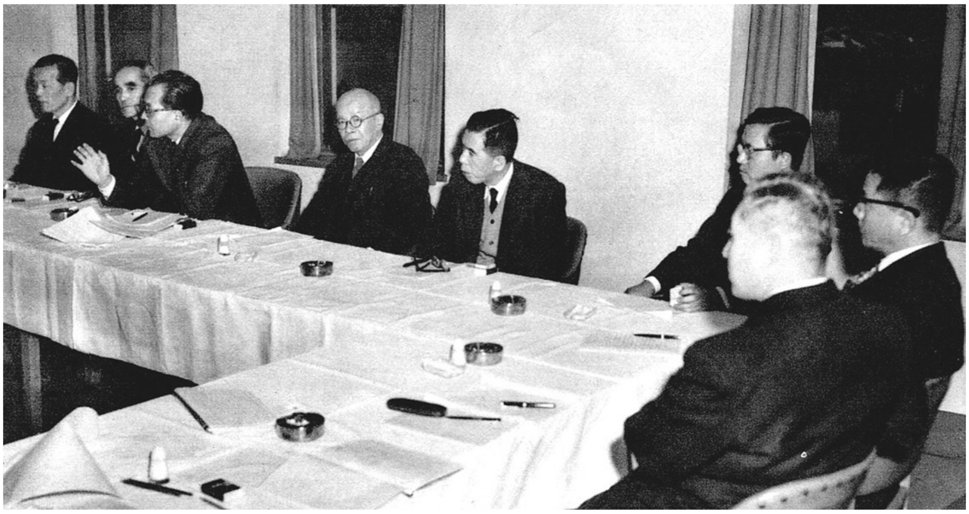


Fig. 6 Meeting of the Japanese Bathyscaphe Steering Committee held on 22 March 1958. The fourth from the left is the chairman of the committee, Professor Yoshikatsu Matsuike, President of Tokyo University of Fisheries (ASAHI SHIMBUN, 1958).

1) Study on the ecology of deep-sea swimming organisms,
2) Study on the ecology of deep-sea benthic and sedentary organisms,
3) Study on deep-sea luminescent organisms,
4) Study on deep-sea bottom bacteria,
5) Study on deep-sea fishing methods,
6) Study on fish reefs,
7) Study on DSL (acoustic false bottom image of ultrasound: so-called ghost seabed),
8) Study on marine optics such as attenuation polarisation and scattering of underwater light,
9) Study on deep-water currents,
10) Study on the chemical composition of deep seawater,
11) Study on trace elements in deep seawater,
12) Study on radioisotopes in deep seawater,
13) Study on the determination of the age of deep seawater by radiocarbon,
14) Study on ripple marks (striped pattern on the sand seabed),
15) Study on the topography and sediments of the deep-sea floor,
16) Study on topographic and sedimentary changes caused by artificial blasting and
17) Study on the structure of the Kuroshio Branch Current.

In addition, enquiries were made to universities and research institutions across Japan and some requests were received, but the majority fell into these 17 research items. However, the details of implementation were finally decided with Captain Gorges Houot after his arrival to Japan on 14 May 1958.

5. FNRS III's dives off Sanriku and surrounds

Bathyscaphe FNRS III finally arrived in Japan in May 1958, about two and a half years after Professors Lous Fage and Tadayoshi Sasaki had decided to bring bathyscaphe FNRS III to Japan in January 1956. The bathyscaphe FNRS III arrived on a trestle welded to the rear deck of NYK Atsuta Maru and securely tied down with ropes (Fig. 7). The members of the FNRS III crew and maintenance support were *Capitaine*

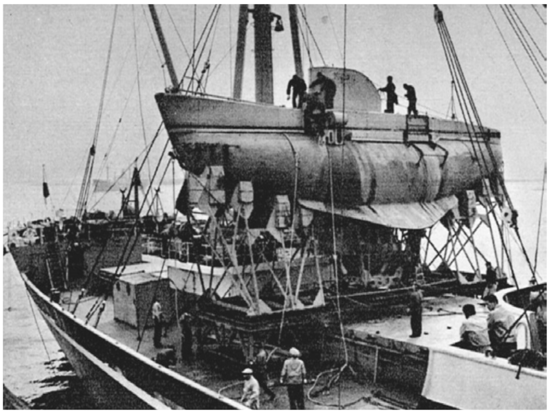


Fig. 7 Bathyscaphe FNRSIII arrives at the Port of Yokohama on a trestle welded to the rear deck of NYK Atsuta Maru and securely tied to a rope (ASAHI SHIMBUN, 1958).

de Corvette Georges Houot, *Enseigne de Vaissau* Gabriel O'Byrne, Petty Officer Daniel Rost, Petty Officer Michel Thébault, Petty Officer Clément Serrant and Petty Officer Marcel Berthelot. The title "Six Samurai of bathyscaphe" was used in an article about the crew of the French Navy's FNRS III coming to Japan, in reference to Akira

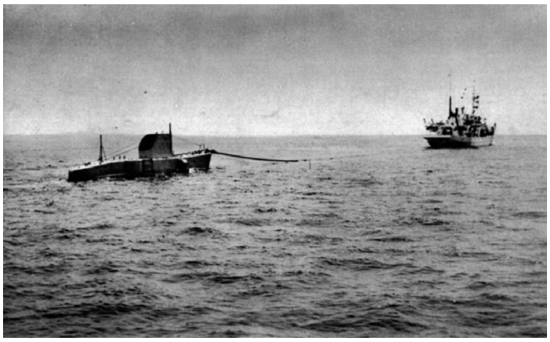


Fig. 9 FNRS III towed by TV Shinyo Maru from the Port of Yokohama to the Port of Onagawa on 1 June 1958 (ASAHI SHIMBUN, 1958).

Kurosawa's film Seven Samurai, which was released in 1954 and was highly acclaimed in Europe (Fig. 8).

On 1 June 1958, FNRS III was towed from Yokohama to Onagawa by TV Shinyo Maru of Tokyo University of Fisheries (Fig. 9), and on 7 June arrived at the Port of Onagawa, where the crew received a warm welcome (Fig. 10). FNRS III preparing to dive off Onagawa on 20 June 1958.

Fig. 8 A photograph of the crew welcoming bathyscaphe on the deck of NYK Atsuta Maru on her arrival at the port of Yokohama (left) and a scene from Akira Kurosawa's Seven Samurai (right: http://blog.nc-net.or.jp/nc/2011/11/post_178.html). The photo on the left was published in a French newspaper and shows, from left, *Enseigne de Vaissau* Gabriel O'Byrne, *Capitaine de Corvette* Georges Houot, Chief Petty Officer Daniel Rost, Petty Officer Michel Théveaut, Petty Officer Clément Serrant and Petty Officer Marcel Berthlot.

Fig. 10 The crew of the FNRS III received a great public welcome when they arrived in the Port of Onagawa on 7 June 1958 (ASAHI SHIMBUN, 1958).

Fig. 11 French and Japanese scientists aboard bathyscaphe FNRS III during a diving expedition in Japan (ASAHI SHIMBUN, 1958). Top row, left to right: Professor Tadayoshi Sasaki, Tokyo University of Fisheries (physical oceanography); Professor Jean-Marie Pérès, Aix-Marseille University (marine biology); Professor Hiroshi Niino, Tokyo University of Fisheries (seafloor geology); bottom row, left to right: Professor Takeharu Kumagori, Tokyo University of Fisheries (ocean acoustics); Professor Izuo Kubo, Tokyo University of Fisheries (marine biology); Professor Takuo Chiba, Fisheries Training Institute, Ministry of Agriculture, Forestry and Fisheries (marine planktonology).

A total of six Japanese and French scientists conducted deep-sea research aboard the bathyscaphe FNRS III. Professor Sasaki, specialist in marine physics, Professor Jean-Marie Pérès, Professor of University of Aix-Marseille in marine biology, Professor Hiroshi Niino of Tokyo University of Fisheries in seabed geology, Professor Takeharu Kumagori, of Tokyo University of Fisheries in ocean acoustics, Professor Izuo Kubo of Tokyo University of Fisheries in marine biology and Professor Takuo Chiba of Fisheries Training Institute, Ministry of Agriculture and Forestry in marine planktology (Fig. 11).

Some of the research results obtained by these professors are presented below. On 20 June, Professor Sasaki dived into the Japan Trench at a bottom depth of 3,000 m off Kinkasan (Fig. 12). He measured that the current on the seabed was 2 cm s^{-1}. Figure 13 shows Professor Sasaki attaching the current meter to the bathyscaphe.

Professor Pérès dived into the Japan Trench at a bottom depth of 1,000 m off Kinkasan on 26 June and at 1,650 m on 5 July to investigate the relationship between rapid changes in water temperature and plankton species in the mixed zone between the warm Kuroshio and Oyashio currents. On the seabed, animals were sketched and observed (Fig. 14). Sketches of deep-sea animals observed by Professor Pérès are shown in Fig. 14.

On 20 June 1958, Professor Sasaki and *Capitaine de Corvette* Houot dived to a depth of 3,000 m in the Japan Trench. At this time there was a plan to dump nuclear waste into the deep sea. Based on this observation, Professor Sasaki considered that radioactive waste should not be dumped, even in deep water, because of the currents on the seabed (Fig. 15).

The map of bathyscaphe FNRS III dive sites

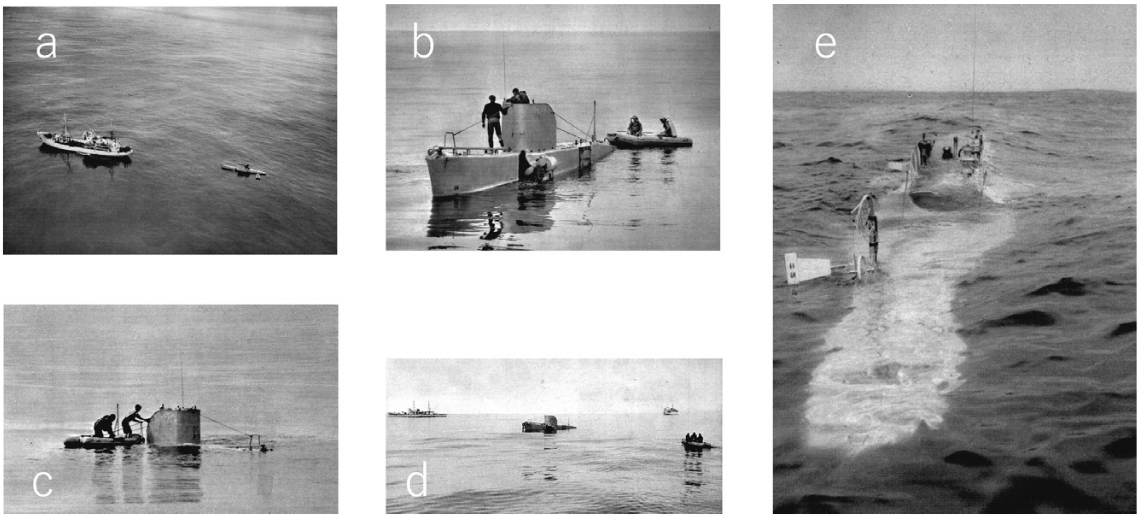


Fig. 12 Photos of FNRS III towed off Onagawa on 20 June 1958 (a), prepared to dive (b, c, d) and began diving (e) (ASAHI SHIMBUN, 1958).

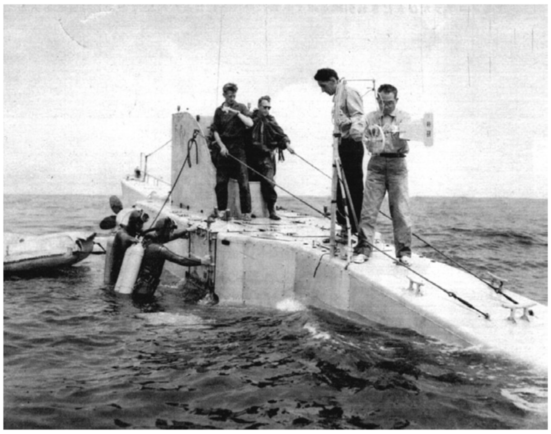


Fig. 13 Professor Tadayoshi Sasaki, Tokyo University of Fisheries, attaching a current meter to the deck of the FNRS III just before diving (ASAHI SHIMBUN, 1958).

over a period of nine dives, with the exception of the first and seventh dives where one journalist of Asahi Simbun Mr Jitsuo Kusaka and one cinematographer of Nippon Eiga Shinsha Mr Shigeo Hayashida, respectively, were on board. Therefore, scientific dives were conducted at three sites in the Japan Trench off Kinkasan, three sites off the Boso Peninsula and one site in Sagami Bay. The first dive off Kinkasan was to a depth of 3,000 m (Fig. 16).

On 27 August, the crew and bathyscaphe FNRS III returned to Toulon by sea from the Port of Yokohama (Fig. 17). On 31 August 1958, *Capitaine de Corvette* Houot, Chief Petty Officer Rost returned to Toulon by air from Haneda Airport. A number of Japanese could be seen seeing off the two on their return from Haneda Airport (Fig. 17). The Japanese were enthusiastic about the bathyscaphe FNRS III at this time and thanked France for its cooperation.

Professor Sasaki reported that, according to the original plan, Asahi Shimbun was to provide 18 million yen in funding, but in the end paid 50 million yen (SASAKI, 1967). The transport of bathyscaphe FNRS III from the Port of Toulon to the Port of Yokohama and back alone cost 20 million yen, in 1958. The bathyscaphe FNRS III diary of stay in Japan is summarized in Table 2.

Fig. 14 Photos of marine animals on the deep-sea floor observed by Professor Jean-Marie Pérès of Aix-Marseille University (left: the third dive; middle: the forth dive) and recorded in his notebook (right) (Asahi Shimbun, 1958).


朝日新聞

バチスカーフ
三千㍍潜水に成功
深海の水も流れる
佐々木教授が測定

闇内になお両論
中共対策 政府、見解調整へ

原子炉の廃棄物 捨て場は危険

海底三千㍍の一時間半
佐々木忠義教授手記

二匹のカニ発見
潮の流れは毎秒2㌢

米英仏加で代表七
準備終りソ連へ

ユニオン カーボン

社会戯評

Fig. 15 Front-page article in the 21 June 1958 issue of the Asahi Shimbun newspaper reporting that the bathyscaphe FNRS III had successfully made a dive to a bottom depth of 3,000 m in the Japan Trench. Professor Sasaki, who was on board the FNRS III, also reported a current speed of as much as 2 cm s^{-1} on the seabed. (Asahi Shimbun, 1958).

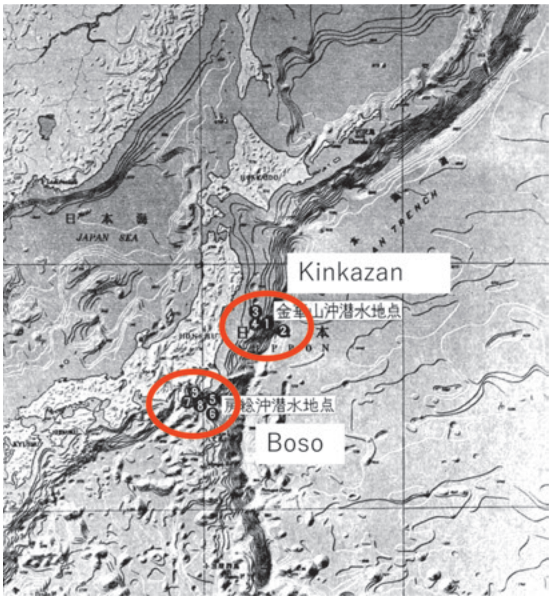


Fig. 16 Chart showing the dive locations of the FNRS III with Japanese and French researchers on board, with numbered dots 1 to 4 indicating dive locations off Kinkasan and dots 5 to 9 indicating dive locations off Boso (Asahi Shimbun, 1958).

6. Impacts of the successful dives by the bathyscaphe FNRS III

The success of the bathyscaphe FNRS III dives led to the development of French-Japanese cooperation in oceanography. On 7 April 1960, the first general meeting was held by Professor Sasaki and his colleagues at the Maison franco-japonaise to establish the Japanese-French Oceanographic Society. French-Japanese cooperation was further developed and in 1962 the newly built bathyscaphe Archimède came to Japan (Fig. 18).

On 25 July 1962, Henri-Germain Delauze, head

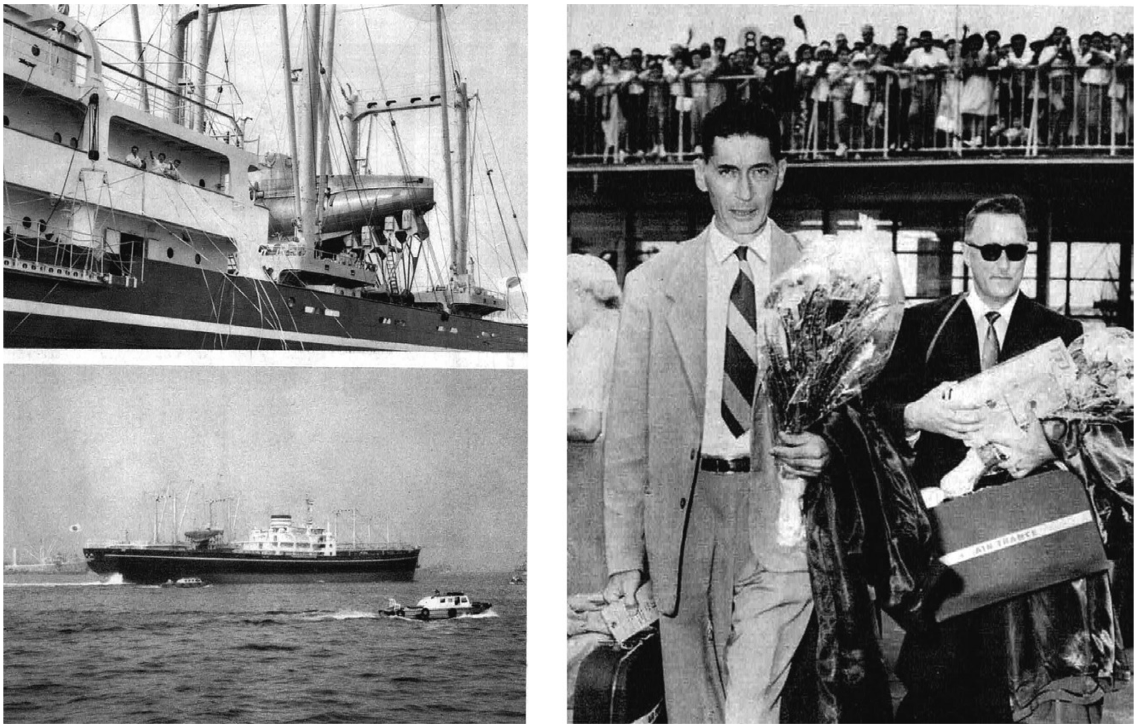


Fig. 17 NYK Suruga Maru (top and bottom left phots) departing from the Port of Yokohama for Toulon with bathyscaphe FNRS III on deck; *Capitaine de Corvette* Houot and Chief Petty Officer Rost (right photo) depart from Haneda Airport for Toulon, seen off by many Japanese (Asahi Shimbun, 1958).

of the bathyscaphe laboratory at CNRS, *Lieutnant* Gabriel O'Byrne (Fig. 19) and Professor Sasaki reached a bottom depth of 9,545 m in the Kuril Islands Trench on the Archimède (Fig. 20). On 15 July, *Capitaine de Corvette* Houot and Engineer Pierre Willm (Fig. 19) dived to reach a diving record of a depth of 9,200 m. To celebrate this dive by French crew, a commemorative postage stamp was issued in France (Fig. 21).

"La mer", the journal of the Japanese-French Society of Oceanography, was launched in August 1963 and continues to be published (Fig. 22). The first article, of which Professor Sasaki was the lead author, was on the analysis of the chemical composition of seawater collected in a dive that reached a depth of 9,545 m off the Kuril Islands in 1962.

French-Japanese cooperation in deep-sea research continued in 1967 with the bathyscaphe Archimède visited Japan and surveyed the Kuril Islands Trench. Subsequently, Japan built its first manned submersible, the Shinkai, in 1969. The practical maximum depth was 600 m. In 1989, the Shinkai 6500 was built to a practical maximum depth of 6,500 m. A new model, the Shinkai 12000, is currently under construction.

The development of French-Japanese cooperation in oceanography after the bathyscaphe expedition to the Japan Trench is briefly described. For example, the KAIKO-Project in 1984, led by Professor Xavier Le Pichon and Professor Kazuo Kobayashi, included the French research vessel "Jean Charcot". The KAIKO-NanTroSEIZE

Table 2. Bathyscaphe FNRS III Diary of stay in Japan (ASAHI SHIMBUN, 1958).

Month	Day	Event
May	15	Arrival of *Captaine de Corvette* Georges Houot, *Enseigne de Vaissau* Gabriel O'Byrne and Chief Petty Officer Daniel Rost to Japan via air. Arrival of NYK Atsuta Maru on which bathyscaphe FNRS III was loaded with three Petty Officers, Marcel Berthelot, Clément Serrant and Michel Thébault at the Port of Kobe.
	19	Arrival of NYK Atsuta Maru arrived at the Port of Yokohama and landing of FNRS III on the water.
	21	Welcome reception for the French FNRS III team by the Japan Bathyscaphe Steering Committee.
	26	Filling the FNRS III's float with petrol in the Port of Yokohama.
June	1	Departure of FNRS III pulled by R/V Shinyo Maru from Yokohama to Onagawa.
	3	Evacuation of FNRS III to the Port of Tateyama due to rough sea condition.
	4	Departure of FNRS III from the Port of Tateyama.
	7	Arrival of FNRS III at the Port of Onagawa.
	11	Departure of FNRS III for the first dive from the Port of Onagawa but return to the Port of Onagawa due to rough sea condition.
	13	Departure of FNRS III again for the first dive from the Port of Onagawa.
	14	Start of FNRS III dive at 37° 54' N, 143° 1' E at a bottom depth of 1970 m at 9:04 am piloted by *Captaine de Corvette* Houot. The Asahi Shimbun's Science Department reporter Jitsuo Kusaka on board for general observation. Surfacing of FNRS III at 10:35 am due to rapid ascent from a depth of 1,200 m by wrong button for ballast operation on the way.
	15	Return of FNRS III to the Port of Onagawa.
	19	Departure of FNRS III for the second dive from the Port of Onagawa.
	20	Start of FNRS III dive at 37° 46' N, 143° 7' E at a bottom depth of 3,000 m at 9:58 am piloted by *Captaine de Corvette* Houot. Professor Tadayoshi Sasaki on board to measure deep-sea currents and study the optical properties of seawater. Surfacing of FNRS III at 4 pm.
	21	Return of FNRS III to the Port of Onagawa.
	25	Departure of FNRS III for the third dive from the Port of Onagawa.
	26	Start of FNRS III dive at 38° 7' N, 142° 16' E from the station at a bottom depth of 1,000 m at 6:23 am piloted by *Enseigne de Vaissau* Gabriel O'Byrne. Professor Jean-Marie Pérès on board to observe ecology of deep-sea fishes. Surfacing of FNRS III at 10:40 am.
July	4	Departure of FNRS III for the fourth dive from the Port of Onagawa. Move to the Port of Uraga after the fourth dive.
	5	Start of FNRS III dive at 37° 55' N, 142° 52' E at a bottom depth of 1,650 m at 7:25 am piloted by *Enseigne de Vaissau* O'Byrne. Professor Pérès on board to observe ecology of deep-sea fishes. Surfacing of FNRS III at 11:03 am. Move of FNRS III to the Port of Uraga.
	6	Departure of Professor Pérès by air.
	8	Arrival of FNRS III at the Port of Uraga.
	17	Departure of FNRS III for the fifth dive from the Port of Uraga.
	18	Start of FNRS III dive at 34° 46' N, 140° 4' E at a bottom depth of 2,800 m at 7:15 am piloted by *Captaine de Corvette* Houot. Professor Hiroshi Niino on board to study geology of deep-sea floor. Surfacing of FNRS III at 0:30 pm.
	19	Return of FNRS III to the Port of Uraga.
	29	Departure of FNRS III for the sixth dive from the Port of Uraga.
	30	Start of FNRS III dive at 34° 46' N, 140° 7' E at a bottom depth of 2,860 m at 6:45 am piloted by *Enseigne de Vaissau* O'Byrne. Professor Takeharu Kumagori on board to study ghost seabed. FNRS III was swept down into a valley at a depth of 3,000 m by strong currents and struck rock. Surfacing of FNRS III at 10:46 am due to emergent asecnt to avoid more damage.
	31	Return of FNRS III to the Port of Uraga.

August	2	Departure of FNRS III for the seventh dive from the Port of Uraga.
	3	Start of FNRS III dive at 35° 10' N, 139° 27' E at a bottom depth of 1,000 m at 9:05 am piloted by *Captaine de Corvette* Houot. Mr Shigeo Hayashida, chief cinematographer of Nippon Eiga Shinsha, on board to take scientific film "Record of bathyscaphe". Surfacing of FNRS III at noon. Return of FNRS III to the Port of Uraga at 7:00 pm.
	6	Departure of FNRS III for the eighth dive from the Port of Uraga.
	7	Start of FNRS III dive at 34° 41' N, 129° 42' E at a bottom depth of 2,300 m at 9:00 am piloted by *Enseigne de Vaissau*. O'Byrne. Professor Itsuo Kubo on board to study distribution and ecology of deep-sea animals. Surfacing of FNRS III at 2:38 pm.
	8	Return of FNRS III to the Port of Uraga.
	10	Departure of FNRS III for the nineth dive from the Port of Uraga.
	11	Due to an accident just before the dive, FNRS III was two tonnes short of ballast, so the Hayabusa Maru went to Uraga to retrieve ballast and replenish FNRS III. Start of FNRS III dive at 35° 7' N, 139° 30' E at a bottom depth of 750 m at 2:02 pm piloted by *Captaine de Corvette* Houot. Professor Takuo Chiba on board to observe ecology of plankton. Surfacing of FNRS III at 4:53 pm.
	12	Return of FNRS III to the Port of Uraga.
	14	Withdrawal of Uraga base. FNRS circumnavigates the Port of Yokohama.
	15	Gasoline draining operation from the float of FNRS III at the Yamashita Pier, the Port of Yokohama.
	16	Gasoline draining operation from the float of FNRS III at the Yamashita Pier, the Port of Yokohama.
	17	Flushing operation of FNRS III's tank.
	19	Cleaning work of FNRS III's hull landed at the Shinko Pier.
	24	Farewell party for the French FNRS III team by the Japan Bathyscaphe Steering Committee.
	25	Landing FNRS III on the sea and mooring at the Shinko Pier.
	27	Loading FNRS III onto NYK Suruga Maru.
	28	Departure of NYK Suruga Maru from the Port of Yokohama with three Petty Officers, M. Berthlot, C. Serrant and M. Thébault.
	31	Departure of *Captaine de Corvette* Houot and Chief Petty Officer Rost by air from Haneda Airport.
September	18	Departure of *Enseigne de Vaissau* O'Byrne by air from the Haneda Airport.

Project in 2010, led by Professor Pierre Henry and Professor Juichiro Ashi.

A cooperation relationship has been established in the field of oceanography between the French National Oceanographic Institute (*Institut français de Recherche pour l'Exploitation de la Mer*) and the Japanese Marine Research and Development Organisation (JAMSTEC) and in the field of fisheries science between Ifremer and the Japan Fisheries Research and Education Agency (FRA).

A sister society, the Japanese-French Society of Oceanography France, has been created since 1984, continuing the cooperation in scientific research between the two societies and the two societies work together and organized, since that date, 18 scientific meeting named "Japanese-French Oceanography Symposium", alternatively in Japan and in France. The 19th symposium is held in Caen, France in 2023. In this way, the cooperation between French and Japanese researchers in oceanography and fisheries science has developed since the cooperative surveys in Japan with the bathyscaphe FNRS III in

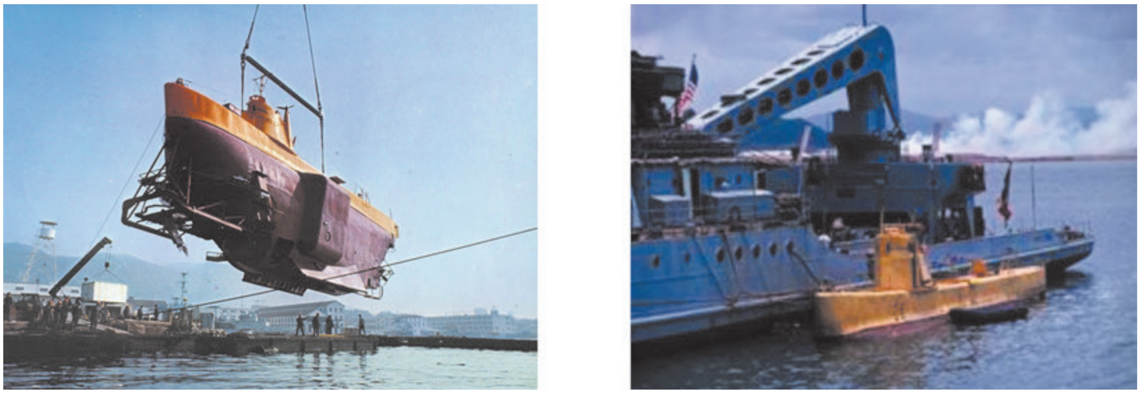


Fig. 18 Bathyscaphe named Archimède newly built in 1962 (photo on the left: https://ja.m.wikipedia.org/wiki/%E3%83%95%E3%82%A1%E3%82%A4%E3%83%AB:bathyscaphe_Archimede.jpg) and its diving support vessel Marcel Le Bihan (photo on right: https://ja.m.wikipedia.org/wiki/%E3%83%95%E3%82%A1%E3%82%A4%E3%83%AB:bathyscaphe_Archimede.jpg).

Fig. 19 Henri-Germain Delauze responsible of CNRS Laboratory of Bathyscaphes (left : Delauze *et al.*, 2010) and French members of the Archimede (right) who came to Japan in 1962 and embarked on board the Archimede's mother ship, Marcel Le Bihan. L-R: Engineer Pierre Willm, Engineer H.-G. Delauze, *Capitaine de Corvette* George Houot and *Enseigne de Vaissau* Gabriel O'Byrne.

1958.

7. What bathyscaphe has left us

We have considered what bathyscaphe has left us.

1) Cooperation based on trust and friendship between the French and Japanese stakeholders,
2) Links between French and Japanese oceanographers with a passion for marine science and
3) Supports from French and Japanese governments and private sectors for marine research.

These led to the invitation of the bathyscaphe FNRS III to Japan and its successful dive to a

朝日新聞

改造人事 今夜から大詰へ

閣僚、各派均衡を維持

前尾 大平 両氏の留任まず確実

赤城 水田 留任説も

参院から小沢氏ら

「後任議員会長」

衛星

九千五百メートル潜水に成功

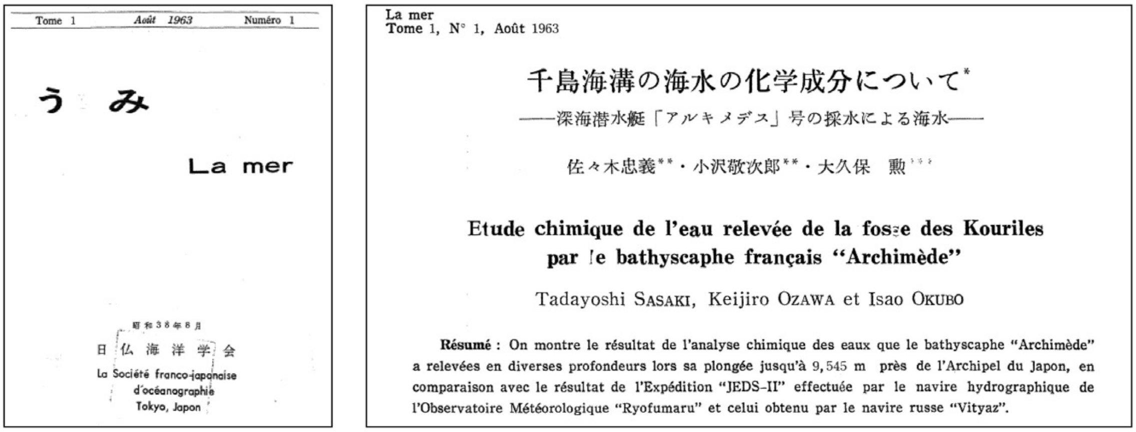
アルキメデス号 日本海溝の最深記録

海底にやや強い流れ

豊富な生物 柔かい泥積もる

Fig. 20 Front page of the Asahi Shimbun newspaper that reported the Archimède had reached a bottom depth of 9,545 m in the Kuril Islands Trench on 25 July 1962 with Henri-Germain Delauze, head of the bathyscaphe laboratory of the CNRS, *Enseigne de Vaissau* O'Byrne and Professor Sasaki (Asahi Shimbun, 1962).

Fig. 21 Engineer P. Willm (left photo: https://www.meretmarine.com/fr/science-et-environnement/deces-de-pierre-willm-l-un-des-peres-du-bathyscaphe) and *Capitaine de Corvette* Co G. Houot dived to reach a diving record of a depth of 9,200 m in Kurile Islands Trench. To commemorate this dive by French crew, a commemorative postage stamp was issued in France (right photo).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La Société franco-japonaise d'océanographie

Tokyo, Japon

La mer
Tome 1, N° 1, Août 1963

千島海溝の海水の化学成分について*

——深海潜水艇「アルキメデス」号の採水による海水——

佐々木忠義**・小沢敬次郎**・大久保 勲***

Etude chimique de l'eau relevée de la fosse des Kouriles par le bathyscaphe français "Archimède"

Tadayoshi SASAKI, Keijiro OZAWA et Isao OKUBO

Résumé : On montre le résultat de l'analyse chimique des eaux que le bathyscaphe "Archimède" a relevées en diverses profondeurs lors sa plongée jusqu'à 9,545 m près de l'Archipel du Japon, en comparaison avec le résultat de l'Expédition "JEDS-II" effectuée par le navire hydrographique de l'Observatoire Météorologique "Ryofumaru" et celui obtenu par le navire russe "Vityaz".

Fig. 22 La mer, the journal of the Japanese-French Society of Oceanography, was launched in August 1963 and has been published continuously. Its cover (pictured left) and the first published article (pictured right) reporting the results of an analysis of the chemical composition of seawater collected by the submersible Archimède on the bottom depth of 9,545 m in 1962.

bottom depth of 3,000 m in the Japan Trench in June 1958. This laid the foundations for subsequent French-Japanese cooperation in oceanography. Seawater and floating organisms in the ocean flow beyond territorial waters. Thus, international cooperation is necessary for the sustainable use of the marine environment and resources. And it is important that this cooperation between two countries is equal and can be approached from different perspectives. France and Japan have a different historical and cultural relationship with the sea, but we share the same enthusiasm for the ocean and marine sciences. In other words, both countries perfectly fulfil these conditions. We will further develop cooperation between France and Japan in the field of oceanography and fisheries science, while always respecting the achievements made by the bathyscaphes.

Acknowledgements

This paper is a rewrite based on our presentation at the 18th Japanese-French Oceanography Symposium on "60 years of French-Japanese co-operation in oceanography" organised by Japanese-Frence Oceanographic Society of Japan, the Japanese-French Oceanographic Society France and the *Institut français de recherches sur le Japon à la Maison franco-japonaise* and co-organised by the Maison franco-japonaise. We would therefore like to thank Director Bernard Thomann and the staff Ms Miki Nakajima of the *Institut français de Recherches sur le Japon à la Maison franco-japonaise* and officers of the *Maison franco-japonaise* for their joint efforts with us, the Japanese-French Societies of Oceanography of Japan and France, in realising this symposium. We would also like to thank the Ministry of Education, Culture, Sports, Science and Technology, the Science and Technology Department, Embassy of France in Japan, the Japan Agency for Marine-Earth Science and Technology, the *Fondation franco-japonaise Sasakawa*, the Oceanographic Society of Japan, the Japanese Society of Fisheries Science and the Japanese Society of Fisheries Oceanography for their support for the 18th Japanese-French

Oceanography Symposium. Finally, we thank to Professor Yasuyuki Koike for his critical reading of this paper.

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Société franco-japonaise d'Océanographie, Tokyo

Exchanges between Japan and France in the field of fisheries science, triggered by the mass oyster die-off in France and the export of Sanriku oyster seeds to France

Yasuyuki KOIKE[1)*] and Teruhisa KOMATSU[1, 2)]

Abstract: In 1960, the Japanese-French Oceanographic Society (SFJO) was established and co-operation with France on oceanography began. In the late 1960s, oysters farmed in France died in large numbers due to diseases, and oyster farming was in danger of extinction. French researchers then approached SFJO member Professor Takeo Imai of Tohoku University to see if Sanriku oysters resistant to the diseases could be exported to France. The research team led by Professor Imai conducted quarantine and pathological tests to succeed in exporting 10,000 t Sanriku single-seeded oysters (spat) to France. This export brought the French oyster farming industry out of crisis. Subsequently, French-Japanese cooperation also extended to fisheries science, and SFJO France was set up in 1984. On 11 March 2011, a huge tsunami hit off the coast of Sanriku, devastating aquaculture facilities. Immediately afterwards, SFJO France and French oyster farmers including another French groups contacted SFJO to support oyster farmers in Sanriku in return for their spat export. These organisations and SFJO donated essential equipment for oyster seed collection, such as microscopes and plankton nets, to the prefectural fisheries experiment stations and prefectural fisheries cooperatives in Sanriku. This article outlines the French-Japanese exchange on these fisheries science.

Keywords : *Japanese-French Oceanographic Society, mass oyster die-off in France, Sanriku seed oysters, tsunami in Sanriku*

Introduction

In 1958, Japanese scientists invited the French submersible bathyscaphe, FNRS III, the most advanced submersible in the world at that time, to Japan and conducted joint research in the Japan Trench and its surroundings, making many discoveries about the deep sea (KOMATSU, 2023). This led to the establishment of the Japanese-French Oceanographic Society (*Société franco-japonaise d'Océanographie*: SFJO) in 1960, led by

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Professor Tadayoshi Sasaki of the Tokyo University of Fisheries and Professor Takeo Imai of Tohoku University. Exchanges in the field of fisheries began in the 1960s with the Japanese side's cooperation, led by Professor Imai, a member of SFJO, to save French oyster farming, which was suffering due to the mass die-off of cultured oysters in France. This article looks back at the history of exchanges between France and Japan in the field of fisheries science, particularly with regard to oysters.

Export of seed oysters from Japan to France in the 1960's

The mass production of seed oysters (spat) in Japan, started in the 1920's in Mangoku-ura Inlet, Ishinomaki City near Sendai, Miyagi Prefecture. The spat produced in Miyagi Prefecture were shipped to all regions, where oyster culture was conducted, around the Japanese coast. The export of these spat to the United States started in 1923 and continued until 1978, with the suspended period of 5 years from 1941 due to the World War II.

In the 1960's the oyster farming in France was greatly damaged by the mass mortality of *Crassostrea angulata* called Portuguese oyster due to "gill disease" outbreak in 1966 (COMPS and DUTHOIT, 1976) caused by an iridovirus (COMPS *et al.*, 1978). On the French Mediterranean coast, farming of the endemic flat oyster *Ostorea edulis* continued until 1950, when high mortality occurred, and its farming was terminated (FAUVEL, 1985). In Brittany, endemic flat oyster *Ostorea edulis* was decreased by infection of the protozoan *Marteilia refringens* broke out in 1968 and by another disease in 1979 caused by the exotic parasite *Bonamia ostreae* (BUESTEL *et al.*, 2009). Production dropped from 20,000 t to 2,000 t and remains very low despite numerous efforts to assist its recovery (BUESTEL *et al.*, 2009).

Facing the crisis of oyster culture industry in France, Dr Trochan, the director of La Tremblade Institute (former *Institut scientifique et technique des Pêches maritimes*) contacted a member of SFJO, Professor Takeo Imai of Tohoku University to ask if spat of Japanese oyster *Crassostrea gigas* resistant to these diseases could be exported to France.

Professor Imai established the research team of which members were Professor Takeo Imai (Tohoku University), Dr Akimitsu Koganezawa (Miyagi Prefectural Fisheries Experimental Station at that time, and afterward, National Institute of Fisheries in Tohoku), Mr Kunio Goto (Miyagi Prefectural Fisheries Experimental Station) and Scientific Counselor of French Embassy in Japan (Fig. 1). The research team conducted pathological and epizootic examinations of seed oysters. They asked Japanese oyster farmers to produce single oyster seedlings in cooperation with Mangoku-ura Fisheries Cooperative because Japanese oyster culture uses clumps of oyster seedlings settled on the empty scallop shells. After the examinations and preparations, they started to export from Sanriku to France.

The first trial of mass export by air took place successfully in 1969 under the authorization of both countries (Figs. 2, 3, 4). At that time, Professor François Doumenge of Montpellier University visited Ishinomaki City Hall to discuss on the best way to export oyster spat to France with Mayor of Ishinomaki City (Fig. 5). This project was continued until 1979 (GOTO, 2012, KOGANEZAWA, 1984). According to BUESTEL *et al.* (2009), 10,000 t Sanriku spat were imported from Japan to France, and production increased quickly in France. Spat capture developed rapidly in Arcachon and Marennes along the Atlantic coast, so that further spat imports

Fig. 1 Photos of Professor Takeo Imai of Tohoku University (a) provided by Yasuyuki Koike (YK), Dr Akimitsu Koganezawa of Miyagi Prefectural Fisheries Experimental Station (b) provided by Mr Kunio Goto (KG), Mr Kunio Goto of Miyagi Prefectural Fisheries Experimental Station (c) provided by KG and Scientific Counselor of French Embassy in Japan (d) provided by Mr Minji Fukuda (MF).

became unnecessary. Finally, in 1990 the oyster production in France was restored to about 140,000 t (Fig. 6).

Stimulated by this revival of the French oyster farming industry, exchanges between SFJO and France subsequently began in the field of aquaculture, and in 1984 a sister society of the French-Japanese Oceanographic Society France (SFJO France) was established in France. Its president was Professor Dr Hubert Jean Ceccaldi of *Ecole pratique des hautes Etudes* and French President of *Maison franco-japonaise de Tokyo* at that time. Henceforth, the original SFJO is abbreviated as SFJO Japan to distinguish it from the SFJO France.

Fig. 2 Photos on preparations of Sanriku single seed oysters cultured in Mangoku-ura Inlet (a, b) and shipments of single seed oysters for France (c, d) provided by KG.

Aid from France after the Tsunami disaster in the Sanriku region

In Japan, on 11 March 2011 a huge Tsunami hit the Sanriku Coast and heavily damaged the fishery facilities, especially those of aquaculture, along the coast (Fig. 7). Just after the disaster, many French members of SFJO France contacted us to ask how the tsunami damaged the society of Sanriku Coast and offered supports for the fisheries along the Sanriku coast. Especially, Professors Hubert Jean Ceccaldi, President of SFJO France at that time and Catherine Mariojouls, President of *Association pour le Développement d'Aquaculture* (ADA), proposed to collect contributions for the Sanriku fisheries. To respond to their proposals a special committee was formed between the French and Japanese members of the two SFJOs.

Japanese oyster farmers collect in the sea in summer when oyster larvae settle on the hard substrate by deploying the scallop shells in the sea. The timing to deploy the empty scallop shells is very important for collecting oyster seedlings because other shell seedlings settle on the scallop shell in the case of the deployment when the number of oyster larvae just before settlement are less. Oyster farmers measure water temperature to examine whether the water temperature is suitable for oyster settlement, and count the number of oyster larvae sampled with a plankton net using a microscope by themselves in cooperation with prefectural fisheries research organisations. Therefore, the special committee decided to donate microscopes and plankton nets to examine the density of oyster larvae in sample waters in the first spawning

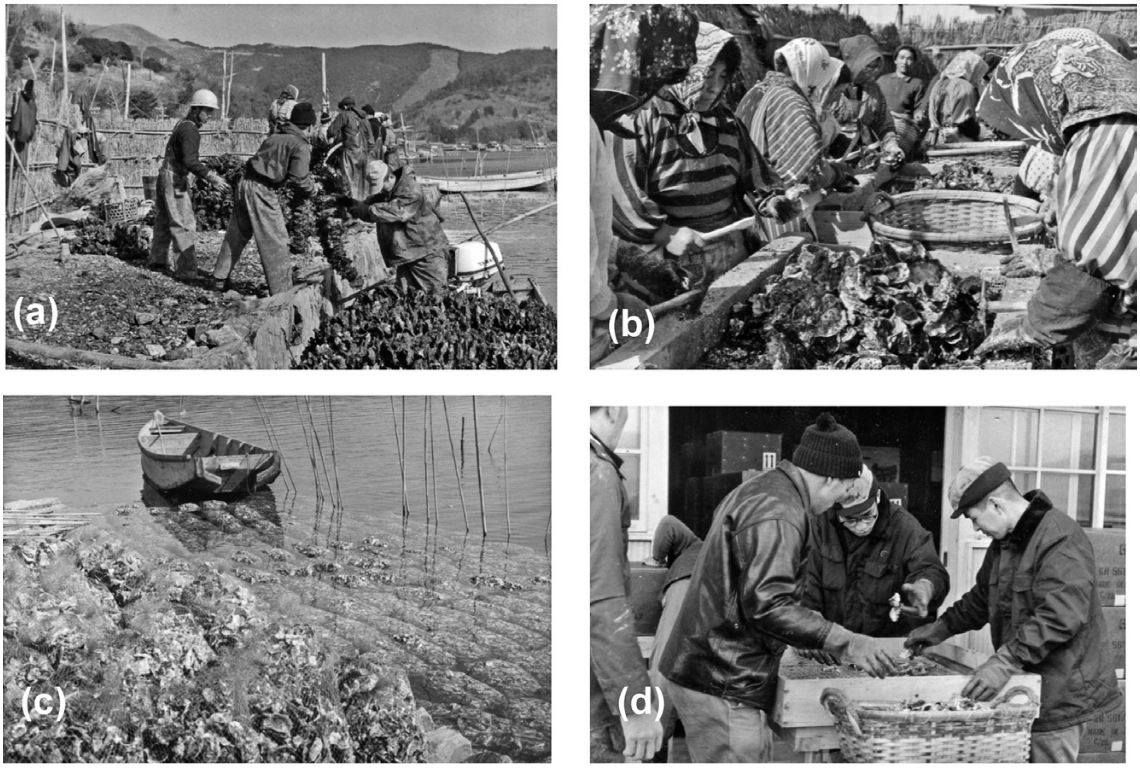

Fig. 3 Photos on harvesting (a), cleaning (b), culturing (d) and preparing shipment on land Sanriku oyster single seeds at Mangoku-ura Fisheries Cooperative provided by MF.

season of oyster during the summer just after the Tsunami through discussion with researchers and members of fisheries cooperatives of Sanriku coast. These materials are essential for scientific surveys to collect oyster seedlings in the sea that had been lost by the Tsunami and were urgently needed in summer of 2011.

The organizations that supported this collaboration are as follows:

1. *Société franco-japonaise d'Océanographie-France* (SFJO France),
2. *Association pour le Développement de l'Aquaculture* (ADA),
3. *La Fondation d'Entreprise Air Liquide / Teisan*,
4. Rotary Club Saint-Jean Marseille,
5. Gambalo Japan Project: Region of Bretagne,
6. Okaeshi Project: Marennes-Oléron area and
7. *Société franco-japonaise d'Océanographie du Japon* (SFJO Japan)
(ex-President Shiro Imawaki, President Teruhisa Komatsu, Secretary Yasuyuki Koike and Tsutomu Morinaga).

These organisations started the donations as one group from July 2011 and continued until October 2012. The list of donations was as follows:

1. Nine microscopes and five plankton-nets for Miyagi Prefecture,
2. Eight microscopes and five plankton-nets for Iwate Prefecture,
3. Life jackets for Taro Cooperative (Iwate Prefecture) by Gambalo Japan Project and
4. Buoys and ropes for Cooperatives of Miyagi

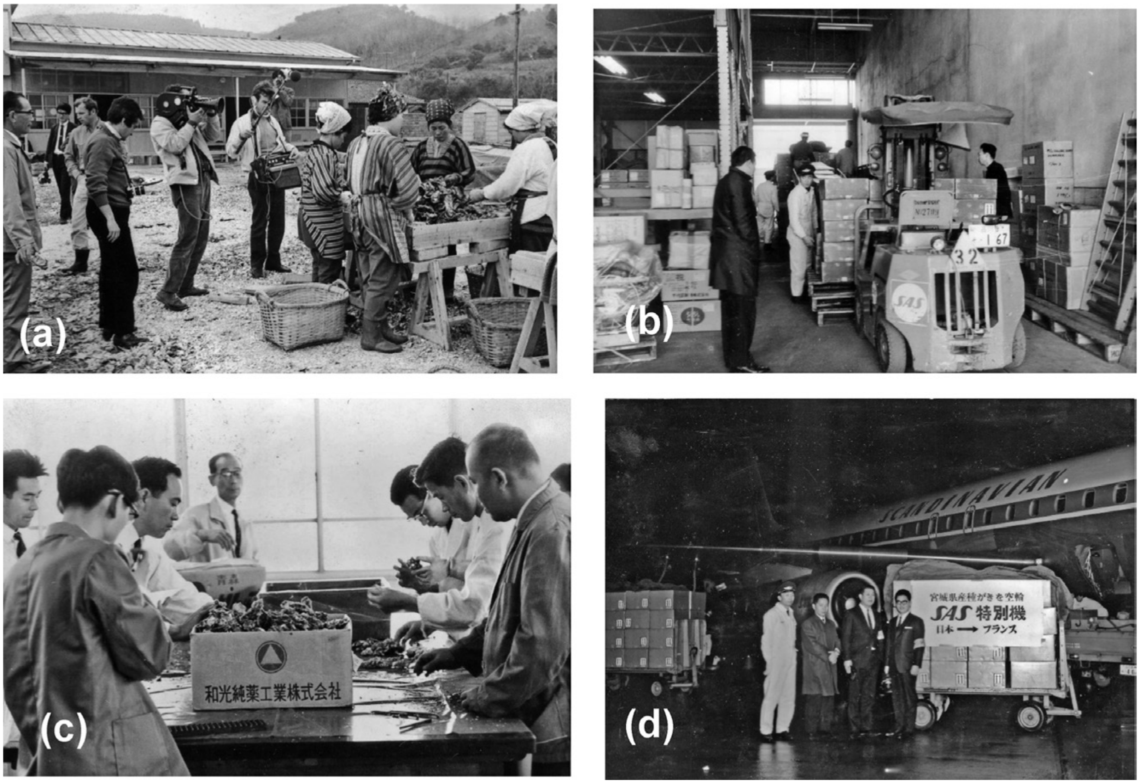

Fig. 4 Photos on the French TV crew filming women cleaning Sanriku single seed oysters (a), view of boxes containing Sanriku single seed oysters being transported from the Mangoku-ura Fisheries Cooperative to the airport (b), sanitary and pathological check (c) and boxes containing Sanriku single seed oysters with a banner saying "SAS Special Aircraft from Japan to France for the airlift of seed oysters from Miyagi Prefecture" (d). Photo (a) is provided by MF.

Prefecture by Okaeshi Project.

The organisations greatly appreciate Olympus Medical Science Co. Ltd. and Rigosha Co. Ltd. for the reduction of their prices and all members belonging to their own organisations for their contributions (Fig. 8).

At the end of the year 2011, Professor Dr Catherine Mariojouls of AgroParis Tech, President of ADA visited the Sanriku region, related organizations and regional fisheries cooperatives to encourage them (Fig. 9). In the beginning of February 2012, Professor Dr Hubert-Jean Ceccaldi, President of SFJO France, and Dr Georges Stora of *Centre d'Océanologie de Marseille*, Vice-Secretary of SFJO France, visited there also (Fig. 10).

Visit of French delegation to Sanriku Coast and French-Japanese joint Seminar on restoration of oyster culture in Sanriku

In September 2012, about one and a half years after the disaster, thanks to a donation of *Maison franco-japonaise de Tokyo*, a joint seminar was held in the Sanriku region with a French delegation. Members of the delegation consisted of French researchers invited by SFJO Japan with the funds provided by *Masion franco-japonaise de Tokyo* and *Fondation Sasakawa franco-*

万石浦産の種ガキを輸入しているフランスの水産専門家が二十日、石巻市を訪れ「日本に空輸しているシラスウナギの帰り便を使って、日本産種ガキの輸入をふやしたい」と語った。
この人はモンペリエ大学で漁業地理経済を研究するフランソワ・ドワーマンジュ教授。同教授は日本の養殖技術導入をはかるため十五日から三週間の予定で来日しているもので、二十日午前、石巻市役所を訪れ、千葉市長から水産行政の実情をきいたあと、県水産林業部大阪武技師らの案内で石巻魚市場、県水試などを訪れ、養殖の

千葉石巻市長から市の水産行政を聞くドワーマンジュ教授（右側）

Fig. 5 Photo on the newspaper taken when French fisheries expert Professor François Doumonge (right), who negotiated to import Mangoku-ura single seed oysters as an agent, visited Ishinomaki City and met Mayor Chiba (left). Professor Doumenge said, "France wants to increase the import of Mangoku-ura single seed oysters by using the return flights of French glass eels that are airlifted to Japan".

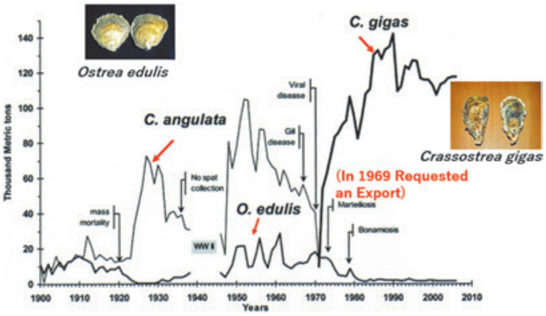

Fig. 6 Historical trend of French oyster production modified from Buestel *et al.* (2009). *Crassostrea angulate* shown with a thin line is Portuguese oyster in UK or "*les huître portugaises*" in France. *Ostera edulis* shown with an intermediate thickness line is common oyster in UK or "*les huîtres plates européennes*" in France. *Crassostrea gigas* shown with a fat line is Pacific oyster in UK or "*les huîtres creuses du Pacifique*" or "*les huîtres japonaises*" in France.

japonaise, Professor Dr D. Bailly of *Université de Bretagne Occidental*, Professor Dr Catherine Mariojouls, Dr Jean Prou, Director of laboratory in La Tremblade belonging to *Institut français pour l'Exploitation de la Mer*, Ifremer, Mr Olivier Laban, President of Aquitaine and Arcachon Regional Committee of Shellfish Culture, two researchers of *Université de Bretagne Occidentale* and eight oyster farmers funded by the French Government.

The French delegation first visited Iwate Prefecture to observe the areas ravaged by the tsunami at Taro, Yamada and Otsuchi fisheries cooperatives. At the Iwate Fisheries Technology Center in Kamaishi, a ceremony of last donation of microscopes was realized by Professor Catherine Mariojouls (Fig. 11). Then, they visited Shizugawa and Ishinomaki fisheries cooperatives (Fig. 12) and Miyagi Prefectural Fisheries Technology Institute. On the third day of the visit to Sanriku coast, a joint seminar was held at Tohoku National Fisheries Research Institute at Shiogama with participations of the members of the two SFJO and Iwate Fisheries Technology Center of Iwate and Miyagi Prefectural Fisheries Technology Institute, researchers of universities and oyster farmers of Sanriku coast (Fig. 13a, b, c). After returning to Tokyo, another open Seminar was carried out at the Maison franco-japonaise de Tokyo at Ebisu quarter (Fig. 13d). The visit of French delegation and their encouragement to Sanriku oyster farmers and fishermen, and exchange between oyster farmers in France and Sanriku have been highly appreciated by both countries.

Fig. 7 Photos on the hit of huge tsunami at the coast of Sanriku on 11 March 2011 (a) and debris of aquaculture facilities stranded on land just after the hit of tsunami (b) provided by RS.

Fig. 8 Photos on the donation of microscopes and plankton-nets additionally purchased by the groups from Professors Yasuyuki Koike (left) and Teruhisa Komatsu (centre) of SFJO Japan to Director Akira Kemuyama (right) of Iwate Prefectural Fisheries Research Center (a) and donated plankton nets and microscopes (b) on 1 May 2012. Photos are provided by YK.

Participation of Japanese delegation to the Oyster World Congress at Arcachon and site visit to oyster farms on the Atlantic Coast

After the joint seminar in Japan, Mr Olivier Laban, the president of the First Oyster World Congress, proposed the Japanese members to attend the World Congress and they presented information on the cooperation for oyster culture between Japan and France (Fig. 14). This congress was an epoch-marking event because of the organiser was not researchers but the group of French oyster farmers associated with several research institutes. The date was from 28 November to 2 December 2012. About 250 participants from 27 countries attended. The members of the Japanese delegation were Dr Tetsuo Seki, a member of SFJO Japan and a board member of Japan Fisheries Science and Technology Association, Mr Kunio Goto, Adviser of Fisheries Cooperative of Shiogama City, Messrs

Fig. 9 Visit of Professor Dr Catherine Mariojouls to workshops of Matsushima Bay in Miyagi Prefecture to discuss with oyster farmers (a) and with an oyster farmer, Mr Watanabe (b) on 28 December 2011. Photos are provided by YK.

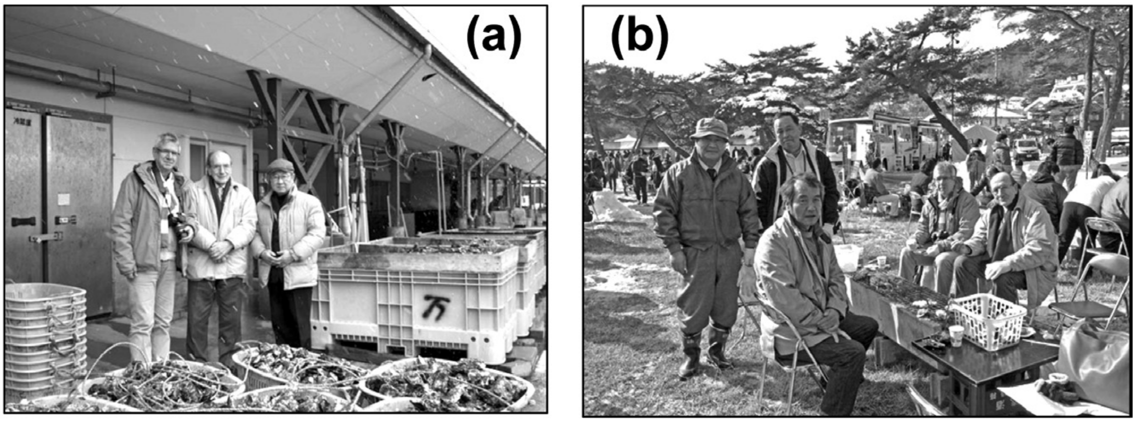

Fig. 10 Visit of Professor Dr George Stora (left), Professor H.J. Ceccaldi (centre) and Professor Yasuyuki Koike (right) in front of the workshops of Ishinomaki Bay in Miyagi Prefecture (a) and discussion with oyster farmers of Matsushima Bay tasting oysters on 5 February 2012 when Matsushima Oyster Festival took place at Green Square in front of Japan Railway East Matsushima Beach Station (b). Photos are provided by YK.

Yoshimasa Koizumi and Tamotsu Suzuki, members of the Miyagi Fisheries Cooperatives, Urato Branch, Shiogama City and the author, Dr Yasuyuki Koike, ex-Professor of Tokyo University of Marine Science and Technology and a counselor of SFJO Japan.

The visit of Japanese delegation yielded fruitful results (Fig. 15). Technical information from various countries were good reference for Japanese oyster culture. Especially, recent pathological information was very important for the seed culture of each country. Our party, including Mr Goto, was widely introduced by the local newspaper under the title of "Revival by

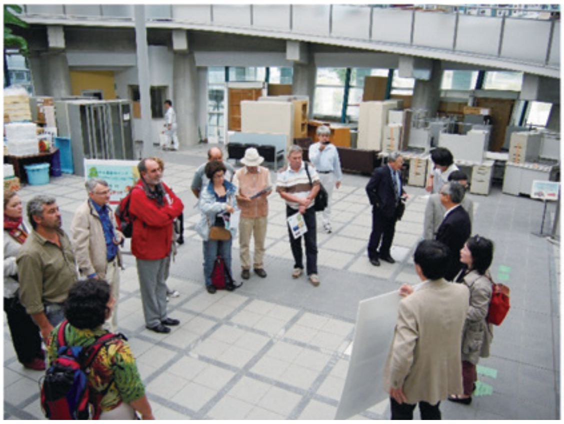


Fig. 11 Visit of French delegation to Iwate Fisheries Technology Center (left) and donation of microscopes additionally purchased by the groups to the director of the station (right) on 2 October 2012. Photos are provided by YK.


Fig. 12 Visit of French delegation to Shizugawa (left) and Mangoku-ura Inlet (right) to see oyster culture and discuss with Japanese oyster farmers on 3 October 2012. Photos are provided by YK.

Japan" (Fig. 15).

After the Congress, the Japanese delegation visited several oyster farms along the Atlantic coast, Arcachon-Aquitaine, Marennes, Bretagne Sud and the stations of Ifremer. In Marennes, Mr Kunio Goto who examined seed oysters before exporting in 1968, was guided to the seabed in Mouillelande where the first seed from Japan were deployed (Fig. 15). Then, he could exchange information with the first oyster farmer who transported the first Sanriku oyster seeds that arrived in Paris to Marennes. It was just an historical moment to recall the memories of 40 years ago.

After the site visit to oyster culture grounds, the delegation visited two stations of Ifremer, La Tremblade and La Trinité sur Mer to exchange important pathological information about the disease and herpes of oysters with specialists of two institutes (Fig. 15d). In the last 5 years in

Fig. 13 Views of "Japanese-French symposium on the recovery of coastal fisheries in Sanriku - in particular the recovery of oyster farming from the tsunami damage" at Tohoku National Fisheries Research Institute (a, b), the reception after the symposium where President of Japanese-French Oceanographic Society, Professor Shiro Imawaki, delivered a speech welcoming the French delegation to Sanriku at Hotel Taikanso, Matsushima City on 4 October 2012 (c) and the seminar for the public on "Franco-Japanese oyster culture: towards the reconstruction of Sanriku" at the Maison franco-japonaise on 6 October 2012. Photos are provided by YK.

France there are the very serious problem of disease in oysters again. The conclusion of the discussion was that seed oysters should not be exchanged from one region to another if there has been risk of pathogens being transferred. It is concluded that the results of research and information about the disease must be open and readily disseminated to related countries (KOIKE, 2015).

As a result of the exchanges resulting from these events, including joint seminars in Japan, the World Oyster Congress and site visits, the French and Japanese oyster farmers and researchers who attended the events were able to obtain important information on French and Japanese oyster farming methods and diseases, understand the differences between the two countries and get tips for new approaches in their own countries.

Fig. 14 Opening presentation by Professor Yasuyuki Koike, SFJO Japan in front of the podium (a) and discussion on the pathological problems of cultured oysters among experts including Dr Tetsuo Seki, SFJO Japan, second from the right (b) at the First World Oyster Congress held in Arcachon on 3 December 2012. Photos are provided by YK.

Fig. 15 Newspaper article reporting on Japanese researchers and oyster farmers visiting oyster farms in Marrennes-Oléron (a); that on visit of Dr Kunio Goto, researcher at the Miyagi Prefectural Fisheries Experiment Station (1960–1970) who prepared the export of Sanriku oyster seeds to France (b); Dr Goto and TV team covering his visit to Moillelande where the first Sanriku oyster seeds arrived in France were cultured in 1967 (c); French and Japanese experts exchange views on oyster diseases at Ifremer's laboratory in Tremblade (d) after the First World Oyster Congress on 6 December 2012. Photos are provided by YK.

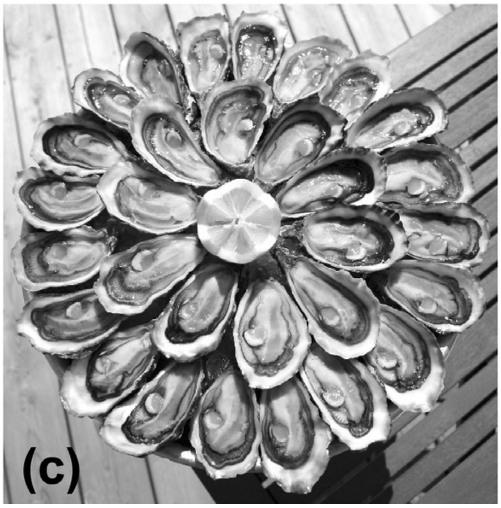

Fig. 16 In France, oysters are served live and raw. Examples of oyster dishes shown by Jean-François de Troy's painting "*Les déjeuner d'huîtres* (Oyster lunch)", 1735 (a) and by a current commercial brochure of an oyster farm in Marennes (b), and the same plate of oysters on the half shell as depicted in the painting (c).

History of oyster eating and farming methods in France and Japan

The cuisine of seafood is traditional and very old. Knowing when and how oysters were eaten is very important for deepening the exchange between Japan and France on oysters. Two countries have a long history of oysters as a food source. In Japan and France, oysters have been consumed in the Jomon period from about 16,000 BC to 3000 BC and in the Roman period from 753 BC to 476 AD, respectively. Oysters have also been cultured since the middle of the 17th century in Japan and the middle of the 19th century in France (OGASAWARA,1980; QUERO, 2016).

The painting "*Déjeuner de huître*", Oyster lunch in English, which once hung in the dining room of the Palace of Versailles, was painted in 1735 by the artist Jean-François de Troy at the request of King Louis XV of France. Raw oysters are served on a silver plate, the china is made in Japan, and the accompanying drink is identified as champagne from the cork flying in the air, depicting a luxurious lunch for the aristocracy (Fig. 16). The photo in Figure 16b is borrowed from a brochure of an oyster farm in Marennes. It shows that raw oysters have been eaten in France at least for 300 years.

Figure 17 shows a typical Japanese oyster dishes, which are often cooked. In Japan, oysters, an ingredient in dishes in which they are usually

Fig. 17 Typical Japanese oyster dishes, most of which are cooked. Oyster pot (a), oyster soba (b), fried oysters (c) and oyster farmers working on shucking oysters (d).

cooked, have come to be regarded as a luxury foodstuff due to the widespread use of raw oysters with shells. Over the past decade or so, the distribution of raw oysters on the shell has gradually increased. However, many oyster farmers still produce oysters without shells as the norm, in line with our traditional cooking (Fig 17d). The differences between the French and Japanese oyster-preparation methods are closely related to the environment of natural oyster habitat and the oyster farming methods adapted to their environments. The natural habitat of Pacific oysters in Japan is the middle level of the intertidal zone, where they fix on rocks and other hard substrates (Fig. 18). On the Atlantic coast of France, where the tidal range is very large (4–14 m), oyster farmers can use the huge intertidal zone horizontally as the culture ground. In Japan, where the tidal range is not so large (2–4 m), oyster farmers must use the coastal water vertically by hanging culture to increase oyster production (Fig. 19). The tidal range relating to the intertidal zone is the most significant difference in the oyster culture

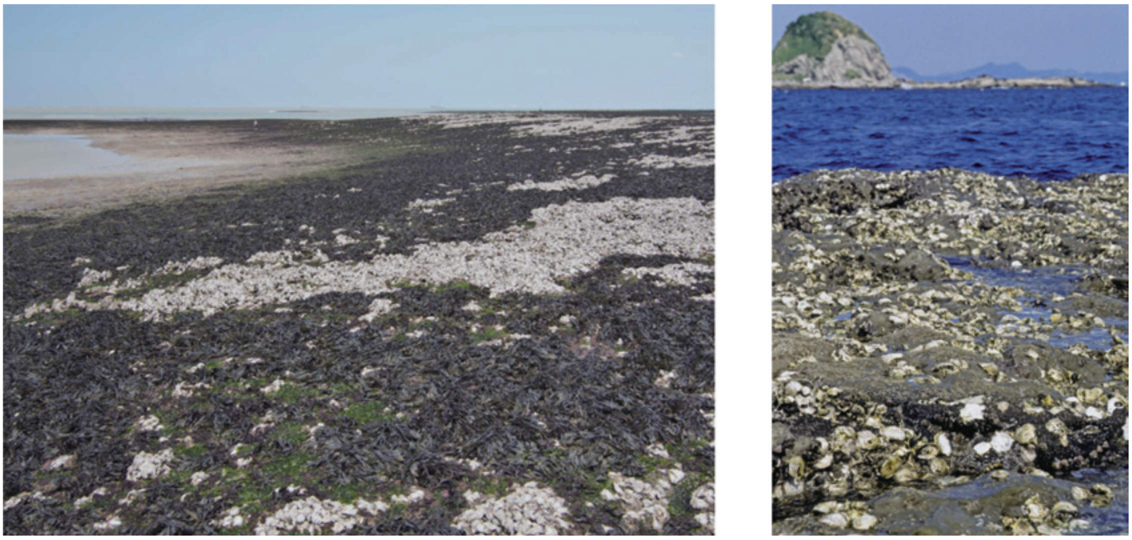

Fig. 18 Typical landscape on the Atlantic side of France comprising natural oyster beds (light area) and seaweed (dark area) in the wide intertidal zone taken at Ile d'Aix (left) and typical landscape in Japan comprising dispersed oyster individuals and rock in the narrow intertidal zone at Kenzaki, Miura Peninsula, Kanagawa (right). Photos are provided by YK.

environment between the two countries (Fig. 19). However, on the French Mediterranean side, oyster farming is similar to that in Japan because the tidal range is small (less than 1 m).

In France, oysters cultured in the intertidal zone take about 3 years to shipping size because oysters which are a filter feeder under the sea cannot feed in the air during the low tide. Their shells are hard and stronger since they are exposed to the air at the period of low tide and need to endure such a condition in the air. Thus, in France, oysters have strong vitality in the air and their edible parts are crunchy and muscular. In the case of Japan, oysters cultured always under the sea grow to shipping size only in 1.5 - 2 y, because they can spend 24 h to feed and grow fast. As they are always farmed underwater, they do not have to withstand airborne conditions and their shells are not as hard. The edible parts of such oysters are soft and fat, and muscle development is weak. Thus, Japanese oysters cannot survive in the air for as long as French oysters. However, shell-less oysters are not expensive and can easily be prepared as a home-cooked dish. This difference between French and Japanese oysters actually brings the eating habit of oysters in each country.

In France, almost all oysters are sold on the shell and eaten raw straight from the shell. Oysters are considered a special dish for parties at the end of the year such as Christmas and New Year's Day. Therefore, most oyster consumption in France occurs in December and January (Buestel *et al*., 2009). As such, the eating habits and method of preparation depend on oysters and culinary tradition between the two countries. To change or increase the quality of the products, consumers' tastes must be well reflected.

It is necessary for Japanese and French to learn the differences in the history and background of oyster consumption and farming

Fig. 19 Oyster farming using the intertidal zone in Brittany on the Atlantic side of France (a) by placing nets containing oysters on shelves on the seabed there (b). Oyster farming using the subtidal zone in Matsushima, Japan (c) to suspend lumps of oysters on the vertical ropes (d). Photos are provided by YK.

for mutually understanding the difference in food cultures.

Technical exchanges between the two countries in aquaculture

Technology learned from France

In the Mediterranean Sea, Lake Tho, where the tidal range is exceptionally small in France, a method of growing single oysters by attaching them to ropes with cement was developed (Fig. 20). In Japan, where hanging culture is very popular, this efficient method has been adopted in the disaster areas of Sanriku and is proving effective.

Under the guidance of Dr Tetsuo Seki and Mr Kunio Goto mentioned above, a test oyster culture was conducted on Urato Island in Shiogama City. In this pilot culture, the French method of placing oysters in the intertidal zone has been modified by suspending nets containing oysters at a depth that is intertidal (Fig. 20). In Japan, scallop shells are used as a substrate for collecting oyster seedlings, while in France, a highly efficient plastic collector called "*coupelle*" in French is used. It has now been imported from France to Japan and used for farming

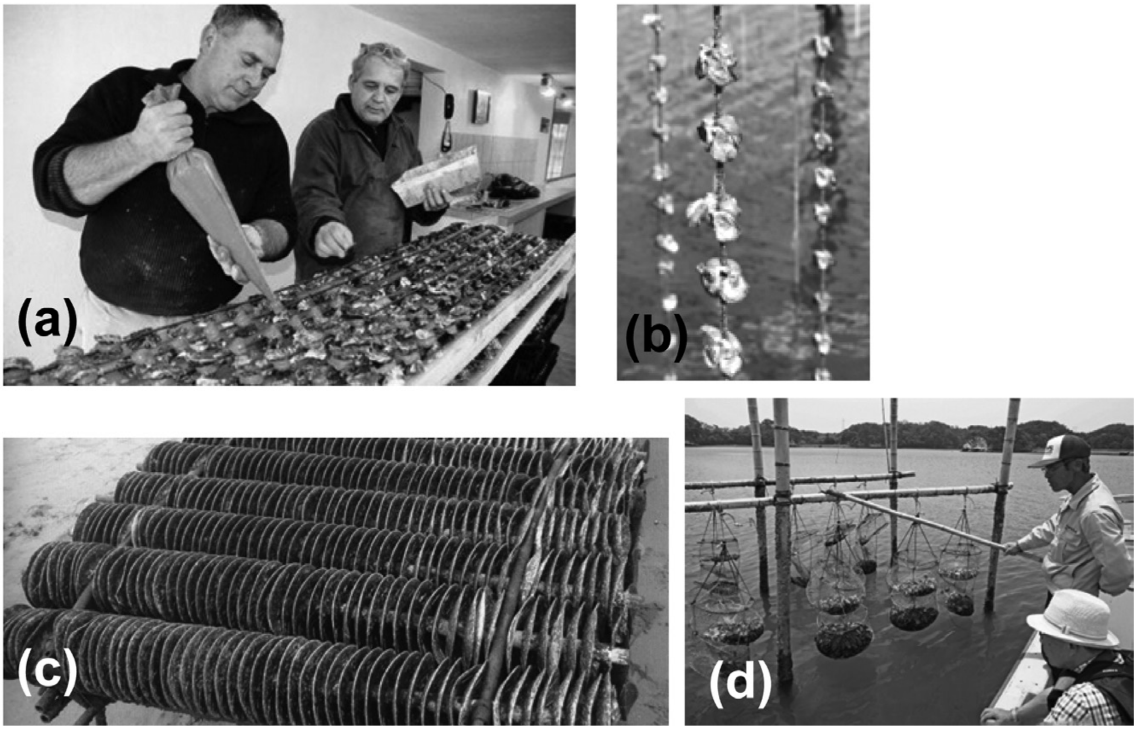

Fig. 20 Two oyster farmers fixing oysters to the rope with cement (a), oysters secured to a rope emerging from the sea during low tide in the Thau Lagoon facing on the Mediterranean side of France (b), oyster seed collectors, which were imported from France to Japan, placed on the seabed in the intertidal zone (c) and nets containing single seed oysters placed in the intertidal zone in Matsushima Bay, Japan (d). Photos are provided by YK.

single seed oysters (Fig. 20) because oysters with shell are more valuable than those without shell. The oysters raised in the intertidal zone are now commercialised as raw oysters with shell under the brand "*Atamakko-gaki*" (Fig. 20).

In the case of Manila clams, the traditional method of Manila clam culture in Japan relies on natural seed collection but overfishing and degradation of the marine environment have necessitated artificial seedlings. In France, the technology, called the up-welling system, uses cylindrical rearing tanks with water flowing from the bottom to overflow from the top of the tank enabling to accommodate rearing seed clams at a higher density than with conventional methods (Fig. 21). The water flow is evenly distributed to the juveniles, thus increasing the feeding efficiency. Researchers in Chiba Prefecture have adopted this latest technology from France.

Technology learned from Japan

In 1977, Dr Dao and Dr Buestel from the *Centre Océanologique de Bretagne* (COB) visited Japan and introduced scallop culture materials of the Tohoku region to France (Fig. 22). In France, these materials are also used for oyster culture (Fig. 22).

In 1989, researchers and oyster farmers from France visited Japan, and after visiting aquaculture facilities in various regions, a

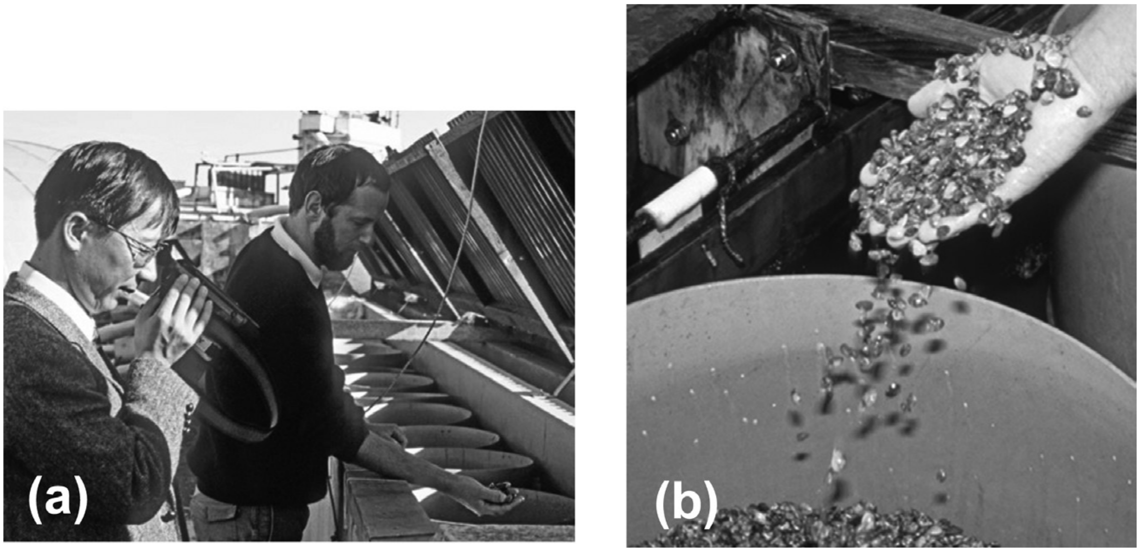

Fig. 21 Seed production system of Manila clam (a) and seeds of Manila clam produced (b) in Normandy. Photos are provided by YK.

Fig. 22 Two researchers, Dr J. C. Dao and Dr D. Buestel of *Centre Océanologique de Bretagne* (COB) belonging to *Centre National pour l'Exploitation des Océans* (CNEXO), the forerunner of Ifremer, visiting to Moüra facing Mutsu Bay, Aomori Prefecture in Tohoku Region for surveying shellfish culture methods in Japan in 1977 (a), the same types of scallop farming materials they imported from Japan to France (b) and the baskets used for scallop farming in Japan are used for oyster farming in Brittany, France (c). Photos are provided by YK.

Fig. 23 French-Japanese seminar on aquaculture held in 1989 at the *Maison franco-japonaise* de Tokyo at Ochanomizu, Tokyo. On the far left is Professor H. J. Ceccaldi, then French President of the *Maison franco-japonaise de Tokyo*, and on his right Professor Yutaka Uno of the Tokyo University of Fisheries. Photo is provided by YK.

technical seminar was held at the *Maison franco-japonaise de Tokyo* with Professor H. J. Ceccaldi, French President of MFJ, and Professor Y. Uno of Tokyo University of Fisheries (Fig. 23).

Finally, as for the first author's achievements, from 1973 to 1976, the author stayed at the COB in Bretagne, and succeeded in producing the first seedlings of French abalone (Ormer), *Haliotis tuberculata*, by applying Japanese technology, and was able to release many juveniles in a closed fishing zone (Fig. 24).

Conclusion

The history of technological exchange between Japan and France in the field of shellfish culture since the founding of the Society was reviewed. At the time of its establishment, Japan was one step ahead of France in terms of history and development in this field. Since the 1980s, France has made remarkable progress in technological development. Since the 1990s, technological exchanges between the two countries have flourished, and they have been studying each other's technologies. In the oyster farming, in particular, there is a history of mutual assistance between the two countries as mentioned above, which has resulted in mutual overcoming crises. At a time when there is concern about the impact of global climate change on the coast and the ocean, exchanges between the two countries in various fields of fisheries science and oceanography including fisheries cooperatives, fishermen and oyster farmers are crucial to overcome future problems caused by global warming and to develop sustainable shellfish culture and other fisheries. Further cooperation between the two countries is strongly desired.

Acknowledgments

The authors appreciate the courtesy of Messrs Kunio Goto (KG), Minji Fukuda (MF) and Ryo Sasaki (RS) for their agreements to use the

Fig. 24 Professor Yasuyuki Koike who was the first to apply the Japanese abalone aquaculture method to the French abalone *Haliotos tuberculata* and succeeded in producing its seedlings (a), Grown *H. tuberculata* (b), release of grown *H. tuberculata* into the sea (c, d) and measurement of shell length of grown abalone in the field (e) in 1975 when he has conducted research at COB from 1973 to 1976. Photos are provided by YK.

historical pictures. They thank *Maison franco-japonaise de Tokyo* and *Fondation Sasakawa franco-japonaise* for providing funds to invite French researchers in Japan in 2012.

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Creation of French-Japanese Ocean Development Sub-Committee and its subsequent activities

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Abstract: This article outlines the creation of the French-Japanese Ocean Development Sub-Committee, which was established under the Agreement on Scientific and Technological Cooperation between France and Japan signed in 1974 and its subsequent activities. In July 1974, the French side expressed interest in krill harvesting and utilization, fish pathology, and manganese nodules at the Japan-France Joint Committee on Cooperation in Science and Technology. The first meeting of the French-Japanese Ocean Development Sub-Committee was held in April 1975, during which the Japanese side expressed interest in diving technology, coastal development and marine structures, and marine observation equipment. In October of the same year, at the second meeting of the sub-committee, discussions were held on bluefin tuna farming and marine energy in both France and Japan. In recent years, the conference of the sub-committee has been expanding with reports on continuing, new and completed projects under the main themes of marine research, marine technology and research infrastructure, marine resources, marine biotechnology, deep-sea ecosystems, coastal ecosystems and social ecosystems. The sub-committee plays a significant role in promoting cooperation between France and Japan in the ocean development.

Keywords : *French-Japanese Ocean Development Sub-Committee, Japan-France Joint Committee on Cooperation in Science and Technology, Ifremer, Mext*

1. Congratulatory message to the Japanese-French Oceanographic Society on the occasion of its 60th anniversary.

Thank you very much for the opportunity to speak today at the symposium '60 Years of Japanese-French Cooperation in Oceanography', jointly organised by the Japanese-French Oceanographic Societies (Société franco-japonaise d' Océanographies: SFJOs) of Japan and France, the *Institut français de recherches sur le Japon à la Maison franco-japonaise* and the *Maison franco-japonaise*.

First of all, I would like to congratulate the Japanese-French Oceanographic Society on its 60th anniversary last year 2020, which is the 60th year of the zodiac, when the twelve signs of the Chinese zodiac come full circle. The 60th anniversary is regarded as a kind of rebirth in our

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country, and we have a tradition of wearing red kimono and celebrating our return to "*Akago* (meaning *Aka* is red and *go* is a baby)", namely baby hood. The year 1960, when the Japanese-French Oceanographic Society was founded in Japan and the year 2020, when the Society celebrates its 60th anniversary, fall on Kano-ne in the twelve signs of the Chinese zodiac, and are said to be good years to start something new. I don't know whether those involved in the establishment of the Japanese-French Oceanographic Society were aware of this or not, but it was established in a very good year and has become a long-lasting initiative. Congratulations once again.

2. Self-introduction of the author

I have been in this role as Co-Chair of the Japanese side of the Japanese-French Ocean Development Sub-Committee since July last year. To give a brief background of myself, I have long been involved in forestry and forestry administration and overseas forestry cooperation at the Forestry Agency of the Ministry of Agriculture, Forestry and Fisheries. Prior to this position at the Ministry of Education, Culture, Sports, Science and Technology, I was dispatched to the National Directorate of Forest in the African country of Mozambique as an expert for the Japan International Cooperation Agency (JICA), where I advised on forest management and the reduction of global warming gas emissions by preventing deforestation and forest degradation. Do you know what the official language is in Mozambique? Most African countries are either English or French speaking, but Portuguese is the official language of Mozambique, which is rare amongst African countries. Unfortunately, I do not yet speak French, but I feel familiar with it because it is of the same Latin origin as Portuguese.

3. Creation of the Japanese-French Ocean Development Sub-Committee and its backgrounds

The Japanese-French Ocean Development Sub-Committee, which I co-chair on the Japanese side, is based on the Agreement on Scientific and Technological Cooperation between France and Japan signed on 2 July 1974 (Fig. 1). Under this agreement, a Japanese-French Joint Committee on Cooperation in Science and Technology was established, under which provisions for a sub-committee consisting of experts were made. The first meeting of the Japan-France Joint Committee on Cooperation in Science and Technology was held in the same month as the signing of the agreement on 2 July, during which the French side immediately expressed its specific interest in the ocean sector and agreed to set up a Japanese-French Ocean Development Sub-Committee under the Agreement to promote cooperation.

One of the reasons why the Japan-France Joint Committee on Cooperation in Science and Technology agreed to promote cooperation in ocean development soon after the signing of the agreement was, as already mentioned in the presentation by Hubert-Jean Ceccaldi, Honorary President of the Japanese-French Oceanographic Society of France and Teruhisa Komatsu, President of the Japanese-French Oceanographic Society of Japan, that in 1958 the Bathyscaphe FNRS Ⅲ was sent to Japan, which led to the proposal and establishment of the Japanese-French Oceanographic Society in the following year, 1960 (Komatsu and Ceccaldi, 2023). This was undoubtedly one of the reasons for the proposal and establishment of the Japanese-French Oceanographic Society in 1960. The launch of the Intergovernmental Oceanographic Commission under UNESCO in the same year is another indication of the growing interest in

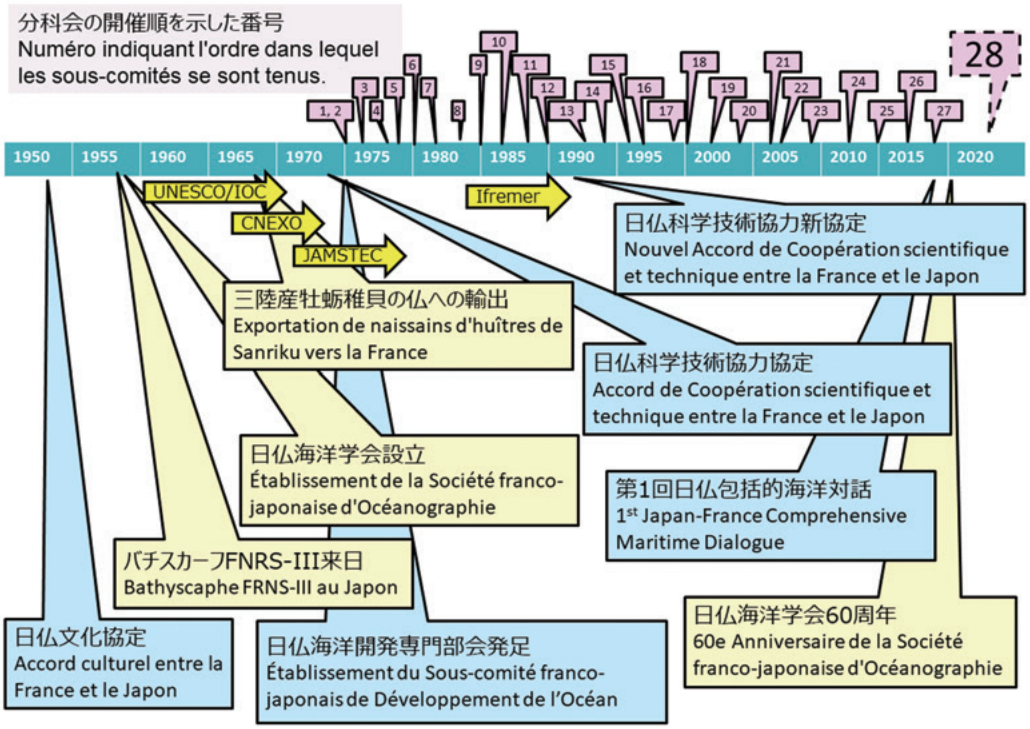

Fig. 1 Diagram showing the history of scientific and technological exchanges on oceanography and fisheries science between Japan and France. At the top of the diagram, the numbers (on a light red background) indicate the order in which the sub-committees were held, with a band of dates below them. Below that, at the base of the horizontal arrows (yellow background), the founding years of UNESCO-Intergovernmental Oceanographic Commission, CNEXO, Ifremer and JAMSTEC are indicated. At the bottom of the diagram, events related to the Japanese-French Oceanographic Society (light yellow background) and events between the French and Japanese governments (blue background) are shown.

oceanography worldwide (Fig. 1).

There was a scientific comic book I read when I was a child called The Secrets of the Sea (Fig. 2). It was published in 1974 under the supervision of Professor Noriyuki Nasu of the University of Tokyo, and in it there were descriptions of the Bathyscaphe FNRS Ⅲ, the Bathyscaphe Archimedes, the Japanese Kuroshio, as well as the Precontinent Project and the Japanese SEATOPIA Project, an experiment in undersea living, which were very exciting to me. When I took up this position in July last year, more than 40 years after my contact with the Japanese-French Ocean Development Sub-Committee, I was again struck by a quiet excitement as the word 'Bathyscaphe' brought back memories I had forgotten.

Furthermore, as presented by Professor Yasuyuki Koike of the Japanese-French Oceanographic Society, there was already a cooperative relationship in the marine sector, with oyster spats from Sanriku being exported in 1969 in response to the mass mortality of oysters in France (Koike and Komatsu, 2023).

Fig. 2 The cover of a scientific comic book, The Secret of the Sea, which the author read as a child and which was published in 1974 under the supervision of Professor Noriyuki Nasu of the University of Tokyo. The book contained descriptions of the manned submersible for deep-sea scientific research, FNRS Ⅲ, Archimèdes, and Japan's Kuroshio, as well as the undersea living experiments, the Precontinent Project and the Japanese SEATOPIA Project.

Conversely, when oyster farming in Sanriku was severely damaged by the Great East Japan Earthquake of 2011, members of the Japanese-French Oceanographic Societies extended a helping hand more than 50 years later. We understand that the Japanese-French Oceanographic Societies have been instrumental in providing support. This support has greatly aided the recovery of production in Sanriku oyster farming, both materially and morally.

In addition, it should be noted that in both countries, the momentum to promote the development of marine technology was at an all-time high, with the establishment of the Centre *National pour l'Exploitation des Océans* (CNEXO) in France in January 1967, the predecessor to Ifremer, and Japan Marine Science and Technology Center (JAMSTEC) in Japan in October 1971.

JAMSTEC, established in 1971, celebrated its 50th anniversary last 1 October and a commemorative stamp was issued (Fig. 3). The Shinkai 2000, depicted in a cute illustration, is a manned submersible for deep-sea scientific research using the bathyscaphe principle and was completed in 1981; in 2017 it was recognised as Japan's Mechanical Engineering Heritage No. 87.

4. Subsequent activities of the sub-committee after its creation

4.1 1970s

In July 1974, the French side expressed interest in (1) krill harvesting and utilisation, (2) fish pathology and (3) manganese nodules at the Japan-France Joint Committee on Cooperation in Science and Technology, and at the first French-Japanese Ocean Development Sub-Committee in April 1975 (Fig. 1) the Japanese side expressed interest in three issues: (1) diving technology, (2) coastal development and marine structures and (3) marine observation equipment. This is when the French-Japanese Ocean Development Sub-Committee began.

Only six months later, in October of the same year, at the second meeting of the French-Japanese Ocean Development Sub-Committee, in addition to the exchange of information on the six agreed areas, discussions were also held on bluefin tuna farming and marine energy in both France and Japan (Fig. 1). However, in order to

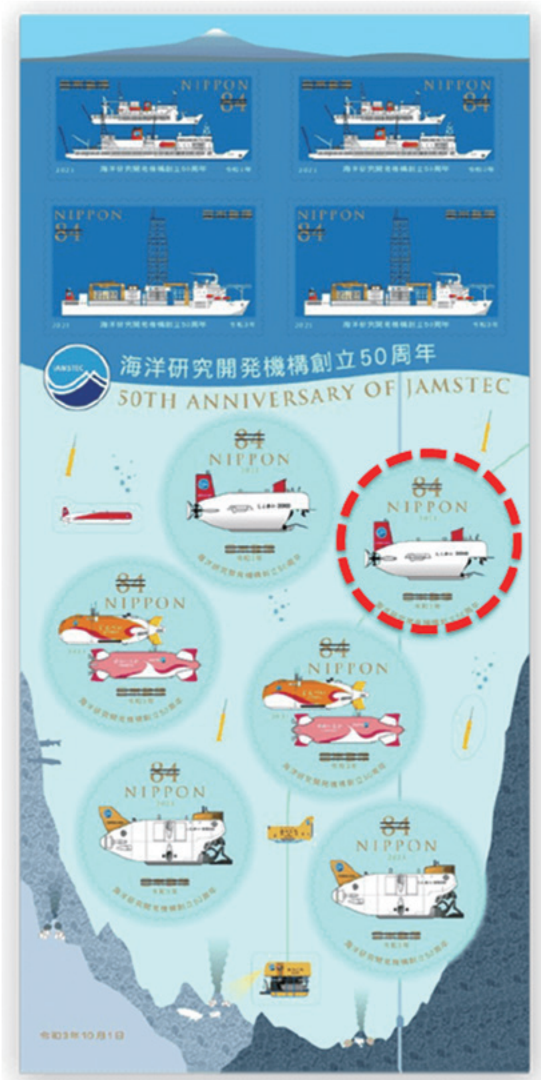

Fig. 3 Commemorative stamp for the 50th anniversary of the establishment of JAMSTEC, which was founded in 1971. The Shinkai 2000, depicted in a cute illustration, is a manned submersible for deep-sea scientific research using the bathyscaphe principle, completed in 1981 and registered as Japan's Mechanical Engineering Heritage No. 87 in 2017.

avoid a double track with the Energy Sub-Committee, it was decided that marine energy would not be dealt with directly by the French-Japanese Ocean Development Sub-Committee. From this session, a proposal was made to use the Bathyscaphe Archimède jointly for research in the seas around Japan, but the Japanese side was relatively cautious. (Presumably there were problems with cost sharing etc.)

Eight months later, at the third meeting of the French-Japanese Ocean Development Sub-Committee in June 1976 (Fig. 1), concrete discussions began to take place not only on information but also on the exchange of personnel, including offers of boarding research vessels. On the other hand, the limits of what could be done between governments also became apparent, as it was discussed that there were restrictions on the exchange of information on commercially protected intellectual property rights on a private basis with regard to the mutual dispatch of researchers on diving technology.

After three intensive meetings in the first year since its start, the next fourth meeting of the French-Japanese Ocean Development Sub-Committee was held in March 1978 (Fig. 1), one year and nine months later, at the Technical Centre for Marine Development in Brittany. Cooperation on diving technology was confirmed and mutual exchange of information was actively pursued. On the other hand, the French side expressed a decline in interest in krill, in which France had initially shown interest.

The fifth meeting was held a year and a half later, in November 1979 (Fig. 1). In order to reduce dependence on oil and to focus on the development of alternative energy sources, marine energy was also dealt with in this French-Japanese Ocean Development Sub-Committee. At this meeting, it was agreed to consider feasibility conditions for joint research in the Japan Trench using the deep-sea submersible SM97, leading to the KAIKO project, which was to continue for a long time, changing phases.

The sixth meeting followed a year later, in November 1980 (Fig. 1). Steady co-operation was confirmed in each theme, and the initiation of data exchange between the Japan Coast Guard Hydrographic Department's Marine Data Centre (JODC) in Japan and the French BNDO (National Marine Data Office) was raised.

4.2 1980s

A year and a half later, in June-July 1982, the 7th meeting was held (Fig. 1). By then, significant progress had been made in cooperation in the field of deep-sea diving, including the completion of JAMSTEC's submersible Shinkai 2000 and the participation of French researchers in the diving simulation experiment Sea Dragon IV. The report of the Study Working Group on the Japan Trench Joint Survey was submitted, and it was decided to seek direction from the Japan-France Joint Committee on Cooperation in Science and Technology. A manganese nodule workshop was also held immediately before the 7th meeting and was successfully completed. It was agreed that future cooperation should be pursued in the areas of manganese nodules and deep-sea hydrothermal polymetallic sulphides, and the exchange of information on both the geology of the Southwest Pacific and deep-sea seabed mineral resources. It was proposed by the French side and agreed by the Japan side that the subject, which has been treated as 'manganese nodules' since the first meeting, be treated as 'deep-sea geology and mineral resources' in a developmental manner from the 8th meeting.

At that time, the Japanese side reported that the krill samples provided by France had a good taste and colour and were suitable for food, and it can be seen that Japan continued to be interested in krill as food, although the French side expressed a decline in interest.

The 8th meeting was held in February/March 1984 (Fig. 1), and was preceded by a visit to Japan in November 1983 by delegations from the French Institute of Fisheries Sciences (*Institut scientifique et technique des pêches maritimes:* ISTPM) and the French National Centre for Ocean Development (*Centre National pour l'Exploitation des Océans:* CNEXO), including proposals of interest presented at that time. The Japan Trench joint research programme introduced by the Japan-France Joint Committee on Cooperation in Science and Technology is now being promoted under the alphabetical name 'KAIKO Project'. Despite the remarkable start of the joint project, it was agreed that red tides, which were showing signs of recurrence in the French coastal regions, would be taken up as a theme, and that krill, which the French had already lost interest in, would be dropped from the theme. On the other hand, it was agreed on the possibility of initiating cooperation in the technical committee on shellfish, particularly oyster aquaculture. It was reported that CNEXO had sent three egineers to JAMSTEC for three months to participate in research on the Shinkai 2000 and Natsushima, confirming the significant progress made in cooperation on deep-sea diving. This 1984 was also the year that CNEXO, the organisation that chaired the French side of the French-Japanese Ocean Development Sub-Committee, was reorganised into Ifremer.

The 9th meeting was held a year and a half later, in September 1985 (Fig. 1). The symposium was preceded by a two-day symposium on French-Japanese Ocean Development, which was a great opportunity for researchers to interact with each other. At this meeting, it was agreed that oceanographic instruments, which had been the theme of the first meeting, would no longer be the subject of the French-Japanese Ocean Development Sub-Committee.

The French-Japanese Ocean Development Sub-Committee has since then been holding stable meetings in alternating cycles of 18 months to two years in Japan and France. The main areas of cooperation have been the KAIKO project for joint research in the Japan Trench, which has been continuously addressed in different phases, such as KAIKO-TOKAI, KAIKO-SFJ and KAIKO-NANTRO, the joint research programme on lift systems (STARMER programme) and marine biotechnology, along with other traditional topics.

4.3 From 1990s to now

On 5 June 1991, a new French-Japanese Agreement on Scientific and Technological Cooperation was signed, which is the basis for the establishment of this sub-committee (Fig. 1). The Science and Technology Agency, which initially co-chaired the Japanese side, was reorganised into the Ministry of Education, Culture, Sports, Science and Technology in 2001 during a major reorganisation of Japanese ministries, and in 2004 the Japan Marine Science and Technology Centre became the Japan Agency for Marine-Earth Science and Technology. While undergoing such major changes, the French-Japanese Ocean Development Sub-Committee had met a total of 27 times by May 2018 (Fig. 1).

In recent years, the conference of the sub-committee has been expanding with reports on continuing, new and completed projects under the main themes of marine research, marine technology and research infrastructure, marine resources, marine biotechnology, deep-sea ecosystems, coastal ecosystems and social ecosystems. It would be difficult to report in detail on the evolution of these projects in an oral report. This is testimony to the strong will of both countries to cooperate in development, which we hope to be able to document later when the results of this symposium are compiled in the journal of the Japanese-French Oceanographic Society *La mer*.

This is an unprecedented interval of more than three years. However, the UN Decade of Ocean Science for Sustainable Development (2021–2030) will be launched this year in 2021, raising expectations and interest in ocean science worldwide. In May this year, Iceland and Japan co-hosted the 3rd Arctic Science Ministers' Meeting (ASM3) in Tokyo, where Japan reported that it had started construction of a new Arctic research vessel with icebreaking capabilities this year, and expressed its intention to use it as an international platform. Russia and France, the next chairs of the Arctic Council, offered to co-host the 4th Arctic Science Ministers' Meeting, and the handover from the ASM3 co-chairs to the ASM4 co-chairs took place at the Arctic Council General Assembly held in Reykjavik last week. The passing of the baton from Japan to France as non-Arctic co-chair may also be due to the marine science ties between the two countries.

5. For future cooperation between France and Japan for Ocean Devlopment

Thus, the French-Japanese Ocean Development Sub-Committee, which started 15 years after the establishment of the French-Japanese Oceanographic Society in 1960, is progressing well, and new seeds of cooperation are beginning to emerge. Although it is difficult for researchers to come and go between the two countries at this time of the world, we take this milestone as a positive opportunity to look back on the past and take the next big step forward to promote long-lasting cooperation between French and Japanese marine science, and as Japanese co-chair of the French-Japanese Ocean Development Sub-Committee, I would like to help in any way I can. I would like to be of assistance in this regard.

I would like to conclude my presentation by wishing you a successful series of symposia and wishing you all good health and happiness.

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Plastic oceans

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Abstract: With annual global production of artificial polymers (plastics) exceeding 400 million tonnes, the oceans are among the areas most affected by plastic pollution. The distribution of plastics in these oceans is influenced by human activities. Plastic pollution is found on beaches, on the surface and, for more than 90%, on the seabed worldwide. Plastic degrades at sea into microplastics or nanoplastics, constituting, together with industrial pellets or primary microplastics, a heterogeneous group of particles, varying in size, shape, colour, chemical composition and density. Little is known about the extent of the impacts caused by marine litter and microplastics. Some of the most important are the entanqlement of organisms, ingestion by organisms, release of contaminants and long-range transport of species. There are also impacts on certain sectors of the economy, including tourism and fisheries, but also risks to navigation and health impacts. In addition to reduction measures based on circular economy, recycling, water purification, selective cleaning and education, global initiatives (United Nations Environment Assembly, G7 and G20), establish a framework within which states must take management measures to achieve a better state of the environment. However, the risks remain high, environmentally, socially, economically and for human health.

Keywords : *Marine litter, plastic pollution, microplastic, social and ecological damages*

1. Introduction

With around 4 billion tonnes of waste including plastics generated worldwide each year and annual plastic production reaching 400 million tonnes by 2021, the world's ocean receives around 20 million tonnes each year, of which 8 million tonnes is plastic from the continents. No sea, no ocean is spared and the most remote areas, beyond the polar circles, also receive some. For specialists, marine litter consists of all materials or objects that are directly or indirectly, voluntarily or involuntarily, discarded or abandoned in marine aquatic environments or connected to the seas and oceans. This definition covers a very wide range of sizes from mega-waste (> 1 m), to microplastics (1–5,000 μm: Fig. 1) and even nanoplastics (< 1 μm). They are classified according to the nature of the material, such as plastic, metal, glass, rubber or wood, or according to sources or uses, such as fishing gear, industrial pellets, sanitary ware and single-use plastics.

According to the United Nations Group of Experts (GESAMP, 2019), plastics consist of

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polymers synthesised from hydrocarbon or biomass molecules with thermoplastic or thermoset properties. It is the main component of marine litter and has a wide range of properties, shapes and compositions. Depending on the area, these materials can account for up to 100% of marine litter and their increase in the marine environment has long been ignored, reinforced by economic policies that favour single-use, disposable and non-repairable products. In a few years, the problem has become global.

The problem of litter pollution is not really new. In chapter 11 of his famous book "Twenty Thousand Leagues Under the Sea" (VERNES, 1870), published in 1870, Jules Vernes describes in Chapter 11 the accumulation of debris in the Sargasso Sea, an accumulation attributed to the circular currents that allow boards and other floating ropes to be concentrated. However, the share of plastics, which was non-existent at the beginning of the 20th century, has become very important in recent years. Although the first descriptions of plastic floating on the surface of the oceans date back to the 1970s, in the Atlantic and Pacific Oceans, all compartments of the marine environment are now affected. It is estimated that 1–5 trillion plastic bags are consumed globally each year (UNEP, 2018). At sea, about 40% of the waste is single-use plastic packaging, made to be light and strong, but unfortunately persistent in the environment.

Marine litter is present in all habitats, from densely populated areas to remote regions (BARNES *et al*., 2009), from beaches and shallow waters to deep ocean trenches (PIERDOMENICO *et al*., 2019). Sources are often diffuse and mainly land-based. Wastes come from rivers, sewage, sewage overflows, inappropriate or illegal discharges or dumping and runoff, and directly from some human activities such as tourism. It is estimated that more than one million tonnes of plastic waste enter the ocean each year from the 20 most polluting rivers, mostly in Asia, accounting for a significant percentage, between 60 and 80% of the world's total plastic at sea (GALGANI *et al*., 2021b).

Through degradation and fragmentation, plastic waste is transformed into microplastics. The diversity of polymers that form these plastics and their properties makes understanding their fate very complex, some sinking immediately, others, of low density such as polyethylene and polypropylene, moving on the surface with the currents. Primary microplastics such as industrial granules or microbeads used in cosmetics are designed to be small and represent a significant fraction of microplastic inputs, but the vast majority of these, known as secondary, are derived from the fragmentation and degradation of larger debris. The most recent work has shown the importance of certain sources such as textiles, via washing cycles in machines or emission of fibres into the atmosphere, tyres, from rubbing or on tarmac, or fragments from boat paints. Plastic pollution also enters the marine environment due to deficiencies in treatment infrastructure, including water treatment. For plastic microparticle streams alone in water from wastewater treatment plants in Europe, concentrations can reach up to 10 million particles/m^3 (GALGANI *et al*., 2021b).

Other sources of marine litter can be attributed to shipping, industrial exploration and offshore oil platforms, fisheries and aquaculture (GESAMP, 2015; 2019), as well as to the intentional loss or disposal of, for example, containers, ballast weights and cargoes. Fishing waste (Fig. 1) is most characteristic, particularly in the Western Pacific and Indian Ocean where it is not uncommon to see buoys or pieces of net accumulating on isolated archipelagos where they have been transported. In some fishing areas, marine litter consists entirely of abandoned, lost or discarded fishing gear (Pham *et al.*, 2014). The amount of such litter is not well known, although some estimates are available. About 640,000 tonnes per year, according to Macfayden *et al.* (2009), and about 70% (by weight) of floating macroplastics in the high seas are fisheries-related (Eriksen *et al.*, 2014). It is also estimated that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost globally each year (Richardson *et al.*, 2019).

On a more local scale, microplastic granules, which are synthetic industrial products lost during production or shipping, become plastic waste before they are even used. These inputs constitute a risk of future accidental pollution, as illustrated by recent events such as the stranding of plastic microbeads on the Sri Lankan coastline in 2021 following the loss of containers (The Washington Post https://www.washingtonpost.com/world/2021/06/01/nurdles-sri-lanka-ship-wreck-plastic-pellets/ accessed on 1 October 2021).

Inputs from extreme events and natural disasters, such as hurricanes, floods, earthquakes and tsunamis, as well as accidents, can reach millions of tonnes each year and match the magnitude of regular inputs from the land (Carlton *et al.*, 2017). The tsunami in Japan in 2011 is the most representative and recent example of massive accidental waste inputs, this event generated about 5 million tonnes of waste discharged into the sea (Ministry of the Environment of Japan, 2012), some of which drifted to the surface towards the convergence zones and the eastern coasts of the Pacific Ocean (Murray *et al.*, 2018).

The nature of the litter varies greatly depending on whether it is beach, surface or seabed based, and on the activities in a region. Observation, trawling, aerial surveys, plankton collection, aerial photography, use of submersibles or scuba diving are the various possible approaches to assessment, each corresponding to a particular site, region or biotope. Numerical modelling completes the methodological approaches. It allows the location of likely accumulation areas and the prediction of the fate of objects at sea, including indications of transboundary transport.

At sea, the duration of degradation is subject to external factors such as luminosity and the presence of oxygen, which is less at depth, or the possibility of abrasion, particularly on beaches. Thus, the lifespan of waste is very variable, from two weeks for newsprint, a few years at least for fine plastics and several hundred years for certain polymers such as telephone cards (1000 years) or fishing lines (600 years). Glass, considered inert, can persist for thousands of years.

In the coastal environment, at the surface of the sea, plastics are mainly made up of polyethylene, polypropylene and expanded polystyrene. But in addition to these three types of resins, there are a dozen other polymers in lesser proportions. These are all polymers that are less dense than sea water and can therefore remain on the surface. In the open sea, still at the surface, we still find mainly polyethylene (90%) and polypropylene (10%), the polymers most produced in industry and probably the most persistent in the open sea. The water column has been much less explored than the sea surface. It seems that from a few metres down in the water column, microplastics are distributed differently. They are mainly small microplastics and synthetic fibres, which are only a few hundred or even tens of micrometres in size, whereas at the sea surface, the particles detected measure several hundred micrometres to a few millimetres.

In the sediments, denser polymers such as polyesters or polyacrylics are found (77% on

Fig. 1 Plastic pollution affects all areas of the marine environment: (A) Microplastics collected on the surface, Mediterranean Sea, (B) Beach litter, Northwest Atlantic, (C) Fishing litter, Northwest Atlantic, (D) Accumulation of plastic litter on the bottom, Mediterranean Sea, Ramoge campaign, 2200M.

average) but surprisingly, fragments of polymers less dense than seawater are also found (GALGANI *et al*., 2022), which have therefore undergone vertical transport from the surface to the bottom via processes that are very poorly understood. These processes could include colonisation by micro-organisms or integration into aggregates made of organic matter and responsible for the normal process of transferring this organic matter to the bottom.

2. Beach litter

Most work on plastics at sea has focused on coastal areas due to proximity to sources, ease of access/assessment and for aesthetic reasons. Data is most often based on measurements of quantities or flows of waste categories, on transects of varying width and length. This makes it difficult to build up an overall quantitative picture of beach litter. In addition to scientific work, beach clean-ups are important sources of data, sometimes providing information on the number of items, their weights; types of materials, and even their use or origin. These assessments reflect the long-term balance between inputs, land-based sources or strandings, export to the sea, burial, degradation and clean-ups. Certain factors largely influence densities, including storms, rainfall, tides, and hydrological changes.

The most common scientific approach is to conduct regular post-cleanup surveys to reveal long-term patterns and cycles of accumulation, while not requiring a lot of time. In particular, this approach allows the assessment of flows. It mainly concerns the space between the sea and the upper submerged limit of beaches, at sites most often chosen for their ecological relevance, accessibility and particular anthropogenic activities and sources. Beach shape, location and nature of debris are also important selection criteria (TURRA *et al.*, 2014). In addition, most surface sediment counts do not take into account the overlay and burial of debris, grossly underestimating the quantities present. It appears that glass and hard plastics accumulate more easily on rocky shores (GALGANI *et al.*, 2015). Waste often washes up on beaches without strong prevailing winds (Fig. 1), which can carry it offshore (GALGANI *et al.*, 2000). Furthermore, the abundance and composition of litter often varies between different parts of an individual beach, with the highest amounts frequently found at high tide or storm lines. For this reason and because of beach topography, patchy distribution is a common distribution pattern on beaches, particularly for smaller, lighter items that are more easily dispersed or buried. High concentrations range up to 78.3 items/m^2 or even more than 5,000 items/m^2 in the case of extreme events such as typhoons or floods (GALGANI *et al.*, 2015). In general, the results indicate the prevalence of plastics, with higher loads near urban areas and tourist regions (BARNES *et al.*, 2009). However, other types of waste may also be important in some areas, in terms of type (wood) or use (e.g., fishing gear). The lack of large-scale trends (GALGANI *et al.*, 2021b) in many beach studies is probably due to the heterogeneity of sources and factors that may influence the small-scale distribution.

3. Litter on the seabed

The seabed remains the least known part of the oceans. Litter has been observed on almost all types of seabeds, but the highest concentrations have been observed in canyons and trenches (GALGANI *et al.*, 2022), due to their physical and geomorphological characteristics. Recent work has assessed human impacts on deep-sea environments, determined temporal trends, shown the presence of characteristic objects or sources, and evaluated the effectiveness of measures. Some studies have even covered the deepest areas, such as the Mariana Trench (CHIBA *et al.*, 2018). However, with a poorly described distribution and circulation of water different from surface currents, one of the major issues of the coming years, a real challenge of the 21st century, will be to discover these remote and deep areas where large amounts of debris probably accumulate.

Generally speaking, average densities range from 0 to more than 7,700 items/km^2. The highest densities of plastic litter are found in coastal areas, in enclosed bays, including coral reef lagoons, fjords and at the heads and upper slopes of marine canyons. They very often end up at the bottom of canyons or in areas of low circulation where sediments can accumulate. High densities have been found in the Barents Sea, the North Sea, the Bay of Biscay and the Western Pacific. In addition to canyons, the presence of deep, converging currents, leading to high sedimentation rates, accounts for accumulations at great depths. Distant regions such as the Arctic regions can receive substantial amounts of waste (5,351–8,082 items/km^2; TEKMAN *et al.*, 2017), probably due to deep and converging currents (GALGANI and LECORNU 2004; TEKMAN *et al.*, 2017). However, the quantities are much smaller in the Antarctic region.

Piles of several tonnes of waste have been demonstrated in some underwater areas, sometimes several tens of miles offshore. In the abyssal plain, high densities are the result of populated areas and intense maritime activities (MORALES-CASELLES *et al.*, 2021). Extreme average values, above 10,000 items/km^2, have been found in Sardinia, Malta, California and the South China Sea. In some areas of the Mediterranean, densities of up to 10,000 items/km^2 have even been identified (Fig. 1). This is mainly heavy waste, metal, glass, plastics or dense packaging (HARRIS, 2020). This situation is linked to the high population density on the coast, the high volume of maritime traffic, the presence of large rivers (Nile, Po) and the intensive tourist activities around this closed basin (UNEP, 2015).

Finally, the accumulation of microplastics on the seabed is still very poorly documented, even though it is known that many macro-waste products are stored in the seabed away from light and therefore have extremely slow degradation kinetics. In general, microplastics in deep-sea sediments are present in greater quantities than in surface waters, which supports the hypothesis that they constitute a reservoir of microplastics (HARRIS, 2020).

These microparticles have been found in sediments all over the world (GALGANI *et al.*, 2022) with higher average concentrations in fjords, estuarine environments, and in shallow coastal environments. Unlike macroplastics, microplastic concentrations are generally not associated with local sources of contamination. Of particular interest are the high densities observed in the Arctic; up to 6,595 items/kg of sediment, comparable to those observed in populated areas and even higher than the amounts reported by many other studies, including marine canyons. These densities are likely related to atmospheric transport and deposition, a now-recognised pathway for microplastics in remote areas (BERGMANN *et al.*, 2019). Finally, several studies have highlighted the importance of fibres, most of which account for more than 50% of microplastics, often reaching 70–90% of total microplastics (e.g. HARRIS, 2020).

4. Floating litter

It is estimated that there are 24 trillion floating microplastics on the surface of the oceans (ISOBE *et al.*, 2021). Although the coasts are generally the most affected, transport at sea can take place over long distances, sometimes from one continent to another. Imagine the massive arrival of several dozen species fixed on floating waste and acclimatising in an area, disrupting interspecific relations and in particular the organisation of ecosystems. This situation is demonstrated by the arrival of 289 new species of macro-fauna and macro-flora counted on the coasts of North America, without regard for microorganisms, on plastic objects that crossed the North Pacific Ocean within 6 years of the 2011 Japanese tsunami (CARLTON *et al.*, 2017).

At sea, the main principles of geostrophic current dynamics condition the 'journey' of waste. Due to the trade winds at the equator, the mean residual surface circulation, dependent on interactions with the atmosphere, is oriented westward in the three ocean basins of the Pacific, Atlantic and Indian Oceans. The inflow of water to the west of these three basins causes water to flow north or south, generating significant water movements. Five major currents for each of the North and South Atlantic, North and South Pacific and Indian Ocean basins flow back and forth at high latitudes towards the east, as a result of the Coriolis force, and bring the water masses towards the eastern coasts and then partly back to the equator, closing the oceanic vortex which functions like a vortex or, more graphically, like the draining of water from a sink. At the centre of these moving water masses are areas of low dynamism, known as 'convergence zones' or ocean gyres. All floating objects and living organisms are then moved by the currents to these areas of weak circulation. Floating piles of plastic waste in these areas have been in the news recently because of the convergence zones, which have been exaggeratedly described as plastic continents that exist in all ocean basins. In the Western Pacific, for example, the waste arrives with the equatorial current and bifurcates towards Australia, via the Australian Current, or towards Japan in the north, via the current known as the Kuro Shio. Before heading back eastwards where they will create, through the giant gyre, these famous concentration zones.

Together with the oceanic gyres, these zones alone should receive between 35 and 60% of all plastic waste at sea within thirty years. The collective imagination is very sensitive to this information. However, while the image is spectacular, as is that of plastics concentrated in a plankton net after collecting samples from several thousand square metres, the quantities of plastics are greater in certain coastal areas such as the Mediterranean, the Bay of Bengal and South-East Asia are the most affected areas (Eriksen *et al.*, 2014), and the actual quantities in the gyres represent only a few thousand tonnes. In coastal areas, the problems can be even greater due to massive inputs and lack of dilution.

5. Long-term trends

In a comprehensive article on the evolution of quantities in the different compartments of the marine environment, a number of realities have been mentioned (Galgani *et al.*, 2021a). While the production and input of plastics in the sea has increased since the 1950s, several modelling studies predict a further increase in these respective quantities in the coming years. The compilation of scientific literature on marine litter trends is mainly based on monitoring programmes. These are very often partial, very diverse, and frequently focus on limited components of the marine environment in different regions, covering a wide spectrum of marine litter types, with limited standardisation. Increasing amounts of plastic are found in some regions, especially in remote areas, but the large number of studies does not demonstrate a consistent temporal trend. The observation of a steady state of plastic amounts in many marine compartments, as well as the fate and transport of plastic in the marine environment, remain areas that require further research.

Most studies indicate constant amounts of litter in coastal marine ecosystems in recent years until 2019. The increase in the amount of plastic observed in remote areas over time could therefore be interpreted as a long-term transfer of litter from directly affected areas to areas with little or no human activity. Nevertheless, while the total amount of plastic waste predicted globally is increasing, as models suggest, the apparent steady state of plastic amounts observed in coastal systems calls into question our ability to predict the sources and fate of plastic. More standardisation and coordination are needed before we can reliably report on plastic waste trends. A reduction in marine temporal trends is possible for some types of plastics, subject to societal reduction measures, as is the case for industrial granulates, which have received much attention in regional action plans following changes in industrial practices. Until there is a better understanding of the mechanisms behind the apparently stable amounts of plastics recorded in marine surveys, identifying possible trends will remain a challenge. There are still many gaps and uncertainties in the rates of degradation, burial and transport of plastics in the marine domain.

6. Impact of litter on ecosystems

Throwing waste into nature is not without consequences as it can remain there for a long time. In recent years, the known number of species impacted by waste has reached 1,400 species (Claro *et al*., 2019). The impacts of plastics at sea can be presented in two main types (Galgani *et al*., 2020): global impacts at the ecosystem scale mainly related to species transport and impacts at the organism and population scale.

In terms of ecosystems, plastics constitute a new habitat for many species at sea, particularly benthic macro-organisms such as arthropods, molluscs, hydrae, bryozoans, and many micro-organisms, bacteria, viruses, fungi, micro-algae of the dinoflagellate genus and diatoms (Fig. 2). These species will rapidly colonise plastic waste at sea, attaching themselves to it and even developing. Not only do they encourage the colonisation of new environments, sometimes thousands of kilometres away, but the alteration of the balance of ecosystems, caused by the transport of species, also represents a major risk. There is also clear evidence of the presence of invasive, toxic or pathogenic species that can alter the marine organisms of the regions to which they are transported.

At the individual level, the impacts of plastic waste at sea are particularly visible on large marine animals, including seabirds (Fig. 2), mammals and turtles trapped in large plastic waste such as ghost nets. The ingestion of microplastics by plankton or certain fish or even whales are other examples of effects. The most significant case is that of sea turtles, so common in the tropics, where up to 100% of individuals, depending on the region of the world, have waste in their stomachs. However, compared to macroplastics, microplastics are far more numerous and affect the entire marine food chain more widely. Because of their small size, they are easily ingested by a very large number of species. Once ingested, these microplastics can either obstruct the digestive system or simply pass through it, the primary route observed in the laboratory. However, the smallest particles, such as nanoplastics, can also pass through the digestive membranes and migrate into the circulatory system or even into other organs, as has been observed in fish. In any case, even a simple transit of microplastics through the digestive tract (Fig. 2) induces major changes in the biology of the animal that has ingested them: changes in digestion that disrupt energy input via the diet, a direct source of cellular stress, with disruptions in the major physiological functions of growth, immune defences and reproduction. In addition, the additives contained in plastics can also be released in the particular conditions of the digestive tract during transit and cause chemical disruption, with associated endocrine disruption for example. The entire life cycle of an organism can thus be affected with trans-generational repercussions. The interactions between prey, predators, the environment and microplastics require a complex approach, on a community scale, taking into account the diversity of plastic waste, as this has a strong influence on its fate and behaviour at sea and therefore on its toxicity.

Because of the adsorption properties of microplastics, particularly persistent organic pollutants which can be attached to their surface thanks to their hydrophobic properties, contaminants can be carried. Polychlorinated biphenyls or polycyclic aromatic hydrocarbons, heavy metals (Hg, Cd, Pb…) and pesticides can be found on their surface. However, even if the accumulation of persistent organic pollutants has

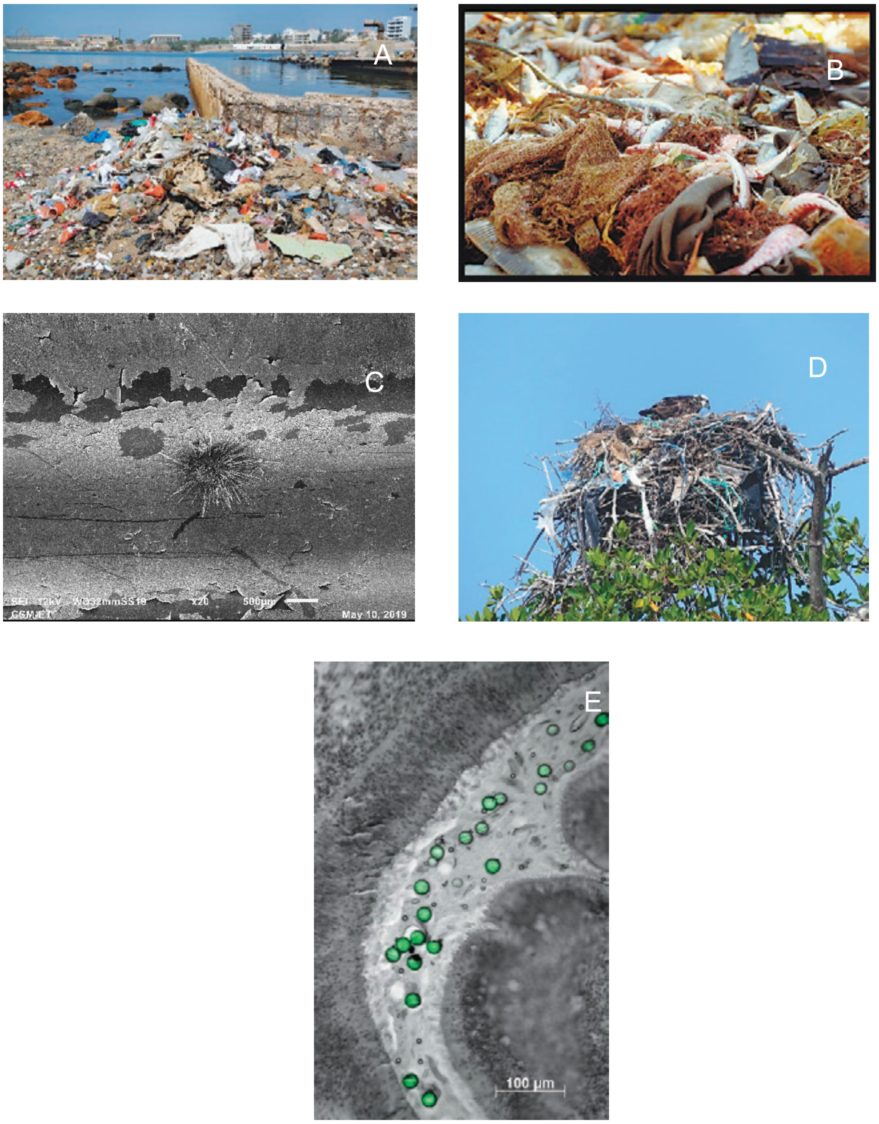

Fig. 2 Impacts caused by plastic are environmental, social, economic and can affect human health: (A) Aesthetic impact in an equatorial beach of eastern Atlantic, (B) Bycatch of litter in bottom trawl fisheries affecting fishermen's community in the Mediterranean Sea. (C) Radiolaria colonies formed on a bottle submerged at depths of several hundred metres (Mediterranean Sea, RAMOGE cruise, 2018). Transport of invasive species, with or without risk, may affect biodiversity and in some cases human health. (D) Fish-eating bald eagle nest buit with a mix of wood and plastic (Pacific coast of Mexico). The mixing of litter has significant impacts on marine species. (E) Experimental ingestion of microplastic fluorescent polyester particles accumulated in the digestive gland of an oyster (Ifremer/A. Huvet). The ingestion of plastic by marine organisms may have environmental costs, and impact on human health.

been demonstrated in certain organisms, microplastics are apparently not the main vectors compared to other particles suspended in the seas and oceans. Furthermore, the effect on bioaccumulation in marine organisms does not seem to be predominant in human food. Indeed, from a chemical point of view, despite an identified risk, the levels of polymer constituents and/or their additives (phthalates, bisphenol A) in the sea remain well below toxicity thresholds and if plastics play a role as vectors of pollutants, this remains a minor route of contamination of the marine environment, much less important than traditional pollution, particularly in urban or industrial areas.

7. Socio-economic impacts

The costs generated by plastics at sea are most often linked to human activities (Table 1). These costs amount to millions of euros each year for some communities and in some regions of the world, they affect a significant percentage of fishing fleets (Fig. 2). The first obvious economic impact is related to the consequences of the pollution of coastal areas, particularly beaches and foreshore areas, by plastic. The heritage value of the sites is largely affected, and the economic stakes linked to tourism can be strongly affected (recent closures of very touristy beaches for example). These impacts are often of an aesthetic nature (Fig. 2) and are reflected and quantified by the significant costs of cleaning.

Along the coastline, aquaculture activities can be the cause of significant inputs of plastics to the marine environment, particularly in shellfish production areas (oysters, mussels and other shellfish) due to losses of material, whether unintentional or not. Socio-economic impacts also concern underwater interventions on the bottom of ports or along the coastline as well as environmental awareness and education programmes. The most bulky waste also poses risks to shipping and in some countries, such as Japan, can account for up to two thirds of the damage paid by insurance companies to fleets. In addition to transport, these impacts are also significant for fishing vessels, with additional costs for cleaning and repairing nets or lines, as well as indirect costs related to the alteration of fish stocks due to unintentional catches of lost or abandoned nets. This issue of ghost nets is particularly critical in certain regions of Europe (South Brittany, North Adriatic, Gulf of Lion) where stock losses can reach 2 to 3% of an entire population of certain species (GALGANI *et al.*, 2020). More generally, the costs associated with the socio-economic impacts are still poorly known, with costs estimated at around 260 million euros for marine litter in European waters alone. For the world's oceans as a whole, the financial damage is estimated at around 12 billion euros per year (UNEP, 2021). Finally, this economic pressure also affects recreational boating due to the frequent accidents caused by plastic nets or sheets caught in boat propellers or cooling systems.

Whether they are mainly washed up or sometimes floating, it should never be forgotten that waste can have effects on human health, including pieces of glass, syringes and medical waste that can cause injury or even contamination. It is now a fact that microplastics are present in all compartments of our environment and have entered our food. In particular, their presence has been shown in commonly consumed seafood products such as mussels and other shellfish, with quantities varying according to geographical location. Microplastics have also been found in crustaceans, and also in many species of fish, mainly in their digestive systems. The presence of significant quantities of microplastics in table salt should be highlighted. Moreover, human

Table 1. Summary of the impacts of marine litter on the economic sector with an estimation of their respective importance (modified from UNEP, 2015). += Low; ++= moderate; +++= high,; ?= unknown

SECTOR	IMPACT	IMPORTANCE
	Health risks	++
	Legal action	+
	Hidden cost	?
Municipalities	Removal of waste	++
	Beach cleaning	+++
	Negative publicity	++
	Cost of bad labelling	+
Tourism	Cost for beaches	+
	Negative publicity	++
	Promotion de the region	++
	Reduced income	+++
	Reduced recreational opportunities	++
	Loss of aesthetic appeal	++
Industry	Damage to equipment	+
	Increased maintenance	+
	Time lost per facility and staff	+
	Removal of waste	+
Aquaculture	Manual removal of waste	+
	Damage to vessels and time lost by staff	+
	Cleaning of nets	+
Navigation	Damage to vessels	+
	Cost of rescue operations	+
	Legal obligation	+
	Negative publicity	+
	Cleaning and dredging of ports	+
	Labelling for ports	+
Non-governmental organisations	Operational costs	++
	Financial support	++
	Volunteers' time	+++
Fisheries	Repair of damage to fishing gear	++
	Replacement of lost gear	++
	Reduction/contamination of catches	++
	Reduced fishing time	+
	Cleaning of gear	+
Ecosystem services	Costs of degradation	+

exposure to microplastics is not limited to the food chain, but can also occur through inhalation of microplastics and airborne fibres. This route of entry may be even more important than food, but it varies greatly depending on the environment and is often associated with certain work environments. Concerning the impact on the health of consumers of products containing microplastics, there is still relatively little knowledge and several questions are currently being asked about the composition of microplastics, polymers and additives, mainly phthalates, bisphenol A, brominated flame retardants and nonylphenols, which are known to be potentially toxic.

8. What measures?

Limiting the input of plastic waste into the environment is the first solution to improve the state of our seas and oceans. Reduction, Reuse and Recycling must be developed by all manufacturers, retailers, communities and consumers. This requires joint efforts and improvement of collection and processing infrastructure: increasing the performance of materials kept in the system and finally, reducing the negative impact of plastic packaging. Wastewater treatment plants are also strategic investments in the fight against marine pollutants, enabling the removal of pollutants. In addition to the removal of macro-waste in sewage systems, usually by screening, sewage systems must take into account micro-particles, which have recently become a significant source of pollution. Wastewater treatment plants are not specifically designed to retain them, but can nevertheless play an important role in limiting the input of microplastics into the marine environment. However, the varying concentrations, nature of the discharges, different materials, shapes and sizes make it difficult to implement homogeneous processes. The purification capacities depend on the degree of elaboration, but specific modules are needed to achieve almost 100% elimination in the most elaborate systems. Moreover, abatement does not mean the disappearance of particles but their trapping, most often in sewage sludge. Therefore, the reuse of sludge, especially in agriculture, poses the problem of its return to the natural environment, as no current "post-treatment" allows for their total elimination. In the end, the current approach remains mainly useful for water purification, for reuse by humans, including for everyday consumption, rather than a real solution for preventing pollution of the natural environment.

For several years, research has focused on the development of sustainable biobased polymers, *i.e.*, polymers obtained from renewable resources, while being both persistent and therefore difficult to degrade. Examples include developments in bio-based polyethylene, polyamides and polyurethanes, and even polyethylene terephthalate (PET). Thus, substituting fossil carbon with biosourced carbon, known as renewable or "short cycle" carbon, can be considered a relevant strategy for limiting greenhouse gas emissions, whose repercussions on climate change are now real. Nevertheless, obtaining sustainable bio-based materials is far from neutral. From an environmental point of view, competition for resources and the potential for deforestation and water depletion remain a problem. In addition, the substitution of petrochemical plastics by their biobased counterparts does not solve the problems of pollution and accumulation of plastics in the terrestrial and aquatic environment.

Numerous studies have been initiated in the research world to develop new polymers with a biodegradation resistance time equivalent to the time of use. Plastic waste from these so-called "biodegradable" materials would thus have the advantage of being able to biodegrade *in situ* (water, soil, compost), which appears to be a particularly relevant strategy in the case of plastic waste, which is becoming uncontrolled waste at the origin of the contamination of all ecosystems, and the marine environment in particular. These new materials, biodegradable and biosourced (at least in part), will have to meet certain requirements in terms of functional properties and use. All studies today tend to develop models to help design 'tailor-made' (bio) degradable polymers whose (bio) degradation could be controlled by playing on previously identified physical and chemical factors intrinsic to the polymer. Designing a rapidly biodegradable material in an environment as complex and constraining as the marine environment implies, however, being able to evaluate and demonstrate this property in a repeatable, reliable and unequivocal manner using a set of standardised methods and analytical conditions.

Cleaning the seas or oceans can only be justified when the waste has value. This value can be direct, such as lost fishing nets that could be repaired or recycled, or it can be indirect, such as in the case of coastal clean-up where the recovered plastic itself has little value but its absence maintains the heritage value of a site. It is this reason and the economic aspect attached to certain places such as beaches that justify the significant expenditure on clean-up.

The case of a large-scale organised clean-up, particularly in oceanic convergence zones, presents problems in terms of implementation costs linked to the distance of these zones, the risks of failure of the systems operated and the associated repair costs, and the accidental capture of marine organisms with passive behaviour such as floating plastics (plankton, young turtles, small fish). The heterogeneity and non-recyclability of plastics that have been at sea for a long time demonstrate the hypothetical nature of this approach, which is nevertheless supported by the public. In the same way, it is inconceivable to imagine collecting waste on the seabed because of the costs involved. Thus, in general, apart from valuable objects, cleaning up at sea will not provide the necessary solutions to the problem. It is only justified locally, in tourist or urban areas, on the basis of citizens' initiatives or locally for economic reasons.

The management of plastic pollution at sea is exceptionally complex and requires an integrated approach encompassing scientific, legislative, economic and social aspects. New technical approaches, using tools such as automated sensors, remote systems, or new indicators, should be able to support the acquisition of new knowledge. In terms of understanding the effects of plastics on wildlife and the environment, risk assessment, including assessment of the spatial extent of interactions between animal species and plastics, holds great promise.

The main knowledge gaps for scientists and managers also relate to accurate counting using standardised methods, the degradation of plastic in the various compartments of the marine environment and the measurement of the smallest particles and their effects. More studies are also needed to determine the transfer of contaminants to organisms, including the transfer of additives, and the role of plastic debris as a vector for the transport of pathogens, or more generally of species at risk. More generally, the need for a better understanding of the links between marine litter flows and their costs for targeted measures is very important in order to propose more adapted and targeted means of control. These include the generalisation of more sustainable production and consumption patterns, as well as conditions for the scaling up of alternative, more environmentally friendly products.

Other, more recent avenues, show the importance of research, particularly in solving problems related to the recyclability of materials. The scientific community has recently proposed more sustainable technical solutions, allowing for the permanent and total recyclability of plastics, thus opening up a way to give value to polymers at the end of their life. In the field of social sciences, research is still scarce, and knowledge on the link between economic and social activities and the presence of plastics in the oceans is still mainly built by actors involved in the fight against waste, most often locally. The fate of plastics in the sea therefore remains an emerging research topic that raises many questions for the scientific community. These questions can currently be divided into different areas, including the actual state of contamination, the long-term impacts of such quantities of plastics on organisms and on the functioning of ecosystems, and the risks for human societies, particularly on health.

9. Future actions

As a result of a more global approach, international agreements provide a legal framework for coordinated action. The UN's 2011 "Honolulu Strategy", supported by industry, the actions of the regional seas conventions under the UN Environment Programme or the recent G7 initiative for global action are the best examples of coordinated initiatives. Of course, the success of these initiatives will be measured over time. Successive management and fiscal measures since the 2000s in favour of limiting and banning checkout bags have led to a reduction in the quantities of packaging bags in the retail sector in many countries. However, there are still many unanswered questions, particularly about the extent of the problem, the sources, the methods of dissemination and the mechanisms of degradation. The future should bring new materials that are more environmentally friendly and there should soon be a better understanding of the social or economic impact of marine litter. Probably the most important environmental issue is that of environmental education, which is necessary to better deal with the diversity and complexity of individual behaviour that is a major cause of the problem of marine litter.

It seems that not all actors in society are yet fully aware of the urgency of the situation and the efforts required to emerge from this era marked by "all plastic" with its waste that is becoming our main and unique marker in geological time. Industrialists, politicians, NGOs and scientists must join forces to advance knowledge and promote its dissemination to the general public in order to raise awareness of this issue throughout society. This is the meaning given to the global approach underway within the United Nations General Assembly for the Environment (UNEA), whose ongoing negotiations should make it possible to reach a global treaty by 2024, which will make it possible to coordinate significant actions.

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Citizen engagement : a driver for ocean protection

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Abstract: Marine litter is a global environmental concern affecting all the oceans and coastlines of the world. More than 8 million tons of plastic enter the oceans each year, contributing to an estimated total abundance of at least 24.4 trillion pieces of plastic particles in the world's upper oceans. They can be found floating on the surface, in the sediments, in the ice or covering the ocean floor. Since 1990 Surfrider Foundation Europe, has put the fight against marine litter at the forefront of its action. Surfrider acts to better understand this pollution, to reduce the quantitative amount of litter entering the marine environment and its impacts on the marine environment and humans. The NGO's leverages start with raising public awareness, stimulating scientific research to initiating political action in order to tackle at source this problem. The community and citizens are the heart of action programs, public engagement is the root. Citizens participate in collecting data and answering remaining questions about characteristics, distribution, transport pathways of marine litter and potential impacts on wildlife and humans as well as in policing-making. As a whistle-blower, an expert and an actor of change, Surfrider promotes the dialogue between citizens, scientists and decision-makers.

Keywords : *marine litter, monitoring, citizen science, advocacy*

An NGO committed to protecting the marine environment and its users

Surfrider Foundation Europe (SFE) is a non-profit organization whose purpose is to protect the marine environment and its users, created in 1990 by a collective of surfers who had noticed the degradation of the coastline and the pollution of the ocean - places essential to their sports practices and their well-being.

The most visible pollution, which is the reason the non-governmental organisation (NGO) was founded, is pollution due to marine litter and especially plastic. Year after year, the amount of plastics and microplastics washing up on beaches and floating at bathing water levels has increased, inciting surfers to mobilize in order to protect their environment. From the very beginning, the association has placed the fight against marine litter at the forefront of its actions. Since then, it has been working to better understand this pollution and to stop the amount of waste entering the environment based on several levers: awareness, expertise and lobbying. Since 30 years, the association has grown and reinforced its professional status through the development of specialized expert processes

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(Bencivengo *et al*., 2018) and scientific instruments (Bruge *et al*., 2018).

Surfrider's community is composed of ordinary citizens, students, teachers, experts, activists, athletes and artists who share a common passion for the ocean. SFE's actions in service of ocean-related issues revolve around three major themes: Water Quality and Health, Marine Litter, and Coastal Management and Climate Change.

With over 15,000 members and 49 local chapters in 12 European countries, citizen mobilisation in favour of the protection of the ocean is now more than ever a strong value on which the association bases all of its actions.

Citizens at the heart of the Surfrider Foundation Europe movement

People, whether water sports enthusiasts, activists, or simple citizens, are the first to be affected by environmental damage to their territory. They have in-depth knowledge of their territory, as they are the ones who live there. They are witnesses of environmental changes and pollution that impact their surroundings. Thus, they act to protect the territory where they live and provide highly useful information for scientists and decision-makers.

The first years of SFE's actions were marked by its desire to respond to the concerns of its community regarding environmental or health issues that public authorities or research institutes paid little to no attention to. To address water quality and health issues, the association has developed independent analysis laboratories in concerned territories. Since then, the results of weekly samplings allow water sports enthusiasts to check the quality of the coastal waters where they live all year round, all while providing support to local administrations and decision-makers engaged in actions focused on remediation, investigation and communication.

Since 1995, SFE has strived to draw European citizens' attention to the issue of marine litter through its emblematic programme, the Ocean Initiatives. The Ocean Initiatives aim to raise awareness among the general public through the organisation of and participation in marine litter collection operations. By joining these collection operations, participants become direct observers of the scale and diversity of litter pollution in their local area. Education through action is a way to raise awareness and show the impact of human activity on aquatic and coastal environments.

The people who take part in these collections are often dismayed to see the places they care about polluted by litter. This gives them a sense of commitment to address the problem. Beyond simply cleaning up their territory, citizens do not always have the right levers of action to act and reduce pollution at the source. They feel that their concerns will not be taken into consideration by elected officials, companies, or scientists. This is why SFE has structured its programme so as to collect their testimonies and echo their concerns, and to make sure that their voice and that of the ocean are heard by relevant stakeholders. To successfully carry out this mission, the association has developed an extensive litter data acquisition programme. Furthermore, the Ocean Initiatives bring together a growing number of active participants around the world. These ever-committed volunteers truly know their territory and are therefore the best-suited to share essential data on pollution: the types of litter accumulation zones, local specificities, information sources, etc.

SFE analyses, compares and disseminates this data to research institutions and promote the message from citizens to both public decision-makers and private sector (Bio Inovation

Service, 2018). The data collected by the association is now fully integrated into European monitoring programmes such as European Beach Litter assessment (Kideys and Aydin, 2020).

Surfrider Foundation Europe: a bridge between citizen engagement and the world of research

Until the end of the 20th century, the world of research was relatively restrictive with very few partnerships with civil society actors. With the emergence of citizen science, a new dynamic has been set in motion in the research community (Strasser *et al.*, 2019).

Citizen science connect scientists with citizens who wish to engage in a meaningful way in the protection of the environment. Through inclusive approaches and the development of simple and accessible protocols, citizens can actively participate in projects and scientists can access data on a large scale.

SFE is actively involved in the implementation and the development of the citizen science movement by offering citizens an opportunity to take part in scientific endeavours and redefine the limits of research topics. The scale and diversity of the SFE community enable to mobilise a lot of people across Europe, very quickly. In order to make the most of its community's involvement and ensure that the collected data is exploited, the association seeks to adapt scientific protocols and reduce bias.

Indeed, citizen science projects may be subject to certain biases that could potentially affect the quality of the data. To limit this concern, SFE strives to develop play-based tools and methodologies that make its processes easier to use (Ocean initiatives monitoring guide). Despite this precaution, there may still be biases in the database. The NGO therefore monitors the data and reserves the right to manually retain or exclude information in order to ensure the data's validity before sharing it with scientific organisations.

OSPARITO: a protocol adapted to young audiences

As part of its OSPARITO project, SFE has adapted the harmonised protocols for the monitoring of marine litter on beaches (OSPAR/DCSMM) in order to make them fun and accessible for 10-year-olds. Here, OSPAR and DCSMM are Oslo-Paris Convention and Directive-cadre stratégique pour le milieu marin (Maritime Strategic Framework Directive), respectively. Digital and physical tools have been developed to break these protocols down into several stages. The key challenge is to keep children's attention while collecting data. The project design is based on the idea of a police investigation in order to immerse pupils in a game-like context. In this way, children are able to follow a scientific protocol with the same constraints as those imposed on associations or research organisations. The data collected and processed through this project feeds into the French beach litter monitoring programme.

Using data: a major challenge for the association

The way in which data - collected by SFE community as part of official monitoring programmes such as the French National Marine Debris Monitoring Programme or by scientific institutes - is used represents a major challenge for the association. The use of citizen mobilisation to acquire data on a problem or a phenomenon must be purposeful and contribute to the improvement of scientific or societal knowledge. Therefore, the association has strived to reinforce its professional status within the world of research and in the field, to ensure the quality of the data. The data collected by its community is shared at local, national and European levels with scientists and coordinators of monitoring programmes.

It is essential to share data in the most approachable and accessible way possible, so that participants are aware of the importance of their actions and participation. As part of the Ocean Initiatives programme, we produce an annual environmental report using the data provided by marine litter collection organizers. The results are shared in a simple way using clear analogies so that citizens can understand the data and see the importance of their involvement. In 2021, more than 60,000 participants took part in data collections, thus enabling drafting and dissemination of this report to European communities, administrators and policy-makers.

This close relationship between the scientific community and citizen collectives is a win-win situation, allowing SFE to further its expertise regarding marine litter. Its data and projects are validated and then used by the scientific community. This recognition brings legitimacy in the eyes of relevant institutions.

Surfrider Foundation Europe is proactive on emerging issues

Thanks to the expertise it has acquired, the association can demonstrate great responsiveness and proactivity when it comes to identifying new types of pollution, dealing with emerging issues and proposing solutions to reduce their impact.

This is demonstrated in the way its community comes together to resolve problems, through the development and implementation of data collection tools, protocols and methodologies, and in the dialogues established with stakeholders including research institutes, local actors and the private sector.

From local testimonies to large-scale investigations: the case of "biomedia"

In 2009, SFE was alerted by its volunteers of the recurrent presence of a large number of small plastic cylinders along the coasts of the Bay of Biscay. Faced with these unidentified plastic objects, SFE teams conducted an investigation with the support of the SFE community and discovered that they were dealing with biomedia, also known as biocarriers. These biomedia are used to treat wastewater in collective or industrial wastewater treatment plants (WWTP). They allow bacteria to settle and proliferate, and thus improve purification rates by accelerating the digestion of suspended solids in the water.

SFE has been the first association to focus on the problem caused by the spread of these plastic media in the marine environment and the resulting increase in plastic pollution flowing into the oceans. The association has therefore started monitoring the evolution of biomedia pollution at the European level by developing a protocol to characterise and quantify them, by mobilising its community and other NGOs. As the general public is largely unaware of this type of pollution, the association has worked to raise awareness among stakeholders through educational tools, communication campaigns and videos.

A study has been carried out on the processes and ways of identifying wastewater treatment plants where accidents have led to biomedia leakage into aquatic environments (Bencivengo *et al.*, 2018). Thanks to proven cases of malfunctions and dialogue with professionals in the sector, this study has generated recommendations aimed at reducing the release of bio-carriers into the environment.

SFE has become a reference for its expertise on the subject (Bencivengo *et al.*, 2018; Karapanagioti *et al.*, 2019). The data collected through the mobilisation of its community in the field serves as the basis for several research projects carried out by scientific organisations.

The association is a driving force for new ideas and initiates data acquisition projects when it identifies environmental issues that are seldom or not yet the subject of research work. The nature and consequences of both macro- and micro-plastic pollution in the marine environment are well-documented and are the subject of numerous studies and research programmes (BRAHNEY, 2021). These studies have demonstrated the significance of land-based inputs of litter transiting through river networks before entering the oceans (LEBRETON *et al.*, 2017). They are considered the main source of plastics (all sizes included), more than litter directly released into the marine environment (GESAMP, 2016). Although rivers have been identified as an important pathway vector (JAMBECK *et al.*, 2015), very little knowledge has been compiled about the amount or composition of litter from land-based sources.

Participatory and innovative projects in the service of research

The SFE community, composed of water sports fans and volunteers who take part in litter collection operations along rivers, had also alerted the association to this issue. In 2014, SFE set up a project called "Riverine Input" to improve general knowledge about the role that rivers play in marine litter pollution. The project initially focused on the Adour watershed in South-West France. Two initial protocols were developed and tested: a protocol for sampling macro-litter stranded along the riverbanks, and a protocol for sampling micro-and macro-litter in the water column using "manta" trawls (BRUGE *et al.*, 2018). Subsequently, this project was the subject of a collaboration with the LEESU (Urban Water, Environment and Systems Laboratory). Namely, it focused on improving the sampling protocol, addressing the amount of time it takes to deploy the trawls, as well as the number of samples needed in order to obtain micro-plastic load values that are representative (BRUGE *et al.*, 2020). The analysis of samples from the Gave de Pau river (tributary of the Adour river) made it possible to provide an initial estimate of the amount of micro-plastics transiting via this river.

The Riverine Input project provided an insight as to the amount and characteristics of macro-litter that can be found in rivers. It helped to launch a movement at the European level for studying litter from land-based sources. However, several parameters influence the presence of this type of litter in rivers (e.g. hydromorphology; proximity of cities; waste management in the area; presence of industrial, agricultural and recreational activities; exposure to floods and wind), which makes it necessary to implement monitoring across all European rivers in order to obtain a spatio-temporal overview of macro-litter pollution. However, as the Riverine Input protocol is both time-consuming and human-intensive, there was no way it could be applied on such a scale; it thus became necessary to develop a fast, simple and reproducible methodology. In order to obtain a large amount of data that was previously non-existent, Riverine Input gave way to Plastic Origins, a citizen science project aimed at mapping a single indicator: the amount of litter per kilometer of riverbank. This indicator is calculated by monitoring sections of rivers along which citizens can report the presence of litter stranded on the riverbanks using a mobile application. In close collaboration with a large ecosystem of players in the digital world, SFE has developed an innovative technology using artificial intelligence to automatically detect the presence of waste based on videos taken by volunteers using the application.

The mapping of collected data, enable the identification of the most affected territories by this pollution; offering solutions to local actors, in order to reduce litter at the source; and ultimately, to integrate this waste indicator into the assessment for the good ecological status of rivers.

Appealing to decision-makers: data at the service of advocacy

Associations have become key players in public policies and play a decisive role in the preservation of the environment. Lobbying is fundamental for SFE if it is to appeal to decision-making institutions, to make them aware of the urgency of the situation and to bring about change. SFE's lobbying consists of advocating for international, European, national and local institutions to adapt the legislative framework and public policies to the challenge of protecting the ocean.

With regard to plastic, SFE ensures the adoption and proper implementation of a legislative and regulatory framework for prevention and reduction at the source, which are necessary for the ecological transition and the establishment of a true circular economy. To do so, the association has a team of lobbyists who keep up with legislative, scientific and economic news, as well as citizens' actions, and present concerns and claims to the policy makers. SFE works either alone or in coalition with other NGO groups in order to strengthen its actions.

One of SFE's defining characteristics is the strong ties with both its network of volunteers in the field and the relevant decision-making institutions: its main mission is therefore to establish connections between citizens and policymakers. The association brings the results of citizen science programmes to the attention of decision-makers in order to show them the scale of citizen mobilisation and the reality on the ground.

The data collected is analysed, compared and controlled for validation. This data supports an inventory of pollution schemes with major trends, accumulation zones and litter to be targeted in priority, because of its extent or its impact on the environment. Thanks to technical data and consultation with external experts, the teams establish hypotheses on the origin of the pollution and develop arguments in order to propose measures to decision makers, to reduce pollution at the source. SFE also ensures that the measures proposed are not counterproductive (e.g. Replacing one material with another with the same level of harm) or purely superficial in their effect. The aim is to be proactive and to insist on preventing litter rather than removing it downstream, once it has already become a problem.

In 2019, the European Union adopted one of the most ambitious pieces of legislation in the world to tackle plastic pollution: the SUP (Single-Use Plastics) Directive, Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (Text with European Environment Agency relevance). This text, which applies to the 27 member countries of the European Union, aims to prevent and reduce the environmental impact of the plastic products most frequently found on beaches, and to promote a transition towards a circular economy. This Directive introduces a series of measures to reduce the use of certain single-use plastic products at the EU level. These measures include the ban of single-use plastic products for which reusable alternatives already exist; reducing their consumption or production; establishing extended producer responsibility schemes; and requiring markings that stipulate the presence of plastic in certain products.

Decades' worth of fieldwork conducted by the association to quantify and characterise plastic pollution on European beaches, as well as awareness campaigns, citizen mobilisation and appeals made to decision-makers, had created solid foundations for the adoption of this text. SFE extensive knowledge and understanding of the issue also allowed the development of strong arguments and influence the proposed measures throughout the negotiation of the text.

Surfrider status, as an NGO with a vast network of volunteers, allows to quickly modify data collection so that they are adapted to new items (e.g. COVID-19 pandemic related items) and take into account improved knowledge and legislative developments. Thus, Surfrider Foundation Europe has included all the single-use products covered by the aforementioned European Directive as part of the master list of the Ocean Initiatives protocol. This amendment will make it possible to ascertain whether or not the amount of certain types of litter along European riverbanks and beaches has decreased, so as to monitor the effectiveness of the measures adopted by each of the Member States. The association can thus react quickly and propose further modifications and corrective measures.

The SFE community also alerts the association in case of chronic and local accidental pollution. This is namely the case with pre-production plastic pellets: raw material used in the manufacture of all everyday plastic objects. These are released throughout the chain of production, processing, distribution and recycling of plastic due to poor industrial practices, poor handling and transport accidents. These incidents can thus lead to very large accumulation areas near the industrial sites. Volunteers from the association have therefore initiated local monitoring programmes (e.g. Tarragona, Spain; Écaussinnes, Belgium) to quantify pollution, determine its source and identify the most heavily impacted areas. The data collected by citizens makes it possible to call out local companies and hold them accountable, but also to justify the request for the adoption of preventive measures to national and European decision-makers.

Plastic pellet pollution has become a global phenomenon; these plastic pellets, which are very light, can be carried by both wind and rain and go on to circulate in water networks, rivers and the ocean, where they release harmful chemical pollutants (OHGAKI *et al.*, 2021).

Currently, there is no legislation that addresses this issue. There are voluntary agreements within the industry designed to prevent losses (Operation Clean Sweep), but field observations conducted by volunteers as close as possible to industrial and port sites prove them to be inefficient. It is therefore on the basis of concrete cases that Surfrider Foundation Europe calls on European institutions to adopt regulatory measures in order to prevent spills and stop plastic pellet pollution, by obliging companies in the supply chain to take action and holding them responsible in case of releases into the environment (GRAVIER *et al.*, 2020).

Citizen engagement in knowledge acquisition operations is a way of involving people in the decision-making process. In the same vein, Surfrider encourages citizens to take part in debates by explaining to them the ongoing legislative processes and showing them the ways in which they can contribute to and influence decisions through (dedicated communication and mobilisation campaigns, public consultations, etc.).

Conclusion

Since its creation in 1990, Surfrider Foundation Europe has witnessed a growing social awareness regarding plastic pollution of the ocean, thanks to active engagement of the NGO and scientific communities. Encouraged by the NGOs, citizens have been mobilizing to actively protect the environment, namely by taking part in participative science programmes. The data collected since more than 10 years have allowed to highlight the situation on the ground to decision-makers and to make the adoption of the very first measures against plastic pollution a reality. However, as we are facing the rising world production of plastic and thus, even more ocean pollution, it is crucial to demonstrate real political ambition. We have to ensure that whistle-blowers that act in the field every day, are heard. Decision-makers also have to show a greater reactivity for a more efficient ruling. Finally, public institutions and private sector face the major challenge of better considering citizen data, that is real time and covers plastic pollution all along European coasts.

There is an urgent need to act and apply the precautionary principle to protect the ocean.

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Plastic contamination in coastal areas around Japan: A review

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Abstract: Publications describing the concentration and distribution of plastic litter, microplastics (> 350 μm and < 5mm), and small microplastics (< 350 μm) in seawater, sediments, and beaches around the coast of Japan are reviewed. Plastics from food packaging and polyethylene plastic bags are widely distributed along the Japanese coast. The concentration of expanded plastics and plastic bottles is high in the region of the East China Sea. Microplastics on the sea surface are widely distributed along the coast of Japan, and the average concentration of microplastics in seawater off the Japanese coast is very high compared with other regions of the world. A two-ply, double neuston net, comprising an internal net with a 350-μm mesh and an outer net with a 50-μm mesh, was used to quantify small microplastics (> 50 μm, < 350 μm) and microplastics (> 350 μm, < 5 mm) in Tokyo Bay. The concentration of small microplastics was about 10 times the concentration of microplastics. Conventional techniques used to quantify microplastics may underestimate plastic concentrations.

Keywords : *microplastic litter, mesoplastics, microplastics, Japan*

1. Introduction

Several million tonnes of mismanaged plastic litter is estimated to be discharged annually from the land into the ocean (LEBRETON *et al.*, 2017; SCHMIDT *et al.*, 2017). Of this plastic material, only 0.27 million tonnes are estimated to be floating on the sea surface (ERIKSEN *et al.*, 2014), with the remainder unaccounted for. The plastic that is not found floating is termed 'missing plastic' (LEBRETON *et al.*, 2019). Many pieces of missing plastic are likely to be sinking to the seabed or drifting in the seawater, but the exact distribution of this material is unknown. However, WEISS *et al.* (2021) assert that the flux of plastic from rivers is overestimated and that there is no missing sink.

Plastic litter at the sea surface is weathered and degraded by UV radiation and/or wave motion (ARTHUR *et al.*, 2009; COLE *et al.*, 2010; GALGANI *et al.*, 2013), gradually breaking into smaller pieces. Plastic fragments that are 5 mm or less in size are referred to as microplastics

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(MPs) (ANDRADY, 2011). Contamination by MPs can have an adverse effect on organisms living in the ocean (GALL and THOMPSON, 2015). Surveys conducted globally have shown that MPs are distributed throughout the ocean and across the globe.

ISOBE *et al.* (2015) reported that the concentration of MPs in East Asian Seas is 1.72 million pieces km^{-2}, 27 times greater than in other oceans around the world. However, the concentration and distribution of plastic litter and MPs in the coastal waters of Japan is poorly understood and needs further investigation.

This review covers the methods used to survey macroplastics and studies that have investigated the concentration and distribution of macroplastic litter of visual size (> several cm), MPs (350 μm to 5 mm), and small MPs (< 350 μm; SMPs) in the coastal area around Japan. In addition, new data on the abundance of SMPs and MPs in Japan coastal waters are also reported.

2. Macroplastic litter

Ghost fishing resulting from lost or dumped fishing gear, has attracted attention in Japan since the 1980s, and research groups have been investigating marine litter in Japanese coastal waters since the 1990s (e.g., KANEHIRO *et al.*, 1996; KURIYAMA *et al.*, 2003; FUJIEDA *et al.*, 2006). The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) created a database of deep-sea images based on visual analysis of submersible video images from 1983–2014. A total of 3,370 pieces of debris were identified from 4,552 surveys in the northwestern Pacific Ocean, of which 1,108 pieces were plastic debris (CHIBA *et al.*, 2018). Research into plastic pollution slowed during the 2000s, but increased again recently as the adverse effects of plastics on marine life is being recognized.

2.1 Methods

Universities and research institutes in Japan started a macroplastic litter survey in 2014, under the leadership of the Ministry of the Environment. A number of training and research vessels from Japanese universities, including the *Kagoshima maru* (Kagoshima University), *Nagasaki maru* (Nagasaki University), *Oshoro maru* (Hokkaido University), and *Shinyo maru* and *Umitaka maru* (Tokyo University of Marine Science and Technology) have participated in the survey, which has been conducted annually since 2014. The location of observation stations used in the 2019 survey are shown in Figure 1.

The survey is conducted by trainees and crews on the training ships, using visual observations. Observers stand on the deck beside the bridge and record information describing the floating objects observed, using a proprietary application software installed on a tablet (Fig. 2). When the observer sights a floating object, an icon is tapped to record the object type, size, distance to the object, number of objects, and color. Floating objects are divided into four categories: artificial objects, fishing gear, natural objects, and unknown. Categories are further divided into subcategories. For artificial objects, subcategories include food packaging plastics, plastic bags, expanded plastics, plastic bottles, glass objects and metal objects. Within the fishing gear category, the subcategories include net (s), buoy (s), and other (s), and for natural objects the subcategories are wood, floating seaweeds, and other (s).

2.2 Concentration and distribution

The results of the 2019 survey were reported by the Ministry of the Environment, Japan, in 2019 (http://www.env.go.jp/water/marine_litter/h31.html accessed on 22 November 2021). The

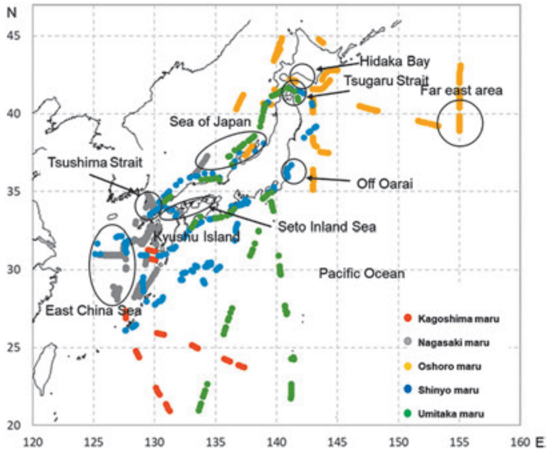

Fig. 1 Location of observation stations used to survey macroplastic litter in 2019. Dots indicate observation points. (Ministry of the Environment of Japan, 2019). The coloured dots represent stations observed by different research vessels.

Fig. 2 Tablet screen showing the interface used to input the floating litter data. (Ministry of the Environment, Japan, 2019)

results from the 2019 report are summarized in Table 1. of the 637 observation stations, food packaging plastics were recorded from 227 stations (36%). The average abundance of food packaging plastic was 2.2 items km^{-2}. The highest density of plastics used in food packaging was 30 items km^{-2}, which was recorded from the Seto Inland Sea. The average abundance of plastic bags was 2.5 items km^{-2}, and the highest density of plastic bags was 167 items km^{-2} reported from an observation point 900 km to the east of northern Japan. Plastic was also abundant in the East China Sea (71.6 items km^{-2}), Tsushima Strait (45–57 items km^{-2}), and to the east of Tsugaru Strait (39.2 items km^{-2}).

The spatial distribution of expanded plastics, polyethylene terephthalate (PET) bottles, and other plastics at the sea surface was similar. The highest abundance of these plastics was recorded from the East China Sea (northwest of Okinawa Island). The average density of expanded plastics was 9.3 items km^{-2}, and the highest density was 116 items km^{-2}. The average density of PET bottles was 1.7 items km^{-2}, and the highest density was 52.4 items km^{-2}. The average density of other plastics (e.g., rope, plastic sheets, buckets) was 21.9 items km^{-2} and the highest density was 304 items km^{-2}.

Expanded plastics, PET bottles, and other plastics were most abundant in the East China Sea, whereas plastic bags and plastics from food packaging, were more abundant offshore from northeastern Japan and in the Seto Inland Sea, respectively (Table 1). Expanded plastics and PET bottles float easily compared with plastic

Table 1. Concentration of macroplastic litter around Japan in 2019.

Plastic type	Detection station ratio (%)	Mean concentration (items km^{-2})	Highest concentration (items km^{-2})	Highest concentration area
Packaging plastics	36	2.2	30.0	Seto Inland Sea
Plastic bags	31	2.5	167	Far east area
Expanded plastics	71	9.3	116	East China Sea
PET bottles	44	1.7	52.4	East China Sea
Other plastics	65	21.9	304	East China Sea

bags, and therefore, the distribution of these plastics is more likely to be affected by ocean currents and winds.

The 2019 report from the Ministry of the Environment also included the results from a bottom trawl survey that examined plastic litter on the seabed. The survey was conducted at three locations, the East China Sea to the west of Kyushu Island, at Hidaka Bay in the south of Hokkaido, and off Oarai to the east of Ibaraki Prefecture (Fig. 1). There were 17 items of marine litter identified from the East China Sea and 37 items from Oarai, of which 47% and 73% were plastics, respectively. However, 3,806 items were recovered from Hidaka Bay, of which 96% were plastics. Hidaka Bay is defined as the area bounded by a line connecting Cape Esan and Cape Erimo (OHTANI, 1981). There is a valley on the adjacent land surrounding the bay which may act as a conduit for plastic waste entering the sea. A peninsula of land extends into Hidaka Bay. The topography of Hidaka may have contributed to the accumulation of marine litter (KURODA *et al.*, 2020).

3. Microplastics

3.1 Methods

Microplastics (MPs) are defined as plastics from 0.33 to 5 mm in size (e.g., ANDRADY, 2011). Microplastics were collected using a 350-μm mesh neuston net in Japan (e.g., ISOBE *et al.*, 2014; ISOBE *et al.*, 2015; NAKANO *et al.*, 2021a, b). Microplastics were taken back to the laboratory and Fourier Transform Infrared (hereafter FTIR) spectroscopy was used to identify polymer types. Most researchers pretreat samples (e.g., oxidation treatment or density separation) to remove natural organic matter such as phytoplankton and zooplankton, prior to using FTIR spectroscopy (NAKANO *et al.*, 2021a). Pretreatment was not performed in earlier MP studies (e.g. ISOBE *et al.*, 2014, 2015).

3.2 Concentration and distribution

According to previous reports (ISOBE *et al.*, 2014, 2015), the average density of MPs around Japan (East Asian Seas) was 3.74 pieces m^{-3}, which is 10 times the recorded density of mesoplastics (5–40 mm) at 0.38 pieces m^{-3} (Table 2). The density of MPs in the coastal waters of Japan is 27 times greater than those reported from other oceans around the world (ISOBE *et al.*, 2015). The density of MPs in the Seto Inland Sea is 0.4 pieces m^{-3} (ISOBE *et al.*, 2014), and the resident population of the adjacent area is about 30 million (https://www.env.go.jp/water/heisa/heisa_net/setouchiNet/seto/g2/g2cat01/index.html). A chemical sample pretreatment (oxidation and density separation) for removing organic matter such as phytoplankton and zooplankton, prior to using FTIR spectroscopy (NAKANO *et al.*, 2021a), was not performed in these earlier MP

Table 2. Concentrations of mesoplastics (> 5 mm), microplastics (MPs), and small microplastics (SMPs) around Japan.

Sea area	Classification	Particle size (mm)	Concentration (pieces m^{-3})	Total particle count (pieces m^{-2})	Reference
East Asian Sea	meso	5 <	0.38	—	Isobe *et al*., 2015
East Asian Sea	micro	0.35 < 5	3.74	1.72	Isobe *et al*., 2015
Seto Island Sea	micro	0.35 <	0.4	0.4	Isobe *et al*., 2014
Canal in Tokyo Bay	micro	0.31 << 1	—	2.4–3.2	Matsuguma *et al*., 2017
Tokyo Bay (Summer)	micro	0.35 << 5	3.98	0.42	Nakano *et al*., 2021a
Tokyo Bay (Winter)	micro	0.35 << 5	0.55	0.03	Nakano *et al*., 2021a
Hiroshima Bay	micro	0.3 << 5	—	0.03–0.24	Sagawa *et al*., 2018
East China Sea	micro	0.35 <<	1.26	—	Nakano *et al*., 2021b
Offshore Tokai region	small micro	0.05 << 0.35	1060–5901	—	Xu *et al*., 2022
Tokyo Bay	small micro	0.05 << 0.35	3028–3220	—	Xu *et al*., 2022

studies (e.g. Isobe *et al*., 2014, 2015).

This population size is high compared with the resident populations adjacent to the Sea of Japan and the East China Sea, where the concentration of plastic litter was much higher. Modeling suggests that MPs that have accumulated in the Sea of Japan may have originated in the south, before being moved northwards by the Tsushima current (Iwasaki *et al*. 2017). Based on these results, it is difficult to identify the origin of MPs. However, modeling suggests that the MPs found around Japan mainly originate from Japan and its neighboring countries (Iwasaki *et al*., 2017).

In the report by the Ministry of the Environment of Japan (2019), MPs were categorized into three groups based on shape; described as plastic fragments, expanded plastics, and fibers. There were small amounts of fibers in each size class. The larger-sized expanded plastics (> 5 mm) were present in greater quantities compared with smaller sized pieces (< 5 mm). In contrast, a high proportion of plastic fragments were of a smaller size (< ca. 2 mm). However, it is difficult to collect plastics that are 1 mm or less in size, using a 350-μm mesh neuston net (Isobe *et al*., 2015; Tokai *et al*., 2021). Temporal changes in the concentration of MPs during 2014–2019 were also examined in the report. Plastic fragments were the dominant shape identified in the survey each year. The relative concentrations of each of the three plastic groups were stable every year between 2014 and 2019 (Table 3).

Tokyo Bay is an enclosed bay which is subject to a large amount of anthropogenic activity. Samples were collected from five stations in Tokyo Bay in May 2019 and January 2020, using a neuston net (Nakano *et al*., 2021a) (Table 2). The highest concentration of MPs identified in the study was 17.8 pieces m^{-3} from the center of the bay collected in May 2019. In January 2020, the highest density of MPs recorded was 2.4 pieces m^{-3} from the bay mouth. This result suggests that the concentration of MPs in the bay varies greatly among locations and seasons. This is likely to be related to variation in human activities among locations and seasons. In addition, the movement of plastics in the ocean is greatly affected by currents, which can vary seasonally.

Table 3. The concentration of three major categories of MPs around Japan, 2014–2019.

MPs shape	Concentration (pieces m^{-3})						
	2014	2015	2016	2017	2018	2019	Average
Plastic fragments	3.74	2.38	2.15	0.53	3.71	1.8	2.4
Expanded plastics	1.25	0.28	0.32	0.09	0.46	0.25	0.42
Fibers	0.13	0.06	0.09	0.01	0.05	0.05	0.07

4. Small microplastics

4.1 Methods

To collect small MPs less than 350 μm, a double neuston net consisting of an internal net with a 350-μm mesh and external net with a 50-μm mesh was designed (Fig. 3; XU *et al.*, 2022). This allows capture of MPs, and small microplastics (SMPs) (50–350 μm) at the same time, from the sea surface.

The double net was used to collect SMPs from Tokyo Bay. The collected samples were subjected to oxidation treatment and density separation, collected on a polytetrafluoroethylene (PTFE) filter, and infrared spectra of the sample were measured using microscopic FTIR (IRT7200, JASCO, Tokyo, Japan). The spectrum was matched against the database KnowItAll (Bio-Rad Laboratories, Inc., Hercules, USA) to identify the type of plastic.

4.2 Concentration and distribution

The average concentration of SMPs from Tokyo Bay was 3,028–3,220 pieces m^{-3} (Table 2, XU *et al.*, 2022). The concentration of larger MPs (> 350 μm) in Tokyo Bay was 3.98 pieces m^{-3} (NAKANO *et al.*, 2021a). This indicates that concentration of SMPs in Tokyo Bay could be ca. 1000 times higher than the concentration of MPs. The concentration of SMPs was 1,060–5,901 pieces m^{-3} at the sea surface offshore from the Tokai region (XU *et al.*, 2022). It is difficult to compare the concentration of SMPs with values from other regions because the methods for sample collection are not standardized. However, the concentration of SMPs is much higher compared with MPs in studies from all regions.

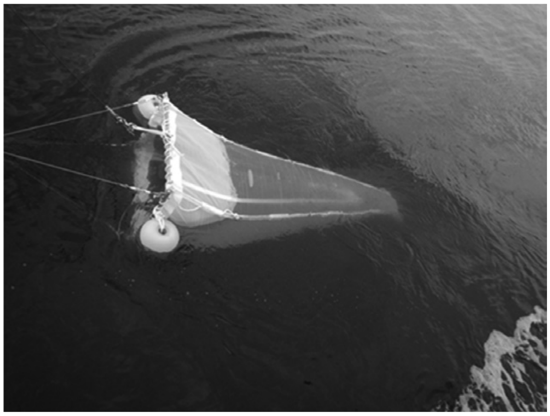

Fig. 3 The double neuston net. The double neuston net has two nets which are set within a single frame. The interior net has a 350-μm mesh and the exterior net has a 50-μm mesh.

The concentration of SMPs on the seabed was reported for Tokyo Bay (WANG *et al.*, 2021). This study showed that the concentration of SMPs in seabed sediments was higher in the inner part of the bay.

5. Future research needed

A literature search using the 'Web of Science' database (accessed on 12 October 2022) and the keywords "marine", "microplastics", " distribution" and the country name resulted in 399 articles from China, 136 articles from the USA, 80 articles from France and 64 articles from South Korea. In contrast, there were 53 articles from

Japan. This low number of studies on plastic pollution around Japan compared with other nearby countries, highlights the need to increase research effort on this topic.

In most published studies, macroplastics are quantified by visual inspection and video photography, however studies that aim to quantify MPs and SMPs mainly use net sampling. The definition of particle size in each category (e.g., macroplastics, MPs, SMPs) is also inconsistent among studies. It is necessary to develop consistent methodology so that comparisons can be made among studies and study locations.

The units used to describe the concentration (or density) of plastics in seawater also differ due to differences in methods. The density of sea surface microplastics and plastic litters is mainly expressed as "items km^{-2}", whereas the concentrations of MPs in seawater mainly expressed as "pieces m^{-3}", while the concentration of SMPs are mainly expressed as "pieces m^{-3}". Attention must be paid to differences in units when comparing the concentration of plastics among studies.

There are very few independently analyzed studies describing the quantity of mesoplastics (> 5 mm) in oceans. ISOBE *et al.* (2015) is the only report on mesoplastics from the waters surrounding Japan. In some studies, mesoplastics have been lumped together with MPs. More rigorous analytical techniques are required to accurately understand the behavior and fate of marine plastic litter.

Surveys of marine debris using resources from the Ministry of the Environment and university training and research vessels allow observations to be made across a wide geographic area. This could be supplemented using volunteers on other vessels to increase the area covered. As the methods used to collect and analyze MPs and SMPs become well established, more results are expected to be reported in the near future. The concentration of MPs in seawater varies greatly among locations and seasons (NAKANO *et al.*, 2021a), however more detailed investigation is needed to understand the conditions and mechanisms that influence the concentration and distribution of MPs.

ISOBE *et al.* (2014) showed that the MPs collected by a neuston net with a 350-μm mesh reached a maximum value at a particle size of about 1 mm, suggesting that SMPs are not efficiently captured. TOKAI *et al.* (2020) also showed that particles with a major axis larger than the mesh opening size were not collected efficiently. The double neuston net captured small particles that went through the 350-μm mesh net. The use of this method will contribute to our knowledge of the behavior and fate of MPs and SMPs.

However, MPs and SMPs are not distributed only on the sea surface. To accurately understand the distribution and behavior of MPs in the marine environment, it is necessary to investigate a range of marine habitats including the coast, the seabed and the water column, and to examine distribution patterns through time.

6. Conclusion

Although there are a few reports describing microplastics in Japan, there are few surveys designed to investigate the quantity and types of plastic litter in the waters around Japan. The distribution of plastic litter differs depending on the type and shape of the plastic. Plastic litter in the waters around Japan is likely to originate not only from Japan but also from other East Asian and Southeast Asian countries. Microplastics are present in high concentrations in seawater along the coast of Japan (average 3.7 pieces m^{-3}). The concentration of small microplastics (SMPs) in seawater is much higher compared with larger microplastics. The concentration and distribution of SMPs requires more detailed investigation.

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Changes in nutrients and their effects on fisheries after the introduction of land-based nutrient loading regulations in the Seto Inland Sea since 1973: A review

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Abstract: Nutrient decrease and their effects on fisheries in the Seto Inland Sea, Japan were discussed. It suffered from heavy eutrophication during Japan's period of high economic growth starting in the 1960s. At that time, red tides often occurred and fish culture was severely affected. Recently, water quality has dramatically improved. Although total nitrogen (TN) and total phosphorus (TP) runoff load from the land were reduced by 40% and 60%, respectively, TN and TP concentrations in seawater have apparently not decreased, despite the apparent nutrient concentration decrease. Nutrient decrease was not due to only nutrient runoff load from the land, and it was thought that nutrient release from the bottom sediment was also important. Despite the water quality improvement, fish catches have gradually decreased. Phytoplankton primary production did not response simply to nutrient decrease, and according to zooplankton, there is no data set to show their biomass variation. The conclusion is that the reason of fish catch decrease is still unknown. Whereas nutrient concentrations decreased, and presumably nutrient decrease will be a contributing factor, land reclamation, decreases in the area of tidal flats and algal/seagrass beds, global warming, and overfishing should be also thought as reasons contributing to fish catch decreases.

Keywords : *nutrient, Seto Inland Sea, phytoplankton, fish catch*

1. Introduction

The Seto Inland Sea is a large, enclosed sea in Japan (Fig. 1), known for its beautiful Mediterranean-style landscape and including about 600 islands. This sea is also an industrially developed area with about 30 million people living in the coastal area. During the period of high economic growth in Japan, beginning in the

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1960s, the Seto Inland Sea suffered from heavy eutrophication due to pollution with organic matter from industrial effluent and urban wastewater. At that time, red tides often occurred, and fish culture was heavily affected. In 1972, the *Chattonella antiqua* red tide that occurred in Harima Nada, the eastern part of the Seto Inland Sea, caused a catastrophic mass mortality of 14 million cultured yellowtail (*Seriola quinqueradiata*) with a value then of about 7.1 billion Japanese yen (OKAICHI, 2002).

To resolve the situation, "Law concerning Special Measures for Conservation of the Environment of the Seto Inland Sea" was enacted in 1973. Since then, under this law, industrial effluent and urban wastewater have been regulated by a "Fundamental Policy for Reduction of Total Pollution Load (FPRTPL)" which requires that chemical oxygen demand and total nitrogen and phosphorus loading from the land surrounding the Seto Inland Sea must decrease by scheduled amounts every five years. Subsequently, the number of red tide occurrences decreased from 300 times to 100 times per year and is now consistently below 100 times annually (IMAI *et al.*, 2006). The environmental condition of the Seto Inland Sea is already well documented (OKAICHI and YANAGI, 1997; INTERNATIONAL EMECS CENTER, 2008). Recent situations of marine environment and fisheries were also well documented (CENTRAL ENVIRONMENTAL COUNCIL, 2021; JAPAN FISHERIES SCIENCE AND TECHNOLOGY ASSOCIATION, 2017; ABO and YAMAMOTO, 2019).

Although water quality has improved and nutrient concentrations of seawater decreased (ABO *et al.*, 2018), recently commercial culture of *Pyropia* sp. (widely known by its Japanese name 'nori') has often suffered from bleaching due to lack of nutrient and, consequently, nori culture in the eastern part of the Seto Inland Sea has suffered from heavy losses in both annual yield (Japanese yen) and production (tonne or production number) (MATSUOKA *et al.*, 2005; HORI *et al.*, 2008 ; TADA *et al.*, 2010; ABO and YAMAMOTO, 2019). Fish catches, too, have gradually been decreasing (TANDA *et al.*, 2014; ABO, 2016). YAMAMOTO (2003) had already reported on the oligotrophic condition of the Seto Inland Sea.

The present paper reviews changes in water quality of the Seto Inland Sea over the last 50 years and addresses the recent decrease in nutrient content, partly focusing on Harima Nada (Fig. 1), based on information obtained during previous studies (NISHIKAWA *et al.*, 2010; ABO *et al.*, 2018). Nutrient dynamics, phytoplankton biomass, primary production and fish catch decrease are also reviewed (cf. TANDA *et al.*, 2014; ABO *et al.*, 2016; TADA *et al.*, 2014; TADA *et al.*, 2018; NISHIJIMA *et al.*, 2018; NISHIJIMA *et al.*, 2019).

2021 was the start of the United Nations Decade of Ocean Science for Sustainable Development (UNDOS), which lists seven social outcomes for an ocean that is clean, healthy and resilient, predicted, safe, sustainably harvested and productive, inspiring and engaging, with transparent and accessible data and technology (INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, 2020). The present study is in line with the basic policy of "a clean ocean" and is also concerned with ensuring a "sustainably harvested and productive" ocean (The united nations decade of ocean science for sustainable development (2021–2030)) (UNESCO-IOC, 2021). It falls within the UN Sustainable Development Goal (SDG) no. 14, to "conserve and sustainably use the oceans, seas and marine resources for sustainable development" (UNITED NATIONS, 2015).

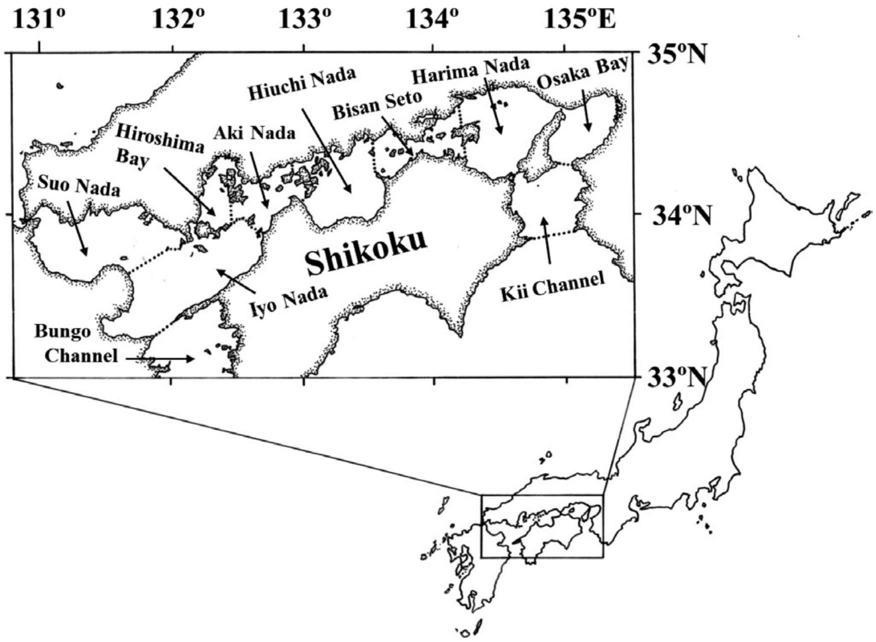

Fig. 1 Location of the Seto Inland Sea, which is composed of the sea areas known as Suo Nada, Iyo Nada, Bungo Channel, Hiroshima Bay, Aki Nada, Hiuchi Nada, Bisan Seto, Harima Nada and Osaka Bay from West to East.

2. The decrease of nutrient concentrations and its dynamics

2.1 The decrease of nutrient concentration

Nutrient concentrations (NO_3, NH_4, and PO_4) in the Seto Inland Sea have apparently decreased since the 1970s (TARUTANI, 2007; NISHIKAWA *et al.*, 2010; TANDA *et al.*, 2014; ABO *et al.*, 2018). For example, since 1983, dissolved inorganic nitrogen (DIN: NO_3 + NO_2 + NH_4) concentrations in surface seawater have decreased every decade in almost all parts of the Seto Inland Sea (Fig. 2). Since 2002, nori culture has been particularly heavily damaged in the eastern part of the sea due to a lack of nutrients, because nori growth is directly influenced by nutrient concentrations (TADA *et al.*, 2010). Note that the amounts of total nitrogen (TN) and total phosphorus (TP) run-off load from the land in the Seto Inland Sea were reduced by 40% and 60%, respectively, from 1979 to 2009 by implementation of the "FPRTPL" (Fig. 3): TP load was reduced from the 1980s, probably due to such policies as the use of phosphorus-free detergents; TN load showed a reduction only after the 1990s, and the reduction was predominant after 2000. However, TN and TP concentrations in seawater have shown no marked decrease and they were almost constant or slightly decrease. (Fig.4). These data suggest that the apparent decrease of nutrient concentrations cannot be explained only by reduction of TN and TP loading from the land. In seawater, sum of DIN, DON (dissolved organic nitrogen) and PON (particulate organic nitrogen) are TN (DIN + DON + PON = TN). According to the DIN and TN, it was reported that the annual variations of TN concentration was large and did not show the certain trend, whereas DIN concentration was

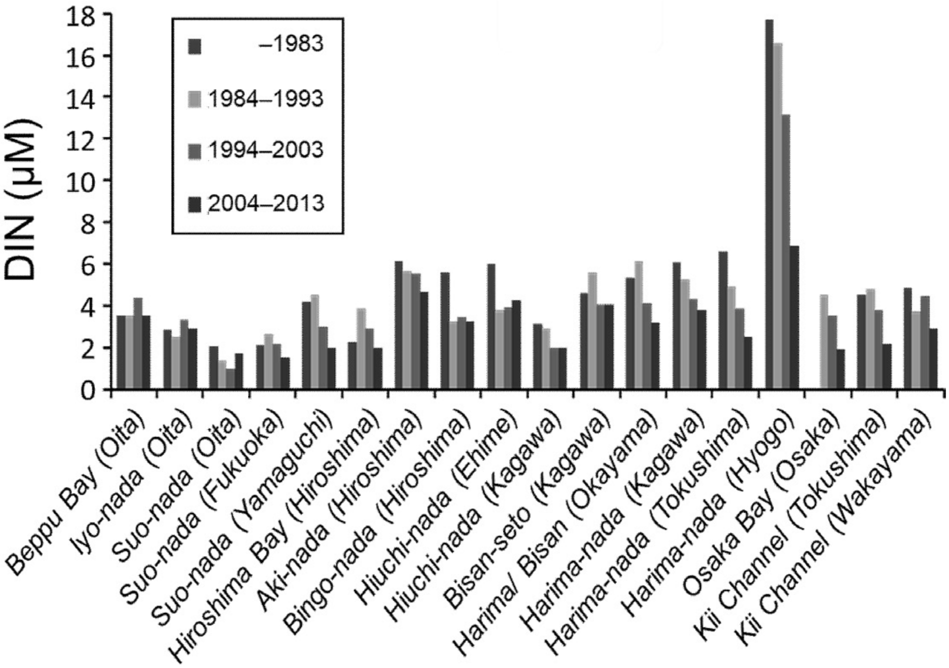

Fig. 2 Average DIN concentration per decade in different parts of the Seto Inland Sea reproduced from Abo *et al.* (2018) with the authors' permission. Names in parentheses are the associated Prefecture names.

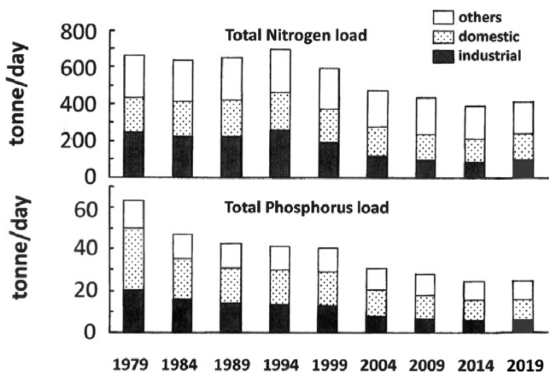

Fig. 3 Changes in the total nitrogen and phosphorus load in the Seto Inland Sea modified from Central Environmental Council (2021); Setouchi Net, 2011a).

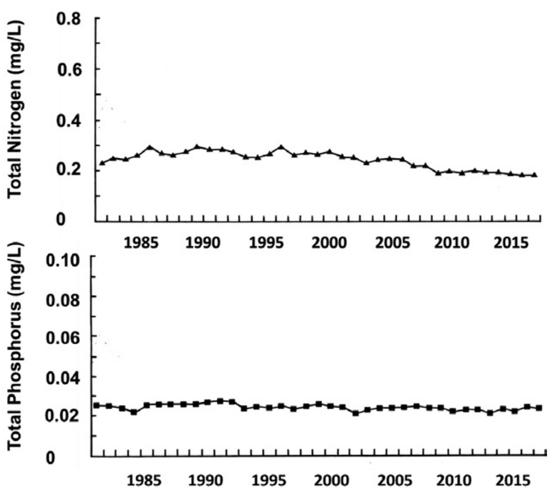

Fig. 4 Yearly changes in total nitrogen and phosphorus concentrations in the Seto Inland Sea (Setouchi Net, 2021b).

clearly decrease after 1990 (Tada *et al.*, 2010). Kobayashi *et al.* (2009) reported that the annual average ratios of DIN, DON and PON for TN in surface layer of Harima Nada were 0.22, 0.55 and 0.23, respectively, and the annual variation of DON concentration was smaller than those of

DIN and PON. ASAHI *et al.* (2019) also reported similar results about for the seasonal average ratios of DIN and DON in surface seawater of the entire of the Seto Inland Sea. They also reported that DIN concentrations decreased from 1990 to 2010, whereas DON concentrations did not decrease.

2.2 Nutrient dynamics in the coastal waters of the Seto Inland Sea

To explain the observed nutrient conditions, it is necessary to understand the mechanism of nutrient circulation and fate. Nutrient concentration should be the result of a balance of nutrient inflow and outflow at three sites (Fig. 5a): freshwater inflow from rivers; the interface between inshore and offshore waters; and the interface between the bottom sediment and bottom water.

Surprisingly and unintuitively, more than half of the N and P content in the Seto Inland Sea originates in the Pacific Ocean (FUJIWARA *et al.*, 1997; YANAGI and ISHII, 2004; HAYAMI *et al.*, 2004). Despite problems with methods to estimate the amount of ocean-origin nutrients in coastal seas, TAKEOKA (2006) considered that about 60% of N and P is of oceanic origin. Therefore, since TN and TP concentrations in Seto Inland Sea seawater apparently have not decreased, despite the decrease in TN and TP runoff from the land, it seems that N and P load from the land is a much smaller fraction compared to the contribution from the open ocean and bottom sediment (Fig. 5a).

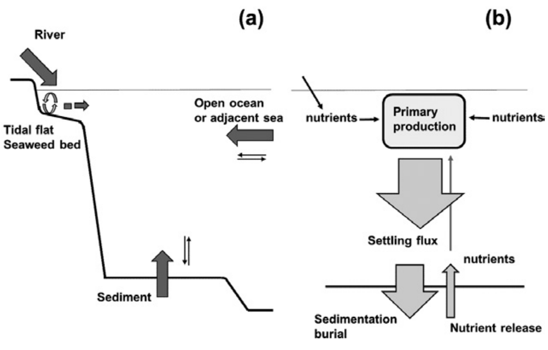

Fig. 5 Diagrams illustrating (a) nutrient supply, and (b) the nutrient cycle via phytoplankton primary production and bottom sediments in coastal waters (TADA, 2021).

Among these three sources of nutrients, there have been few measurements of nutrient flux from bottom sediment in the coastal water in Japan including the Seto Inland Sea. Therefore, upward nutrient fluxes were monitored across the overlying water-sediment interface using the core incubation method. In Harima-nada, it was estimated that the DIN release flux from the sediment was 46.4 tonnes d^{-1} (TADA *et al.*, 2014). It is about 3.2 times larger than nutrient inflow from rivers, which was estimated at 14.5 tonnes d^{-1} (YAMAMOTO *et al.*, 1996). In this regard, this ratio changed depending on the coastal water body (ABO *et al.*, 2015).

DIN and Si $(OH)_4$ fluxes from bottom sediment were proportional to bottom sediment temperature in Tsuda Bay, which is a small bay adjacent to Harima-Nada (TADA *et al.*, 2014). The PO_4 flux was not measured. Nutrient flux measurements at 8 stations in Harima-Nada and Osaka Bay revealed that DIN fluxes were proportional to TN content in the surface sediment layer (0–1 cm) and bottom sediment temperature. From these results, DIN (NH_4) fluxes from bottom sediments are expressed by the following equations (TADA *et al.,* 2018).

$$NH_4 \text{ flux } (\text{mg m}^{-2}\, \text{d}^{-1}) = G_T \times (C_N - 1.301),$$
$$G_T = 1.8020 \times \exp(0.1277 \times T),$$

where C_N and T are TN content (mgN.g^{-1}) in surface sediment layer (0–1 cm) and bottom sediment temperature (℃), respectively. The results suggest that nutrient flux can be forecast simply by TN content and the temperature of

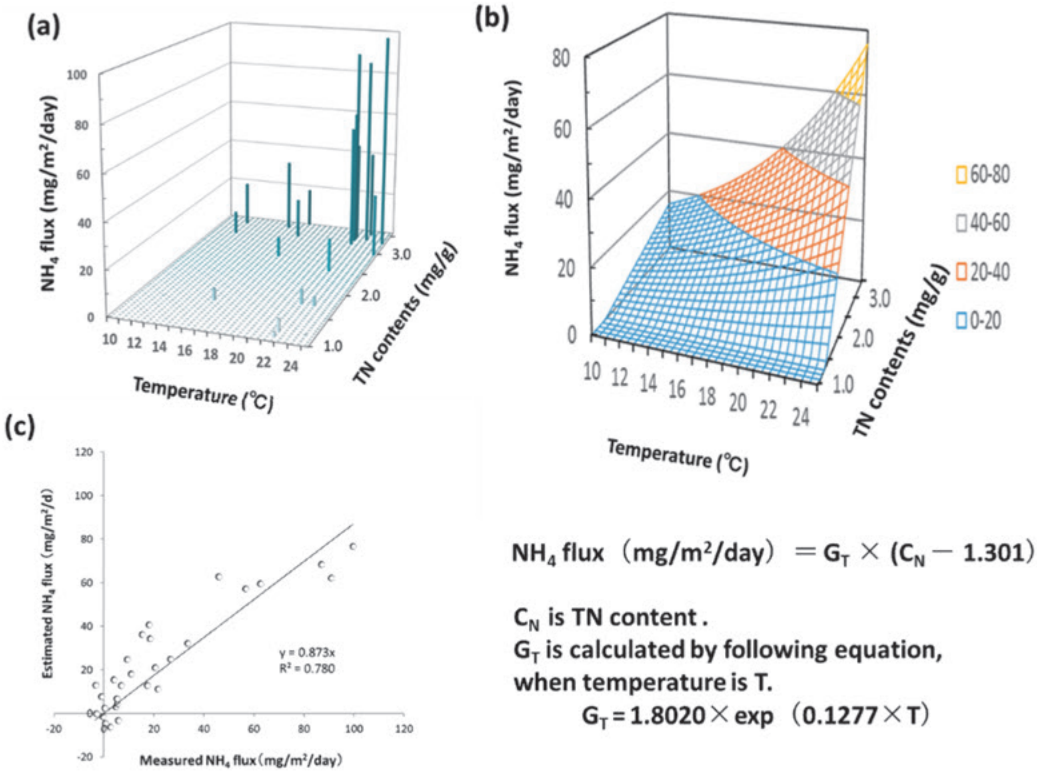

Fig. 6 (a) Relationship between NH_4 flux from bottom sediments, surface sediment temperature and TN content; (b) estimated upward NH_4 fluxes using the equation shown below; (c) relationship between measured fluxes and estimated fluxes (TADA *et al*., 2018).

the surface sediment, although it is generally considered that nutrient upward flux depends on the sediment grain size (Fig. 6).

To further investigate the nutrient dynamics of the Seto Inland Sea, current research is attempting to calculate the budget of the nutrient cycle in the water column, including primary production by phytoplankton, organic matter settling fluxes, decomposition of settling matter in the bottom layer, and upward nutrient fluxes from bottom sediments (Fig. 5b).

3. Phytoplankton assemblage and primary production

3.1 Phytoplankton cell density and community composition

During the period of nutrient concentration decrease, long-term data sets of phytoplankton abundance in the Seto Inland Sea are rare. NISHIKAWA *et al.* (2010) demonstrated the nutrient and phytoplankton dynamics in Harima-Nada during a 35-year period from 1973 to 2007 (Fig. 7). They revealed that from the 1970s to the late 1990s, DIN decreased by half from about 10 μM to 5 μM. Before 1990, higher total cell densities were often observed. Recently, maximum cell densities rarely exceed 4,000 cells ml^{-1}, whereas this was often observed before 1990

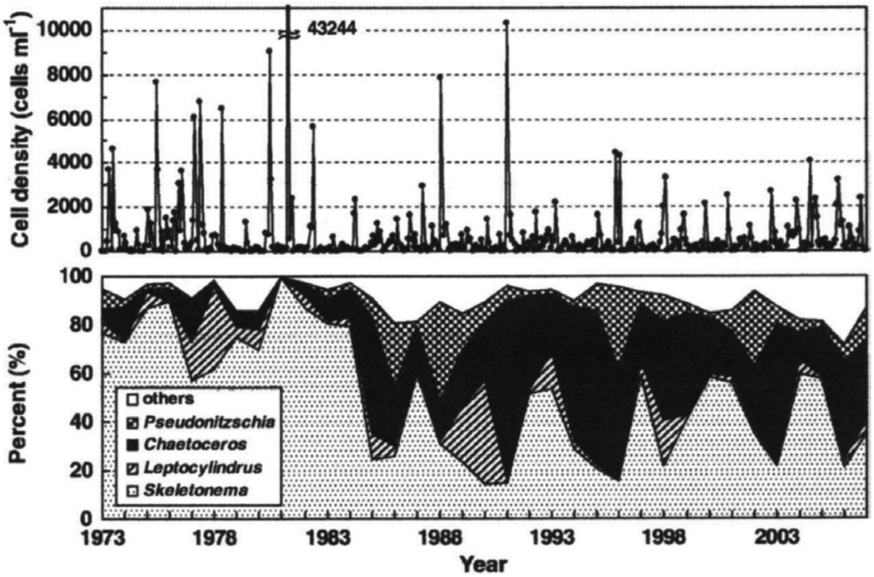

Fig. 7 Long-term variations in monthly total cell density and yearly percent species composition of diatoms in the surface layer of Harima-Nada, Seto Inland Sea, over the 35 years from 1973 to 2008 reproduced from NISHIKAWA *et al.* (2010) with the authors' permission.

(Fig. 7). Diatoms were the dominant phytoplankton group (> 90%) throughout this 35-year period and, interestingly, in the mid-1980s there was a dramatic shift from *Skeletonema* dominance (up to 70%) to *Chaetoceros*, which may be attributed to differences in the life cycle of *Skeletonema* and *Chaetoceros* and response to the decrease in DIN concentration.

3.2 Phytoplankton primary production

The ^{14}C (STEEMAN NIELSEN, 1952) and ^{13}C (HAMA *et al.*, 1983) methods for measuring the primary production of coastal waters have rarely been used in Japan, except for the study by TADA *et al.* (1998). Therefore, the long-term relationships between primary production and nutrient concentration were unknown. Recently, however, NISHIJIMA (2018, 2019) estimated primary production in the Seto Inland Sea and reported changes over an extended period: the distribution of Chl *a* concentration in autumn from 1980 to 1985 in the Seto Inland Sea is shown in Fig. 8. Concentrations higher than 10 μg L^{-1} of Chl *a* were located in Osaka Bay and the northern part of Hiroshima Bay, accounting for 6% of the total area of the Seto Inland Sea and these areas were defined as 'red tide' (TSUTSUMI *et al.*, 2005).

NISHIJIMA (2018, 2019) classified their monitoring sites into five groups, based on Chl *a* concentration in 1981 to 1985 (Fig. 8). They showed that the decrease in primary production was characteristic for each group. The group with Chl $a > 10$ μg L^{-1} in 1981 to 1985 showed a decrease in primary production of approximately 45%, much larger than the decrease of other group (Fig. 9). The decrease was only 14% in the groups with a Chl *a* lower than 10 μg L^{-1} in 1981 to 1985, but these groups cover 94% of the total area of the Seto Inland Sea. These results show clearly that the decrease in primary production since the 1980s did not occur uniformly

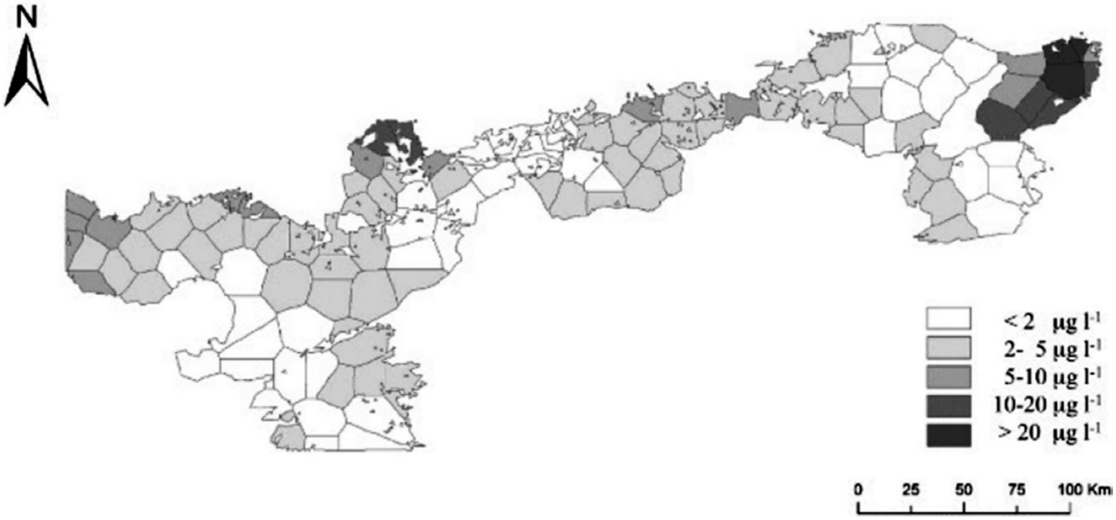

Fig. 8 Spatial distribution of mean autumn chlorophyll *a* concentration from 1980 to 1985 reproduced from NISHIJIMA (2018) with the authors' permission.

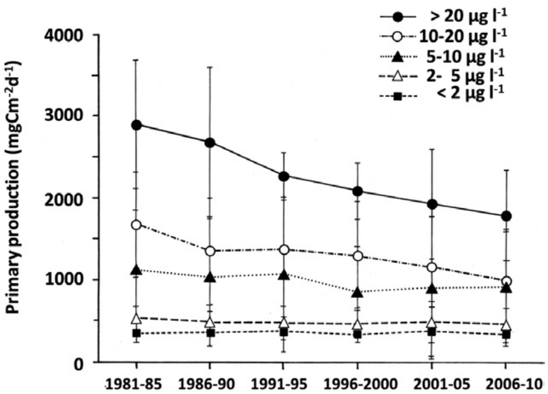

Fig. 9 Historical changes in primary production of each group classified by mean chlorophyll *a* concentration, from 1980 to 1985 reproduced from Nishijima (2018) with the authors' permission.

within the Seto Inland Sea, and the decrease was small in most areas (94%). The greatest decrease was observed in areas with a large urban watershed with high loading of nutrients and, conversely, a small decrease was observed in offshore areas with a low loading of nutrients. Their data suggested that phytoplankton primary production does not respond simply to nutrient decrease.

4. Decrease of Fish catches

Another current problem is the decrease of fish catches (ABO, 2016) (Fig. 10), which is thought to be related to the nutrient decrease (TANDA *et al.*, 2014). Fish catches were highest at the beginning of the 1980s, after which they decreased steadily. However, curiously, fish catches were high when red tide occurrence was also high (Fig. 10). Now, fish catches are lower than in the days when red tides occurred often, although water quality has improved. The relationships among fish catches, red tides and water nutrient content are thought to be as represented in Fig. 11. Before the period of high economic growth in Japan, water quality was good and biomass was high. At that time, the nutrient cycles were considered to be relatively simple and the ecosystem was productive. However, due to ensuing environmental degradation as the period of high economic growth progressed, water quality deteriorated, although fish catches did not decrease. In latter half of 1970s and first

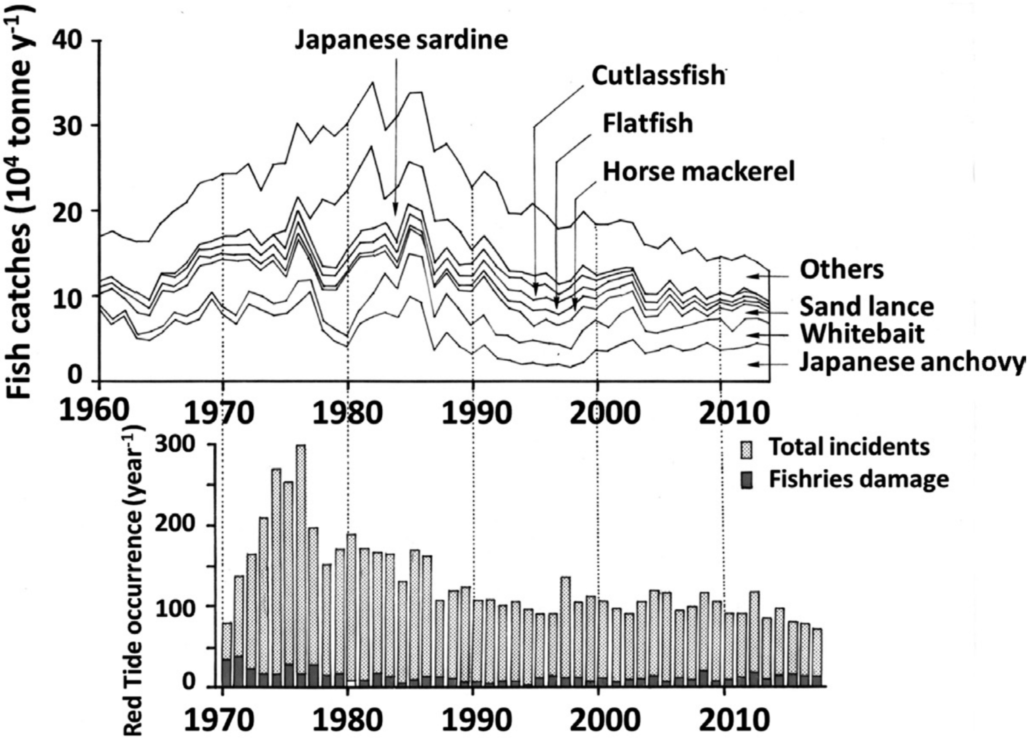

Fig. 10 Annual catches of different fish species, excluding fish culture modified from Abo (2016) and (below) the annual number of red tide occurrences (Setouchi Net, 2021c).

half of 1980s, Japanese sardine and Japanese anchovy catch was high and they were cheap, while expensive fish such as red sea bream were rare. Therefore, fish biodiversity was thought to be low, although biomass did not decrease. The aim of enacting "Law concerning Special Measures for Conservation of the Environment of the Seto Inland Sea", in 1973, was to recover the simple nutrient cycle and productive ecosystem. However, almost 50 years have passed but although water quality has improved, fish biomass has decreased. In Fig.11, the present status is at higher water quality but a biomass lower than in the 1970s.

In the Seto Inland Sea, the areas of tidal flat and algal/seagrass bed have decreased due to land reclamation (Fig. 12). Algal/seagrass beds are refuges for egg laying and aiding juvenile

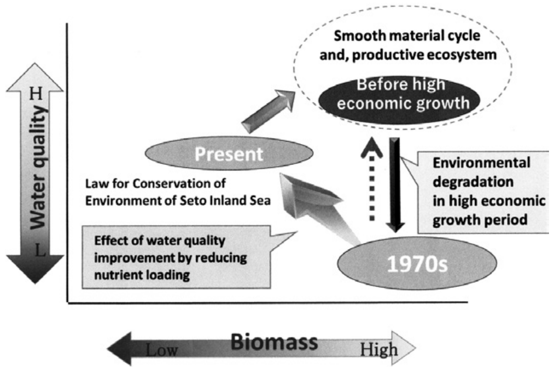

Fig. 11 Conceptual illustration of environmental conservation (modified from Ministry of the Environment; Conceptual representation of "Marine Healthy Plan 〔Project on the Normalization of Material Circulation in Coastal Marine Environment〕")

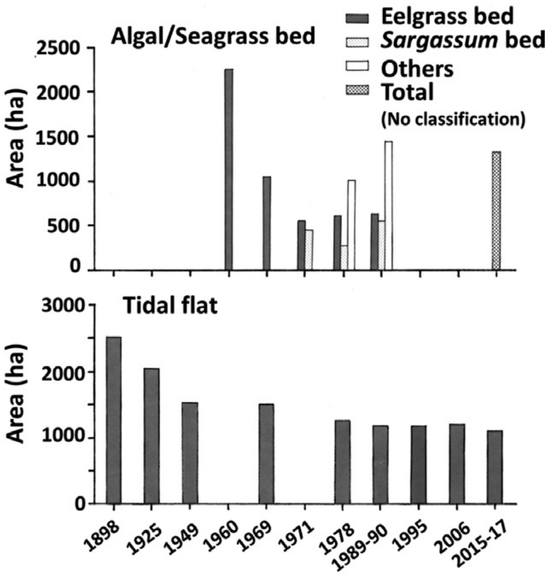

Fig. 12 Changes in area of algal/seagrass beds and tidal flat in the Seto Inland Sea modified from CENTRAL ENVIRONMENTAL COUNCIL (2021) and SETOUCHI NET (2021).

fish to resist predation until they reach adulthood. SHOJI *et al.* (2007) conducted the experiments in mesocosm to indicate that *Zostera marina* habitat reduces vulnerability of red sea bream juvenile from the predation by piscivorous fish, and seaweed bed increases the survival rate of the juveniles. Loss of such areas during the last 50 years may explain the currently low fish biomass, despite improvements in water quality. Overfishing also should be considered as a reason of fish catch decrease. For example, it was pointed out that fishing pressure was high for the Spanish Mackerel *Scomberomorus niphonius* and mud dab *Pleuronectes yokohamae* in the Seto Inland Sea (NAGAI *et al.*, 1996; NAGAI, 2003; IMOTO *et al.*, 2007).

It seems, then, that improvement of water quality alone does not guarantee a sustainable harvest and a productive coastal ecosystem. The reason for the fish catch decrease is still uncertain. As described above, phytoplankton primary production did not respond simply to the nutrient decrease, and there is no time series of data available for zooplankton production in this sea, so the relationships among coastal nutrients, phytoplankton, zooplankton and fishes are unclear. Moreover, the increase in water temperature associated with global warming induces changes in fish fauna. For example, recently the impact of warming on the physiological condition of ridged-eye flounder *Pleuronichthys lighti* in the central part of Seto Inland Sea was reported (YAMAMOTO *et al.*, 2020). Presumably land reclamation, the decrease in areas of tidal flat and algal/seagrass beds, global warming and overfishing are all reasons for fish catch decreases, but the contribution of nutrient decrease is still unclear. However, some fishes have increased in the Seto Inland Sea, despite of nutrient decrease. YAMAMOTO *et al.* (2019) revealed that red sea bream *Pagrus major* catch has increased from 297 tons in 1972 to 2,039 tons in 2010 in eastern Seto Inland Sea.

5. Conclusion

Nutrient concentrations apparently have decreased over the last 50 years in almost all parts of the Seto Inland Sea but TN and TP concentrations in the seawater have remained almost constant or slightly decrease. Nutrient release from the bottom sediment has been shown to be larger than nutrient loading from the land runoff during the summer period in Harima-Nada. Unfortunately, there are few data sets providing comparative information on previous nutrient fluxes from bottom sediment. Fish catches also gradually decreased after the 1980s but the reasons for this are unclear. However, clearly, poor nori harvest is directly related to a lack of nutrients. Phytoplankton primary production does not respond simply to nutrient decrease. Substantial phytoplankton production decrease was only observed at a very small part (6% of the total area) of the Seto Inland Sea, and there was only a marginal decrease in most areas (94%), despite nutrient decrease in all parts of this sea. The conclusion is that the reason of fish catch decrease is still unknown. Whereas nutrient concentrations decreased and presumably nutrient decrease will be a contributing factor, land reclamation, decreases in the area of tidal flats and algal/seagrass beds, global warming, and overfishing should be thought as reasons contributing to fish catch decreases.

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Marine biodiversity in the Mediterranean in the era of global warming

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Abstract: The Mediterranean is a semi-enclosed temperate to locally warm sea. It is a hotspot of species, functional and ecosystem diversity, characterized by a high rate of endemism and a number of unique ecosystems. Between 12,000 and 17,000 marine species have been reported in the Mediterranean. Only one species is totally extinct and less than ten are extinct in the Mediterranean but still present elsewhere. In contrast, many species are functionally and/or regionally extinct. The progressive arrival of a thousand non-native species has in fact considerably increased the ε species diversity of the Mediterranean, contrary to the naive beliefs of some environmentalists. Several of the emblematic ecosystems of the Mediterranean (e.g. the dune-beach-*banquette* ecosystem, the *Lithophyllum byssoides* algal rim, the seagrass *Posidonia oceanica* meadow, the reef fucalean forests and the coralligenous) are currently in decline. Finally, the functioning of ecosystems (relative abundance of key species, carbon and nutrient flows, food webs, and interactions between ecosystems) has been profoundly altered. The causes of this impact on biodiversity are various; the three major causes are coastal development, overfishing, and biological invasions. Global warming is beginning to play a role, which will increase significantly over the course of the 21st century, but it is currently far behind other human-induced causes. The concern over the growing and irreversible effects of global warming is totally justified; but the underestimation of other threats derives from issues which may be political or related to human perceptions and science funding, and which are discussed here.

Keywords : *biodiversity, biological invasions, global warming, overfishing*

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1. Introduction

The Mediterranean is an east-west semi-enclosed sea, the largest in the world ocean (COLL *et al.,* 2010), 3,800 km long (from the Alboran Sea to the Levantine basin) and up to 900 km wide, with a surface area of ~2.5 million km^2. It communicates with the Atlantic Ocean, through the narrow (14 km) Straits of Gibraltar, and with the Black Sea. Since 1869, the Mediterranean has also communicated with the Red Sea, *via* the man-made 193 km long Suez Canal (NICOLE, 1870; POR, 1978; BOUDOURESQUE, 1999). The Mediterranean is for the most part a temperate sea, i.e. a sea where the winter sea surface temperature (SST) ranges between 10 and 20℃; however, the westernmost part of the Levantine basin, with winter SST close to or over 20℃, can be regarded as subtropical (LÜNING, 1990; LEONI *et al.,* 2021; TMEDNET, 2021). It has been compared to a miniature ocean and studying it can shed light on issues concerning the global ocean (LEJEUSNE *et al.,* 2010).

Due to the northwards push of Africa, the communication between the Mediterranean and the Atlantic Ocean was closed between 5.7 and 5.3 million years ago. The Mediterranean, which has a water deficit due to its dry climate and the insufficient flow of tributary rivers, then partially dried up (the Messinian crisis) (GARCIA-CASTELLANOS *et al.,* 2009; MILLOT and TAUPIER-LETAGE, 2005; DANOVARO and BOERO, 2019). This resulted in the disappearance of most of its flora and fauna; after the opening of the Straits of Gibraltar and the refilling of the Mediterranean, this sea was predictably repopulated by species originating from the Atlantic (BOUDOURESQUE, 2004; LEJEUSNE *et al.,* 2010).

During the Pleistocene climatic glacial cycles, North-Atlantic species periodically shifted their latitudinal ranges, northwards (interglacial episodes) or southwards (glacial episodes), allowing species of warm and cold affinities, respectively, to enter the Mediterranean *via* the Gibraltar Straits. Once in the Mediterranean, because of reduced opportunities for north-south migration in response to changing sea temperatures, populations of these species were subject to higher evolutionary pressures. In addition, the Alboran Sea, at the entrance to the Mediterranean, acts as a buffer reducing gene flow, and the 46,000 km of Mediterranean coasts are highly compartmentalised into relatively isolated sectors. This mechanism can account for the high rate of endemism in the Mediterranean, the sea functioning as a 'species factory' or a 'diversity pump' from the Atlantic, as coined by Carlo Nike Bianchi (BIANCHI, 1996; BIANCHI and MORRI, 2000; BOUDOURESQUE, 2004; LEJEUSNE *et al.,* 2010; BIANCHI *et al.,* 2012a).

2. The concept of biodiversity

'Biodiversity' is today a term that has gained popular currency, widely used not only by scientists but also by political leaders, government officials, conservationists, environmentalists ('greens') and the public at large. However, the modern scientific concept of biodiversity is sometimes worlds away from its popular definition, as used in the environmentalist's jargon. For the latter, biodiversity is synonymous with species richness, which in fact represents a rather limited part of the species diversity concept, itself a relatively small part of the biodiversity concept. Finally, the term 'biodiversity' is now often used to reflect a concern for the natural environment, nature conservation and species extinctions, without any real relation to the scientific concept to which it properly refers.

For many managers, politicians and 'greens', species richness held sacred. The more species there are in a habitat or an area, the more important that habitat or area is and the more it deserves to be protected. This belief is incorrect for several reasons (SALA and KNOWLTON, 2006; BOUDOURESQUE, 2014; BOUDOURESQUE *et al.,* 2017a). **(i)** Many habitats are relatively poor in species (at least for certain 'noble' taxa favoured by environmentalists and NGOs - e.g. flowering plants, mammals), while having high heritage value; this is the case for belts of terrestrial halophilic vegetation on rock, *sansouïres* (mud-flats subject to sea inundation, colonized by salicorniae of the genus *Arthrocnemum*), beach-dune systems and coastal lagoons. **(ii)** The species richness is very dependent on the scale (see below): point diversity (scale of the sample), α species diversity (scale of the ecosystem in a region), γ species diversity (all the ecosystems of a region), and ε species diversity (all the ecosystems of a vast biogeographical region, such as the Mediterranean Sea). It is important to note that the species diversity in a given habitat may be high at one scale (e.g. point diversity) and low at another (e.g. α species diversity), or the opposite (see examples *in* BOUDOURESQUE *et al.,* 2017a). Furthermore, the same human impact (e.γ. pollution, biological invasion) can increase the α species diversity in one ecosystem (e.g. a coastal sandy bottom) and reduce it in another (e.g. a *Posidonia oceanica* seagrass meadow). **(iii)** In most cases, non-extreme disturbances, e.g. pollution, do not reduce species diversity, but increase it (CONNELL, 1978; MOLINO and SABATIER, 2001; SALA and KNOWLTON, 2006; OURGAUD *et al.,* 2013, 2015). In a 11,000-m^2 bathing area close to the commercial port of Barcelona (Catalonia, Spain), a marina and the outfall of a sewage treatment plant, a high γ species diversity was observed (517 taxa), including heritage value species such as the fan mussel *Pinna nobilis* and the dusky grouper *Epinephelus marginatus* (PONTES *et al.,* 2021). In a seagrass *Zostera noltei* meadow, artificial detritus increased point diversity of invertebrates (COSTA *et al.,* 2021). (iv) For a given ecosystem, the right species diversity is its 'natural' value, either high or low. It is therefore inappropriate to think that a decline in the number of species is a negative effect, while an increase would be positive, as some authors claim (see e.g. GRIBBEN and WRIGHT, 2006; WRIGHT and GRIBBEN, 2008; ANTON *et al.,* 2019). In fact, both the decline and the increase in species richness, relative to the 'natural' value, are negative effects.

Biodiversity means the variety of life, encompassing levels of complexity from within species to across ecosystems, and includes five dimensions (SALA and KNOWLTON, 2006; GAERTNER *et al.,* 2010; BOUDOURESQUE, 2014; BOUDOURESQUE *et al.,* 2017a). **(i)** Evolutionary scale, i.e. diversity within species (genetic diversity), diversity between species, diversity between taxa higher than species (genera, families, orders, classes, phyla, kingdoms, etc.) and phylogenetic diversity (mean phylogenetic distance between taxa; FAITH, 1992; WARWICK and CLARCK, 1995, 2001). **(ii)** Functional scale, i.e. diversity in the functional role of species, functional groups and guilds within ecosystems, e.g. photosynthetic or chemosynthetic primary producers, diazotrophic species, filter-feeders, suspension-feeders. **(iii)** Organizational scale, i.e. diversity between patches, communities, ecosystems, landscapes/seascapes, including beta-diversity. **(iv)** Spatial scale, from local and regional to global (RAMADE, 1994; GRAY, 2000). As far as the species diversity is concerned (evolutionary scale), it can be considered at the scale of a sample (point diversity), of an ecosystem within a region (α diversity), of all the ecosystems of a region (γ diversity) and of all the ecosystems of a large biogeographical province (ε diversity). The spatial (geographical) scale matters a great deal for biodiversity estimates (WARWICK, 1998; WILLIS and WHITTAKER, 2002). (**v**) Finally (heterogeneity scale), biodiversity includes the proportional distribution of the individuals among the species, the so-called heterogeneity diversity, abundance diversity or evenness (SHANNON and WEAVER, 1949; PIELOU, 1975; HEIP *et al.,* 1998; GRAY, 2000). Like other measures of biodiversity, heterogeneity diversity is sensitive to spatial scale (FRASCHETTI *et al.,* 2006).

Biodiversity is, *par excellence*, a multidimensional concept. The choice with regard to the meaning (qualitative or quantitative, compositional or functional, scale, etc.) depends primarily on one's goals and interests. Biodiversity can therefore be measured in different and complementary ways and thus involves the use of at least 200 different metrics (SALA and KNOWLTON, 2006; BOUDOURESQUE, 2014; BOUDOURESQUE *et al.,* 2017a). This complexity of meanings, scale and units makes it impossible to assess the state of biodiversity using a single measure or index.

3. Biodiversity of the Mediterranean Sea

The Mediterranean Sea is a hotspot of ε species diversity; the number of reported species has been estimated to range between 12,000 and 17,000 species (BOUDOURESQUE, 2003, 2004; COLL *et al.,* 2010; BIANCHI *et al.,* 2012a; CONIDES and PAPACONSTANTINOU, 2020). It is also a hotspot in the terrestial realm (BLONDEL and MÉDAIL, 2009). Mediterranean taxa represent 17% of the earth's marine species diversity for brown algae (Phaeophyceae) (BOUDOURESQUE, 2004), 10% for Hydraria (GRAVILI *et al.,* 2013) and Porifera (GRENIER *et al,* 2018) and 8% for seagrasses (GERAKARIS *et al.*, 2019). The point species diversity can also be very high in coastal habitats (BELLAN-SANTINI, 1962, 1968): up to 109 species of macroalgae in a 400 cm^2 sample in a photophilous reef habitat at 10 m depth (Port-Cros Island, Provence) (COPPEJANS and BOUDOURESQUE, 1975).

At the end of the Messinian crises, 5.3 Ma ago, the Mediterranean was mostly repopulated by species originating in the Atlantic Ocean. It is therefore not surprising that, several million years later, the majority of species, ~50%, are common with those of the Atlantic (PÉRÈS and PICARD, 1964; GIACCONE and GERACI, 1989; BOUDOURESQUE, 2004; BIANCHI *et al.,* 2012b). Endemic species represent more than 30% of Mediterranean species, as a result of the 'Mediterranean species factory' (see above) (LEJEUSNE *et al.*, 2010; BIANCHI *et al.,* 2012a). This percentage is constantly increasing, at the expense of that of the Atlantic species, which is actually an artifact; when molecular studies are carried out on species that are believed to be common to the Atlantic and the Mediterranean, they generally result in the conclusion of the existence of distinct cryptic species in the Mediterranean and the Atlantic. For example, the Atlantic sea anemone *Actinia equina* is replaced in the Mediterranean by *A. mediterranea* (MONTEIRO *et al.,* 1997); the Atlantic red alga *Radicilingua thysanorhizans* is replaced in the Mediterranean by *R. mediterranea* (WOLF *et al.,* 2021); the Mediterranean red alga *Botryocladia chiajeana* is replaced in the Atlantic by *B. macaronesica* (AFONSO-CARRILLO *et al.,* 2006). The most iconic endemic species in the Mediterranean are the seagrass *Posidonia oceanica* (Fig. 1), the fan mussel *Pinna nobilis*, the precious red coral *Corallium rubrum*, and the orange stony coral *Astroides calycularis*, although the two latter also occur on the neighbouring Atlantic coasts (DEN HARTOG, 1970; ZIBROWIUS *et al.,* 1984; BASSO *et al.,* 2015; ROUANET *et al.,* 2015; PRADA *et al.,* 2019; LEDOUX *et al.,* 2021). Finally, non-indigenous species (NIS) represent almost 10% of Mediterranean species (BOUDOURESQUE and VERLAQUE, 2002;

Zenetos *et al.*, 2005; Galil, 2008; Zenetos and Galanidi, 2020). Most of them are definitely or probably introduced, i.e. naturalized: new generations in the non-native area, the Mediterranean, are born without human assistance, thus constituting self-sustaining populations (Boudouresque and Verlaque, 2002a, 2012). In the eastern Mediterranean, the Suez Canal, inaugurated in 1869, and widened and deepened several times since, is the main vector of NISs (Nicole, 1870; Por, 1978; Boudouresque, 1999; Galil *et al.*, 2015). In the western Mediterranean, by contrast, aquaculture is the main vector: escaped reared species and especially species accompanying the reared species (e.g. epibionta and parasites) (Verlaque *et al.*, 2007; Grigorakis and Rigos, 2011; Boudouresque *et al.*, 2020). Other vectors are the fouling on ship hulls (Boudouresque and Verlaque, 2002b; Petrocelli *et al.*, 2019), ballast waters (David *et al.*, 2007), the aquarium trade (Meinesz and Hesse, 1991; Meinesz and Boudouresque, 1996) and packaging material used for shipment of seafood (Ruitton *et al.*, 2021).

About fifty ecosystems have been described in the Mediterranean (Pérès and Picard, 1964; Pérès, 1967; Rodrigues, 1982; Boudouresque, 1984; Bianchi and Morri, 2001; Bevilacqua *et al.*, 2021). Their delineation and number differ from one author to another, but this question is outside the scope of this article. They are distributed from the supralittoral zone, above mean sea level, to the abyssal zone, whose maximum depth is, in the Mediterranean, 5,267 m. Some ecosystems straddle several zones, such as the Dune-Beach-*Banquette* ecosystem (supralittoral and midlittoral) and the coralligenous ecosystem (infralittoral and circalittoral).

Some Mediterranean ecosystems are unique, endemic to this sea. Below, we list a few of them, going from the supralittoral zone to the abyssal zone. **(i)** The Dune-Beach-*Banquette* ecosystem (DBB) differs from worldwide beach-dune systems by the presence and the overwhelming role of the *banquette*, a thick (up to 2 m) layer of dead *Posidonia oceanica* leaves cast ashore by storms and covering the beach (Fig. 2). In addition to feeding local food webs, these leaves are in part exported to the dune and the foredune, where they constitute the main source of nitrogen. The remaining leaves of the *banquette* return to the sea during storm episodes and play a pivotal role in coastal food webs (Gauci *et al.*, 2005; Deidun *et al.*, 2007; Cardona and García, 2008; Deidun *et al.*, 2009; Boudouresque *et al.*, 2012; Simeone *et al.*, 2013; Boudouresque *et al.*, 2017b). **(ii)** The *Lithophyllum byssoides* algal rim is a bioconstruction built by a calcareous red alga a few centimetres above the mean sea level, in the midlittoral zone of rocky and relatively shady habitats, under semi-exposed and exposed conditions (Fig. 3). It can reach 2 m in width and its upper surface is flat, hence the name *trottoir* (after a French word meaning sidewalk) which is usually given to it. *Trottoir* occur in exposed and shady habitats. Their construction requires

Fig. 1 The front of a *Posidonia oceanica* meadow, with plagiotropic rhizomes (creeping) and bundles of leaves (shoots). Port-Cros Island (eastern Provence, France). Photo © Sandrine Ruitton.

Fig. 2 A *banquette* of cast ashore dead *Posidonia oceanica* leaves on a beach. The figure (MPB and her dog Diego) shows the scale. In the background, the dune with the European beachgrass *Ammophila arenaria* and the backdune with a *Juniperus phoenicea* forest. Beach of Barcaghju, Capicorsu, Corsica. Photo © Charles-François Boudouresque.

Fig. 3 The *Lithophyllum byssoides* algal rim (*trottoir*) of Punta Palazzu (western Corsica) in the early 1980s. Photo © Jean-Georges Harmelin, courtesy of the author.

periods of relative stability of the sea level for several centuries (PÉRÈS and PICARD, 1964; LABOREL *et al.*, 1983; BIANCONI *et al.*, 1987; LABOREL, 1987; FAIVRE *et al.*, 2013; INGROSSO *et al.*, 2018; BEVILACQUA *et al.*, 2021; FAIVRE *et al.*, 2021). **(iii)** The *Posidonia oceanica* seagrass meadow extends from the sea level down to 30–40 m depth, in sandy and reef habitats of the infralittoral zone (Fig. 4). It is a hotspot of α species diversity and provides many ecosystem services (e.g. high primary production, carbon sequestration, sand factory, protection of beaches against erosion, export of dead leaves to all other Mediterranean ecosystems, spawning area, nursery). Dead leaves are exported towards all the Mediterranean ecosystems, from the supralittoral and midlittoral DBB to deep bathyal canyons, where they constitute a valuable food resource (Fig. 5) (MOLINIER and PICARD, 1952; MAZZELLA *et al.*, 1992; MATEO *et al.*, 2006; BOUDOURESQUE *et al.*, 2012, 2016; PAOLI *et al.*, 2018; MONNIER *et al.*, 2020; RIGO *et al.*, 2021). **(iv)** The reef fucalean forests are built by erect large and long-lived brown algae (Fucales, Phaeophyceae, kingdom stramenopiles) belonging to the genera *Sargassum* and *Cystoseira sensu lato*, such as *Ericaria brachycarpa* and *Gongolaria montagnei*. They dwell on reefs of the infralittoral zone (THIBAUT *et al.*, 2017; BEVILACQUA *et al.*, 2021; SANT and BALLESTEROS, 2021a). **(v)** The coralligenous ecosystem is a bioconstruction built by calcareous red algae and calcified metazoans (cnidarians, bryozoans, molluscs, etc.). In addition, gorgonians (*Paramuricea clavata, Eunicella* spp.), the precious red coral *Corallium rubrum* below overhangs, the Fucales *Gongolaria zosteroides* and *Sargassum* spp., build a mixed animal and seaweed forest (Fig. 6).

Fig. 4 A *Posidonia oceanica* seagrass meadow. Bagaud Island, Port-Cros Archipelago Marine Protected Area (MPA), eastern Provence. Photo © Sandrine Ruitton.

Fig. 6 A coralligenous ecosystem, 20 m depth, at La Ciotat (western Provence, France). Photo © Sandrine Ruitton.

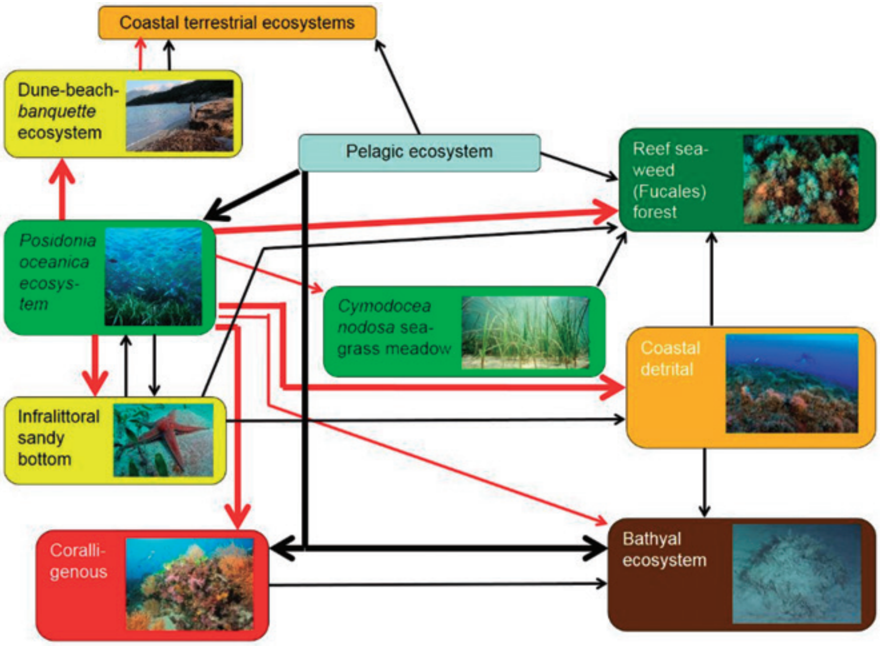

Fig. 5 Interactions (flow of carbon and nutrients) between some Mediterranean coastal ecosystems. The *Posidonia oceanica* ecosystem interacts, *via* the export of dead leaves (red arrows), with all coastal ecosystems. Black arrows: other flows. Width of the arrows: high, medium or low flows. Original figure © Charles-François Boudouresque.

Gorgonians, red coral and Fucales are long-lived species. This ecosystem dwells in the lower infralittoral zone and in the circalittoral zone (BALLESTEROS, 2006; RUITTON *et al.,* 2014; CAPDEVILA *et al.,* 2016; BOUDOURESQUE *et al.,* 2017c; CAPDEVILA LANZACO, 2017; BEVILACQUA *et al.,* 2021; SANT and BALLESTEROS, 2021b).

Other ecosystems, although not unique to the Mediterranean Sea, deserve special attention, such as the vermetid platforms (GORDÓ-VILASECA *et al.,* 2021) and the *Zostera marina* seagrass meadows (BOUDOURESQUE *et al.,* 2009; PERGENT *et al.,* 2012).

Two main features characterize the functioning of the Mediterranean ecosystems: the extreme oligotrophy of Mediterranean waters and the scarcity of native macro-herbivores. The oligotrophy results from the drought which characterizes part of the Mediterranean catchment area (the south and the east) and from the weak contributions of the tributary rivers. The Nile was once the main tributary river. Since the construction of the Aswan dam in 1970, the Nile has almost dried up before reaching the Mediterranean. It is therefore the Rhône River which is today the main provider of water and nutrients (SADAOUI *et al.,* 2016). The nitrogen deficit is partly compensated by diazotrophic bacteria (capable of fixing dinitrogen N_2 into a biologically useful form, ammonia), both in the pelagic ecosystem and in the seagrass *Posidonia oceanica* ecosystem (BÉTHOUX and COPIN-MONTÉGUT, 1986; BÉTHOUX *et al.,* 1992; GARCÍA-MARTÍNEZ *et al.,* 2005; BOUDOURESQUE *et al.,* 2006; GARCIA *et al.,* 2006). Macro-herbivore species are few in ecosystems belonging to supralittoral, midlittoral, infralittoral and circalittoral zones, i.e. the zone which houses primary producers. The most conspicuous are the teleost fish *Sarpa salpa* and *Sparisoma cretense* (the latter mainly in the eastern Mediterranean, but currently spreading in the western basin) and the sea urchins *Paracentrotus lividus* and *Arbacia lixula* (MAGGIORE *et al.,* 1987; VERLAQUE, 1990; VERGÉS *et al.,* 2009; ASTRUCH *et al.,* 2016; TSIRINTANIS *et al.,* 2018; BOUDOURESQUE and VERLAQUE, 2020; ESPOSITO *et al.,* 2021). The giant limpet *Patella ferruginea*, in the midlittoral of the western basin, should also be taken into account (GUERRA-GARCÍA *et al.,* 2004; COPPA *et al.,* 2011). *Sarpa salpa, Sparisoma cretense* and *Paracentrotus lividus* are browsers: they pick plants from above, like terrestrial large herbivores. *Arbacia lixula* and *P. ferruginea* are grazers: they scrape benthic organisms from the side, like a bulldozer; as a result, they engulf both plants and metazoans, which is the case of *A. lixula*, the isotopic signature of which is that of a predator (WANGENSTEEN *et al.,* 2011). The role of omnivorous fish, such as *Diplodus vulgaris, Coris julis* and *Thalassoma pavo*, should also be taken into account, as they either consume macroalgae or cut them off them when feeding on invertebrates (PAPADAKIS *et al.,* 2021). Overall, in most undisturbed coastal benthic ecosystems, the detritus-feeder path, or the suspension-feeder and filter-feeder paths, are the dominant pathways in the ecosystem functioning (BOUDOURESQUE *et al.,* 2005a, 2017a).

4. Threats to Mediterranean biodiversity

4.1. Stressors

A variety of stressors threaten Mediterranean biodiversity (GIAKOUMI *et al.,* 2015; HOLON *et al.,* 2015, 2018; RUITTON *et al.,* 2020; BEVILACQUA *et al.,* 2021; GAGLIOTI and RADLO, 2021); one way to assess their respective severity is to determine their degree of reversibility (Table 1) (BOUDOURESQUE *et al.,* 2005a; MEINESZ, 2021). **(i)** Coastal development. The impact is direct when land is reclaimed from the sea, for example Nice airport (French Riviera), or in ports and

Table 1 Time needed for recovery, after the end of the forcing disturbance. +: yes; ±: yes or no; -: no. From BOUDOURESQUE *et al.* (2005a), updated.

Disturbance	Human origin?	Natural origin?	Recovery (years: y)	Key references
Domestic pollution (soft substrates)	+	-	< 1–10 y	BELLAN *et al.*, 1999
Artisanal fishing (fish abundance)	+	-	< 5–10 y	RAMOS, 1992; ROBERTS *et al.*, 2001
Oil spill	+	-	< 10 y	RAFFIN *et al.*, 1991; BOUDOURESQUE *et al.*, 2019a
Disease of marine species	±	+	> 10 y	MOSES and BONEM, 2001
Loss of long-lived species	+	±	10–100 y	SOLTAN *et al.*, 2001
Coastal development	+	-	Millenia	MEINESZ *et al.*, 1991
Over-fishing (genetic change)	+	-	Millenia?	CONOVER, 2000; LAW, 2000; KENCHINGTON *et al.*, 2003; OLSEN *et al.*, 2004
Climate warming	+	+	Glacial cycle?	ZWIERS and WEAVER, 2000; BARNETT *et al.*, 2001
Biological invasions	+	-	Irreversible	CLOUT, 1998; BRIGHT, 1998
Species neo-extinction	+	-	Irreversible	CARLTON, 1993; POWLES *et al.*, 2000

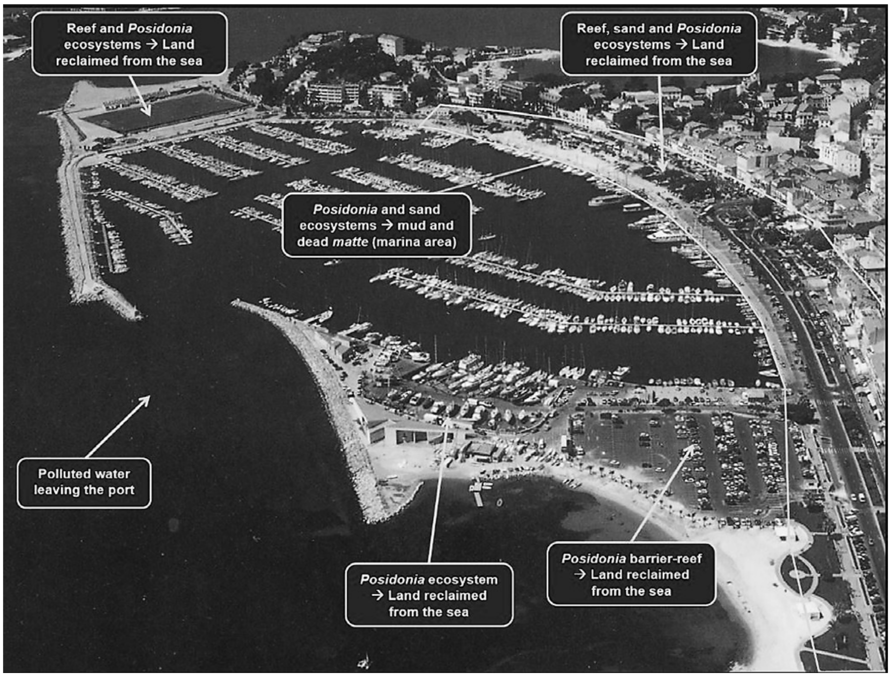

Fig. 7 Coastal development: the city and marina of Bandol (Provence, France). Land reclaimed from the sea and marina area, with ecosystems possibly formerly occurring there.

marinas (Fig. 7). It is also indirect, due to the resulting pollution and turbidity (MEINESZ *et al.,* 1991; MEINESZ, 2021). **(ii)** Biological invasions. Invasive species deeply alter the functioning of host ecosystems. The most concerning species are the seaweeds *Caulerpa cylindracea, C. taxifolia, Womersleyella setacea* and *Rugulopteryx okamurae* and the teleosts *Siganus luridus, S. rivulatus* and *Pterois miles* (BOUDOURESQUE *et al.,* 1995; VERGÉS *et al.,* 2014; GIOVOS *et al.,* 2018; RUITTON *et al.,* 2021). **(iii)** Overfishing. Most fish stocks are overexploited worldwide, which has resulted in a decline in catches, despite the considerable increase in fishing effort (WATSON and PAULY, 2001; PAULY *et al.,* 2003; CHASSOT *et al.,* 2010). The same occurs in the Mediterranean, where 90 % of fish stocks are overexploited and depleted (COLLOCA *et al.,* 2017; CONIDES and PAPACONSTANTINOU, 2020; AKBARI *et al.,* 2021). In addition, catch, as reported by FAO, is widely underestimated (PAULY and ZELLER, 2016); Illegal, Unreported and Unregulated (IUU) fishing can be responsible for catches equal to or much greater than those from official professional fishing, such as in Sicily (Italy) (FALAUTANO *et al.,* 2018); recreational fishing can represent considerable catches in the most touristic regions in the world, such as the Mediterranean (BOUDOURESQUE *et al.,* 2005b; LLORET and FONT, 2013, LLORET *et al.,* 2019); trawling is responsible for havoc in coastal ecosystems, in particular the seagrass *Posidonia oceanica* meadows (BOUDOURESQUE *et al.,* 2012; PERGENT *et al.,* 2013; SALA *et al.,* 2021); to harvest the borer mollusc *Lithophaga lithophaga*, divers break the rock with special sledgehammers, in Apulia (southern Italy) and in some other Mediterranean areas, which results in the devastation of the reef fucalean forests (FANELLI *et al.,* 1994; FRASCHETTI *et al.,* 2001; GUIDETTI *et al.,* 2004); fishing with explosives (dynamite) was widely practiced, and is still practiced in a few areas (FAGET, 2015); finally, lost fishing gear continues to fish and harm benthic ecosystems (RUITTON *et al.,* 2019a). **(iv)** Pollution. It comes from atmospheric fallout, tributary rivers channeling water from the catchment area, discharges from coastal towns and aquaculture (MIRACLE, 1994; ROMAÑA and GUILLAUD, 1995; PERGENT-MARTINI *et al.,* 2006; PERGENT *et al.,* 2011; RICHIR *et al.,* 2015; BOUDOURESQUE *et al.,* 2020). Along the northern Mediterranean coast, thanks to the binding directives from the European Union (EU), applied willingly or unwillingly by States, pollution has been considerably reduced since the 1980s; most sewage water today passes through sewage treatment plants, with some positive consequences (DE LOS SANTOS *et al.,* 2019). However, at the scale of the entire Mediterranean, 50% of wastewater remains untreated (MEOLA and WEBSTER, 2019). **(v)** Other stressors should be taken into account, e.g. seawater warming (BIANCHI *et al.,* 2013; RIVETTI *et al.,* 2014; SHALTOUT and OMSTEDT, 2014; GUY-HAIM *et al.,* 2016a, 2016b; RIVETTI *et al.,* 2017; HOEGH-GULDBERG *et al.,* 2019), the rise in sea level (VACCHI *et al.,* 2017; PERGENT *et al.,* 2019), water acidification (TEIXIDÓ *et al.,* 2018; BARRUFFO *et al.,* 2021) and macro- and microlitter (DEUDERO and ALOMAR, 2015; ASENSIO-MONTESINOS *et al.,* 2019; ANGIOLILLO *et al.,* 2021); their actual role, in relation to the stressors mentioned above, will be discussed later.

When assessing the respective importance of stressors, it is important to consider what the target is: humans? Or marine life? The general public often confuses the two targets (MEINESZ, 2021). Pollution has by definition an impact on the target 'humans'; by contrast, the impact of contamination on the target 'marine life' is very diverse, and in some cases it may be slight. Regarding the target 'marine life', it is important to distinguish the scale of the individual from that of the population and that of the ecosystem: stress on the individual may not have an impact on the population and even less on the ecosystem. Many authors confuse an impact on the individual (which is stressed), a very real and documented impact, with an impact on biodiversity or the ecosystem, an impact generally not demonstrated (see e.g. LIONETTO *et al.*, 2021). The paradigm example is that of *Homo sapiens*: millennia of wars, pandemics and pollution have stressed or killed hundreds of millions of people, but have not even slowed the proliferation of *Homo sapiens*.

4.2. Threats to species diversity

Only one species is definitely extinct, the great auk *Pinguinus impennis*; it was present in the Mediterranean and northern Atlantic, was depicted by man in the Cosquer Cave, near Marseilles, 18 000–19 000 years ago, and became extinct in 1844 (CLOTTES and COURTIN, 1994; PLANHOL, 2004; BRUGAL, 2021). Several species have never been recorded for more than 70 years, up to 150 years, e.g. the brown algae *Compsonema minutum* and *Ectocarpus siliculosus* var. *subulatus* (CFB, AB and TT, unpublished data); as these are species that are difficult to distinguish, of uncertain status, their extinction is just a hypothesis. Some species are considered as extinct in the Mediterranean, but still occur in other areas, e.g. the Atlantic Ocean. This is the case of the hydroid *Tricyclusa singularis* (BOERO and BONSDORFF, 2007), the whales *Eubalaena glacialis* and *Eschrichtius robustus* (RODRIGUES *et al.*, 2018) and the harbour porpoise *Phocaena phocaena* (BEAUBRUN, 1995; FONTAINE, 2016). In contrast with the relatively low number of extinct or possibly extinct taxa, a much higher number of species are functionally or regionally extinct. The monk seal *Monachus monachus* is extinct in the western Mediterranean Basin (MARCHESSAUX, 1989; BOUDOURESQUE, 2003; VOULTSIADOU *et al.*, 2012). Regional and functional extinctions are common in brown algae of the order Fucales (Table 2) (THIBAUT *et al.*, 2005; BLANFUNÉ *et al.*, 2013, 2016a; THIBAUT *et al.*, 2016, 2017; BLANFUNÉ *et al.*, 2019).

For the general public, environmentalists, managers and journalists, biodiversity often means 'How many species?', which is incorrect, and the erosion of biodiversity means 'How many extinct species?' Environmental NGOs often publish ambiguous or exaggerated press releases which the press in turn exaggerates. It must be said that some of the general public and politicians are only sensitive to the cataclysmic news, whereas true and therefore more complex information goes unnoticed, even when it may actually be more of a concern in the long run than more dramatic news. Information such as '*Over 40 years, 50% of species have seriously declined*' becomes '*In 40 years, 50% of species have become extinct*'. The following anecdote illustrates this (BOUDOURESQUE, 2021). Recently, following such a press release of this kind, a French television journalist called the first author (CFB): '*I am putting together a program on the erosion of biodiversity in the Mediterranean; I am missing some important information: what is the percentage of recently extinct species? 20%? 30%? 40%?* ' The author tried to explain to her that very few species had disappeared in the Mediterranean and that, on the contrary, human impact had considerably increased the number of species. He did not have time to explain to her that biodiversity is not, for the most part, 'How many species?', and that the erosion of biodiversity is as much 'more species' than 'less species'; she told him '*I was misled in thinking you were an ecologist*' and hung up on me with barely a

Table 2 Current status of species of Fucales (Phaeophyceae, Stramenopiles) in French Mediterranean regions. RE: regionally extinct. FE: functionally extinct. -: naturally absent. +: unchanged status or no dramatic decline. md: missing data. Data from Thibaut *et al.* (2005), Blanfuné *et al.* (2013), Thibaut *et al.* (2014, 2015), Blanfuné *et al.* (2016a), Thibaut *et al.* (2016) and Blanfuné *et al.* (2019).

Accepted name	Synonym	French Catalonia	Western Provence	Eastern Provence	French Riviera and Monaco	Corsica
Carpodesmia caespitosa	*Cystoseira caespitosa*	FE	md	md	-	md
Cystoseira compressa		+	md	md	+	md
Cystoseira foeniculacea		RE	md	md	FE	md
Cystoseira jabukae		-	-	-	+	+
Ericaria amentacea	*Cystoseira amentacea*	-	+	+	+	+
Ericaria brachycarpa	*Cystoseira brachycarpa*	-	md	md	FE	md
Ericaria crinita	*Cystoseira crinita*	RE	FE	+	FE	+
Ericaria funkii	*Cystoseira funkii*	RE	md	md	-	md
Ericaria mediterranea	*Cystoseira mediterranea*	+	-	-	-	-
Ericaria zosteroides	*Cystoseira zosteroides*	FE	md	md	+	md
Gongolaria barbata	*Cystoseira barbata*	RE	md	md	FE	md
Gongolaria elegans	*Cystoseira elegans*	FE	md	md	RE	md
Gongolaria montagnei	*Cystoseira spinosa*	RE	md	md	FE	md
Gongolaria sauvageauana	*Cystoseira sauvageauana*	RE	md	md	FE	md
Gongolaria squarrosa	*Cystoseira squarrosa*	-	md	md	RE	md
Sargassum acinarium		RE	RE	FE	FE	+
Sargassum hornschuchii		RE	RE	FE	RE	RE
Sargassum vulgare		RE	FE	+	FE	+

goodbye - and chose 30%! Similar anecdotes were reported by Pavé (2019) and Cheinet (2020). Unfortunately, some scientists play a role in the propagation of cataclysmic forecasts, which subsequently prove to be erroneous. Ehrlich and Ehrlich (1981) wrote, in an influential book, that 50% of the species present in 1980 would have become extinct by 2000, which obviously did not happen.

4.3. Threats to ecosystems

Regarding threats to ecosystems, we focus here on five iconic ecosystems in the Mediterranean: the dune-beach-*banquette* ecosystem (DBB), the *Lithophyllum byssoides* algal rim, the seagrass *Posidonia oceanica* meadow, the reef fucalean forest and the coralligenous ecosystem. Deep ecosystems also merit consideration (Fanelli *et al.,* 2021).

(i) The DBB ecosystem (Fig. 2) is mainly threatened by the decline of *P. oceanica* meadows in front of the beaches, which protect beaches from erosion by waves and swell, and by the destruction of the dunes (urbanization, roads, trampling), which prevents the back and forth movements of the sand essential for the equilibrium of the beach. It is also threatened by the removal of the *banquette* of cast ashore dead leaves of *P. oceanica* by ill-informed local authorities, which results in further beach erosion (Cancemi and Buron, 2008; Simeone, 2008; Boudouresque *et al.,* 2012; Simeone and De Falco, 2013; Boudouresque *et al.,* 2017b; Roig-Munar *et al.,* 2019).

(ii) The *Lithophyllum byssoides* algal rim (Fig. 3) is a slow growing bioconstruction; its formation corresponds to cold climate episodes, when the polar ice sheets stop melting and Alpine glaciers advance, more or less stabilizing the sea level (Faivre *et al.,* 2013). By the end of the LIA (Little Ice Age; mid-19th century), the sea level had resumed its rise. This rise was at first slow (0.4 mm y^{-1}), but, due to the human-induced amplification of climate warming, resulting in the melting of polar ice sheets and of mountain glaciers together with the thermal expansion of the seawater, the sea-level rise steadily accelerated. It is now too fast, so that *L. byssoides* rims have begun to be submerged throughout the Mediterranean. The ecosystem engineer species *L. byssoides* then dies and is covered by infralittoral species such as soft red algae and articulated corallines (e.g. *Corallina caespitosa*). Subsequently, the dead, 'subfossil' algal rim is bioeroded by endolithic photosynthetic and heterotrophic borers, and by grazers. (Fig. 8) (Thibaut *et al.,* 2013; Blanfuné *et al.,* 2016b; Boudouresque *et al.,* 2021a ; Faivre *et al.,* 2021).

(iii) The seagrass *P. oceanica* meadow is mainly threatened by coastal development (ports, marinas, land reclaimed from the sea; Fig. 7), pollution (water quality, including from fish farms), trawling and anchoring of large yachts and cruise ships (Sanchez-Lizaso *et al.,* 1990; Boudouresque *et al.,* 2009, 2012; Alami *et al.,* 2014; Giakoumi *et al.,* 2015; Abadie *et al.,* 2016; Deter *et al.,* 2017; Boudouresque *et al.,* 2020; Blanco-Murillo *et al.,* 2022). Noise is an unexpected further cause of *P. oceanica* meadow alteration (Solé *et al.,* 2021). At least along the northern EU coasts of the Mediterranean, the importance of pollution as a cause of *P. oceanica* decline is diminishing (Jackson *et al.,* 2006). In some Mediterranean areas (e.g. Italian Liguria, French Riviera, Sardinia, Marseilles and Barcelona areas), the decline of *P. oceanica* has been conspicuous (Montefalcone *et al.,* 2007; Boudouresque *et al.,* 2009; Burgos *et al.,* 2017; Di Muro *et al.,* 2018); however, this is not the case for most of the Mediterranean, e.g. Provence (Leriche *et al.,* 2006), Corsica (Pasqualini, 1997; Bonacorsi *et al.,* 2013) and Sicily; the decline may therefore have been

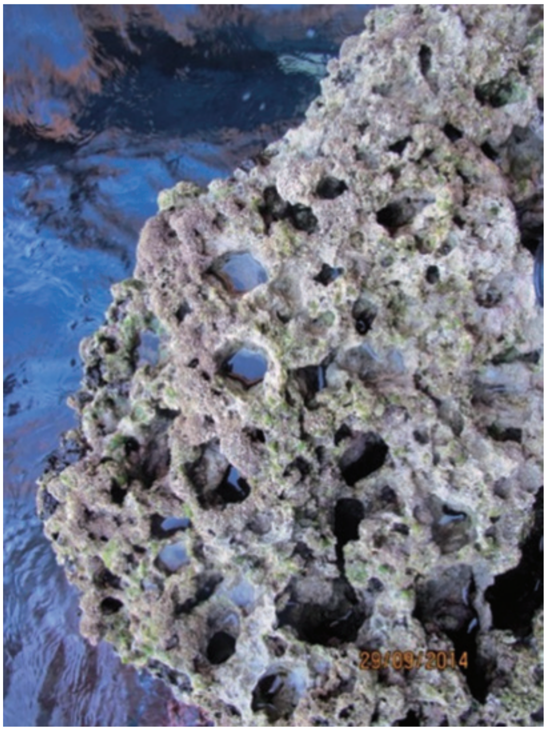

Fig. 8 A dead, highly eroded, *Lithophyllum byssoides* rim, in 2014, at Punta Palazzu, Scàndula Nature Reserve, Corsica. Photo © Thierry Thibaut.

Fig. 9 A barren ground with the sea urchin *Paracentrotus lividus*, in an area formerly occupied by a fucalean forest and ravaged by overfishing. Montenegro, 5–6 m depth. Photo © Thierry Thibaut.

overestimated (BOUDOURESQUE *et al.,* 2009; PERGENT-MARTINI *et al.,* 2013; BOUDOURESQUE *et al.,* 2021b). The estimates indicating that between 13% and 50% of the overall area of *P. oceanica* was lost during the last 50 years (MARBÀ *et al.,* 2014), and that the loss was about 6.9% per year, although possible at a very local scale, are totally unrealistic at Mediterranean-wide scale; less than 10%, maybe 5%, over the last 50 years, is probably a more realistic estimate (BOUDOURESQUE *et al.,* 2009, 2021b); a decline of 10% in total seagrass area by 1900 has been suggested (DUNIC *et al.,* 2021). In addition, the natural recolonization of *P. oceanica*, when stressors have ceased to work, has been observed in many areas (BOUDOURESQUE *et al.,* 2021b; BLANCO-MURILLO *et al.,* 2022); on the scale of the Mediterranean, the seagrass recolonization is conspicuous, the seagrass area returning to the supposed values of the 1920s (DUNIC *et al.,* 2021). As far as future sea water warming is concerned, it should cause a withdrawal, at the limit of the range area, in the warmest regions of the Levantine Basin, e.g. in Turkey, and an advance in the currently too cold regions of the northern Mediterranean. In the regions between the two, the effects are complex, e.g. an increase in the density of the shoots and a decrease in the width of the leaves (PANSINI *et al.,* 2021). In addition, the increase in temperature causes a decline in the primary production (PI) and rise of the deep lower limit, where PI is a limiting factor; the rise of the lower limit has been actually observed in Turkey (MAYOT *et al.,* 2005; MEINESZ, 2021).

(iv) The reef fucalean forest is mainly threatened by the overgrazing of the sea urchins *Paracentrotus lividus* and *Arbacia lixula*; their proliferation results for the most from the overfishing of their fish predators; the forest is then replaced by a barren ground, which constitutes an alternative stable state in a regime shift context (Fig. 9) (SALA and ZABALA, 1996; BONAVIRI *et al.,* 2011; COMA *et al.,* 2011; FRASCHETTI *et al.,* 2011; AGNETTA *et al.,* 2015; LING *et al.,* 2015; BLANFUNÉ *et al.,* 2016a, 2016c; BOUDOURESQUE and VERLAQUE, 2020; BEVILACQUA *et al.,* 2021). In the eastern Mediterranean, the invasive rabbit fish *Siganus luridus* and *S. rivulatus* are responsible for the extirpation of the fucalean forests (SALA *et al.,* 2011). The destruction of habitats due to coastal development has also played a role (FRASCHETTI *et al.,* 2011; THIBAUT *et al.,* 2015; ORFANIDIS *et al.,* 2021). Warming was suggested by ORLANDO-BONACA *et al.* (2021) in the northern Adriatic and by FALACE *et al.* (2021) in Sicily (Italy). Pollution, put forward in the 1970s-1980s, could have been overestimated as a cause of decline (BOUDOURESQUE, 2003; MANGIALAJO *et al.,* 2008; THIBAUT *et al.,* 2014). Natural recovery has been recorded in the northern Adriatic Sea (IVEŠA and DEVESCOVI, 2014).

(v) The coralligenous ecosystem is threatened by heat waves, which cause mass mortality of gorgonians, precious red coral, sponges and

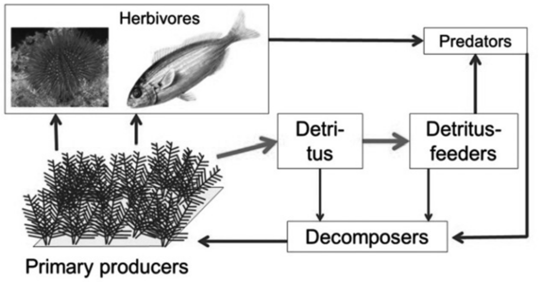

Fig. 10 A simplified sketch of food-webs in undisturbed Mediterranean marine benthic ecosystems. Here, a reef fucalean forest. Herbivores are the sea urchin *Paracentrotus lividus* and the teleost *Sarpa salpa*. The intensity of the flow is proportional to the width of the arrow between functional compartments (widest arrow: the main path). From BOUDOURESQUE *et al.* (2017a).

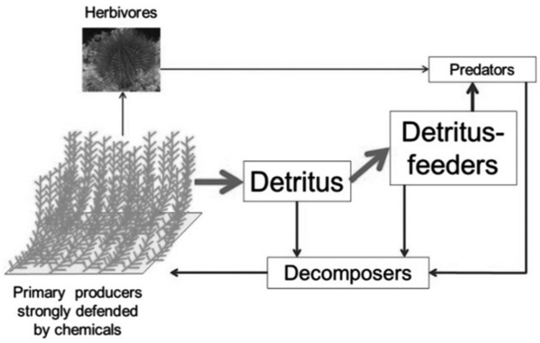

Fig. 11 A simplified sketch of a food-web in a Mediterranean benthic ecosystem, in the presence of non-palatable primary producers, here *Caulerpa taxifolia*. The possible increase in the DOC (Dissolved Organic Carbon) release towards the pelagic ecosystem is not considered here. The herbivore is *Paracentrotus lividus*. The intensity of the flow is proportional to the width of the arrow between functional compartments (widest arrow: the main path). From BOUDOURESQUE *et al.* (2017a).

other metazoans (CERRANO *et al*., 2000; PEREZ *et al.,* 2000; LINARES *et al.,* 2008a; BOUDOURESQUE *et al.,* 2017c; VERDURA *et al.,* 2019; CHIMIENTI *et al.,* 2021; GARRABOU *et al.,* 2021). There are synergistic effects between invasive species (e.g. the red alga *Womersleyella setacea*) and the warming, resulting in the drastic decline of crustose coralline algae (CEBRIAN *et al.,* 2021). The coralligenous is also threatened by over-frequentation by divers (LINARES *et al.,* 2008b; CASOLI *et al.,* 2017) and by fishing gear which uproot gorgonians, erect sponges and the Fucales *Sargassum* spp. and *Ericaria zosteroides* (THIBAUT *et al.,* 2016; GENNARO *et al.,* 2020; AZZOLA *et al.,* 2021; FERRIGNO *et al.,* 2021).

In addition to the five above-mentioned ecosystems, it is worth emphasizing the severe threats to ecosystems such as the vermetid platforms (GORDÓ-VILASECA *et al.,* 2021).

Undisturbed Mediterranean benthic ecosystems are characterized by a low level of herbivory; as a result, the food web is usually driven by the detritus-feeders rather than by the herbivores. Most macrophytes have not developed chemical defences against herbivores (Fig. 10).

(i) In the north-western Mediterranean, the dramatic arrival of strongly defended and poorly palatable invasive species, such as *Caulerpa taxifolia* (Chlorobionta), *Asparagopsis armata, Lophocladia lallemandii* and *Womersleyella setacea* (Rhodobionta; kingdom Archaeplastida), has profoundly changed the functioning of the ecosystems, with a further reduction of the flow running through the herbivores being expected (Fig. 11; BOUDOURESQUE *et al.,* 1996, 2005a; RUITTON *et al.,* 2006; DEUDERO *et al.,* 2011; TOMAS *et al.,* 2011a, 2011b; BOUDOURESQUE *et al.,* 2017a).

(ii) In contrast, in the eastern Mediterranean, the arrival of voracious herbivorous teleosts (*Siganus luridus* and *S. rivulatus*) from the Red Sea, *via* the Suez Canal, has strongly intensified the herbivore pressure (Fig. 12) (GOLANI, 2002; GOLANI *et al.,* 2002; BOUDOURESQUE *et al.,* 2005a;

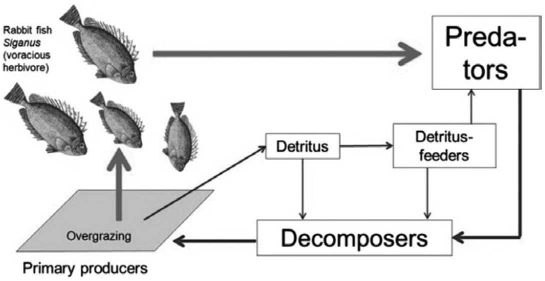

Fig. 12 A simplified sketch of a food-web in a Mediterranean benthic ecosystem, in the presence of herbivorous fish of the genus *Siganus* (eastern Mediterranean), here, a barren-ground. The intensity of the flow is proportional to the width of the arrow between functional compartments. widest arrow: the main path. From BOUDOURESQUE *et al.* (2017a).

AZZURO *et al.,* 2007; SHAKMAN *et al.,* 2009; BOUDOURESQUE, 2017a; CORALLES *et al.,* 2017; GALIL, 2017; DRAMAN, 2018). The arrival in the Levantine Basin of the voracious sea urchin, *Diadema setosum*, has further enhanced the herbivore compartment (YOKES and GALIL, 2006; KATSANEVAKIS *et al.,* 2014). The turnover of primary production is then faster than through the detritus-feeders, which has resulted in an increase in the secondary production of large carnivorous teleosts (GALIL, 2007). This has resulted in an impressive regime shift, from ecosystems dominated by canopy-forming primary producers and under bottom-up control, such as Fucales, to an Alternative Stable State (ASS) dominated by encrusting calcified corallines (red algae) and sometimes also characterized by sea urchin overgrazing (barren ground), with top-down control (SALA *et al.,* 2011, 2012).

(**iii**) Finally, in coastal lagoons harbouring shellfish farm facilities, on natural and artificial hard substrates, the dominance (species richness, cover, biomass) of macrophytes introduced from the cold-temperate northern Pacific Ocean is overwhelming. In Thau Lagoon (Southern France), they represent 32% of the gamma species diversity, 97–99% and 48–95% of the spring and autumn biomass, respectively, and 100% of the cover (Fig. 13) (BOUDOURESQUE *et al.,* 2011). Similar observations have been reported in other Mediterranean lagoons, e.g. the Venice Lagoon (northern Adriatic Sea, Italy) (OCCHIPINTI-AMBROGI, 2000; SFRISO, A. and D. CURIEL, 2007; MARCHINI *et al.,* 2015) and Tunisian lagoons (OUNIFI BEN AMOR *et al.,* 2019).

5. Changing scapegoats

The general public, journalists, who often have literary rather than a scientific culture, and policy makers, need scapegoats, clearly identified enemies, and simplifications. These 'enemies' have evolved over time, and it is often the over-simplifying media that has shaped them. Even today, whether in a working-class district in the north of Marseilles, such as Estaque, or in a district inhabited by well-educated people, in London, a street survey, on the main threats to marine biodiversity collects the same answers, the order of which may vary: pollution, oil spills and climate change.

In the years 1950s-1960s, the world became aware of the serious consequences of the hundreds of atmospheric nuclear weapon tests carried out by the USA and the Soviets; a huge cloud of radioactive particles circled the northern hemisphere, with massive fallout on land and sea (SANCHEZ-CABEZA *et al.,* 2002; AOYAMA *et al.,* 2006). It was the Moscow Partial Nuclear Test Ban Treaty in 1963 that put an end to these atmospheric tests. It has taken several decades for the radioactive cloud to disappear, with radioactive fallout ending up in the soil and at sea (CALMET *et al.,* 1988). This radioactivity has had serious consequences for human health, although

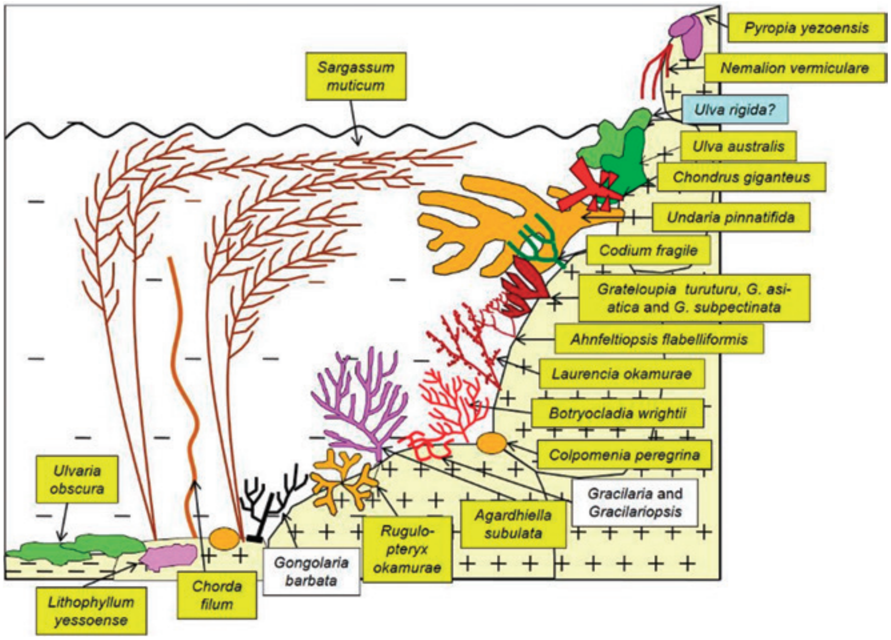

Fig. 13 A sketch of the dominant macrophytes on shallow (down to 1 m depth) rocky substrates of Thau Lagoon (Occitania, France) in spring. Most of these taxa (yellow boxes) are native to the northwestern Pacific Ocean. Blue box: a cryptogenic species, i.e. a species possibly introduced, but the native area of which is unknown. From BOUDOURESQUE *et al.* (2011), adapted.

little was known at the time. In the 1960s, any exceptional climatic event was attributed to nuclear tests: floods, storms, drought, etc.

In the 1970s-1980s, the general public became aware of the dangers of pollution. In those days, rivers (Rhone, Po, Ebro, etc.) had become open sewers; the large coastal cities (Marseilles, Barcelona, Naples, etc.) discharged their sewage into the sea without treatment. In Marseilles, it was in Cortiou, in the heart of what is now the Calanques National Park, that a colossal sewer dumped sewage. Pollution, in particular contamination by metals such as mercury and cadmium, has had serious consequences for human health. Organic pollution has also been responsible for profound changes in ecosystems; at Cortiou, in Marseilles, the halos of completely destroyed, deeply modified, modified and sub-normal benthic stands around the outfall have been accurately described (BELLAN-SANTINI, 1966; COGNETTI and COGNETTI, 1992; BELLAN *et al.*, 1999). At that time, pollution was considered the main cause of all environmental issues, e.g. the decline of edible sea urchins (while pollution actually favors them - BOUDOURESQUE and VERLAQUE, 2020), the decline of *Posidonia oceanica* meadows (while pollution is far from being the main cause - BOUDOURESQUE *et al.*, 2009, 2012), the decline of the Fucale *Ericaria amentacea* (while actually it did not significantly decline - THIBAUT *et al.*, 2014), and the collapse of fish stocks (while overfishing is the main cause, in the Mediterranean as everywhere in the world - PAULY, 1988; GRÉMILLET, 2019).

Today, it is global warming that has become the 'one-size-fits-all' explanation for everything that is happening. It is indisputable that global warming, induced and accentuated by anthropogenic emissions of greenhouse gases, constitutes a severe threat to terrestrial and marine biodiversity; this threat is direct (increase in temperature, acidification of the ocean) but also indirect (rise in sea level) (NEUKOM *et al.*, 2019). Heat waves have been responsible for spectacular mass mortality of a variety of marine taxa, e.g. gorgonians, and the frequency and severity of mortality events are steadily increasing. In addition, species of warm affinities, formerly confined to, or more abundant in the warm waters of the south and east of the Mediterranean, such as the sea urchin *Arbacia lixula*, the teleost *Sparisoma cretense*, the sea turtle *Caretta caretta* and the seagrass *Cymodocea nodosa*, increase in abundance and/or extend their range northwards and westwards, resulting in the 'meridionalization' of the sea (FRANCOUR *et al.*, 1994; BIANCHI and MORRI, 2004; LEJEUSNE *et al.*, 2010; BIANCHI *et al.*, 2013; ASTRUCH *et al.*, 2016; BIANCHI *et al.*, 2018; ENCARNAÇÃO *et al.*, 2019; SBRAGAGLIA *et al.*, 2020; TUNCER *et al.*, 2020; ESPOSITO *et al.*, 2021; GIRARD *et al.*, 2021 ; MARX *et al.*, 2021; MEINESZ, 2021). Acidification potentially threatens calcified species, which represent a sixth of the Mediterranean species ε diversity (MEINESZ, 2021), although its current and/or future impact seems complex, taxon-specific and controversial (BAGGINI *et al.*, 2014; FOO *et al.*, 2018; HALL-SPENCER *et al.*, 2018; KUMAR *et al.*, 2018; TEIXIDÓ *et al.*, 2018; MECCA *et al.*, 2020). But global warming cannot explain everything, from storms to collapsing marine resources and pelagic zooplankton functional diversity (see BENEDETTI *et al.*, 2018), and can be a scapegoat for other currently more severe human-related impacts.

Unexpectedly for the general public, at the start of the 21st century, by far the main impact on species diversity is the overexploitation of resources, in particular overfishing (PARSONS *et al.*, 1984; PAULY *et al.*, 2002; GRÉMILLET, 2019). Biological invasions (including host shift of parasites and pathogens) and coastal development, with irreversible destruction of coastal habitats, are also major drivers of change. Pollution comes almost second to last and warming last (Fig. 14) (MAXWELL *et al.*, 2016). In France (Occitania, Provence, French Riviera and Corsica), the total (100%) and irreversible destruction of coastal habitats concerns 5,300 ha, while the area provisionally and reversibly altered by more than 50% by pollution from wastewater treatment plants does not exceed 100 ha (MEINESZ, 2021). **(i)** If the Fucale *Sargassum vulgare* is regionally extinct in French Catalonia and functionally extinct in Western Provence and the French Riviera (Table 2; Thibaut *et al.*, 2005, 2015, 2016), this is obviously not due to warming, since it is a species of warm affinities, which would be expected to be in expansion, but to other reasons, such as overfishing and the resulting overgrazing. **(ii)** If the abundance of the invasive green alga *Caulerpa cylindracea* fluctuates strongly from one year to another, it is due to interannual variations in precipitation, wind speed and temperature; but, unexpectedly for some, the peaks of abundance do not correspond to the highest temperatures, but to the lowest temperatures (RAVAGLIOLI *et al.*, 2022). **(iii)** If the vermetid reefs in Israel (Levantine Basin) cannot resist the sea level rise, it is not due to the warming, the main ecosystem engineer *Dendropoma anguliferum* being a species of warm affinities, but to its local functional extinction and the tremendous grazing of invasive *Siganus* teleosts (RILOV *et al.*, 2021). **(iv)** If the dusky grouper *Epinephelus marginatus* is back in the

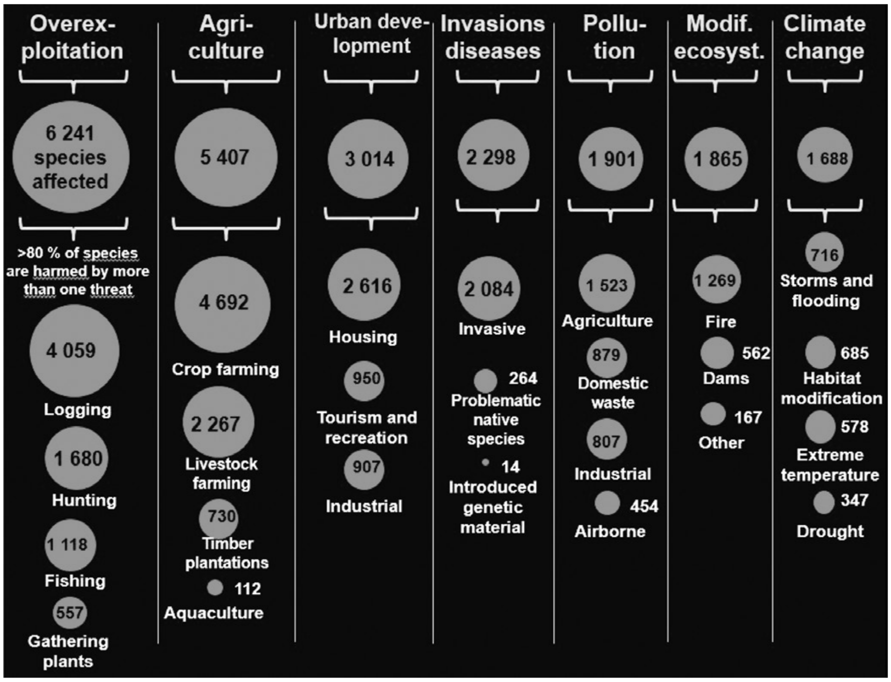

Fig. 14 Threats to species, according to the IUCN red list of threatened species. The values in the circles, or beside the circles, indicate the number of species affected by a stressor. From MAXWELL *et al.* (2016), adapted and redrawn (Charles-François Boudouresque).

northwestern Mediterranean, with even reproductive aggregations, it is less because of the sea warming, as naively claimed by DURAND (2018) and in an interested way by spearfishers, than thanks to the establishment of efficient MPAs; interestingly, the dusky grouper was very common in Provence during the cold episode of the 1950s (BOUDOURESQUE *et al.,* 2005b; HARMELIN-VIVIEN *et al.,* 2007; HARMELIN *et al.,* 2010; RUITTON *et al.,* 2019b). (v) If the number of introduced species is on the increase in the Mediterranean, this not solely due to the warming, which 'pushes' the Red Sea species range area, once introduced, westwards and northwards, but also and mainly to the vectors of introduction, first the Suez Canal and its enlargement, and second the farming of molluscans from the northeastern Pacific (Japan and Korea); unexpectedly, by the 1980s, the percentage of newly introduced species from cold native areas has increased, at the expense of species native to tropical areas (BOUDOURESQUE *et al.,* 2010) (Table 3). At Kos Island (Greece, eastern Mediterranean), BIANCHI *et al.* (2014) compared benthic data collected in 1981 and in 2013, by the same persons and using the same method. During this 30+ year period, increases in Sea Surface Temperature (SST, +1–2℃), human pressure (resorts and hotels, 15 to 163 beds km^{-2}), and NISs (e.g. rabbitfish *Siganus rivulatus* and *S. luridus*) were observed. Huge changes occurred in rocky reef habitats; the once flourishing fucalean forests (*Cystoseira* spp., *Ericaria crinita, Sargassum vulgare*) had disappeared in

Table 3 Biogeographical affinities, in their native area, of the seaweed introduced to the Mediterranean. Tropical: annual SST minimum > 20℃. Temperate: annual SST minimum between 10℃ and 20℃. Cold: annual SST minimum < 10℃. See Lüning (1990) for definitions and SST maps. From Boudouresque and Verlaque (2010).

Period	Number of introduced species	Native area of introduced species		
		Cold areas (North and South)	Temperate areas (North and South)	Tropical areas
1800–1940	21	4.3 (20%)	7.7 (37%)	9.0 (43%)
1941–1980	39	7.7 (20%)	14.0 (36%)	17.3 (44%)
1981–2008	48	16.2 (35%)	17.9 (39%)	11.9 (26%)

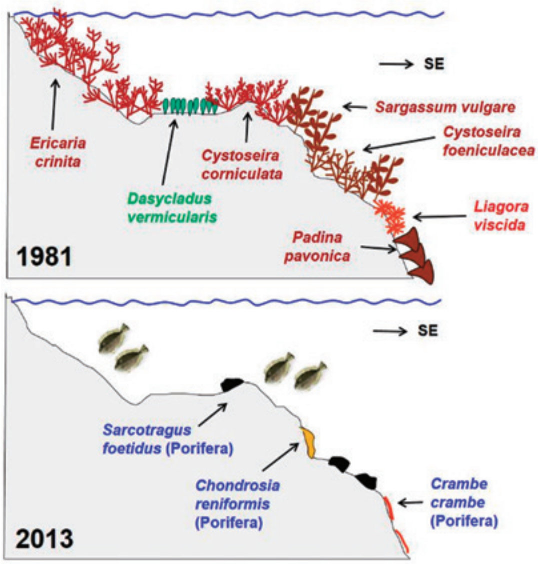

Fig. 15 Schematic profile of a reef slope down to about 7 m depth at Kos Island (Greece), illustrating the impressive change between 1981 (top) and 2013 (bottom). Names of brown algae (Phaeophyceae) are in brown, green algae (Chlorobionta) in green, red algae (Rhodobionta) in red and sponges (Porifera, Metazoa) in blue. The invasive fish is *Siganus luridus*. From Bianchi *et al.* (2014), redrawn by Charles-François Boudouresque.

favour of sponges and wide bare substratum areas (Fig. 15). These changes can be seen as a synergistic action between biological invasions, SST warming and human impact. More realistically, they show the crushing, by NISs (especially overgrazing rabbitfish), of the other stressors, including warming.

A general poleward range expansion of species of warm affinities is expected and has actually been recorded. The corresponding shrinkage in the Mediterranean range of some cold affinity species has been recorded, e.g. the mysid crustacean *Hemimysis speluncola*, which is being replaced by *H. margalefi* (Chevaldonné and Lejeusne, 2003). However, this is not yet observed for most species, e.g. the seagrass *Zostera marina* and the teleost *Sprattus sprattus* (Boudouresque *et al.*, 2009; Pergent *et al.*, 2012; Saraux *et al.*, 2019).

6. Discussion and conclusion

The concern about the growing and irreversible effects of global warming is totally justified (Hoegh-Guldberg *et al.*, 2019); as also the effects of pollution, although in decline. But the underestimation of other threats is based on reasons which may be political or related to human perceptions, in some cases to science funding, and which are discussed hereafter. The general public and policymakers are above all sensitive to what can be seen (e.g. television reports). The (exaggerated?) importance accorded to oil spills is an illustration of this (BOUDOURESQUE *et al.*, 2019a; MEINESZ, 2021). There is a *doxa* (consensual discourse) from which it is difficult to deviate (HUET, 2018a, 2018b).

Let us consider the blatant exaggerations first. WAYCOTT *et al.* (2009) stressed the worldwide acceleration of seagrass decline from 1% per year before 1940, 1–7% per year between 1940 and 1990 to 7% per year since 1990. Although the authors clearly warned that these estimates were based on data available at the time, from a limited number of regions of the world ocean, and reported the geographical and historical bias in their dataset, some later authors cited this article without reference to these caveats. This article, which is the most widely cited in the seagrass world literature, as simplified by further authors, typically announces the apocalypse. In the Mediterranean, MARBÀ *et al.* (2014) claimed that between 13% and 50% of the *Posidonia oceanica* seagrass extent appears to be lost, and that 6.9% of the potential *P. oceanica* vegetation has been lost annually over the last 50 years. Yet, a very simple mathematical model which any student could perform indicates that, if these estimates and predictions were correct, there would be hardly any seagrass meadows left in the world today, and no *P. oceanica* meadow left in the Mediterranean, which is clearly not the case (BOUDOURESQUE *et al.,* 2009, 2012; CALVO *et al.,* 2020; BOUDOURESQUE *et al.,* 2021b). The physicist John Holdren wrote in 1978 that it is conceivable that before 2020, a CO_2/climate-induced famine could kill as many as a billion people (*in* EHRLICH and EHRLICH, 1981); this apparently has not happened.

The positive side of these exaggerations must also be taken into account. They may have helped alert the general public and decision-makers to the risks. We can also consider that, if the forecasts did not come true, it is precisely thanks to these alerts. Moreover, it is easy, long afterwards, to mock erroneous forecasts: this is a risk intrinsic to any forecast, and our conclusions in the present paper will not avoid this risk.

As BOERO (2015) and DUARTE *et al.* (2015) suggested, it is easier to publish in high IF (Impact Factor) journals if you announce the apocalypse than if you describe moderate changes. Deviation from the current mainstream is poorly accepted by journals: you can publish anything if you write that seagrasses are in steep decline and that global warming or acidification are involved; you need a rock solid argument to go against the grain. One of the authors of this article (CFB) has experienced this difficulty twice, when he showed, on the basis of accurate data, that (**i**) the regression of seagrasses (all species combined) in the Mediterranean was much more moderate than announced (BOUDOURESQUE *et al.,* 2009), and that (**ii**) in a bay of mainland France (Saint-Cyr, Provence), despite urbanization, pollution, the construction of harbours, etc., the regression of *Posidonia oceanica* had been much less significant than expected (LERICHE *et al.,* 2006). One of the reviewers wrote: '*Even if your data is reliable, you can't write this! It would be too good news for the developers who are building all along the coast*'.

Secondly, for the marine environment, there are no pressure groups comparable to amateur ornithologists, or to natural history societies (botanists, entomologists, bat specialists, etc.), capable of bringing the problems before public opinion and before the authorities. Seabirds, sea turtles and marine mammals are the exception that proves the rule: the pressure groups that support them constitute the extension of a terrestrial 'culture'. The authorities are first and foremost sensitive to what we are talking about (in the media in particular). The (sometimes exaggerated) importance given to the protection of certain marine mammals is an illustration of this. Even respectable NGOs such as WWF and IUCN, dominated by ornithologists and mammalogists and (it must be noted), sometimes promoting a simplistic vision of biodiversity (e.g. how many marine mammals, on the increase or on the decline?), have more or less completely forgotten the marine environment and its real biodiversity, which is far from being limited to seabirds, sea turtles and marine mammals. It is quite astonishing that some marine species, 1,000 to 10,000 times rarer than terrestrial protected species, which have disappeared from a number of regions and are on the brink of extinction elsewhere, like a marine equivalent of the giant panda, do not benefit from any legal protection status in most of the 21 Mediterranean countries. The cases of the brown algae (Fucales, Stramenopiles) *Sargassum acinarium* and *S. hornschuchii* exemplify this situation, almost to the point of caricature; this is what Thibaut *et al.* (2016) referred to as 'the *Sargassum conundrum*'. Despite the bulk of scientific data concerning some marine species, on the brink of extinction, but unfortunately not relating to sea birds, sea turtles and sea mammals, the IUCN Red List places them in the 'trash category' of 'Data Deficient (DD)' (Boudouresque, 2002; Boudouresque and Bianchi, 2013; Verlaque *et al.*, 2019). The media generally play a negative role, as shown by Compas *et al.* (2007) on an MPA project in Australia; they give priority to the opponents, who, even when they do not dispute the project, criticize the 'lack of consultation' (even if it has lasted for years) and the location of the NTZ (No Take Zone within the MPA).

Thirdly, public sensitivity is selective. Some species are lovable in themselves, at least nowadays: dolphins, seals, grouper. Others are much less so: sharks, annelids, etc. (Laurec, 1997; Faget, 2020; Alessandri, 2021). The breathtaking beauty of the orange stony coral *Astroides calycularis* can explain why it is listed in the annexes of the Bern and Barcelona conventions, while actually far from being threatened (Ledoux *et al.*, 2021). This sensitivity also varies from one region to another: seals attract more sympathy in the countries of southern Europe, where they are rare or absent, than in the North, where they are sometimes considered as invasive (Laurec, 1997). The public can be self-interested, even hypocritical: they sometimes designate as 'ecology' and 'biodiversity' the simple defence of a privilege of enjoyment and/or the search for the payment of damages; this syndrome is called NIMBY (Not In My Backyard) (Gobert, 2015; Meinesz, 2021). Research effort is also selective: vertebrates, which barely represent 3% of species, are the subject of 69% of publications devoted to conservation (Clark and May, 2002). Some 46% of the EU 'Life' funded projects dealt with bird species, versus 8% concerning invertebrates, at least functionally as important as birds and more than 100 times more numerous, and less than 0.01% macroalgae (Mammides, 2019). On a larger scientific scale, in the era of biodiversity launched by the Rio summit in 1992, many scientists consider that the concept of biodiversity has been 'stolen', diverted from its true meaning, by some sort of 'merchants', who openly pursue commercial objectives or belong to disciplines other than ecology. Contrary to what the general public believes, the bulk of funding goes to researchers who do not have extensive knowledge (or none at all) of biology and ecology, but who put forward techniques or concepts, for example modelling, which are appealing to decision-makers (Boero, 2010, 2015). As stressed by Boero (2016), '*the risk of reductionism is to produce a lot of knowledge* *about nothing, and that of holism is to produce a little knowledge about everything*'. A balance between taxonomy and disciplines such as modelling and genetics, both essential, is necessary (GUIDETTI *et al.,* 2014).

Fourthly, for many policymakers, the destruction of the seabed due to coastal urbanization is too simple a cause. A basic calculation makes it possible to determine the lost surface area. We know the depth of the corresponding habitats, and the ecosystems that occupied them, or most likely occupied them. Policymakers often prefer complexity (sometimes simply flamboyant), perhaps because complexity allows for wait-and-see, or a 'headlong rush' into scientific research (MEINESZ, 2021).

Fifth, a perverse effect of a 'total-warming' approach is that we somehow feel helpless in the face of a planetary phenomenon that would require an international response and that irresponsible lunatics in Australia, Brazil, the US and elsewhere continue to deny. What can the individual human actually do? It is then convenient for some managers and policymakers to attribute everything to climate change, and not to causes closer to home, against which it would be possible to intervene, e.g. overfishing, biological invasions and coastal development, but to which one does not wish to draw attention. When they are lucky enough to have a universal scapegoat, some policy makers take advantage of it!

Finally, Marine Protected Areas (MPAs) are a powerful response to biodiversity erosion and to adaptation to warming, in the Mediterranean Sea as everywhere in the world. As stressed by Daniel Pauly (pers. comm.), from the University of British Columbia (Vancouver, Canada), depleted populations of overfished areas cannot evolve in response to warming, in contrast to healthy populations thriving within MPAs. MPAs are therefore the best tool and response to climate warming. Unfortunately, most Mediterranean MPAs are paper parks (fictitious protected areas: lines on an official map without park wardens, management plans, scientific council or even a park director) or mist parks (protected areas intended to fulfill the international commitments of countries; they are often immense, have a real existence - director, premises, officials -, but do not implement any real management measures involving, where necessary, constraints for some of the users) (MEINESZ and BLANFUNÉ, 2015; BOUDOURESQUE *et al.,* 2017b, 2019b, 2021a).

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Species richness of polydorid species (Polychaeta: Spionidae) in the English Channel (France) and on the Pacific Coast of Tohoku District (Japan)

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Abstract: Successive polychaete inventories have reported polydorids in the English Channel and there are some reports describing polydorids from the Pacific coast of Tohoku District, Japan. Species Richness in both areas is compared and discussed. Moreover, in March 2018, French-Japanese collaboration led to the collection of polydorid species from the shells of feral and cultured oysters *Crassostrea gigas* (THUNBERG, 1793) along the western coast of Normandy, France. Some species were also extracted from coralline algae and other calcareous substrates. Eight species were recorded belonging to four genera: *Boccardia, Boccardiella, Dipolydora* and *Polydora*. The two species *Polydora hoplura* Claparède, 1868 and *Dipolydora giardi* (Mesnii, 1893) were previously known in Normandy, along with another member of the genus *Dipolydora* that has not been identified to the species level. *Boccardia proboscidea* Hartman, 1940, *Boccardiella hamata* (Webster, 1879) and *Polydora websteri* Hartman in Loosanoff & Engle, 1943 represent new records in Normandy, while both *Boccardia pseudonatrix* Day, 1961 and *Polydora onagawaensis* Teramoto, Sato-Okoshi, Abe, Nishitani, Endo, 2013 are new species for European waters. We point out that collaboration with polychaete specialists to study well-known seas such as the English Channel would allow us to discover new species, expanding the list of species actually present. This study also highlights the need to continue this partnership further identify which polychaete species infest English Channel oysters.

Keywords : *polydorids, English Channel, new recorded species, Tohoku District*

1. Introduction

The polydorids (Annelida: Spionidae) contain nine genera: i.e. *Amphipolydora* Blake, 1983, *Boccardia* Carazzi, 1893, *Boccardiella* Blake & Kudenov, 1978, *Carazziella* Blake & Kudenov, 1978, *Dipolydora* Verrill, 1881, *Polydora* Bosc,

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1802, *Polydorella* Augener, 1914, *Pseudopolydora* Czerniavsky, 1881 and *Tripolydora* Woodwick, 1964, with each of them having a modified fifth chaetiger. Identification of polydorids remains problematic due to numerous confusions of species and their unknown distribution: i.e. several introduced species occur around the world ocean (SIMON and SATO-OKOSHI, 2015). Moreover, many polydorid species are known as borers in calcareous substrates, and have been reported to inhabit various types of living and non-living calcareous structures including mollusc shells, corals and coralline algae (SATO-OKOSHI, 1999; SATO-OKOSHI *et al*., 2015, 2017; ABE *et al*., 2019). These borers cause severe damage to their calcareous hosts, and polydorid infestation is considered as a serious problem in aquaculture especially for oysters (RUELLET, 2004; SIMON and SATO-OKOSHI, 2015). *Crassostrea gigas* (Thunberg, 1793) was introduced from Japan and, during the 1970s, was cultivated in large quantities along the French coast (KOIKE, 2015). RUELLET (2004) was the first to investigate in detail the polydorid infestation of *C. gigas* in Normandy, showing that cultured oysters were more affected on the eastern coast of the Cotentin peninsula. He identified four species, *Boccardia polybranchia* (Haswell, 1885), *Boccardia semibranchiata* Guérin, 1970, *Polydora ciliata* (Johnston, 1838) and *Polydora hoplura* Claparède, 1868, as well as a species of the genus *Boccardia*, which regularly colonize oysters cultivated in Normandy. DUAULT *et al*. (2001) in their study of the infestation of polydorids on *C. gigas* along the French Atlantic coast in 1999 had accounted until 100 worms per oyster in Normandy where the infestation reaches its maximum in the western part of the Bay of Seine. In addition, the coast of the department of Calvados is partly characterized by a limestone rocky platform strongly infested by polydorids with up to 300,000 individuals per m^2 (RUELLET, 2004). Moreover, north-west residual currents favour the transport of polydorid larvae towards the east coast of the Cotentin, where shellfish farms are located (SALOMON and BRETON, 1981). This continuous water flux and enhanced supply of larvae probably explains the high infestation level observed in oysters on the eastern Cotentin coast from Quineville to Saint-Vaast-La-Hougue. Polydorids create mud blisters that hinder the marketing of oyster products in contaminated areas of the eastern basin of the east Cotentin (RUELLET, 2004; ROYER *et al*., 2006).

ROYER *et al*. (2006) examined the presence of polydorids and other epibionts found on the Pacific oyster *C. gigas* from the Bay of Veys on the western part of the Calvados coast. Although no significant effect of polydorid infestation could be observed to explain the summer mortality of oysters, it has been demonstrated that polydorids have a significant negative effect on host growth. Abundant mud blisters on the inner shell layer are associated with reduced meat and shell weight, thereby causing a potential decrease in oyster productivity. RUELLET (2004) and ROYER *et al*. (2006) carried out a detailed study of the impact of massive infestation by *Polydora* on oyster life traits, but they did not identify the species colonizing the oysters. While the study of the infestation of polydorids in Normandy is of biological and aquacultural importance (DUAULT *et al*., 2001; RUELLET, 2004; ROYER *et al*., 2006), the identification of species and their centres of origin nevertheless remains unclear.

In the 1960s, oyster farming in France was greatly affected by the mass mortality of the Portuguese oyster *Crassostrea angulata* (LAMARCK, 1819), caused by a viral disease and infection from the parasitic protozoans *Marteilia* and *Bonamia* (GRIZEL and HERAL, 1991; OKOSHI and SATO-OKOSHI, 1996). To restore the oyster industry after this catastrophic event, the first mass exportation of spat of the Pacific oyster *C. gigas* occurred from Japan (Sanriku coast on the Pacific shore of Tohoku District, especially from Sendai Bay) to France. This trial took place successfully in 1969 and the project was continued until 1979 (KOGANEZAWA, 1984; KOIKE, 2015). Therefore, to summarize the recent studies on polydorid species infesting oyster shells from the English Channel and Japanese waters it is worthwhile to consider the problem of the introduction of non-native species.

In this review, we summarize the previous studies of polydorids in two sea areas: the Atlantic coast of France, especially the English Channel, and along the Pacific coast of northeastern Japan. In both areas oyster farming is popular and large numbers of oysters have been produced and exported/imported over the past 100 years, which offers perspectives for the development of future joint research between France and Japan.

2. English Channel

2.1 Previous Inventory

The English Channel is a shallow epicontinental sea with a maximum depth of 174 m bordering the coasts of the United Kingdom to the north and France to the south. The shoreline is characterized by a wide variety of landforms, with retreating rocky coasts, sand/gravel beaches, rias and estuaries, as well as sandy beach/dune strand-plains and extensive intertidal flats and marshes (DAUVIN, 2019). The French coast of the western Basin is characterized by rocks that form eroding cliffs, associated with small, sandy pocket beaches, and relatively small rias and estuaries. On the shores of the eastern Basin, along the coast of the Pays de Caux, high chalk cliffs are associated with narrow beaches of sand and gravel (flint/chalk). The English Channel is one of the most anthropogenically affected marine areas in the world. It has attracted numerous industrial activities such as maritime transport, dredging and sediment dumping, granulate extraction, tourism, fisheries, aquaculture and offshore wind-farm projects (DAUVIN, 2019). The French side of the Channel is an important area for aquaculture, principally the Pacific oyster *C. gigas* and the mussel *Mytilus edulis* Linnaeus, 1758. With a current annual production of > 16,000 t of oysters and 35,000 t of mussels, supporting around 500 jobs in the aquaculture industry, the Normandy region is among the leaders of bivalve aquaculture in Europe (DAUVIN, 2019).

There is a long history of invertebrate inventories compiled mainly by marine biological stations such as Roscoff and Dinard in Brittany, Plymouth in England, Luc-sur-Mer in Normandy and Wimereux along the Opal coast in the eastern part of the English Channel. As a result, a total of 13 polydorid species have been reported in the English Channel (FAUVEL, 1927; DAUVIN *et al.*, 2003; RUELLET, 2004, LE MAO *et al.*, 2020) (Table 1). FAUVEL (1927) reported the presence of 10 species including three shell-boring parasites of the oyster *Ostrea edulis* Linnaeus, 1758: *Dipolydora coeca* (Örsted, 1843) (referred to as *Polydora*), *Dipolydora flava* (Claparède, 1870) (referred to as *Polydora*) and *P. hoplura*, while RUELLET (2004) reported five shell-boring parasite species of the oyster *C. gigas* in Normandy, on both the western and eastern coasts of Cotentin: *Boccardia polybranchia*, *B. semibranchiata,* an unidentified *Boccardia, Polydora hoplura* and *P. ciliata*. FAUVEL (1927) is the only author to have examined the polydorids and their distribution before the introduction of Pacific oysters in Normandy.

Table 1. Polydorid species reported along the French coast of the English Channel in the successive inventories. *Presence not confirmed in the English Channel.

Species Worms 2021	Fauvel, 1927	Dauvin *et al*., 2003	Ruellet, 2004	Le Mao *et al*., 2020	Sato-Okoshi *et al*., 2022
Polydora ciliata (Johnston, 1838)	*Polydora ciliata* (Johnston)	*Polydora ciliata* (Johnston, 1838)	*Polydora ciliata* (Johnston, 1838)	*Polydora ciliata* (Johnston, 1838)	
Polydora hoplura Claparède, 1868	*Polydora hoplura* Claparède	*Polydora hoplura* Claparède, 1870	*Polydora hoplura* Claparède, 1870	*Polydora hoplura* Claparède, 1869	*Polydora hoplura* Claparède, 1868
Dipolydora giardi (Mesnil, 1893)	*Polydora giardi* Mesnil	*Polydora giardi* Mesnil, 1896	*Dipolydora giardi* (Mesnil, 1893)	*Dipolydora giardi* (Mesnil, 1896)	*Dipolydora giardi* (Mesnil, 1893)
Dipolydora coeca (Örsted, 1843)	*Polydora caeca* (Œrted)	*Dipolydora coeca* (Oersted, 1843)	*Dipolydora coeca* (Oersted, 1843)	*Dipolydora coeca* (Örsted, 1843)	
Dipolydora flava (de Claparède, 1870)	*Polydora flava* Claparède	*Polydora flava* Claparède, 1870	*Dipolydora flava* (de Claparède, 1870)	*Dipolydora flava* (Claparède, 1870)	
Dipolydora quadriloda (Jacobi, 1883)	*Polydora quadrilobata* Jacobi	*Polydora quadrilobata* Jacobi, 1883*		*Dipolydora quadrilobata* (Jacobi, 1883)	
Dipolydora caulleryi (Mesnil, 1897)	*Polydora Caulleryi* Mesnil	*Polydora caulleyri* Mesnil, 1897	*Dipolydora caulleryi* (Mesnil, 1897)	*Dipolydora caulleryi* (Mesnil, 1897)	
Dipolydora armata (Langerhans, 1880)	*Polydora armata* Langerhans	*Polydora armata* Langerhans, 1880	*Dipolydora armata* (Langerhans, 1880)	*Dipolydora armata* (Langerhans, 1880)	
Boccardia polybranchia (Haswell, 1885)	*Polydora (Boccardia) polybranchia* Haswell	*Boccardia (Polydora) polybranchia* Hasxell, 1885	*Boccardia polybranchia* Hasxell, 1885	*Boccardia polybranchia* (Haswell, 1885)	
Pseudopolydora antennata (Claparède, 1868)	*Polydora (Carazzia) antennata* Claparède	*Pseudopolydora antennata* Claparède, 1870	*Pseudopolydora antennata* Claparède, 1870	*Pseudopolydora antennata* (Claparède, 1869)	
Pseudopolydora pulchra (Carazzi, 1893)		*Pseudopolydora pulchra* Carazzi, 1895	*Pseudopolydora pulchra* (Carazzi, 1893)	*Pseudopolydora pulchra* (Carazzi, 1893)	
Boccardiella ligerica (Ferronnière, 1898)		*Boccardia ligerica* Ferronnière, 1898.	*Boccardiella ligerica* (Ferronnière, 1898)		
Boccardia semibranchiata Guérin, 1970			*Boccardia semibranchiata* Guérin, 1970		
Boccardia proboscidea Hartman, 1940					*Boccardia proboscidea* Hartman, 1940
Boccardia pseudonatrix Day, 1961					*Boccardia pseudonatrix* Day, 1961
Boccardiella hamata (Webster, 1879)					*Boccardiella hamata* (Webster, 1879)
Polydora onagawaensis Teramoto, Sato-Okoshi, Abe, Nishitani & Endo, 2013					*Polydora onagawaensis* Teramoto, Sato-Okoshi, Abe, Nishitani, Endo, 2013
Polydora websteri Hartman in Loosanoff & Engle, 1943					*Polydora websteri* Hartman in Loosanoff & Engle, 1943
					Dipolydora sp

2.2 Recent prospection

New sampling of polydorids took place in March 2018 at six sites around the Cotentin peninsula and on the western part of the Calvados coast, from *C. gigas* oyster farms as well as from feral oysters, limestone substrates and calcareous algae (Fig. 1) (see Sato-Okoshi *et al*., 2022 for details). A total of eight species were identified using morphology and gene sequences (Table 1) (Sato-Okoshi *et al*., 2022): two *Boccardia* species were found (*B. proboscidea* and *B. pseudonatrix* Day, 1961) as well as

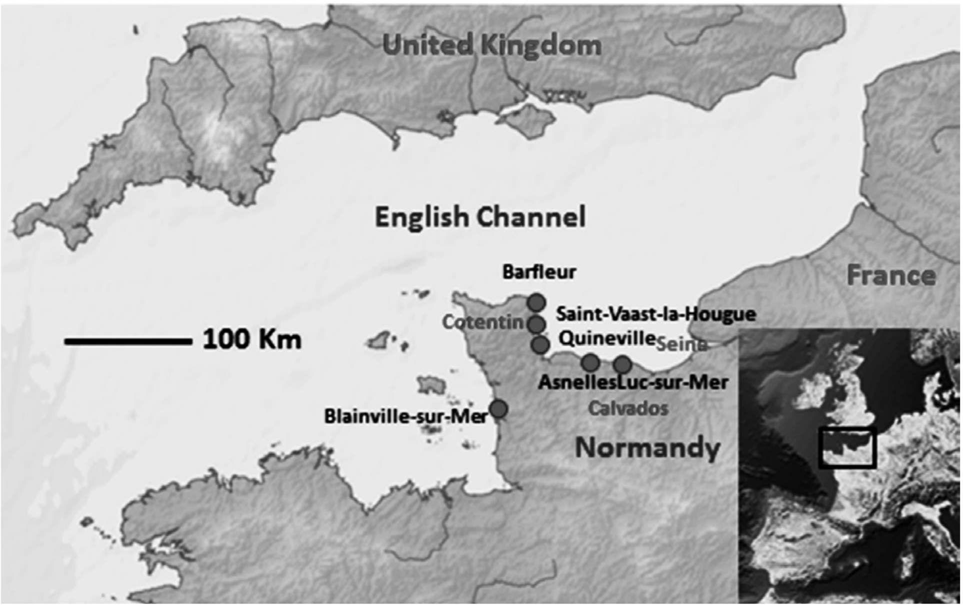

Fig. 1 Location of the sites (closed circles) visited in Normandy in March 2018.

Boccardiella hamata (WEBSTER, 1879), two *Dipolydora* (*D. giardi* (MESNIL, 1893) and one unidentified *Dipolydora*) and three *Polydora* (*P. hoplura*, *P. onagawaensis* and *P. websteri*).

2.2.1 Species previously known in Normandy and in the English Channel

Dipolydora giardi

This species has been reported at Blainville-sur-Mer in the cultured oyster *C. gigas*. It is widely distributed from the western part of the English Channel to the Bay of Seine (DAUVIN *et al.*, 2003; RUELLET, 2004). Found at low tide in *Lithothamnium* calcareous algae, in the crampons of kelp forests (FAUVEL, 1927) and as a shell-boring parasite in the Normandy oyster (RUELLET, 2004).

Polydora hoplura

This species is reported at Blainville-sur-Mer in feral and cultured *C. gigas* oysters. *P. hoplura* is widely distributed from the western part of the English Channel to the Bay of Seine (DAUVIN *et al.*, 2003; LE MAO *et al.*, 2020). It is found in the intertidal zone and shallow waters, among Serpulid polychaetes and in the oyster *O. edulis* as a shell-boring parasite (FAUVEL, 1927).

2.2.2 Species recently reported for the first time in the English Channel

Boccardia proboscidea

SATO-OKOSHI *et al.* (2022) reported the first record in Normandy from the Cape of Barfleur on coralline algae and in cultured *C. gigas* from Asnelles investigated in 2018. PEZY *et al.* (2021) listed this species as probably occurring in Normandy. Our record confirms this proposition.

Boccardia proboscidea was originally described from the west coast of the United States (California) and has been recorded along the French coast of the English Channel, on the Opal coast in the north of France in 2014 (SPILMONT *et al.*, 2018), in north Brittany in 2018 (GULLY and COCHU, 2020), and in the southern part of the

North Sea both along the Belgian and Dutch coasts (KERCKHOF and FAASSE, 2014). It has also been reported from North-west Scotland waters in the UK (HATTON and PEARCE, 2013) and in the south of the Bay of Biscay along the Basque coast (JAUBET *et al*., 2010), as well as along the French Atlantic coast near La Rochelle (SPILMONT *et al*., 2018). It has been widely observed on the coasts of the Pacific Ocean: Canada (SATO-OKOSHI and OKOSHI, 1997), United States, Japan (SATO-OKOSHI, 2000, ABE *et al*., 2019), Australia, South Africa, Argentina (see GULLY and COCHU, 2020 for references therein). In most places, it is considered as an introduced and invasive species (JAUBET *et al*., 2010, 2014, 2018). Its populations are well established in European waters.

Boccardiella hamata

SATO-OKOSHI *et al*. (2022) reported the first record of this species in the English Channel in feral *C. gigas* at Saint-Vaast-la-Hougue. PEZY *et al*. (2021) listed this species as probably occurring in Normandy. Our record confirms this proposition. This species was originally described from the Atlantic coast of North America, and it is now commonly known from the Pacific coasts, e.g., Vancouver Island, Canada (SATO-OKOSHI and OKOSHI, 1997), Japan (SATO-OKOSHI, 2000, ABE *et al*., 2019), China (ZHOU *et al*., 2010), Korea (SATO-OKOSHI *et al*., 2012). It was recently reported in the southern North Sea from Belgium and the southwestern Dutch delta (KERCKHOF and FAASSE, 2014). The species lives in muddy environments as well as amongst Pacific oysters on artificial hard substrates such as coastal defence structures (KERCKHOF and FAASSE, 2014). It has recently been found inhabiting sponges (ABE *et al*., 2019).

Polydora websteri Hartman in Loosanoff & Engle, 1943

SATO-OKOSHI *et al*. (2022) reported the first record of this species in Normandy on the eastern coast of the Cotentin peninsula at Quineville, and from Asnelles, on cultured oyster *C. gigas* investigated in 2018. Studies carried out in 2017 show that *P. websteri* does not live in the shells of cultured oysters from Arcachon (SATO-OKOSHI *et al*., unpublished data). It has also been reported recently in naturalized oyster reefs in the Wadden Sea (WASER *et al*., 2020). *Polydora websteri* originates from the eastern coast of North America and is today recorded from many countries worldwide (SIMON and SATO-OKOSHI, 2015).

2.2.3 Species reported for the first time in European waters

Boccardia pseudonatrix Day, 1961

SATO-OKOSHI *et al*. (2022) reported this species for the first time in European waters from the eastern coast of the Cotentin peninsula, at Saint-Vaast-la-Hougue, on cultured *C. gigas* and at Quineville on feral *C. gigas* investigated in 2018. *Boccardia pseudonatrix* was originally described from South Africa, and was then reported from Australia and Japan (SATO-OKOSHI *et al*., 2008; ABE *et al*., 2019). The main characteristics are transparent palps with irregular colourless spots crossing transversely, giving the appearance as being crossed by white bars in lateral view; conspicuous black pigmentation on the prostomium and a mid-dorsal ridge from chaetiger 5 to the middle of chaetiger 8.

Polydora onagawaensis Teramoto, Sato-Okoshi, Abe, Nishitani & Endo, 2013

This species was found in the Bay of the Seine at Saint-Vaast la Hougue, on feral *C. gigas*, and at Quineville and Asnelles on the cultured *C. gigas*; it was also sampled from limestone and calcareous substrates as well as on concrete blocks at Luc-sur-Mer investigated in 2018. The individuals of *P. onagawaensis* observed in Normandy show some morphological characteristics that are different compared with the Japanese *P. onagawaensis* (Sato-Okoshi *et al*., 2022). The specimens from Normandy can be morphologically distinguished from those collected in Japan (Teramoto *et al*., 2013) by the wider peristomium, occasionally strong intense black pigmentation around the base of both palps, maximum caruncle elongation up to the middle of chaetiger 3, and a smaller number of branchial chaetigers.

3. Pacific coast of Tohoku District

The Pacific coast of Tohoku District, located in north-eastern Japan, is characterized by a series of rias and a complex coastline that includes rocky reefs, sandy beaches, bays, and estuaries (Fig. 2). The bottom sediment varies from rock, gravel, sand to mud. The coastline faces the open sea. The Oyashio cold current and the Kuroshio warm current flowing along the coast make this area a rich fishing ground. As a result, the fishery industry is thriving in the coastal areas, with mollusc aquaculture such as oyster *C. gigas* (Okoshi *et al*., 1987) and scallops *Patinopecten* (*Mizuhopecten*) *yessoensis* (Jay, 1857). Sea squirts *Halocynthia roretzi* (Drasche, 1884), wakame seaweed *Undaria pinnatifida* (Harvey) Suringar, 1873 and nori seaweed *Neopyropia yezoensis* f. *narawaensis* (Kikuchi, Niwa & Nakada) Kikuchi & Niwa, 2020 are cultured subtidally, while salmon fish *Oncorhynchus kisutch* (Walbaum, 1792) introduced from the USA is cultured in the bays. The Tohoku coast has the following characteristic features: 1) located at a latitude of 40°N comparable to 50°N for the English Channel, 2) the area is relatively well researched, 3) a relatively similar length of coastline compared to the English Channel, and 4) there is a history of oysters being exported from the Pacific coast of Tohoku District to France.

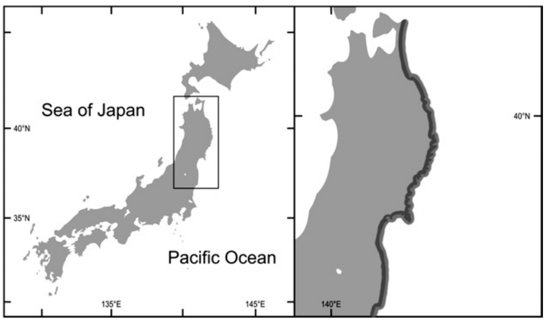

Fig. 2 Map of the Pacific Coast of Tohoku District, Japan. Fat line showing the Sanriku to Joban coast along the east coast of Tohoku District.

A total of nine shell-boring polydorid species have been reported from the southern part of the Pacific coast of Tohoku District, Japan (Sato-Okoshi, 1999; Sato-Okoshi and Abe, 2012, 2013), namely: *Dipolydora bidentata* (Zachs, 1933); *Dipolydora concharum* (Verrill, 1880); *Dipolydora giardi*; *Polydora brevipalpa* Zachs, 1933; *Polydora curiosa* Radashevsky, 1994; *Polydora hoplura*; *Polydora neocaeca* Williams & Radashevsky, 1999; *Polydora onagawaensis* and *Polydora websteri*.

In addition, ten other interstitial, epifaunal and infaunal polydorid species have been reported (Sato-Okoshi, 2000; Abe *et al*., 2016; Abe and Sato-Okoshi, 2021). These species are: *Boccardia proboscidea* (interstitial); *Boccardia pseudonatrix* (interstitial); *Boccardiella hamata* (Interstitial); *Dipolydora cardalia* (Berkeley, 1927) (infaunal); *Dipolydora socialis* (Schmarda, 1861) (interstitial, infaunal); *Polydora cornuta* Bosc, 1802 (infaunal, epifaunal); *Pseudopolydora achaeta* Radashevsky & Hsieh, 2000 (infaunal); *Pseudopolydora* cf. *kempi* (Southern, 1921) (infaunal); *Pseudopolydora paucibranchiata* (Okuda,

1937) (infaunal) and *Pseudopolydora* cf. *reticulata* Radashevsky & Hsieh, 2000 (infaunal). *Polydora neocaeca* and *B. pseudonatrix* have not yet been reported from the Pacific coast of Tohoku District, but they have been identified by the present authors (personal communication) from Sasuhama, Ishinomaki City and Moune Bay, Kesennuma City, respectively, in Miyagi Prefecture, north-eastern Japan.

4. Discussion

The species richness of polydorids from the Japanese Pacific coast of Tohoku District and the English Channel appears to be comparable, with 19 species and 18 species, respectively. Our 2018 surveys lead to the addition of two shell-boring species, *Polydora onagawaensis* and *P. websteri* and three non-boring species *Boccardia proboscidea, B. pseudonatrix* and *Boccardiella hamata*, to the list of the species present in Normandy and in the English Channel (Table 1) (Sato-Okoshi *et al.*, 2022). Moreover, the five newly added species are all oyster-associated species (shell-boring species or species inhabiting mud tubes in the crevices of the shell), and may have been transferred to these waters very recently.

All five genera (*Boccardia, Boccardiella, Dipolydora, Polydora* and *Pseudopolydora*) have been recorded in both Japanese waters and the English Channel.

Four boring species are common in both areas: *Dipolydora giardi, Polydora hoplura, P. onagawaensis* and *P. websteri*, as well as three non-boring species: *B. proboscidea, B. pseudonatrix* and *Boccardiella hamata*.

In his PhD thesis on oyster infestation of the Normandy oyster, Ruellet (2004) reported five species: *B. polybranchia, B. semibranchiata, P. ciliata* and *P. hoplura*, and an unidentified species of the genus *Boccardia*. Our 2018 survey (Sato-Okoshi *et al.*, 2022) was probably insufficient to establish the occurrence of all polydorids actually present in the shells of *C. gigas*. Nevertheless, *P. hoplura* is the only species cited by Ruellet that is in common between Normandy and Japan. Moreover, the unidentified *Boccardia* recorded by Ruellet may possibly correspond to one of the two species *B. proboscidea* and *B. pseudonatrix* identified during our survey in March 2018.

Boccardia semibranchiata was recorded by Ruellet (2004) only in the Bay of Veys. *Boccardia polybranchia* was reported in the Normano-Breton Gulf (Fauvel, 1927; Dauvin *et al.*, 2003; Le Mao *et al.*, 2020), in the Bay of Veys in the western part of the Bay of Seine (Ruellet, 2004). These two species were considered as Non-Indigenous Species (NIS) in Normandy by Pezy *et al.* (2021).

Even though Ruellet (2004) reported the presence of *Polydora ciliata* as a shell-boring parasite of *C. gigas* in Normandy, no *P. ciliata* was identified during our 2018 survey. However, this species was considered to be a non-boring species by Radashevsky and Pankova (2006) and our prospections concern mainly the oyster-boring species and species associated with oysters. Supplementary samplings are needed to verify the presence of *P. ciliata* in the English Channel, especially on rocky shores of the eastern basin along the Opal coast where the species was reported in very high abundances by Lagadeuc and Brylinski (1987).

5. Future perspectives

A total of 152 Non-Indigenous Species (NIS) introduced through human actions have been recorded in Normandy (Pezy *et al.*, 2021), with 54 NIS along the UK and French coasts of the English Channel originating from Japanese waters (Dauvin *et al.*, 2019). These 54 species include 22 algae (7 micro-algae and 15 macro-algae) and 32 invertebrates: one Protozoan, two Hydrozoans, two Anthozoans, one Nematode, two Platyhelminthes, two Polychaetes (*Clymenella torquata* (Leidy, 1855) and *Hydroides ezoensis* Okuda, 1934), eight Crustaceans, one Insect, five Bryozoans, five Molluscs and four Ascidians. SATO-OKOSHI *et al.* (2022) show that *P. onagawaensis* described from Japanese waters is also present in the English Channel; however, its COI gene sequences are more similar to those of US specimens than to Japanese ones.

In the future, we need to determine the biogeographic origin of certain species, not only *P. onagawaensis*, but also *Boccardiella hamata*, *Boccardia proboscidea*, *B. peudonatrix* and *P. websteri*.

The dispersal of these polydorids can be attributed in large part through aquaculture of *C. gigas* with the introduction of oysters for commercial activities in new areas and the repeated transport of oysters back and forth between different areas. Since the actual distribution of many polydorid species remains unknown, supplementary studies should be undertaken to identify shell-boring species present along the French coast of the Mediterranean Sea (Thau basin) and Atlantic coast (Arcachon basin and Marennes-Oléron area) as well as in the English Channel (Normandy and eastern English Channel). Two main aspects should be studied: the presence and occurrence of shell-boring polydorid species in cultivated and feral *C. gigas*, as well as their centres of origin. However, it is clear that morphological observations alone will not be sufficient to achieve this aim and molecular tools are needed to resolve such issues. Since many species are already widespread, these molecular tools should be applied to specimens collected from several possible centres of origin. A real challenge for future collaborative research between Japan and France begins.

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First results on the life cycle and population dynamics of the tanaid *Zeuxo holdichi* Bamber, 1990 colonizing concrete blocks deployed on oyster tables (Bay of Seine, eastern part of the English Channel)

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Abstract: The tanaid *Zeuxo holdichi* is common in intertidal and shallow waters on the French side of the English Channel, with very high abundances along the Calvados coast. The abundances and population dynamics of *Z. holdichi* were studied during a one-year experiment of benthic colonization of artificial blocks placed upon intertidal oyster culture tables 0.5 m above the seabed. Bi-monthly sampling shows that the colonization was rapid, with abundances reaching 2,000 individuals per m^2 in four months. Two peaks were observed at the end of September and the beginning of November, when the abundances exceeded 21,000 individuals per m^2. Allometry measurements show that the length of the cephalothorax is a good proxy to estimate the total length of the individuals. The population is mainly composed of male and female adults measuring up to 5.35 mm. Ovigerous females are present from the middle of June to the end of the study, with a high occurrence in August-October. The number of embryos ranges from 5 to 89 for a mean fecundity of 24 embryos per brood pouch. The mean size of the females is 3.5 mm. The mean female/male ratio is 4.28. Considering these traits of life, *Z. hodichi* possesses high ability to rapidly colonize virgin hard substrates.

Keywords : *Zeuxo holdichi, Bay of Seine, fecundity, abundances*

1. Introduction

Since its description in 1990 based on specimens from Arcachon Bay, in the southern part of the Bay of Biscay, the tanaid *Zeuxo holdichi* Bamber, 1990 has been reported at several locations ranging from the North-eastern Atlantic to the English Channel (EC) coast of France (FOVEAU *et al.*, 2018) as well as in the western approaches of the EC (Scilly Islands, UK). It has also been reported along the Atlantic coast of Spain and Portugal and in the southern part of the North Sea (CUNHA *et al.*, 1999; ESQUETE *et al.*, 2011; BAMBER, 2011; FAASSE, 2013). It was recently reported for the first time in the Mediterranean Sea in the Venice Lagoon (DEL

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Pasqua *et al.*, 2022). However, the native origin of *Z. holdichi* and its alien status in the Mediterranean Sea remain uncertain. Based on recent records of this tanaidomorph species in North Atlantic waters, Faasse (2013) has suggested that *Z. holdichi* might not be native to Europe. This is because crustacean faunas, including tanaids, have been well investigated in Atlantic regions and it would seem exceptional to discover new native crustacean species in well-investigated North-eastern Atlantic areas. The genus (subgenus *Parazeuxo*) is present in the Macaronesian islands though. Bamber (2012) mentions *Z.* (*Parazeuxo*) *exsargasso* from the Cape Verde and Canary Islands (formerly only known from floating Sargassum near Bermuda) and *Z.* (*Parazeuxo*) *coturnix* n. sp. from Cape Verde and Madeira. Moreover, as indicated by Faasse (2013), *Zeuxo holdichi* has no congeners in the north-European waters, which further suggests that its origin may be elsewhere. Another argument supporting this hypothesis is the molecular study performed by Larsen *et al.* (2014) indicating that *Z. holdichi* has closer genetic relationships with the Pacific *Zeuxo normani* (Richardson, 1905) than with other North Atlantic species, as mentioned also by Foveau *et al.* (2018). Furthermore, *Z. holdichi* could be a Non-Indigenous Species involuntarily introduced by humans probably via the transfer of oysters or hull fouling (Leclerc and Viard, 2018). Moreover, *Z. holdichi* could also be an invasive species in the English Channel, due to its rapid progression, particularly along the French coast of the English Channel (Foveau *et al.*, 2018).

Studies on the life cycle and dynamics of tanaids, which are mainly small species with low abundance, concerned mainly intertidal populations from North and South America, such as *Hargeria rapax* (Harger, 1879) on Northwest Atlantic coasts (USA) (Kneib, 1992; Modlin and Harris, 1989); *Kalliapseudes schubartii* Mañé-Garzón, 1949 along the Brazilian coast (Fonseca and D'Incao, 2003; Leite *et al.*, 2003; Pennefirme and Soares-Gomes, 2009); *Sinelobus stanfordi* (Richardson, 1901) from other South-American environments (Slivak *et al.*, 2013; Ferreiraa *et al.*, 2015); *Tanais dulongii* (Audouin, 1826) from the Argentinian coast (Rumbold *et al.*, 2012, 2014, 2015b,b) and north-western Atlantic Ocean populations (Attramadal, 1982; Borowky, 1983; Hamers and Franke, 2000) and *Leptochelia dubia* (Krøyer, 1842) along the California coast (Mendoza, 1982). Masunari (1983) has described the post-marsupial development and population dynamics of *Leptochelia savignyi* (Krøyer, 1842) from Brazil, while Messing (1983) has studied the post-marsupial development and growth of *Pagurapseudes largoensis* (McSweeny, 1982) from a shallow population off south-eastern Florida (North-western Atlantic Ocean).

Ambrosio *et al.* (2014) suggested that tanaids are opportunistic species, and proposed the potential use of tanaids as biological indicators of water quality. Along the same lines, de la Ossa Carretero *et al.* (2010) studied the sensitivity of *Apseudopsis latreillii* (Milne Edwards, 1828) to sewage pollution along the Mediterranean coast of Spain.

Within the RECIF-project framework, an ecological engineering approach has been proposed by incorporating the crushed shells of the queen scallop *Aequipecten opercularis* (Linnaeus 1758) into concrete to develop innovative building materials for artificial reefs (Foveau *et al.*, 2015; Dauvin and Foveau, 2019). In the framework of this project, an inventory was drawn up of the sessile and vagile macrofauna recorded over a period from March 2014 to February 2015 during a survey of concrete blocks positioned on oyster culture tables in the intertidal zone near

Luc-sur-Mer area on the Calvados coast (eastern basin of the EC) (Foveau *et al.*, 2015; Dauvin and Foveau, 2019; Dauvin *et al.*, 2021). More than 100, 000 individuals of the tanaid *Zeuxo holdichi* were collected during the survey (Foveau *et al.*, 2018), allowing us to study the pattern of colonization and the population structure of this species over a period of one year.

2. Materials and Methods

2.1. Experimental strategy

At the beginning of the experiment (19–20 March 2014), 75 blocks (20 × 20 × 40 cm) (total surface 0.6 m^2) were placed 0.5 m above the sea bed on oyster culture tables used in the intertidal zone of Luc-sur-Mer, Normandy (49°19'15"N; 0° 20'55"W) located in the southern part of the Bay of Seine, eastern basin of the English Channel) (Dauvin and Foveau, 2019; Dauvin *et al.*, 2021). The oyster tables are submerged to a water depth of 6.5 m at high tide, located in the infralittoral fringe composed mainly of coarse sediment and natural rocky substrates corresponding to the EUNIS (European Nature Information System) code A5. 125; *Mastocarpus stellatus* and *Chondrus crispus* habitat on very exposed to moderately expose lower eulittoral rock. *Zeuxo holdichi* was counted only on blocks containing 40% of crushed queen scallop *Aequipecten opercularis* (Linnaeus, 1758) shells and 25% porosity. The blocks were collected about every 15 days between 1 April 2014 and 4 February 2015, on a total of 22 sampling dates. At the laboratory, the blocks were immerged in tanks under stagnant conditions for at least 24h. Then, the seawater was filtered on a 0.5-mm mesh sieve to collect the motile fauna including the tanaid *Z. holdichi*. Finally, we had checked whether any fauna remained on the blocks. The retained material was fixed with 96% alcohol.

2.2. *Zeuxo holdichi* treatment

The abundances of *Z. holdichi* are expressed per 1 m^2. The number of *Zeuxo holdichi* was low at the beginning of the study (04 April to 29 July 2014), thus we examined them all. During the rest of the study (12 August 2014 to 02 February 2015), only a sub-sample of 100 individuals taken randomly was recovered and stored in alcohol to study temporal changes of the population structure. Then, a photo of each individual was taken under an Olympus SZX16 binocular using an E6PL3 Olympus camera. Before photographing each individual, it was necessary to calibrate the binocular, because the measurement software (ImageJ) did not allow automatic calibration of the photos. Thus, a picture was taken of graph paper for each amplification of the binocular: i.e. x7, x8, x10, x12.5, x16, x20, x25, x32, x40, x50, x63, x80, x100 and x115. The software ImageJ took measurements in pixels and a conversion factor was applied to convert the measurements of *Z. holdichi* in pixels to measurements in mm following the ratio given in Table 1. Dorsal views were taken, and also lateral views in the case of ovigerous females (Fig. 1).

Following Bamber's (1990) description of the species, 11 segments were measured: cephalothorax, pereonites 1, 2, 3, 4, 5 and 6, pleonites 1, 2 et 3, pleonites 4 + 5 + pleotelson (Fig. 2). A supplementary measurement was made of the width of the cephalothorax.

Female and male of *Z. holdichi* can be distinguished by their morphological characters. The female has a triangular cephalothorax, which is wider than it is long. Pereonites 2 to 5 are successively longer than the previous one. Pereonite 6 is also smaller than pereonite 4. Moreover, mature females carry oostegites and sometimes embryos in their marsupial pouch. The numbers of embryos were counted in a subset of ovigerous females. For the male, the cephalothorax is

Table 1. Summary of the conversion factors calculated for each magnification of the binocular Olympus SZX16.

Magnification	µm	Pixel	µm/pixel
7	24000	3841	6.25
8	20000	3724	5.37
10	16000	3705	4.32
12.5	12000	3471	3.46
16	8000	2965	2.70
20	6000	2775	2.16
25	6000	3475	1.73
32	4000	2996	1.35
40	3000	2794	1.07
50	2000	2338	0.86
63	2000	2966	0.67
80	1000	1891	0.53
100	1000	2370	1.42
115	1000	2772	0.36

Fig. 1 Photos of *Z. holdichi* showing an ovigerous female seen in profile (top), an ovigerous female seen from behind (in the middle) and a male seen from the back (bottom). Photo by Manon Jean.

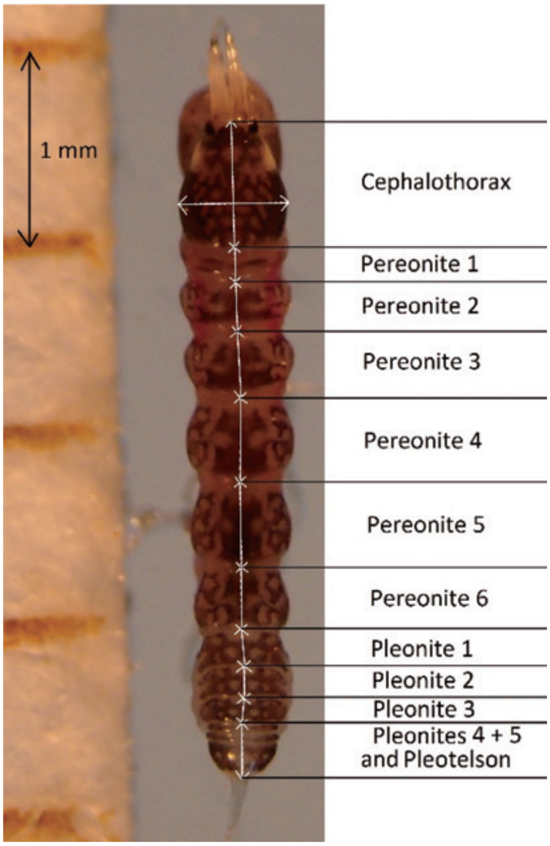

Fig. 2 Measures performed on each individual *Z. holdichi* (female). Photo by Manon Jean.

longer than wide, with pereonites and pleonites proportionally smaller in relation to their width. Its chelipeds are also more developed than in the female in most cases.

The individuals with a total length less than 1.5 mm were considered as juveniles; the other individuals were classified as female or male and then counted to determine the sex-ratio, i.e. the ratio between females and males.

The Pearson correlation coefficient for each allometry linear relationship between the length or width of the main segments and the total length of the body was calculated using R software, and the significance of all analyses was assessed at $p < 0.01$ and < 0.001. Moreover, 500

Table 2. Numbers of females, males and juveniles in the total population from 20 March to 29 July then for 100 examined individuals per date. Sex-ratio females/males and individuals per m^2.

Dates	Females	% ovigerous females	Juveniles	Males	Sex-Ratio	Individuals per m^2
03/20/2014	0	0	0	0		0
04/01/2014	0	0	0	0		0
04/17/2014	0	0	0	0		0
04/30/2014	2	0	0	2	1	7
05/15/2014	2	0	0	2	1	7
05/29/2014	0	0	0	4	1.14	7
06/16/2014	8	50	0	7	2	25
06/30/2014	4	0	0	2	0.5	10
07/16/2014	1	0	0	2	1.37	5
07/29/2014	11	18	0	8	3.95	32
08/12/2014	79	14	1	20	2.81	2853
08/27/2014	73	14	1	26	3.71	3740
09/10/2014	78	18	1	21	5.13	5745
09/26/2014	77	18	8	15	3.62	13758
10/06/2014	76	14	3	21	6.31	6400
10/24/2014	82	5	5	13	6.46	20053
11/05/2014	84	13	3	13	5.27	21120
11/24/2014	79	0	6	15	10.87	9280
12/08/2014	87	1	5	8	12.57	13820
12/12/2014	88	0	5	7	3.17	5653
01/06/2015	73	0	4	23	2.09	2640
01/20/2015	67	3	1	32	2.09	4320
02/01/2015	92	2	1	7	13.14	2133

individuals (males and females) were taken randomly to establish an overall relation between the Total Length (Lt) and the length of the Cephalothorax (Lc).

3. Results

3.1. Abundances

The first individuals (2 males and 2 females) on the blocks were observed on 30 April, i.e. 1.5 month after the beginning of the experiment and one months after the first sampling. The abundance remained very low (7–32 individuals per m^2) before the 12th of August, after which the abundances reached 2,853 individuals per m^2, then remained high 2,000 individuals per m^2 throughout the rest of the experiment (Table 2; Fig. 3).

The peaks of abundance occurred at the beginning of November with 21,120 individuals per m^2, but remained higher than 5,000 individuals per m^2 from 9 September to 22 December 2014. During the winter at the end of the study, the abundance was 2,130 individuals per m^2 on 4 February 2015 (Fig. 3).

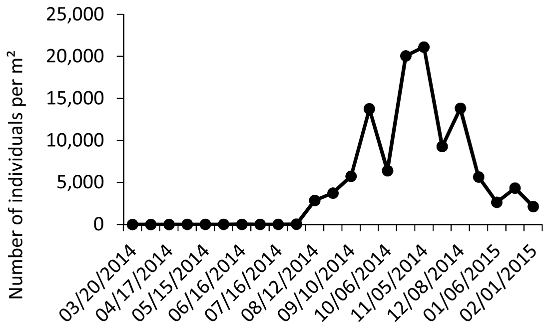

Fig. 3 Evolution of individuals per m^2 of *Zeuxo holdichi* from March 2014 to February 2015.

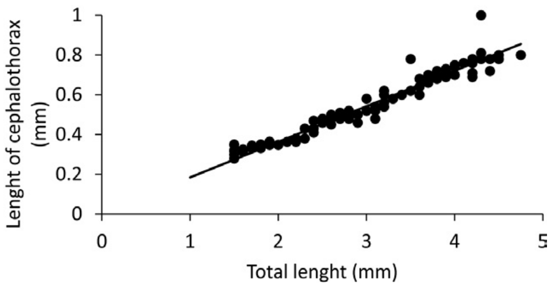

Fig. 4 Relationship between the total length and the length of the cephalothorax established from 500 individuals of *Zeuxo holdichi* (males and females) all seasons confounded.

Table 3. Correlation coefficient of Pearson (R^2) calculated for each allometry linear relationship between the length or width of the main segments of the *Zeuxo holdichi* body and the total length of 1,061 females and 200 males. * $p < 0.01$ and ** $p < 0.001$.

	Females	Males
Cephalothorax length	0.93**	0.88**
Cephalothorax width	0.93**	0.84**
Perionite 1	0.68*	0.32
Perionite 2	0.91**	0.79**
Perionite 3	0.95**	0.88**
Perionite 4	0.96**	0.90**
Perionite 5	0.97**	0.90**
Perionite 6	0.94**	0.69**
Pleonite 1	0.87**	0.80**
Pleonite 2	0.89**	0.81**
Pleonite 3	0.77*	0.61*
Pleotelson	0.80**	0.61*

3.2. Allometry

Table 3 gives the values of the Pearson correlation coefficient (R^2) between total length and the length of different segments for 1,061 females and 220 males.

Except for the Pereonite 1/total length, all the other allometric variables show a significant scaling relationship with total length. The cephalothorax length was easy to determine, thus providing a good means of describing the structure of a *Z. holdichi* population. The Total Length (Lt) and the Length of the Cephalothorax (Lc) relationship is $Lt = 0.1788 \times Lc + 0.0058$ with a Pearson correlation coefficient of 0.96 ($p < 0.01$) (Fig. 4).

3.3. Sex-ratio

A total of 1,311 individuals were sexed, yielding a mean sex-ratio of 4.28, with 1,063 females and 248 males. The sex-ratio shows a seasonal variation, with a regular increase from < 4.0 at the beginning of the study to higher values in the autumn and winter, reaching a first peak at the end of November and the beginning of December 2014 (10.87–12.57) and a second peak at the beginning of February 2015 (13.14) (Table 2).

3.4. Fecundity

Ovigerous females were counted in the populations from the middle of June 2014, when 50% females were ovigerous (but only 8 females were collected on the block), to the end of the study in February. Moreover, the main period of presence of ovigerous females extended from the end of July to the beginning of November, when 5 to 18% of the females carried embryos.

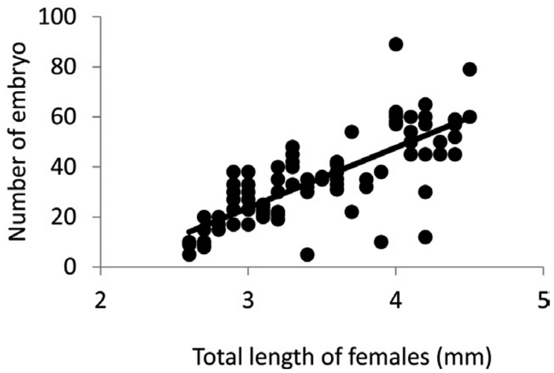

Fig. 5 Relationship between total length of females and number of embryos counted in the marsupial pouch.

The numbers of embryos per female were counted on 89 females and varied from 5 for the smallest individuals (2.6 mm) to 89 for 4.0 mm, while ovigerous females show a minimum size of 2.6 mm and a maximum size of 4.5 mm (Fig. 5). The mean number of embryos per female is 24 (+ /− Standard Deviation of 17). We found a positive linear relationship between the size of females and the number of embryos, with a Pearson correlation coefficient of 0.59 ($p < 0.01$): Number of embryos = 24,114; Total Length = 18.701.

3.5. Population structure

Figure 6 shows the structure of the *Z. holdichi* population at 13 dates from the 18th August 2014 to the 4th February 2015 (in terms of total length of individuals) when the abundance exceeds 2,000 individuals per m^2. The analysis of these size-classes allows us to underline four main points. Firstly, the size of the collected individuals ranges from 0.95 mm for the smallest to 5.35 mm for the largest. Secondly, the numbers of juveniles (size < 1.5 mm) are always very low, showing that the colonization of the present blocks has been ensured by the drifting of individuals and not by the recruitment of juveniles on the blocks. Thirdly, the size-frequency histograms indicate the presence of two main cohorts throughout the experiment. The first cohort grouped together most of the measured individuals with a mean size of 2.4 mm (young individuals) and a second cohort with a low number of individuals and a mean size of 3.8 mm (adult individuals). Fourthly it was not possible to identify any displacement of size-classes (increase in the length of individuals) of these two cohorts during the six months of the experiment.

4. Discussion

This study represents the first time that the biology and popûlation of *Zeuxo holdichi* has been investigated in detail. Firstly, in common with numerous other tanaids, this species is tubicolous and fixes its tubes in anfractuosities of the blocks or on macroalgae colonizing the blocks (Foveau *et al.*, 2015). *Z. holdichi* are found on the blocks 1.5 months after immersion at the end of April 2015 but show dense populations at the beginning of August 2015 only four months after the start of the study (Fig. 6). The species found favourable conditions for their establishment and development on blocks placed on oyster tables 0.50 m above the seabed in the intertidal zone at Luc-sur-Mer. Moreover, the barnacle *Balanus crenatus* Bruguière, 1789 grows as a pioneer species on the blocks, but dies away some months after their emplacement; in this way, the barnacle wall plates offer a new protected habitat for *Z. holdichi* (Dauvin and Foveau, 2019; Dauvin *et al.*, 2021). *Z. holdichi* is very abundant on the blocks from the middle of October to the middle of December, i.e. from seven to nine months after immersion (Fig. 6). From then on, the population decreases towards the end of the study.

As very low numbers of juveniles (sieved on

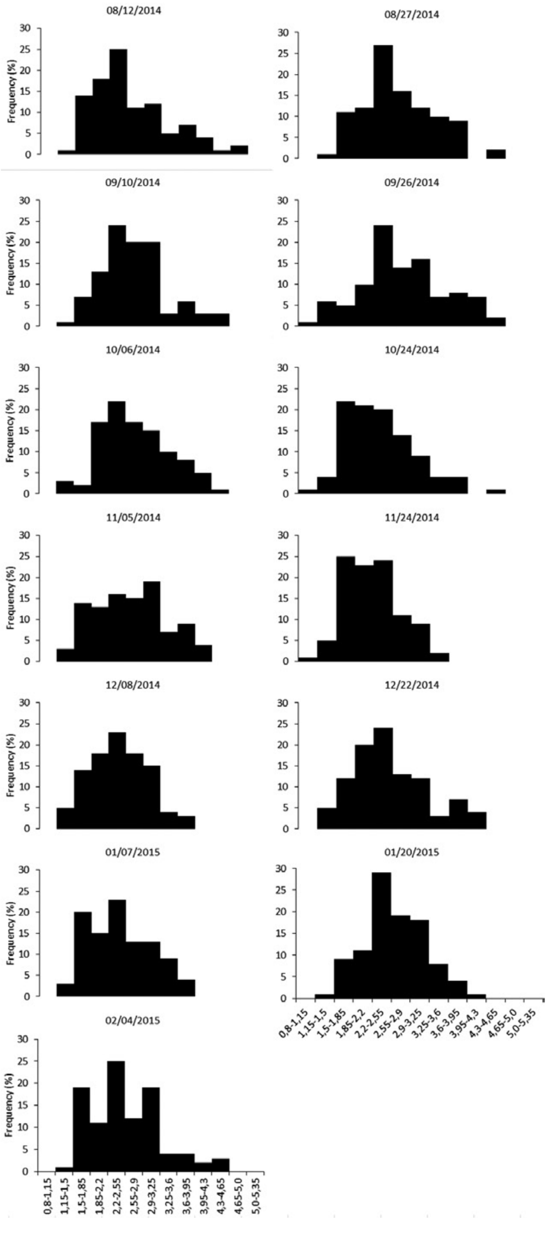

Fig. 6 Size-frequency distribution of *Zeuxo holdichi* at Luc-sur-Mer (Bay of Seine) between August 2014 and February 2015. Total length of individuals are in mm and frequency is in % of measured individuals.

0.5 mm mesh, which probably insufficient to collect all the smallest individuals) are recorded on blocks in spite of the high abundances of adults including ovigerous females, we hypothesize that the juveniles can also settle on coarse sediment and rocky substratum around the blocks. In the Rade de Cherbourg in the North Cotentin, on the French side of the English Channel, *Zeuxo holdichi* has also been recorded on soft-bottom habitats (Foveau *et al.*, 2018; Dauvin *et al.*, 2020). At this site, the species is found under or near salmon cages on heterogeneous sediments ranging from coarse sand to mud. Nevertheless, its abundance reaches only 80 individuals per m^2 under the cages on sand and gravel with a low percentage of fine particles (Dauvin *et al.*, 2020). The same sediment type is observed under the oyster tables at Luc-sur-Mer (Dauvin and Foveau, 2019; Dauvin *et al.*, 2021). Due to the swimming ability of tanaids, young females and adult males of *Z. holdichi* can migrate at night in the water column in relation to their diel migration (Alldredge and King, 1980). In accompaniment of diel migration, drifting of *Zeuxo holdichi* could be also suggested as another source permitting the colonisation of elevated blocks (Thiel and Gutow, 2005; Riera, 2014). Both swimming and drifting seem favourable behaviour to colonise the blocks placed 0.5 m above the sea bed.

The life cycle of the tubicolous *Hargeria rapax* (Harger, 1879) has been studied in the salt marshes on Sapelo Island (Georgia, USA) in tropical environments (Kneib, 1992). The abundance is higher in winter (29,000 individuals per m^2). Although reproductive females are present throughout the year, two peaks in reproductive activity occur in autumn and spring Modlin and Harris (1989) have investigated a *H. rapax* population in tidal pools of Dauphin Island on the Alabama coast (USA) of the Gulf of Mexico where abundances reach a maximum at the beginning of the summer (up to 100,000 individuals per m^2). Females are present throughout the year, but ovigerous females peak in June and

January. Fonseca and D' Incao (2003) have studied the growth and reproduction of *Kalliapseudes schubartii* Mañé-Garzón, 1949 in the Patos Lagoon (Rio Grande do Sul State, southern Brazil). The reproductive activity was observed in spring and summer, and several cohorts appeared in the population during the year. The population biology of this species was similarly studied in the Araçá region (São Sebastião, Brazil) (Leite *et al.*, 2003), where several cohorts with continuous reproduction were identified over the year and the longevity was estimated as 12 months. Later, Pennefirme and Soares-Gomes (2009) studied *K. schubartii* in the Itaipu tropical coastal lagoon (Southeastern Brazil). This species showed a seasonal pattern of abundances, with the proportion of mature females larger than males over the year. Slivak *et al.* (2013) observed a population of *Sinelobus stanfordi* (Richardson, 1901) on the North coast of Rio Grande do Sul state (Southern Brazil). The ovigerous females, juveniles and males showed a continuous reproductive activity throughout the year in this tropical environment. Ferreiraa *et al.* (2015) investigated the ecology of a population of *S. stanfordi* along 155 km of shoreline within the Río de la Plata Estuary (Argentina). The juveniles were abundant in spring and summer, whereas mature individuals predominated in the winter. Females were always twice as abundant as males, and ovigerous females were collected at all seasons. The populations of *Tanais dulongii* (Audouin, 1826) were studied in detail by Rumbold *et al.* (2012, 2014, 2015a, b) around Mar del Plata in the North of Argentina. Reproductive individuals and juveniles were present throughout the year, whereas two main recruitment periods were identified, in spring and in summer, while the life span was 9–12 months.

In contrast with tropical environments, in temperate environments, the reproductive period is mainly concentrated in the summer and at the beginning of autumn (August to October for *Z. holdichi* in the English Channel), with probably one cohort per year versus numerous cohorts in tropical tanaid populations. The structure of the population at Luc-sur-Mer is characterized by two main cohorts, the main cohort present along the study with a mean size of 2.4 mm corresponding to young individuals in 2014 and a secondary cohort with a low number of adult individuals produced in 2013 with a mean size of 3.8 mm and observed until the end of 2014. The largest individuals disappeared at the end of 2015, showing that the longevity attains 16 months. The species is therefore univoltine, with only one cohort and a single year-class per year.

Females are more numerous than males. This pattern is a general feature among the tanaids: for *Zeuxo holdichi*, the mean females/males ratio is 4.28, with high values reaching 13.14. The sex-ratio is strongly female-biased for *Tanais dulongii* (Rumbold *et al.*, 2012, 2014, 2015a, b), with a sex ratio of 1.8 for *Hargeria rapax* (Modlin and Harris, 1989) and a dominance of females for *Sinelobus stanfordi* (Slivak *et al.*, 2013) and *Leptochelia dubia* (Mendoza, 1982), while the sex-ratio is near 1 (1.1) in *Pagurapseudes largoensis* (Messing, 1983). Highsmith (1983) has observed protogynous behaviour in the case of *Leptochelia dubia*, with all the smallest males being derived from females that have reversed sex. Moreover, the females tend not to reverse their sex when males are present and males show a high mortality rate; for *L. dubia*less than 5% of the adults are male. This behaviour could be generalized for other tanaids as *Z. holdichi*, explaining the dominance of females in the populations.

In the Luc-sur-Mer population, the mean

number of embryos was 24, ranging from 5 to 89 for females measuring between 2.6 to 4.5 mm with a positive relationship between the total length of females and the number of embryos in the marsupial pouch. Among the 484 individuals collected from the Rade de Cherbourg in the North Cotentin (English Channel) (FOVEAU *et al.*, 2018), 112 were ovigerous females. The numbers of embryos carried by these females has been counted (unpublished data), yielding a fecundity which varies from 10 embryos for the smallest females (2. 3 mm) up to a maximum of 112 embryos for the largest female (5.3 mm), corresponding to a mean fecundity of 27 (+ /- SD 17). In the case of the Luc-sur-Mer population, there is a positive relationship between the size of the females and the number of embryos, with a Pearson correlation coefficient of 0.62 ($p < 0.01$). *Z. holdichi* in the English Channel shows a high fecundity compared to other tanaid species, with an egg development estimated at 1.5 month at Luc-sur-Mer. For *Z. holdichi* BAMBER (1990) reported 50 eggs for a brooding female collected in the Arcachon basin in the south of the Bay of Biscay.

For *Pagurapseudes largoensis*, the number of embryos ranges from 4–17 (MESSING, 1983), while the mean fecundity is 18 ± 8 eggs per female, with a maximum of 37 and a minimum of five eggs in *Sinelobus stanfordi* (FERREIRA *et al.*, 2015), and between 15 and 20 for *Tanais cavolinii* (JOHNSON and ATTRAMADAL, 1982). A mean number of eggs of 50 varying from 5 for a 1.5 mm female to 80 for a 5.5 mm female had been reported for *Tanais dulongii*, RUMBOLD *et al.*, 2015b). Similarly, *Kalliapseudes schubartii* shows a high fecundity, with a maximum of 86 eggs observed in females having a total length of 6.6 mm (FONSECA and D'INCAO, 2003); for this same species, PENNAFIRME and SOARES-GOMES (2009) reports a mean fecundity of 18 ± 11 ranging from 1 to 63 eggs, while LEITE *et al.* (2003) reports a mean value of 12 eggs (1 to 31) (LEITE *et al.*, 2003).

The fecundity of *Zeuxo holdichi* measured in our one-year and one-site study is among the highest reported for studied tanaid species. Taking into account the presence of two peaks of abundance of the population at Luc-sur-Mer (Table 2), it is possible to estimate the number of juveniles produced by the population. On 26th September, the estimated abundance was 13,758 individuals per m^2, and females carrying a brood pouch at that date represented 18% of the population, i.e. 2,476 individuals per m^2. With a mean fecundity of 24, the number of juveniles produced would be 59,435 individuals per m^2. On 5th November, the estimated abundance was 21,120 individuals per m^2, when females with a brood pouch represented 13% of the population, i.e. 2,745 individuals per m^2. With a mean fecundity of 24, the number of produced juveniles would be 65,895 individuals per m^2.

Commonly, tanaids populations can be very abundant with densities higher than those observed for *Z. holdichi* in the English Channel (21,000 individuals per m^2). HIGHSMITH (1983) reported an average density > 50,000 individuals per m^2 for a North-American population of *Leptochelia dubia*. KNEIB (1992) reported a winter peak of 29,000 individuals per m^2 for *Hargeria rapax* on the coast of Georgia (USA), while the same species reaches abundances of 100,000 individuals per m^2 along the Alabama coast (MODLIN and HARRIS, 1989). High abundances of the tanaid *Apseudopsis latreillii* have also been recorded on soft-bottom communities of the North Cotentin (English Channel), where abundances reach 23,000 individuals per m^2 These *A. latreillii* abundances are among the highest recorded for this species in the world-wide ocean; a maximum of 43,000 individuals per

m^2 is reported in the Dubai creek of the Persian Gulf (DAUVIN *et al*., 2020).

Several authors have suggested an opportunistic life strategy for tanaids. LEITE *et al.* (2003) and PENNAFIRME and SOARES-GOMES (2009) reported that high fecundity, continuous reproduction in tropical environments, linked to fast growth and brief longevity, supported an opportunistic life strategy for *Kalliapseudes schubarti* (LEITE *et al*., 2003). SLIVAK *et al.* (2013) considered that *Sinelobus stanfordi* is an opportunistic species due to its wide geographic range and high variety of habitats. The life traits of *Zeuxo holdichi*, as well as its high fecundity and its presence in numerous habitats along the English Channel, all indicate an opportunistic behaviour. Future studies in other locations should provide evidence to confirm this opportunistic strategy, i.e. the ability to colonise diverse soft-bottom and hard bottom habitats on the intertidal and shallow waters, as well its swimming and drifting behaviour.

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Phytoplankton assemblages in Onagawa Bay from 2012 to 2013 determined by DNA sequencing and pigment analysis

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Abstract: The phytoplankton assemblages in Onagawa Bay were investigated by photosynthetic pigment analysis and DNA sequencing over two consecutive years, from January 2012 to December 2013. Chlorophyll *a* (Chl *a*) concentrations tended to be high from winter to spring, and fucoxanthin, the source of which is mainly diatoms, was also high. Chlorophyll *b* concentration, which is retained in picoprasinophytes, tended to be higher in June. Cyanobacteria tended to appear in the summer, although, at less than 2%, in relatively small amounts. Since picoeukaryotes and cyanobacteria are small, shellfish filters cannot trap them efficiently, so the amount of nutrition obtained from them is relatively low and inefficient. *Dinophysis norvegica* (the causative agent of diarrheal shellfish poisoning) was the dominant dinoflagellate species throughout the study. Two species of dominant cryptophyte that were found are food sources of ciliate *Myrionecta rubra* which is a food source for *Dinophysis* spp., so unfortunately, they render Onagawa Bay susceptible to the growth of *Dinophysis* spp.. *Phaeocystis* spp. was the dominant haptophyte. The combination of pigment analysis by HPLC and DNA Next Generation Sequencing provided good data on seasonal phytoplankton variation, which is necessary to understand the detailed feeding environment for shellfish raised in Onagawa Bay.

Keywords : *NGS, HPLC, Photosynthetic pigments analysis, Sanriku coast*

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1. Introduction

Onagawa Bay is located just to the north of Sendai Bay, in the southern part of the Sanriku rias coastline of northeastern Honshu, Japan (FUJII *et al.*, 2018). It is an important area for the cultivation of scallops, oysters, and ascidians (KATAYAMA *et al.*, 2018), along with important coastal fisheries for various finfish species. Appropriate management of shellfish aquaculture is a necessary contribution to maintaining a sustainable fishery industry in Onagawa. Since the food source for shellfish aquaculture is mainly natural phytoplankton in the seawater, feeding is not required. However, low phytoplankton levels can sometimes lead to insufficient feeding of the shellfish being cultivated, leading to poor growth, death, and a consequent decrease in shellfish production.

In order to understand changes in the feed quantity of shellfish, Chlorophyll *a* (Chl *a*), an indicator of phytoplankton abundance, is frequently measured on a regular basis at aquaculture farms (NAGASAWA *et al.*, 2016, OKUMURA *et al.*, 2017). However, various types of phytoplankton grow within the coastal waters, including diatoms (FURUYA *et al.*, 1993; KUDO *et al.*, 2000; WATANABE *et al.*, 2017), which are generally considered excellent feed for shellfish (IRIGOIEN *et al.*, 2002); dinoflagellates (MASUDA *et al.*, 2014), which are considered unsuitable (TURNER *et al.*, 1998); and small cyanobacteria (FLOMBAUM *et al.*, 2013; TANIUCHI *et al.*, 2017). Some dinoflagellates are poisonous (OFFICER and RYTHER, 1980; SUZUKI *et al.*, 2017), and if the poison accumulates in the shellfish through feeding on these dinoflagellates, harvesting is restricted voluntarily (TANABE and KAGA, 2017). In addition, cyanobacteria and picoeukaryotes, which are smaller than diatoms and dinoflagellates, cannot be filtered by bivalve gills and so they pass through (RIISGÅRD, 1988). Lowered filtration efficiency reduces feeding efficiency, leading to poor growth. Therefore, the data on phytoplankton species composition is important for shellfish aquaculture. Recently, attempts have been made to understand the feeding environment in more detail, for example searching for shellfish feed organisms using stable isotope ratios (KATAYAMA *et al.*, 2018).

Onagawa Bay was affected by the 2011 tsunami, along with other coastal areas in northeastern Honshu ('Tohoku' in Japanese). In order to understand the impact of the disaster and the extent of post-disaster recovery, various surveys have been conducted, such as a post-disaster sediment environment survey (YOKOYAMA *et al.*, 2018), a survey of the benthos growth environment (KANEKO *et al.*, 2018), and construction of habitat maps (FUJII *et al.*, 2018). Seasonal changes in constituents of the phytoplankton (TANIUCHI *et al.*, 2017) and the distribution of diatoms (WATANABE *et al.*, 2017) in Sendai Bay were not affected by the tsunami. However, the incidence of dinoflagellates causing shellfish poisoning is reported to have increased in Sendai Bay (KAMIYAMA *et al.*, 2014), Kesennuma Bay (ISHIKAWA *et al.*, 2015), Ofunato Bay (TAKEHIKO *et al.*, 2016), and in southern Hokkaido Funka Bay (NATSUIKE *et al.*, 2014). Therefore, the effects of the tsunami differed, affecting some taxonomic groups (such as dinoflagellates) but not others (such as diatoms).

For Onagawa Bay, there have been reports of changes to the temporal and horizontal distribution of Chl *a* (FUJII *et al.*, 2018), size fractioned Chl *a* from 2007 to 2009 (ABE *et al.*, 2011), and the occurrence of phytoplankton species between 2018 and 2019 (MASUDA *et al.*, 2022). However, to our knowledge, there have been no reports so far on the composition of taxonomic groups of phytoplankton in the years immediately just after the tsunami. An outbreak of

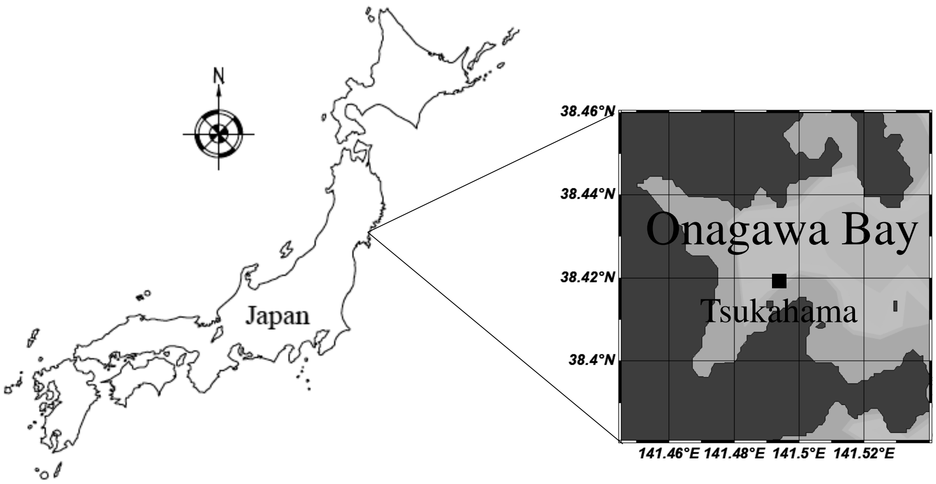

Fig. 1 Sampling site at Tsukahama (black square).

paralytic shellfish poisoning was caused in Onagawa Bay in 2018 by an increase in numbers of *Alexandrium* spp. (MASUDA *et al.*, 2022). There were also more cysts of *Alexandrium* spp. after 2018 in comparison with before the disaster and in 2013 (TANABE and KAGA, 2017). If a data series on phytoplankton species can be collected, it can be used as a medium- to long-term comparison to judge whether or not the coastal ecosystem has been restored to pre-tsunami conditions.

In the present study, pigment analysis and DNA sequencing were conducted on seawater collected between 2012 and 2013 from a site in Onagawa Bay: the Tsukahama area, which is one of the sampling points monitored for the occurrence of shellfish poisoning by Miyagi Prefecture Fisheries Technology Institute (MASUDA *et al.*, 2014). This study had the following objectives: to (1) follow the annual variation of phytoplankton assemblages in detail, (2) consider possible effects of phytoplankton fluctuations on natural feeding aquaculture, and (3) preserve a record of information on the phytoplankton in Onagawa Bay from 2012 to 2013 during the second year following the tsunami.

2. Materials and methods

2.1. Sample collections and pretreatments

A map of the sampling site is shown in Fig. 1. Water was collected at Tsukahama in Onagawa Bay at approximately monthly intervals from January 2012 to December 2013, using a sampling bucket and Van Dorn water sampler. The sampling depths were 0, 5, 10, 15, 20 m, and the bottom minus 1 m (set to 25 m in the contour figure).

2.2. Photosynthetic Pigment analysis

To quantify phytoplankton photosynthetic pigments [Chlorophyll *a* (Chl *a*), Fucoxanthin (Fuco), Chlorophyll *b* (Chl *b*), Alloxanthin (Allo), Peridinin (Perid)], 150 ml samples of seawater were filtered through Whatman GF/F glass microfiber filters (GE Healthcare UK Ltd., Buckinghamshire, UK). The phytoplankton pigments were extracted from the filter with 1 ml methanol and allowed to settle for at least 24 h in a freezer at −20℃. After removing the filter and centrifugation at 17,000 × g for 10 min, pigments in the supernatant were analyzed by high-performance liquid chromatography (HPLC; Shimadzu, Kyoto, Japan) using the method of ZAPATA *et al.* (2000). Contour plots of the annual variation for each major pigment detected by HPLC were made using Ocean Data View software (AWI https://odv.awi.de/).

2.3. DNA extraction, polymerase chain reaction (PCR), Next Generation Sequencing (NGS), and data analysis

NGS was conducted only on surface seawater samples. The DNA extraction method was basically the same as reported previously (OKUMURA *et al.*, 2020). Briefly, seawater samples were filtered using a Durapore filter and DNA was extracted from each filter using 1 mL SNET minus NaCl buffer (0.3% SDS with 5 mM EDTA, and 20 mM Tris HCl pH 8.0) and 40 μL of 5 mg/mL proteinase K (SHIMADZU CORPORATION, 2012), for at least 1 hour at 37℃. After removal of the Durapore filter, DNA extract solutions were centrifuged at 17,000 × g for 10 min and the supernatants were used as PCR templates. PCR was conducted using KOD FX of DNA polymerase according to the manufacturer's protocol (TOYOBO, 2019). The primers used in PCR were the same as those used previously (OKUMURA *et al.*, 2020), with an adaptor for Genome Sequencer-FLX (ROCHE, 2009, ROCHE APPLIED SCIENCE, 2013).

The psb *A* gene, which encodes the D1 polypeptide of the photosystem II reaction center complex, was amplified. PCR was performed under the following conditions: initial denaturation at 94℃ for 2 min; followed by 40 cycles consisting of denaturation at 98℃ for 10 s, annealing at 55℃ for 30 s, and extension at 68℃ for 1 min; and a final extension step at 68℃ for 10 min. DNA sequencing was conducted by Genome Sequencer-FLX (Roche, Basel, Switzerland). After sequencing, phytoplankton species were identified by a homology search using pipeline software QIIME (Quantitative Insights into Microbial Ecology; CAPORASO *et al.*, 2010).

3. Results

3.1. Annual variation of major pigments

Chl *a* concentrations tended to be higher during winter and spring, with a maximum concentration of 9.9 μg/L at 25 m depth on April 6, 2012, and 7.5 μg/L at 20 m on February 12, 2013 (Fig. 2). Fuco showed similar fluctuations to Chl *a*, with a maximum of 13.5 μg/L on April 6, 2012, and 6.7 μg/L on April 30, 2013. Chl *b* concentrations tended to be higher in June, with a maximum of 1.2 μg/L on June 26, 2012, and 1.1 μg/L on June 24, 2013. Perid concentrations tended to be sporadically higher in spring and summer, with a maximum of 0.2 μg/L on March 2, 2012, and 0.43 μg/L on July 29, 2013. Allo concentrations tended to be high during summer and fall, with a maximum of 0.53 μg/L on July 29, 2013, and 0.21 μg/L on October 9, 2012.

The fluctuation of each pigment concentration was related to that of Chl *a* concentration: significant correlations were observed between Chl *a* concentrations and major pigment concentrations (Fuco, Allo, Perid, and Chl *b;* Fig. 3), for all of R^2 values are above 0.28 (when the sample number is > 100 and $R^2 > 0.26$, the result is significant; OKUNO, 1978). The correlation ($R^2 = 0.67$) between Chl *a* and Fuco was the highest among the major pigments.

3.2. Phytoplankton relative abundance detected at the sea surface by NGS

Although the dominant phytoplankton taxa varied with the season, in general, the order was as follows: diatoms (51% of the total number of sequences) > green algae (27%) > haptophytes (9%) > dinoflagellates (7%). These four taxon

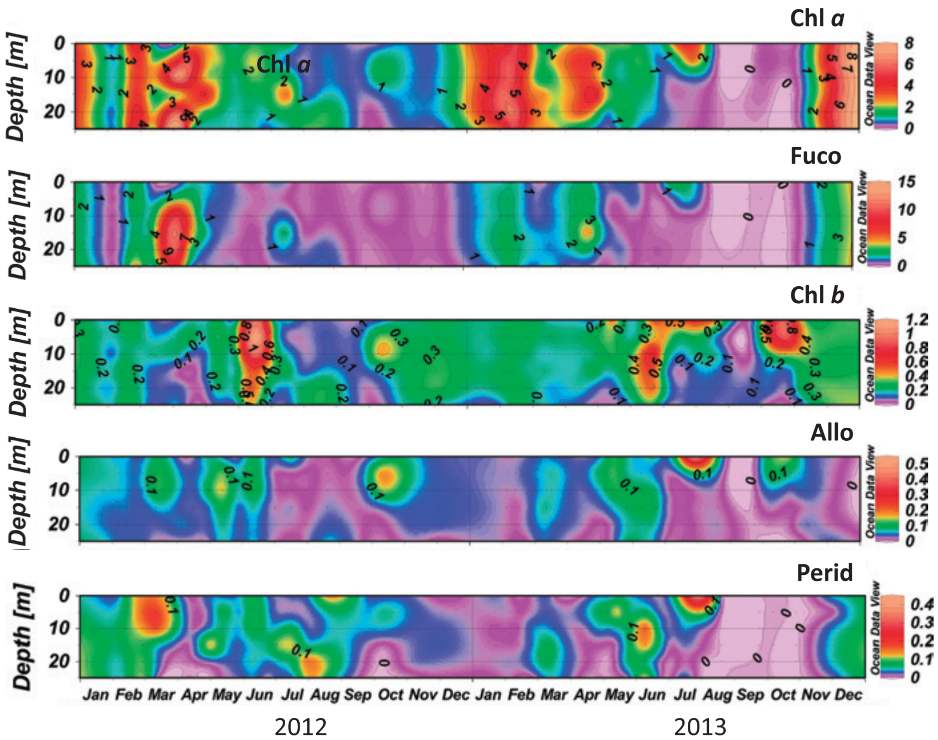

Fig. 2 Depth and temporal variation in pigment concentration at Tsukahama, Onagawa Bay, during the study period. (Color key at right indicates concentration, in μg/L).

groups accounted for more than 90% of the total (Fig. 4).

A total of 35 operational taxonomic units (OTUs) were detected for diatoms, which was the highest of all the phytoplankton groups. The proportion of diatoms tended to increase during periods of high Chl *a* concentration. Chl *a* in the surface layer exceeded 5 μg/L on both February 28, 2012, and February 12, 2013, and the number of diatom sequences was > 70% of the total number of sequences detected at those times. The relative abundance among the diatoms (Fig. 5a) was as follows: *Skeletonema costatum* (20% of the total number of sequences) > *Asterionella* spp. (8%) > *Chaetoceros* spp. (7%) > *Thalassiosira* spp. (7%). The proportion of *S. costatum* tended to increase in spring when it sometimes accounted for 77% of all sequences. From June to August, when the relative abundance of *S. costatum* decreased, the proportion of *Chaetoceros* spp. tended to increase, sometimes up to 60% of the total number of sequences. In winter, the proportion of *Asterionella* spp. increased, up to 81%. *Thalassiosira* spp. show less seasonality than other diatoms, with a maximum of 28%. An approximately seasonal trend was observed, with an increase in the proportion of *S. costatum* in spring, *Chaetoceros* spp. in summer, and *Asterionella* spp. in winter.

For green algae, 24 OTUs were detected, the second highest number after diatoms (Fig. 5b). The proportion of green algae increased as the proportion of diatoms decreased, the former exceeding 70% in June, when Chl *b* increased, in both 2012 and 2013. The relative abundance of green algae genera, dominated by

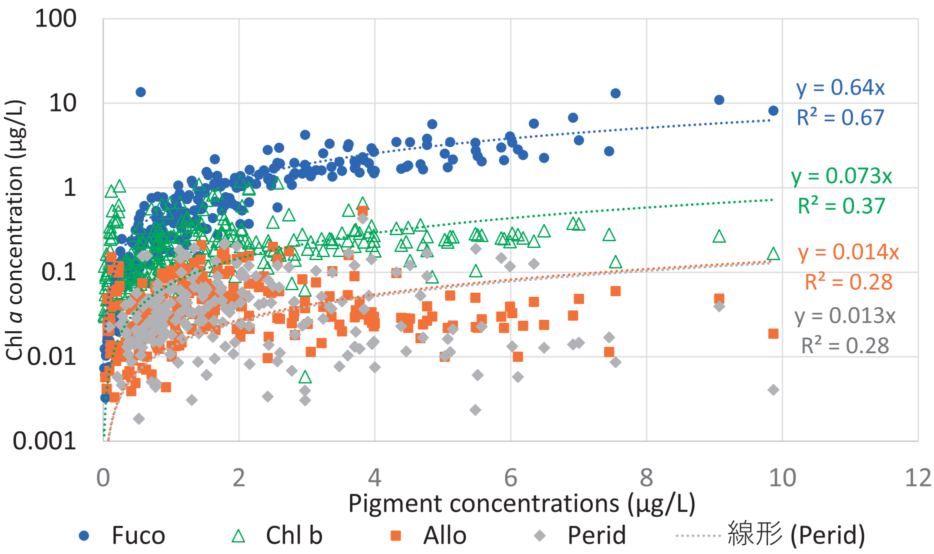

Fig. 3 Scatter plot and correlation equations between Chl *a* (ordinate) and four other pigment concentrations (abscissa). The plots are each pigment concentration by the sampling depths for all observation dates. There were 252 samples of each pigment. Correlation coefficients were calculated by Microsoft Excel. When the sample number is > 100 and R^2 > 0.26, the result is significant (i.e., all the values are significant).

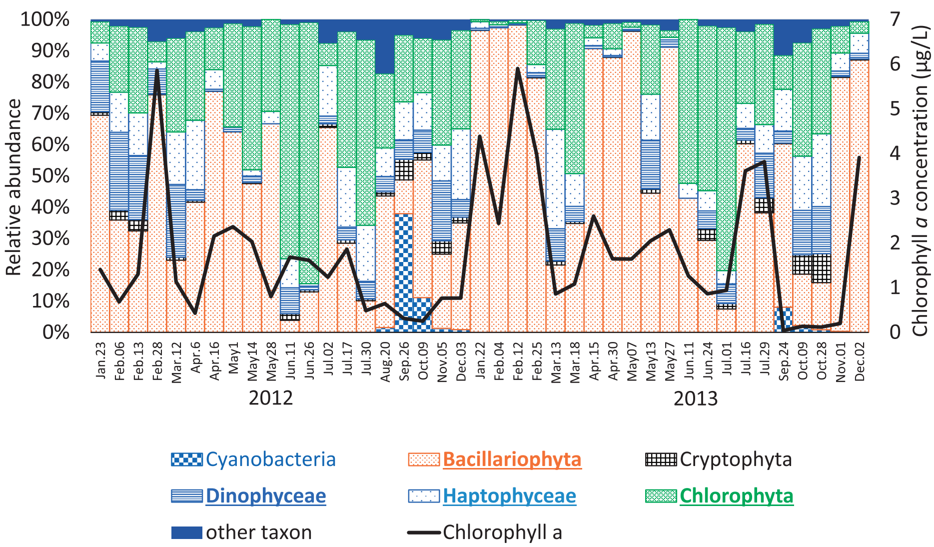

Fig. 4 Chlorophyll *a* concentration and relative abundance of phytoplankton assemblages at the surface at Tsukahama during the years 2012 and 2013. The legends of major phytoplankton groups are shown in bold and underlined. The legend "other taxa" includes Bolidophyceae, Phaeophyceae, Pinguiophyceae, Xanthophyceae, Chrysophyceae, Compsopogonophyceae, Dictyochophyceae, Florideophyceae, Foraminifera, Pelagophyceae, Raphidophyceae, and Synurophyceae.

Prasinophyceae, was as follows: *Micromonas* spp. (14% of the total number of sequences) > *Ostreococcus* spp. (7%) > *Bathycoccus* spp. (2%). In June, the proportion of *Ostreococcus* spp. and *Bathycoccus* spp. also increased with *Micromonas* spp.

The relative abundance of Haptophyta tended to increase in the period when the Chl *a* concentration decreased, sometimes up to 32% (Fig. 5c). The relative abundance of the Haptophyta was as follows: *Phaeocystis* spp. (7% of total leads) > *Emiliania huxleyi* (1%), *Phaeocystis* spp. was the dominant species.

The relative abundance of dinoflagellates changed sporadically and did not show the seasonality observed with diatoms, but the proportion of dinoflagellates to the total number of sequences increased up to a maximum of 25% (Fig. 5d). *Dinophysis norvegica* was the dominant dinoflagellate throughout the observation period: *Dinophysis norvegica* (5% of the total number of sequences) > *Peridinium foliaceum* (0.3%) > *Dinophysis acuminata* (0.2%).

The relative abundance of Cryptophyta was as follows: *Teleaulax amphioxeia* (0.7%) and Cryptophyta sp. CR-MAL11 (0.7%) was dominant regardless of the season (Fig. 5e).

Although the proportion of Cyanobacteria was less than 2% of the total number of sequences for most of the year, there was a maximum of 38% on September 26, 2012 (Fig. 5f). Cyanobacteria also increased in the summer of 2013, reaching approximately 8% in September. The most common species of cyanobacteria detected was *Prochlorococcus marinus*.

4. Discussion

Chl *a* concentration in Onagawa Bay tended to be high during winter and spring. Maximum concentrations were 9.9 μg/L at 25 m depth in 2012 and 7.5 μg/L at 20 m in 2013 (Fig. 2). Phytoplankton growth (Taniguchi, 1983; Doney, 2006) is regulated by water temperature (Trombetta *et al.*, 2019), light intensity (Gle *et al.*, 2007), nutrient concentrations (Colijn and Cadee, 2003), and blooms begin when solar radiation is sufficient, and the mixing depth becomes shallower by stratification (Sverdrup, 1953). Along the Pacific coasts of Tohoku and Hokkaido, phytoplankton blooms have been observed in early spring in Funka Bay (Kudo *et al.*, 2000), Otsuchi Bay (Furuya *et al.*, 1993), Sendai Bay (Taniuchi *et al.*, 2017), and in Onagawa Bay in 2007–2009 (Abe *et al.*, 2011) and in 2018–2019 (Masuda *et al.*, 2022). The timing of blooms in Onagawa Bay from 2012 to 2013 was similar to these other records.

Chl *a* concentration in Onagawa Bay from 2012 to 2013 was similar to, or slightly lower than, the previous reports of slightly above 10 μg/L (Furuya *et al.*, 1993; Kudo *et al.*, 2000; Abe *et al.*, 2011; Taniuchi *et al.*, 2017). While, Chl *a* concentration of about 4 μg/L was observed in July, 2013. Although the increase of Chl *a* concentration during summer was observed in Onagawa Bay in the past (Abe *et al.*, 2011), it differed from the general trends in other parts of the Pacific coasts of Tohoku and Hokkaido. In addition to nutrient and solar radiation limitations, phytoplankton growth also is reduced due to grazing by higher trophic organisms (Abe *et al.*, 2011). The mouth of the Shin-Kitakami River (an 'A' class river managed by the Japanese government) is located approximately 15 km north of Onagawa Bay, and the water from this river tends to flow southward along the coast (Gomi *et al.*, 2021). This river water contributes nutrients to Onagawa Bay, which enriches phytoplankton growth there.

The correlations between Chl *a* concentration and each major pigment concentration were all significant (Fig. 3). In particular, the R^2 value for

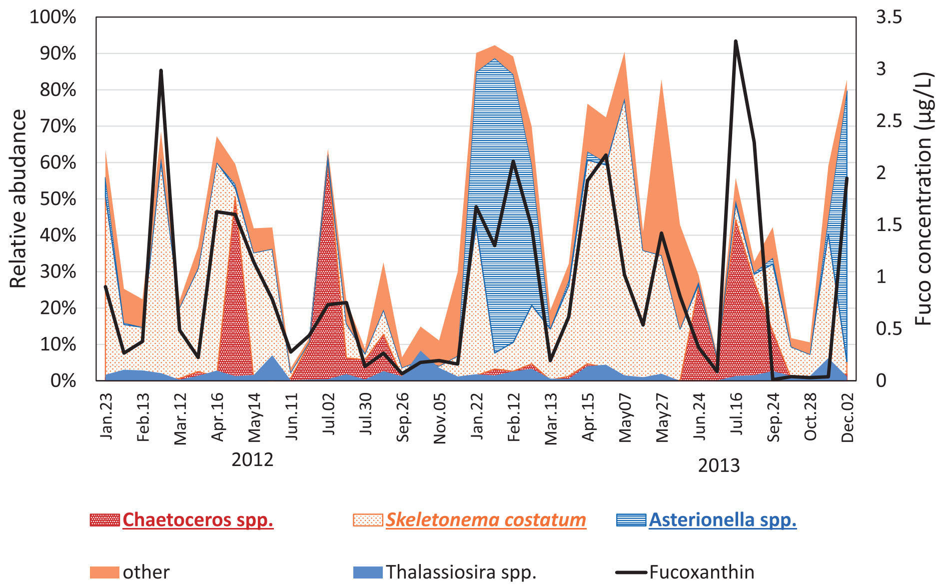

Fig. 5a Fucoxanthin (Fuco) concentration (bold black line) and relative abundance of diatoms during the years 2012 and 2013. The species in bold and underlined were predominant.

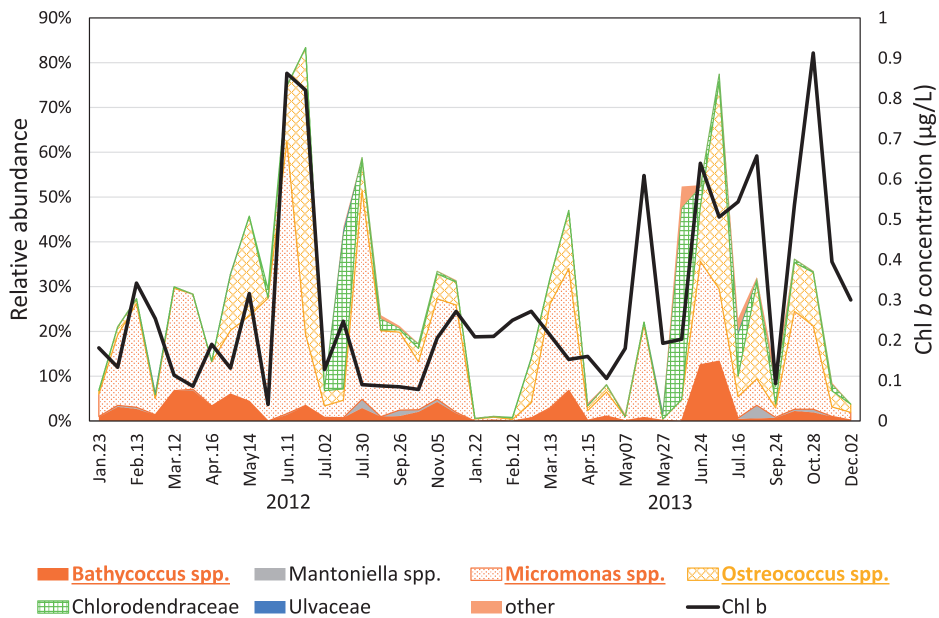

Fig. 5b Chlorophyll *b* (Chl *b*) concentration (bold black line) and relative abundance of green algae during the years 2012 and 2013. The species in bold and underlined were predominant.

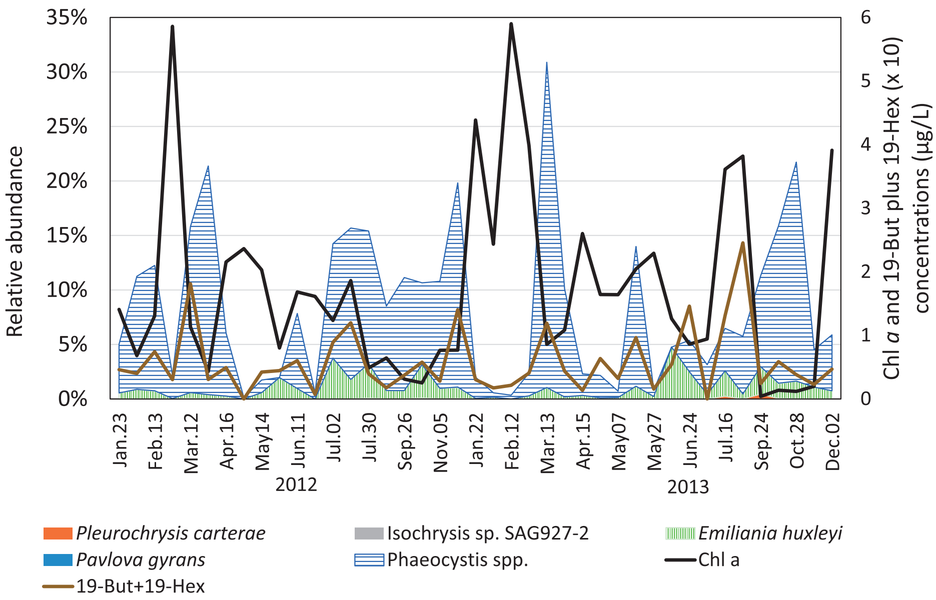

Fig. 5c Chlorophyll *a* (Chl *a*) concentration (bold black line) and relative abundance of haptophytes during the years 2012 and 2013.

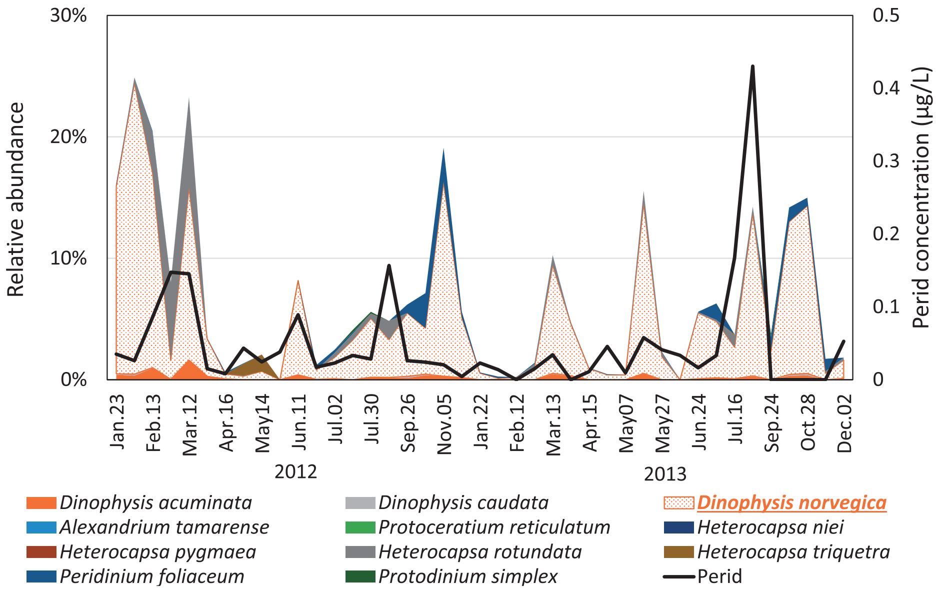

Fig. 5d Peridinin (Period) concentration (bold black line) and relative abundance of dinoflagellates (many species of *Dinophysis* spp. and *Alexandrium* spp. are toxic) during the years 2012 and 2013. The species in bold and underlined were predominant.

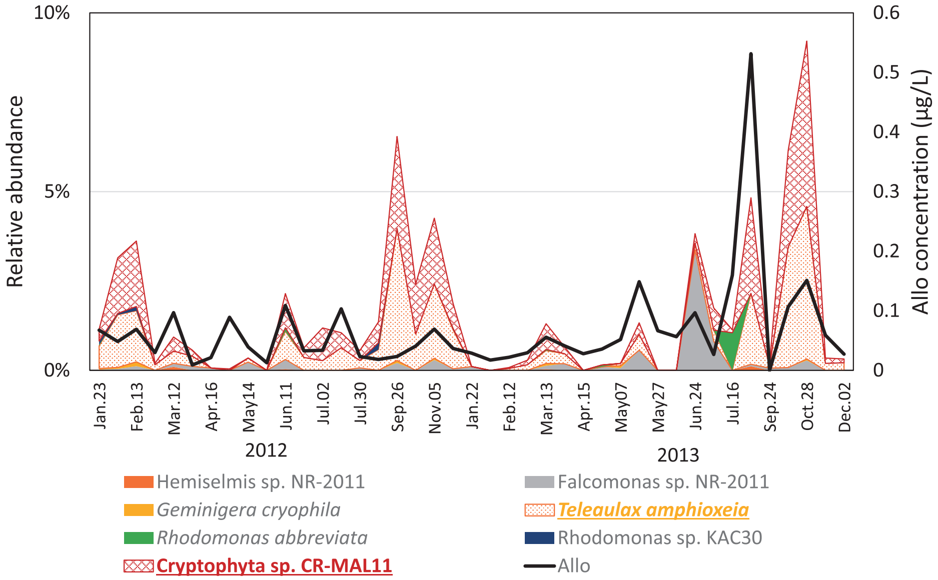

Fig. 5e Alloxanthin (Allo) concentration (bold black line) and relative abundance of cryptophytes during the years 2012 and 2013. The species in bold and underlined were predominant.

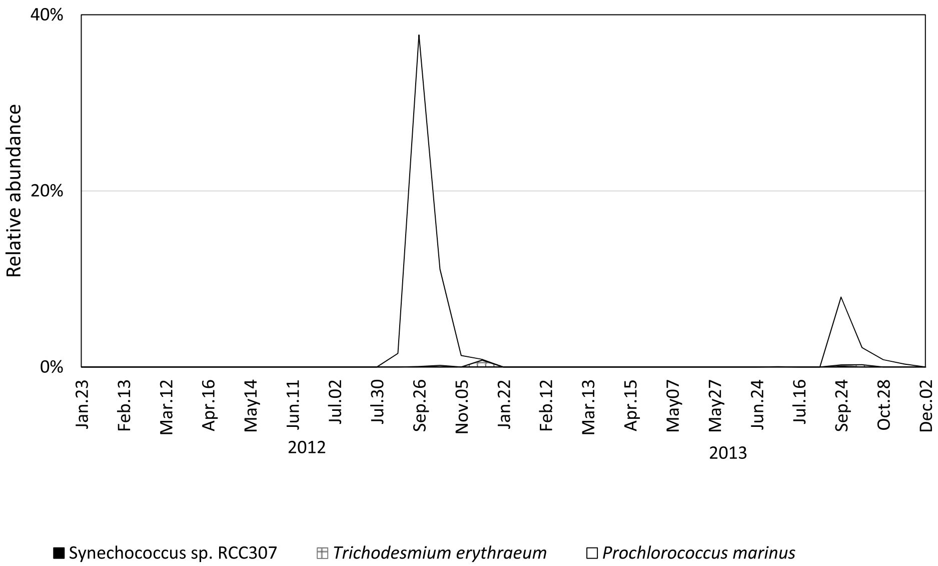

Fig. 5f Relative abundance of Cyanobacteria during the years 2012 and 2013.

Chl *a* versus Fuco was the highest. In general, different groups of phytoplankton have characteristic taxon-specific pigments, such as Fuco in diatoms, Allo in cryptophytes, Perid in dinoflagellates, and Chl *b* in green algae (JEFFREY and VESK, 1997). The high correlation between Fuco and Chl *a* suggests that the variation observed in Chl *a* is due mainly to variation in the number of diatoms present. The high proportion of diatoms during the high Chl *a* period from winter to spring suggests that the spring bloom in Onagawa Bay is mainly caused by diatom growth. Diatoms are generally considered to be dominant in temperate zones (IRIGOIEN *et al.*, 2002). The spring blooms in Funka Bay (KUDO *et al.*, 2000), Otsuchi Bay (FURUYA *et al.*, 1993), and Sendai Bay (TANIUCHI *et al.*, 2017; WATANABE *et al.*, 2017) also have been attributed to the presence of diatoms. Microscopic observations of phytoplankton in Onagawa Bay before the tsunami (ABE *et al.*, 2011), and from 2018 to 2019 (MASUDA *et al.*, 2022) also showed that diatoms were dominant. The spring bloom caused by diatoms in Onagawa Bay from 2012 to 2013 was also considered to be a general seasonal characteristic. However, these microscopic observations, in comparison with the DNA sequencing in the present study from 2012 to 2013 show some inconsistencies. For example, *Pseudo-nitzschia* spp. and *Leptocylindrus danicus* observed by microscope in samples from 2018 to 2019 (MASUDA *et al.*, 2022) were not detected as dominant species by DNA sequences from 2012 to 2013. We speculate that this may be explained by differences in the offshore ocean environment between 2018–2019 and 2012–2013 (Masuda personal communication), or technical problems with DNA sequencing (MEDINGER *et al.*, 2010; XIAO *et al.*, 2014).

Although the correlation between Chl *a* and Chl *b* was lower than that between Chl *a* and Fuco, the number of green algae OTUs was the second highest after those of diatoms. The main species of green algae observed were *Micromonas* spp., *Ostreococcus* spp., and *Bathycoccus* spp.. There are a few reports of green algae from the Pacific Tohoku coast, in comparison with diatoms (WATANABE *et al.*, 2017), which are useful producers in the marine food web, and dinoflagellates (MASUDA *et al.*, 2014), of which some species are poisonous. In Sendai Bay, picoeukaryotes are as abundant as diatoms (TANIUCHI *et al.*, 2017). In Onagawa Bay, picoeukaryotes are commonly observed in summer by microscopic observation (Masuda, personal communication). As *Micromonas* spp., *Ostreococcus* spp., and *Bathycoccus* spp. are less than 3 μm in diameter (VAULOT *et al.*, 2008), it is deduced that the picoeukaryotes commonly observed in Sendai Bay and Onagawa Bay are these three species of green algae.

The proportion of cyanobacteria, which have a diameter < 1 μm, increases during the summer (Fig. 5f). Both cyanobacteria and the picoeukaryotes, which are smaller than diatoms, have better tolerance to low nutrient conditions (FLOMBAUM *et al.*, 2013). These groups seasonally increase in summer with the rise in water temperature (FLOMBAUM *et al.*, 2013; TANIUCHI *et al.*, 2017). Therefore, it is considered that the proportion of green algae in Onagawa Bay was also higher in summer. The fact that *Prochlorococcus* sp. was detected at much higher levels than *Synechococcus* sp. may have been a characteristic at this time at Tsukahama in Onagawa Bay because *Synechococcus* sp. was frequently detected in larger numbers than *Prochlorococcus* sp. in the surface sediment in Onagawa Bay. (Okumura personal observation). Since the filtration rate of shellfish is considered to decrease due to the passage of small-sized plankton, < 5 μm, such plankton groups (RIISGÅRD, 1988) are presumably of lesser importance in shellfish feeding.

Among haptophytes, there were seven times more *Phaeocystis* spp. present than *Emiliania huxleyi*. *Phaeocystis* spp. are ubiquitous, and sometimes red tide, and some species are reported to be toxic (SCHOEMANN *et al.*, 2005; WANG *et al.*, 2021). At present, the occurrence of *Phaeocystis* spp. is low in Onagawa Bay, and this species has not been investigated in natural feeding aquaculture making use of natural phytoplankton such as diatoms and dinoflagellates, but it is necessary to continuously monitor these species in the future.

The cryptophyte pigment Allo was often present in high concentrations in summer and autumn. Among the cryptophytes, *Teleaulax amphioxeia* and the cryptophye species CR-MAL11 were dominant regardless of the season. These two species are food for the ciliate *Myrionecta rubra* (YIH *et al.*, 2004), on which *Dinophysis* spp. feeds (PARK *et al.*, 2006): *Dinophysis* spp. are responsible for diarrheal shellfish poisoning (SUZUKI *et al.*, 2017). However, in Onagawa Bay, the proportions of *Teleaulax amphioxeia* and CR-MAL11 were always high, and therefore provide conditions suitable for the growth of *Dinophysis* spp. If the timing of a high abundance of cryptophytes coincides with the presence of *Myrionecta rubra* and *Dinophysis* spp., diarrheal shellfish poisoning may occur due to the increase in *Dinophysis* spp. Indeed, diarrheal shellfish poisoning caused by *Dinophysis* spp. occurs almost every year in Onagawa Bay (MASUDA *et al.*, 2014).

Analysis of phytopigments by HPLC is a useful technique to determine the amount of each phytoplankton taxon because the concentration of each pigment present can be determined (MACKEY *et al.*, 1996; ZAPATA *et al.*, 2000), even if the phytoplankton species cannot be identified. However, samples cannot be stored for long periods because the pigments are easily degraded (MANTOURA *et al.*, 1997). DNA sequencing by NGS is suitable to identify phytoplankton species, and may sometimes surpass microscopic observation in detecting species in small numbers (MEDINGER *et al.*, 2010; XIAO *et al.*, 2014). When microorganisms are sequenced, samples can be stored for more than ten thousands of years (LEJZEROWICZ *et al.*, 2013). The disadvantage of sequencing is that it is not quantitative, and may not always agree with the results of microscopic observation (MEDINGER *et al.*, 2010; XIAO *et al.*, 2014). In the present study, it was possible to compensate for the shortcomings of these individual techniques by combining pigment analysis by HPLC and DNA sequencing by NGS. The 454 sequencing by Genome Sequencer-FLX used provides less data than with the latest Miseq sequencer (Illumina, California, U.S.A.), the use of which in the future will enable a more detailed understanding of phytoplankton assemblages.

The present study investigated the entire phytoplankton assemblages in Onagawa Bay from 2012 to 2013. In addition to recognizing the presence of diatoms of use in shellfish feeding and dinoflagellates unsuitable for shellfish feeding, it was possible to understand the temporal trends of phytoplankton assemblages. Such useful information is necessary in order to evaluate the feed environment for aquaculture organisms, relying on natural feeding, such as the presence of picoeukaryotes and cyanobacteria (too small for filter-feeding), cryptophytes (indirect food of *Dinophysis* spp.), and haptophytes (some species of which are poisonous). Continued monitoring and accumulation of temporal data over the medium to long term will aid understanding of the feeding environment for shellfish aquaculture.

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Sustainable development and responsible exploitation. As an example, the management and exploitation of diadromous species in the context of small-scale fisheries

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Abstract: The sustainable development policy is a negotiation process among actors. Some are strong, others weak or absent. Some are directly concerned for their social and economic future by the productivity of the natural environment while others not. Some are never present at the negotiation table such as future generations and Nature itself. The Precautionary principle is included in the French Constitutionality Corpus in 2005 but, with some modifications. In particular, the notions of "economically bearable cost" and "effective and proportionate measures" have been added. In that context, the sustainable exploitation of aquatic living resources is more and more difficult to achieve in accordance with the Maximum Sustainable Yield, the level of which continues to decline with the degradation of continental, estuarine and coastal environment under the pressure of many anthropogenic factors. It is the reason why the fisher communities prefer to speak about 'responsible exploitation' rather than 'sustainable exploitation'. A more socio-ecosystem-based approach is needed. This is possible at the local scale for implementation of a genuine environmental governance, (fourth sustainable development component) and to take into account a fifth component which is Culture in the sense of knowledge and know-hows as the expression of intergenerational solidarity.

Keywords : *sustainable development, responsible exploitation, small scale fisheries, diadromous fishes*

1. Introduction

Sustainable development has been primarily defined in a report of the World Commission for Environment and Development (WCED): Our Common Future (WCED, 1987). The well-known diagram of that concept appeared in 1987

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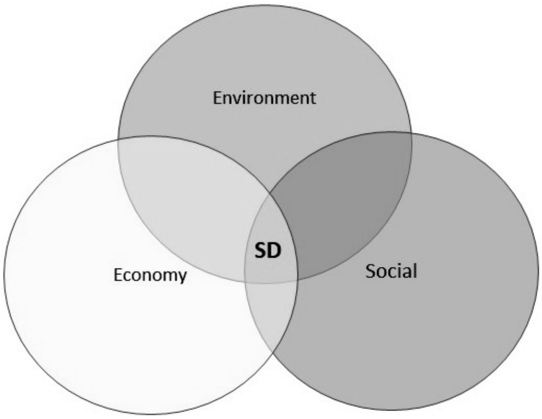

Fig. 1 Diagram of sustainable development (SD) after WCED (1987).

(Fig. 1) and placed sustainable development at the convergence of three areas of equal interest: economy, social and environment.

Responsible exploitation of fisheries resources is a term occasionally used in the academic literature. Scientists, managers and NGOs prefer the term "sustainable exploitation" referring to a fishery biology indicator used by the scientific community and called "the Maximum Sustainable Yield" (GRAHAM, 1935; RICKER, 1954, 1975). The community of fishers prefers to use the term "responsible exploitation" as the sustainability of a given commercial activity based on the productivity of natural environment is a complicated concept that depends on a large diversity of factors, most of these factors are not under the fishers control (BOGASSON, pers. com., 2009; PROUZET, 2010; PROUZET *et al.*, 2019). In fact, the sustainability of their fishing activity is largely driven by the productivity of the aquatic environment (habitat quality and ecological connectivity) constrained by natural and anthropogenic pressures.

In this communication, through the example of diadromous species and more widely of small-scale fisheries, we will show the non-efficiency of sectoral policies in the implementation of the sustainable development as defined by the WCED and the need to implement a more systemic approach at a territorial or local scale as mentioned by the Millennium Assessment (REID *et al.*, 2005). In that socio-ecosystem approach, responsible exploitation and traditional knowledge and know-hows of fishers communities are of particular importance to develop environmental watch, capacity building to observe the trend of aquatic populations and awareness-raising activities in connection with scientists, managers and NGOs. It matches with the foundation of the "Satoumi concept" developed in Japan (YANAGI, 2020; TANAKA and FURUKAWA, 2020; KOMATSU *et al.*, 2020) and the aim of the "Nature and Culture" project defined by the French-Japanese Oceanographic Societies of France and Japan in cooperation with national committees of professional fishers and shellfish farmers. (http://socfjp.com/en/french-japanese-society-of-oceanography/).

2. A genuine sustainable development

The definition of a sustainable development policy is a negotiation among actors characterized by different social and economical status that use the goods and services of the environment. Some are strong, others weak or even absent such as future generations or the Nature itself. In 1995, the Barnier Law (Loi n° 95-101 du 2 février 1995 dite loi Barnier) incorporated in the French legislation, three key principles: the Precautionary principle, the Prevention principle and the Polluter-pay principle. But the text of the Precautionary principle agreed by the French legislator has been somewhat modified from the original definition adopted in the 1992 Earth Summit. In particular, the notions of "economically bearable cost" and "effective and proportionate measures" have been added. On 2

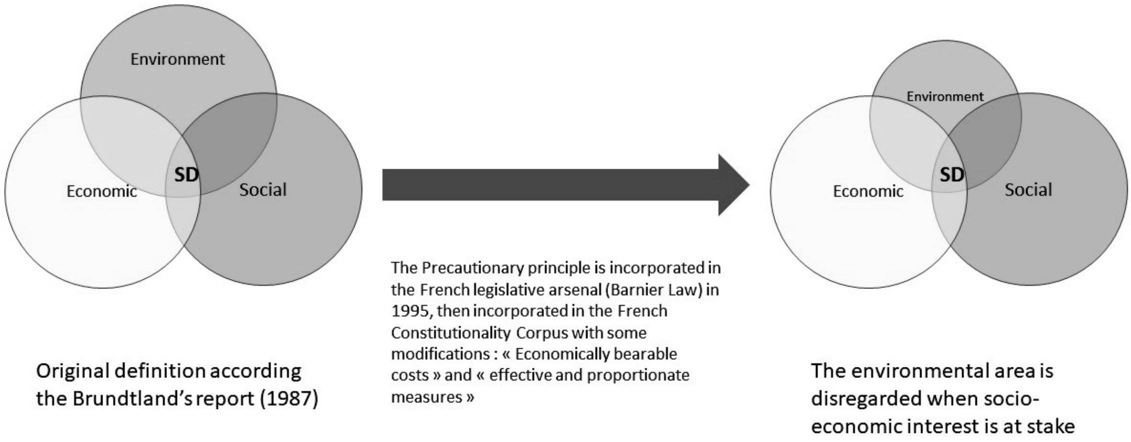

Fig. 2 Shift from balanced to socio-economically centred negotiation (source: PROUZET, 2021).

September 2002, the French President Chirac said to the plenary assembly of the fourth Earth Summit at Johannesburg: "our house is burning and we are looking elsewhere". In 2005, the Precautionary principle is included with the Charter for the Environment in the French Constitutionality Corpus in order to have an equality of treatment with the fundamental 1789 human and civil rights and with the 1946 economic and social rights (LAQUIÈZE, 2012). Despite the inclusion of the Precautionary principle in the French Constitutionality Corpus, it is important to recognize at present the unbalance between environmental and socio-economical needs. Fig. 2 is a schematic description of how sustainable development is considered today: the environmental sphere is disregarded when socio-economic interest is at stake and the balance between the three sustainable development components -economic, social and environmental- is not respected.

In negotiating the definition and implementation of sustainable development policy, weak actors such as communities of professional fishers or fish and shellfish farmers, are usually dependent on the productivity of aquatic environment for their own survival. For hydropower producers or farmers, only the quantity of water available is important, but not its quality. Estuary channelization, protections against floods and rising sea level for urban and tourism development, result in the destruction of functional habitats for many terrestrial or aquatic species (FUSTEC and LEFEUVRE, 2000; ADAM *et al.*, 2008; LE PAPE *et al.*, 2003a; PROUZET, 2010; LE LUHERNE *et al.*, 2016). Many fish species have their spawning and/or their nursery areas in coastal, transition ad continental waters (LE PAPE *et al.*, 2003b; Halpern *et al.*, 2008; ROCHETTE *et al.*, 2010; PROUZET and MICHELET, 2019; FEUNTEUN and PROUZET, 2020) and that destruction has a direct impact on the productivity of fish communities. A mere regulation of fishing without the protection and restoration of degraded or depleted habitats, cannot lead to the sustainability of this age-old activity (PROUZET *et al.*, 2019).

An assessment of this sustainable development policy at a large scale shows that environmental protection objectives are far from being achieved and this is not only due to climate change. In France but also in Europe, since the second half of the 20th century, the organic

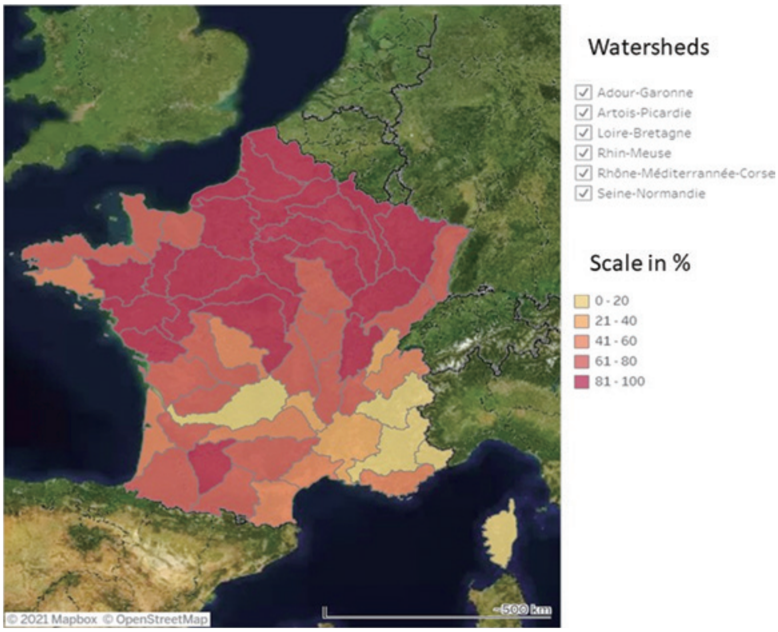

Fig. 3 Level of the ecotoxicity risk index by watershed on the period from 2015 to 2017 (source: http://www.eaufrance.fr/).

pollution is aggravated by the increasing production and use of synthetic chemical products (RABIC *et al.*, 2009; TCHILIAN, 2009). Around 100,000 chemicals are produced, imported and used in the European market and 5,000 of them (5%) are considered dangerous for humans and the natural environment (LOIZEAU and TUSSEAU-VUILLEMIN, 2014; PETIT *et al.*, 2014). France is one of the largest consumers of pesticides in the world, namely, the third country in the world in 2003, with 100,000 t of which 90% was used for agriculture. So, the current water quality assessment is not encouraging. As mentioned in a report of the French Senate (ANONYMOUS, 2003), we can find in freshwater some very high concentrations of phytosanitary products one hundred times higher than the standard for drinking water. In France between 20 and 40% of water masses are in poor chemical status (STAUB, 2021). Fig. 3 shows the ecotoxicity risk index at watershed level. This index indicates a ratio of the substance concentration on its concentration without foreseeable effect on the environment. The larger the number and higher than 1, the higher the risk to the environment. This index does not take into account the cocktail effect of the chemical substances.

Fig. 3 shows the percentage of samples with an index higher than 1 for the different watersheds. We can notice the predominance of dark colours with a level greater than 60% indicating a high risk of ecotoxicity on a great number of watersheds. At a larger scale in Europe, it is the same situation. In 2018, according to the European Environment Agency (EEA) only 40% of the European rivers achieve a good ecological status and 38%, a good chemical status. The objective of the Water Framework Directive (WFD) was to reach the good state of the European water masses by 2015. It is far from being achieved in 2021, shifting the new target to 2027.

Along with the deterioration of the quality of continental water masses, the damage inflicted on functional habitats of aquatic species and ecological connectivity between varied ecosystems, hinder the proper functioning of the life cycle of aquatic species. In 1994, the Bernard report (BERNARD, 1994) mentioned that 2/3 of wetlands in France have disappeared during the last century. The definition of wetlands, here, is given by TURNER (1992): "Any element of the continuum connecting the aquatic environment to the terrestrial environment". These natural ecosystems are not only important for the regulation of river flow or filtration of organic or chemical substances (FUSTEC and LEFEUVRE, 2000), but also for the completion of the life cycle of endangered species such as the European eel (*Anguilla anguilla*) (FEUNTEUN and PROUZET, 2020). Such wetlands loss is a general fact in Europe and even in the World (TURNER, 1992; FUSTEC and LEFEUVRE, 2000, BERNARD, 1994). In addition, many estuaries have been channelized in France and in Europe. For example, the Seine estuary, before 1846, had a marshland area of 250 km^2, the channelization of the estuary, the urbanisation and industrialisation of its banks have reduced the area to 30 km^2, resulting in an irreversible loss of very important habitats for many marine species in the Channel (LE PAPE *et al.*, 2003; LE LUHERNE *et al.*, 2016). LEFEUVRE (1985) and LEFEUVRE *et al.* (2000) indicated that the natural banks of the Loire River have been reduced by channelling and urbanization from 300 to 30 km^2. In Brittany (north western part of France), 65% of the salt marshes have disappeared in less than 50 years by land draining, dyking and land reclamation (PONCET, 1984). The lost of an important part of these wetlands have a direct impact on the productivity of marine and continental aquatic ecosystems. TEAL (1962) showed that 45% of the organic matter produced in the saltmarshes were exported to coastal waters. ODUM (1980) confirms Teal's work and shows that salt marshes are the source of the wealth of coastal marine waters. According to DUGAN (1992), 2/3 of the fish consumed in the World spent part of their life cycle in wetlands.

The edification of many big dams on the rivers since, at least, the beginning of the 20th century has led to the fragmentation of ecosystems and the hindrance of the free movement of migratory fishes: salmon (*Salmo salar*), sea trout (*Salmo trutta*), twaite shad (*Alosa fallax*), allis shad (*Alosa alosa*), European eel (*Anguilla anguilla*), sea lamprey (*Petromyzon marinus*) (PROUZET and MICHELET, 2019; FEUNTEUN and PROUZET, 2020). The improvement of ecological connectivity takes times, costs a lot of money and France, like many countries in Europe that have artificialized their rivers mainly for hydroelectric needs or for water supply, has not achieved the objectives it had set for the restoration of hydrological and ecological balances. Thus, the report of the French National Assembly (ANONYMOUS, 2016) is clear: "France has not given itself the means to achieve its ambition". It was not until the transposition of the Water Framework Directive (WFD-D/2000/60/CE) into French law in 2006 that ecological continuity was really taken into account. Despite this, improvements are slow and in order to achieve the objectives set under the WFD (good status of water bodies) in 2020, the rate of equipment to improve migratory transparency of the remaining 15,000 dams would have to be six times higher than that previously adopted. This is unfortunately not the case. In 2018, the French National Plan for Eel (in the framework of the Council regulation 1100/2007) mentioned that only 19.6% of barriers located on eel critical habitats had been equipped with fish ladders

(Anonymous, 2018). This lack of lateral and longitudinal ecological continuity is a major hindrance to the production of young eels in the lower and middle parts of the catchment areas, which then supply all the functional habitats of the species by diffusion or active migration of young individuals (Prouzet *et al.*, 2019).

Considering the extent of the degradation of continental aquatic ecosystems and its impact on the quality of coastal waters, the objectives of good ecological status foreseen in Marine Strategy Framework Directive (D/2008/56/CE) by 2020 could not be achieved. In 2015, just over 50% of the 179 coastal water bodies are in good or very good ecological status (Lesueur, 2019).

As already mentioned, the intensification in France, but also in many countries, of the migration of human populations and economic activities to coastal areas, and of protection against sea level rise, is leading to increased artificialisation and urbanisation of these areas to the expense of important marine species production areas (Anonymous, 2014).

On the coasts, but also in all the seas and oceans, there are large amounts of plastic (estimated at 268,940 t for the number of fragments of 5,250 billion), 80% of which are land-based. However, these estimations made during the period 2007-2013, are underestimated given that global plastic production reached 288 million tonnes in 2012, i.e. 625% more than that produced in 1975. The plastic waste is dispersed in 5 main areas of accumulation found in the North and South Pacific Oceans; the North and South Atlantic Oceans and the Indian Ocean (Eriksen *et al.*, 2014). Much of these plastics come from the mismanagement of urban waste, which was estimated to have been released into the environment between 5 and 13 million tonnes in 2010. If nothing is done, projections for 2025 could be between 50 and 130 million tonnes.

As plastic particles come in different sizes and are found in all marine ecosystems, they can carry invasive species or be ingested by various components of the food chain. Some absorbed compounds are bio-available and can be bio-accumulated with concentration levels of up to 100,000, which can lead to the contamination of many living resources (Rochman, *et al.*, 2013).

If we add the effects of climate change to the anthropogenic pressures, we have many constraints on ecosystems (especially aquatic ones) and the goods and services that these ecosystems provide. The latest IPBES report (IPBES, 2019) lists the main factors influencing biodiversity loss at the global level. Climate change is an important pressure factor, but less than the effects of changes in the use of marine and terrestrial ecosystems or those caused by the direct exploitation of resources or, in certain environments, the effects of pollution.

In this context, we cannot have a sectoral approach that allows one use (agriculture, industry, urbanization) to make expenses of nature that jeopardize the future of uses that depend directly on the natural productivity of environment (case of small-scale fishing for example).

Hence the need for implementation of a sustainable development policy, to introduce into the negotiation process a fourth dimension which is that of environmental governance based on the principle of responsibility defined by Hans Jonas (1990): "to act in such a way that the effects of your action are compatible with the permanence of an authentically human life on earth". Its objective is to minimise the ecological footprints of different uses on the environment and not just those of the weakest actors (Prouzet *et al.*, 2019).

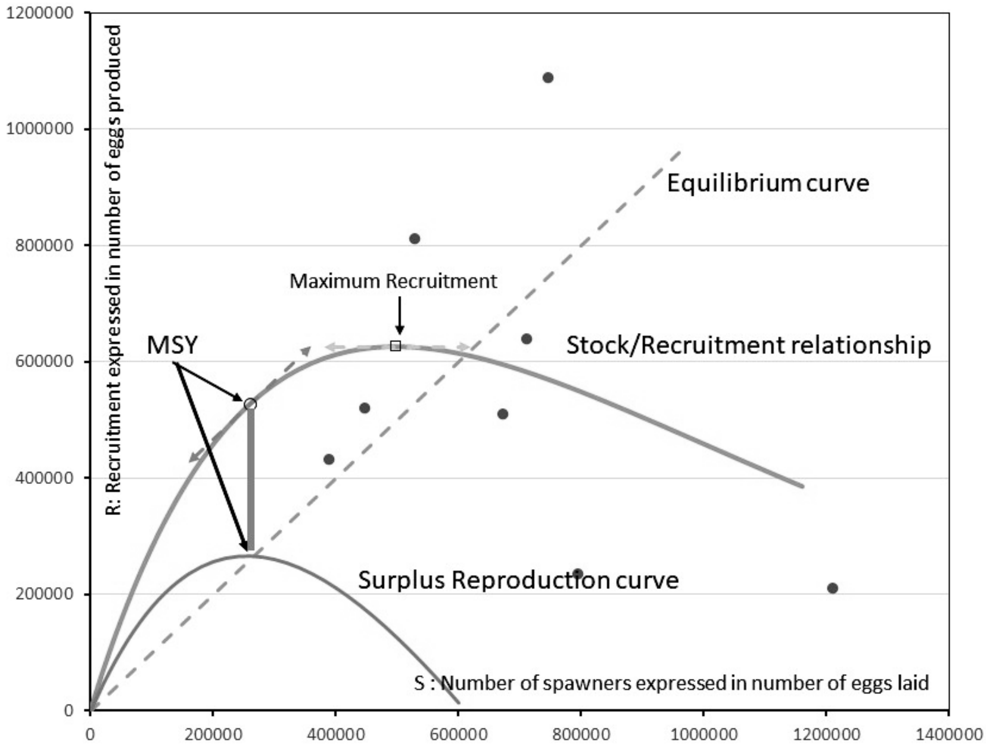

Fig. 4 Example of a Stock-Recruitment curve (S/R curve) and a Surplus Reproduction curve expressed according the RICKER's model showing the position of the MSY (Maximum Sustainable Yield) on the S/R curve corresponding to the maximum of the Surplus Reproduction Curve.

3. Sustainable versus responsible exploitation.

3.1. The Stock-Recruitment (S/R) relationship and the Maximum Sustainable Yield (MSY)

From a scientific point of view, a sustainable exploitation of fish resources is a fishing activity that respect a total amount of catch for a given species around the Maximum Sustainable Yield (MSY) defined by the S/R relationship.

From a schematic viewpoint, there exists two types of S/R relationships defined either by a dome-shaped curve (RICKER, 1954, 1975) or a plateau-shape (BEVERTON and HOLT, 1957). In most reports using this fish biology indicator, the MSY is defined according to a dome-shape relationship as mentioned in Fig. 4.

In that example drawn from Dumas' data (DUMAS and PROUZET, 2003), the observed values are in blue solid circle and expressed in number of salmon eggs. The S/R curve is estimated from a non-linear optimization procedure (PROUZET 2010) and the S/R equation is expressed as follows Eq. (1):

$$R = 3.418\ S^{[-2.01\times 10^{-6}\times s]}, \qquad (1)$$

where R and S are the number of eggs produced and the number of eggs laid by the salmon population of the Nivelle River (southwestern part of France) a given year, respectively.

So, the sustainable exploitation is to harvest in a sustainable manner from the population a maximum number of catches equal to the MSY. However, the level of the MSY depends on the shape of the *S/R* curve mainly defined by the carrying capacity of the environment (and especially for that type of *K*-population of the accessibility and quality of spawning and nursery areas) (MILLER *et al.*, 2015; RIGHTON *et al.*, 2021). Here, *K* is the optimised carrying capacity of the environment. In the original definition of the MSY given by Michael Graham (GRAHAM, 1935), the coordinates of MSY for equation $SY = f(K)$, where SY and K are sustainable yield and carrying capacity (unfished stock biomass), respectively. Then, MSY is positioned at $x = K/2$ and $y = r * K/4$ where r is intrinsic population growth rate.

3.2. The MSY value depends mainly on the environmental productivity

To illustrate the importance of the productivity of the environment and the need for a less sectoral approach, we will take, as an example, the history and population dynamics of the salmon stock of the Adour-Gaves basin. The Atlantic salmon (*Salmo salar* L.) has been exploited by a professional fishery on this basin since very old times (CUENDE, 2003; PROUZET *et al.*, 2009; PROUZET, 2013). Accurate data on the characteristics of captured salmon, importance of catches and kind of fishing gears used have been recorded since the late 19th century (CUENDE and PROUZET, 1992; MARTY and BOUSQUET, 2000; CUENDE, 2003; PROUZET *et al.*, 2009; PROUZET, 2013). The surface of spawning areas as well as smolt production areas and their variations during the end of the previous century have been estimated (SANTAL *et al.*, 2012) with a significant extension of the surface of spawning areas in the upstream course at the beginning of the 21st century. Here, "smolt" means salmon juvenile ready to migrate at sea. On the Adour catchment, the downstream migration of juvenile salmon usually takes place in spring after one or two winters in the river. The egg survival under gravel was estimated from different salmon spawning grounds of the Adour-Gaves basin (DUMAS *et al.,* 2007; BARRACOU, 2007). The fry survival was evaluated in experimental streams (BEALL and MARTY, 1983) and estimated from eggs deposal and parr production in some different areas of the Gave d'Oloron catchment (BARRACOU, 2007). Fig. 5 shows that a part of the spawning areas located on the Gave d'Oloron watershed (downstream the town of Oloron Sainte-Marie) was and is still a poor-quality spawning area. This is also the case for another salmon tributary: the Saison (Fig. 5). However, since 2002 and after the opening to spawning grounds located upstream of Oloron Sainte-Marie on the Gave d'Aspe and Gave d'Ossau, it has been noted a tendency for salmon to spawn more upstream on better-quality areas (BARRACOU, 2007) (Fig. 6). This migration of spawners to areas further upstream where the permeability of spawning grounds is higher, results in a predominance of the juvenile production on the tributaries of the upper course of the Gave d'Oloron basin with, in addition, an increase in total juvenile production compared to the end of the 90s as shown in Fig. 7.

Salmon tagging on an index river: the Nivelle and characterization of the life cycle of the species have resulted in the development of a stochastic model, based on the RICKER model (RICKER, 1975), to simulate the fate of this population under various constraints: quality of spawning grounds impacting egg survival under gravel, surface of production areas influencing juvenile survival and population size, rate of return of salmon after their marine migration (DUMAS and PROUZET 2003, PROUZET 2010). All this knowledge has enabled this model to be

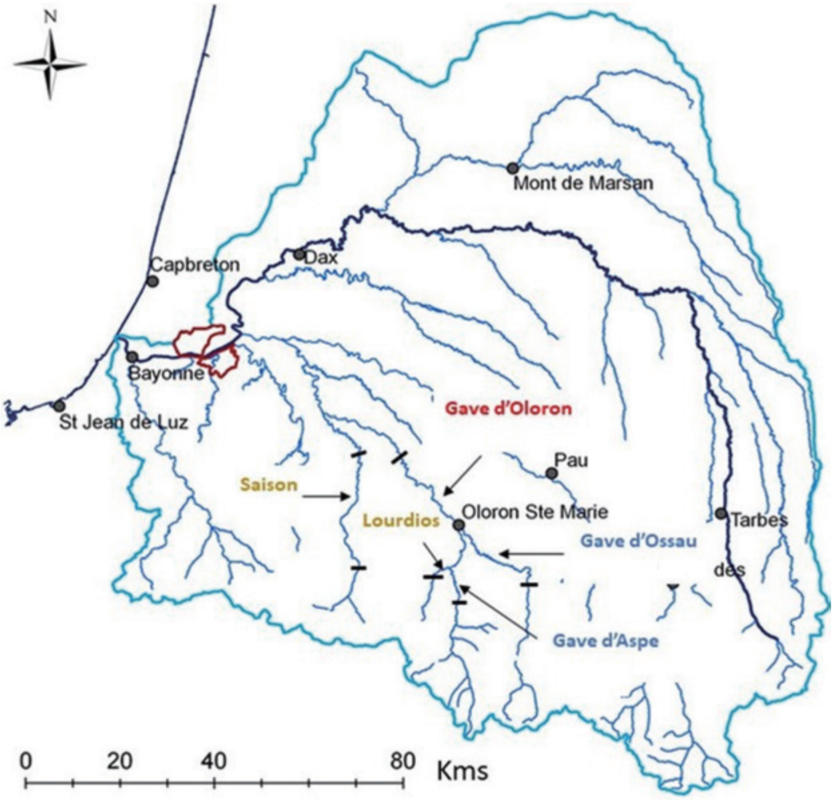

Fig. 5 Distribution of the spawning beds on the Gave d'Oloron catchment and its tributaries, main sub-catchment for the production of Atlantic salmon. The colour indicates the quality of the spawning area: poor quality in red; medium in yellow and good in blue (source: BARRACOU, 2007 and Migradour data).

adapted to the condition of the Adour-Gaves salmon stock and to simulate its fate under various constraints with 3 assumptions of survival rate of fry and migratory constraints with an initial state of abundance corresponding to an egg stock of 10,000,000 units (Table 1).

Case 1 corresponds to optimum quality spawning beds on the entire potential spawning areas; Case 2 is the situation that corresponded to that of the period 1970–1990 with spawning grounds of bad quality confined in the lower course of the Gave d'Oloron and its main tributaries; Case 3 is considered to be the current situation of the salmon population on the Adour-Gaves basin, with good quality spawning grounds in the upstream part (Gave d'Aspe and Gave d'Ossau) but of poor quality in the downstream part of the spawning area (downstream Oloron Sainte-Marie on the Gave d'Oloron).

Fig. 8. Ricker reproduction curves for the Atlantic Salmon population of the Adour-Gaves catchment according 3 scenarios defined in Table 1: Case 1; Case 2 and Case 3. The purple diamond shows the MSY (Maximum Sustainable Yield) for Case 2; the green square the MSY for Case 1 and the red circle, the MSY for case 3. The black circle indicates the starting point of the simulation for the 3 cases. The dispersion of

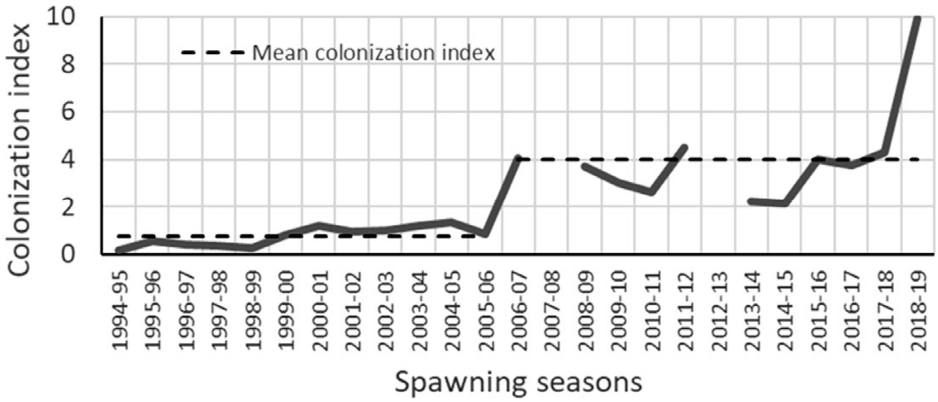

Fig. 6 Trend of the colonization index on the Gave d'Oloron watershed. The colonization index is the ratio of the number counted downstream Oloron Sainte-Marie on the number counted upstream (on the Gave d'Aspe and Gave d'Ossau) (source: Migradour data). More the ratio is high and more the spawning takes place in the upstream part.

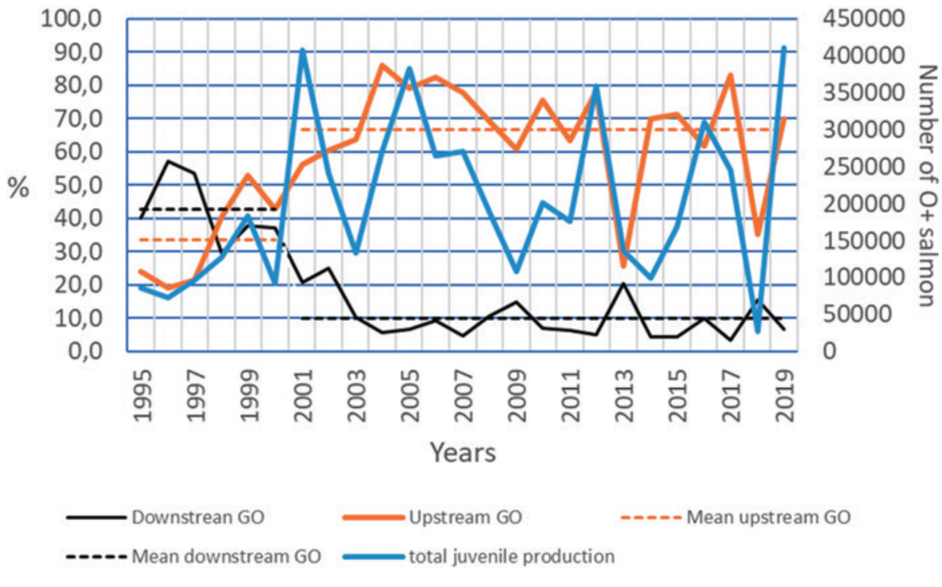

Fig. 7 Trends in % of the annual parr production on areas located downstream (black) and upstream (orange) the Gave d'Oloron (GO) watershed and in number of the total salmon parr (0 +) production (blue) during the period from 1995 to 2019 (source: Migradour data).

points along the reproduction curves is in black for the Case 2, in red for the Case 1 and in yellow for the Case 3.

The analysis of Fig. 8 and Table 2 provides many important considerations for the restoration and management of this salmon

Table 1 Main parameters used and their values for the 3 examples of simulation.

Main parameters	Case 1	Case 2	Case 3
Initial abundance in number of deposited eggs	10,000,000	10,000,000	10,000,000
Surface of juvenile production area in m^2	1,092,000	500,000	1,092,000
Average survival rate from eggs to 0 + parr in % (σ)	5.0 (2.0)	0.5 (0.25)	1.92 (0.98)
Rate of return of 1 SWF in % (σ)	5.5 (2)	5.5 (2)	5.5 (2)
Rate of return of 2 SWF in % (σ)	1.1 (0.3)	1.1 (0.3)	1.1 (0.3)
Rate of return of 3 SWF in % (σ)	0.5 (0.2)	0.5 (0.2)	0.5 (0.2)

1 SWF: One sea winter fish: 2 SWF: Two sea winter fish; 3 SWF : Three sea winter fish

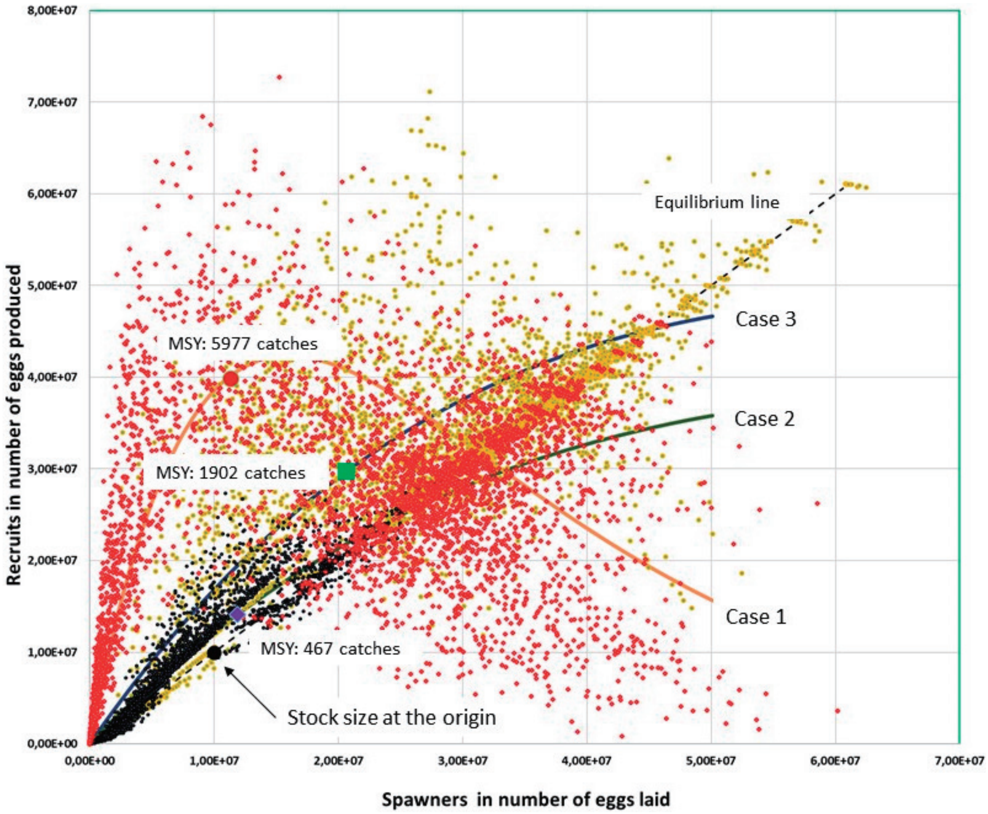

Fig. 8 RICKER reproduction curves for the Atlantic Salmon population of the Adour-Gaves catchment according 3 scenarios defined in Table 1: Case 1; Case 2 and Case 3. The purple diamond shows the MSY (Maximum Sustainable Yield) for Case 2; the green square the MSY for Case 1 and the red circle, the MSY for case 3. The black circle indicates the starting point of the simulation for the 3 cases. The dispersion of points along the reproduction curves is in black for the Case 2, in red for the Case 1 and in yellow for the Case 3.

Table 2 Some characteristics of the reproduction curve for the 3 simulated cases.

	Case 1: optimal situation	Case 2: deteriorated situation	Case 3: current situation
Prob (Stock > 10,000,000 eggs)	78.1	26.4	95.1
Optimal exploitation rate	71.4%	15.7%	30.4%
Maximum Equilibrium Catch (MSY) in number of salmon*	5977	467	1902
Reproduction curve equation	$R=P\ \exp[1.9756(1-3.17^{-8}P)]$	$R=P\ \exp[0.328(1-4.03^{-8}P)]$	$R=P\ \exp[0.667(1-2.21^{-8}P)]$

Mean reproductive potential: 4,750 eggs per salmon (Prouzet and Michelet, 2019)

population:

- Case 2 is the "deteriorated situation". The size of the population, as shown by the black scatterplot, is small and its maximum sustainable yield is low and does not allow a high rate of exploitation.
- Case 3 is the "current state" of this population. The improvement of the free movement of fishes upstream has allowed an increasing part of the salmon population to migrate to better-quality spawning grounds and to increase the production of juveniles from the early years 2000 (cf. Figs. 6 and 7). This resulted in an increase in the productivity of this population with a maximum sustainable yield around 2,000 salmon and an optimum exploitation rate of about 30% (the situation observed presently).
- Case 1 is the "Optimal situation". It could be achieved by the improvement of the quality of spawning grounds in the whole area colonized by salmon spawners. This would increase the maximum sustainable yield (around 6,000 fishes) and the optimum exploitation rate, but the size of the population is more variable due to too high densities of fish on the spawning areas some years.
- The only regulation of the fishery cannot change the shape of the curve and the level of the MSY is linked to the productivity of the population constraints by pressures affecting the quality, the number and dimension of suitable habitats for the species. Only an improvement in the quality of the essential habitats for salmon and the restoration of ecological connectivity make it possible to recover a situation which, historically, would correspond to that which was known in the first half of the 20th century.

3.3. 'Responsible' instead of 'sustainable exploitation'

In 2021, the European fishing fleet consisted of 81,071 vessels in marine waters, to which should be added the fishing vessels operating in the EU inshore waters (Breuer and Dinkel, 2021). According to Eurostat (2021) 88% of the fishing boat have an engine power less than 149 KW. These fishing boats belong to the small-scale fishing fleet and fish in coastal, estuarine or inland areas and represents an important social and economic weight for the European fisheries sector (Macfadyen *et al.*, 2011). Landing values (2006–2008 average) of artisanal (vessel length

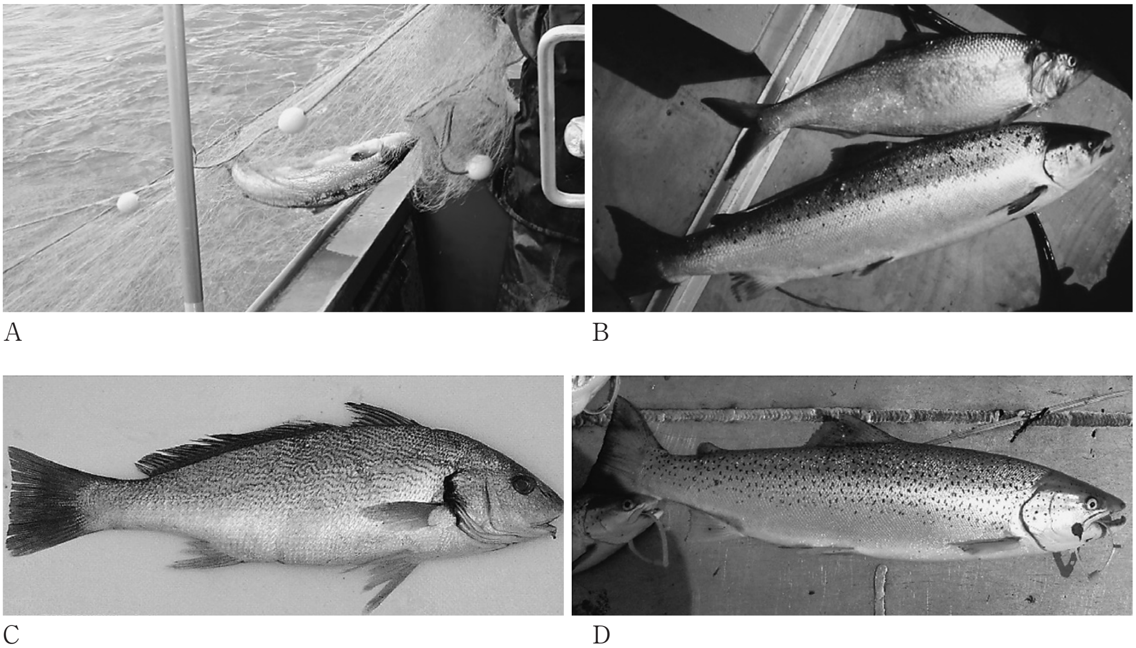

Fig. 9 Photos showing Atlantic salmon catch with trammel net in the Adour estuary (A), Allis shad and Atlantic salmon (B), Meager (C) and Sea trout (D).

< 12 m) and industrial (vessel length >= 12 m) fishing fleets were €297 million and €582 million, respectively. The artisanal and industrial fishing fleets employed 89,492 and 77,763 people (2006–2008 average), respectively. Five European countries - Greece, Italy, France, Spain and Portugal - account for 85% of landing value and 75% of the artisanal workforce (Table 29 on p. 68 in MACFADYEN *et al.*, 2011).

In view of what has been said in the preceding paragraphs, it is understandable why professional fishermen of this segment of the UE fleet do not talk about sustainable exploitation, which is not under their sole control, but about responsible exploitation (PROUZET *et al.*, 2010; BOISNEAU *et al.*, 2016). This responsible exploitation has several aspects: producers of food for society, whistle-blowers, environmental watchers and living resources managers.

3.3.1. Producers of high-quality food for Society

The main social function of professional fisheries is to provide products from the sea or aquatic environments to society at an affordable price for the greatest number of people in compliance with the rules laid down by the European Union and its member states. The landings of this small scale fishery are generally local, fresh fish and for certain species with a high commercial and gustatory value contribute to the gastronomic reputation of certain territories: line hake (*Merluccius merluccius*), atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) from the Basque country; sea lamprey (*Petromyzon marinus*) and meager (*Argyrosomus regius*) from the Gironde; allis shad (*Alosa alosa*) and pikeperch (*Sander lucioperca*) from the Loire; glass-eel (*Anguilla anguilla*) from the Atlantic coast or yellow and silver eels (*Anguilla

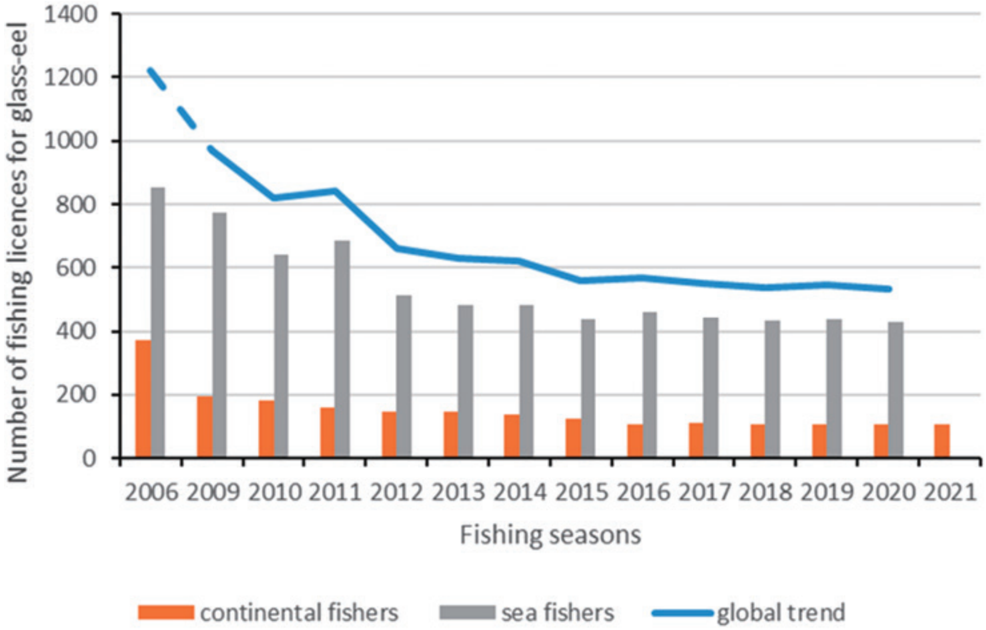

Fig. 10 Trends of the number of glass-eel licenses for the continental and marine fishers from 2006 to 2020 (source: CONAPPED and CNPMEM data).

anguilla) from the Loire or the Mediterranean sea ; king scallop (*Pecten maximus*) from the Channel or whitefish (*Coregonus lavaretus*) from the Alpine lakes or line sea bass (*Dicentrarchus labrax*) from Brittany (north western part of France) (Fig. 9).

Very strict regulations are applied to this type of fishery, which is sometimes managed not only by quotas but also by licences, the number of which is limited. Codes of good conduct are adopted for specific fisheries. This is the case for the glass eel fishery, which defines a maximum fishing speed as well as a maximum power of vessels, a maximum size and number of fishing gears (sieves) used, as well as the presence on board of sorting equipment to separate by-catches (discarded alive immediately after capture) from glass eels, and fish tanks to keep living fish in good conditions, some of them are used for restocking (*Guide de bonnes pratiques pour la filière pêche civelière et la mise en place d'un programme de repeuplement à l'échelle communautaire* https://www.comite-peches.fr/wp-content/uploads/2014/07/GBP-Plaquette-V3.pdf).

For some species, such as the European eel, which is on the IUCN red list and is the object of a restoration plan at European level (EC1100/2007), efforts to reduce the fishing pressure by 60% have been requested by the European Union and accepted by these small-scale fishing communities.

The importance of that reduction in number of glass-eel licenses for the French professional fishery on the period 2006–2020 is 56.4% as shown in Fig. 10.

Unfortunately, regarding the other pressure factors, for which the reduction was to be 75%, it has not been the case, far from it, as shown above on wetland protection and restoration of ecological continuity.

3.3.2. Whistle-blowers

Because of their exploitation of a wide variety of ecosystems: coastal areas, estuaries, ponds, lakes and rivers, as well as the practice of a job that makes them very receptive to any environmental change and also to changes in abundance of resources, fishers in small-scale maritime and freshwater fisheries are able to alert the public authorities to the risks incurred by the degradation of ecosystems as they exploit them.

For instance, it was through their actions in cooperation with the scientific community that, in 1984, the eel was no longer considered a harmful species in salmonid waters by the management structures in France. In 2000, they asked European authorities to implement a management plan for European eel at the scale of its natural distribution area. The plan was adopted in 2007 as Eel regulation plan (CE1100/2007) for the recovery of the stock of European eel. They agreed to include eel in Appendix II of CITES to control the market for this species at international level (Boisneau *et al.*, 2016). Europe and its member states will align themselves with the CITES regulations, but in a stricter manner by prohibiting the export of this species outside the European area. Europe and French government will greatly penalise the economic activity of the French eel industry, which was mainly supported by the Asian market.

In recent years, global warming has been a source of concern, not only because of the rise in temperature that it causes, but also because of the hydrological changes that it generates. All these disturbances seem to strongly favour the proliferation of species such as the wels catfish (*Silurus glanis*) which, near dams, sills or in fish ladders, is a major predator of local migratory species such as shads, migratory salmonids or sea lamprey (Paz-Vinas and Santoul, 2019; Boulêtreau *et al.*, 2020; Anonymous, 2021). It was at the instigation of professional fishermen that the public authorities initiated studies to assess the impact of the development of these non-native but now acclimatised species on the development of local species, the exploitation of which is sometimes prohibited for professional fishermen for reasons of resource protection (Fig. 11). The direct and indirect costs of such an introduction have not been estimated in France as for 90% of the non-native species introduced in this country. It is probably very important as suggested in the publication of Renault *et al.* (2021).

In 2020, for the World Fish Migration Day (https://www.lepecheurprofessionnel.fr/wp-content/uploads/2020/09/Note_compl%C3%A9mentaire_V13.08.2020.pdf), they denounce an over sectoral vision of the management of our ecosystems which has led to a loss of functional habitats for many continental and estuarine aquatic species. This excessively sectoral approach of public policies had already been highlighted by the Bernard (1994) report. This sectoral policy often results in the impact of small scale fishing being used as an adjustment variable to limit the effects and impacts of others anthropogenic pressures on aquatic biodiversity (see negotiation between strong and weak actors § 2).

In 2021, for the UICN world congress, a leaflet titled "Decline of migratory species as a scapegoat" with a subtitle "Reconcile sustainable development, environmental governance and responsible fishing activity" (https://www.lepecheurprofessionnel.fr/wp-content/uploads/2021/08/LIvret-UICN-CONAPPED-2021-VF.pdf) is published. The brochure denounces the joint use of the IUCN red list and the Precautionary principle to argue against the continuation of professional fishing, without taking into account the constant degradation of aquatic environments by agriculture, hydropower production,

Fig. 11 Catfish regulation fishery on the Dordogne and Garonne rivers - tributaries of the Gironde estuary, France) (source: AAPPD Gironde).

urbanisation and insufficient waste treatment.

3.3.3. Environmental watchers and resources management

Investigating estuarine and continental ecosystems characterized by a wide range of habitats is not easy. Techniques used by research structures are very often based on fish inventories using electro-fishing equipment, which is very efficient in shallow waters, but not in deep waters. Counts carried out in capture traps are also methods that can be efficient for migratory species, but for some species fish counters are often placed too far upstream from the habitats they usually colonise for their reproduction (e.g. sea lamprey or allis shad).

Hence the interest in using professional fishing gears to sample and assess the abundance of fish populations or to capture living fishes for tagging to estimate exploitation rates or to study their migratory behaviour. Some examples among many others show the importance of cooperation between scientists and professional fishers and are given below.

- *Acipenser sturio* (European sea sturgeon), anadromous species that breeds in river, was a common species in the Gironde estuary and its tributaries until the middle of the twentieth century (Darlet and Prioux, 1950). A too intensive fishing exploitation in estuary, which has been prohibited since 1982 in France, along the European coasts (bycatch) associated with a degradation of its breeding and nursery areas has led to a quasi-extinction of that species in the Gironde watershed and in Europe. It is now

Fig. 12 Sampling of juvenile European sturgeons in the Gironde estuary by the professional fishery (drift net used to catch meagre in the Gironde estuary in June 2021) and then released alive (source: CAPENA)

listed as critically endangered on the IUCN Red List. In 2007, an action plan for the restauration and conservation of the European sea sturgeon is adopted by the Standing Committee of the Berne Convention. the first French national plan is defined and implemented from 2011 to 2015. It is followed by a conservation plan from 2020 to 2029 (ANONYMOUS, 2019). In June 2007, CEMAGREF (*Centre du Machinisme Agricole et du Génie Rural des Eaux et des Forêts, presently INRAe : Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement*) carried out for the first time the artificial reproduction of the European sea sturgeon, then regularly between 2008 and 2014 (LAURONCE *et al.*, 2014; 2015, 2016). This success in artificial reproduction is a real boost for implementation of a restoration plan which is managed by a steering committee that includes the two official structures for maritime and continental professional fishing. These two official structures contribute to the protection of the species by reducing the impact of their activities (release of by-catch) and to the improvement of knowledge on the distribution of the European sea sturgeon at different stages of its life cycle in the natural environment. They also carry out awareness-raising work at European level with fishing communities. From 2007 to 2015, more than 1.8 million hatchery-produced juveniles were released into the Garonne and Dordogne rivers, both tributaries of the Gironde. Many observations have been collected by professional fishermen in the framework of this environmental monitoring (ANONYMOUS, 2021) (Fig. 12). Between 2006 and 2020, 1,748 sturgeons have been caught by the commercial fishery in the French coastal waters, 99% have been released alive

Fig. 13 Release of glass eels in the Aureilhan lake by professional fishers (South western part of France) (source: ARA France).

(Lise Mas, pers. com.).

・*Anguilla anguilla* (European eel), anadromous species that spawns at sea and has a growth phase in fresh, brackish or coastal waters. Formerly very abundant and classified in France as a harmful species in salmonid waters, it has been considered since 1984 as a species to be protected in response to requests from professional fishers and scientists. Its rarefaction is linked to numerous anthropogenic pressure factors now been identified by research studies coordinated at European level such as the INDICANG project (ADAM *et al.*, 2008). This project made it possible to pool academic and traditional knowledge and know-how and thus to develop techniques for assessing the abundance of this species at different stages of its life cycle. Within this framework, professional fishermen provided technical expertise to implement fish sampling and abundance assessment plans in large river basins (Loire, Adour and Gironde): estimates of the abundance of glass-eel stocks on the Adour estuary (BRU *et al.*, 2009) or in the Loire or Isle River (ADAM *et al.*, 2008); estimates of the abundance of silver eel stocks on the Loire River (BOISNEAU and BOISNEAU, 2014; 2015). Contribution of professional fishers to the EELIAD project to investigate the migratory behaviour of European eel at sea from tagging of eels caught in Mediterranean lagoon (AMILHAT *et al.*, 2016) or in the Loire River (RIGHTON, 2008; AARESTRUP *et al.*, 2009; RIGHTON *et al.*, 2016; BOURILLON *et al.*, 2020), then released in the sea near the shore.

Within the framework of the French eel restoration plan approved by the European Community, 60% of the glass eel quota allocated to the professional fishery must be used to restock continental aquatic environments in Europe. Part of this quota is used to stock aquatic environments in France under the responsibility of an association created by the professional fishing industry: *Association pour le Repeuplement de l'Anguille en France* (ARA France: Association for the Eel restocking in France), which has developed a code of good practices for catching, keeping,

Fig. 14 Tagging of salmon with an acoustic tag on the Adour estuary (source: PROUZET).

transporting and releasing the fry with a maximum efficiency (Fig. 13) (RABIC and GORNET, 2020).

- *Salmo salar* (Atlantic salmon) anadromous species that spawns in freshwater and has a growth phase in river as juvenile (parr), then migrates downstream to the sea as smolt and spends between 1 to 3 years (sometimes 4 years) at sea before to return and spawn in its home river (GUEGUEN and PROUZET, 1994). In 1999 and 2000, a large project of salmon tagging had been undertaken to catch salmon alive and to tag them with radio and acoustic transmitters. The aim of this project undertaken by *Centre National de la Recherche Scientifique* (CNRS: National Centre for Scientific Research), Institut National de la Recherche Agronomique (INRA: National Institute for Agricultural Research) and *Institut français de recherche pour l'exploitation de la mer* (Ifremer: French Research Institute for Exploitation of the Sea) in cooperation with professional fishers and Institution Adour which is a public structure in charge of management of the Adour Basin and its ecosystems was to study the salmon behaviour during its upstream migration in the Adour estuary (BEGOUT *et al.*, 2001) and to estimate the migration speed in estuary in order to adapt the fishing legislation to get a compromise between protection of salmon from gillnet in the estuary and economical loss of the estuarian fishery. The results obtained showed that in average salmon cross the estuary in two days (around 30 km). This made it possible to adapt the legislation of gillnet fishing in the estuary by shifting the weekly time window during which the estuary was free of nets by one day between the mouth and the upper part of the estuary in order to decrease the fishing pressure on migrating salmon. The contribution of professional fishers was to catch the fish alive, to participate to fish tagging and to track tagged salmon with an acoustic receiver (Fig. 14) (MAHAUT and PROUZET, 2009).

4. Conclusion: Need to introduce culture as the fifth dimension of the sustainable development.

As early as 1972, the UNESCO General Convention adopted a resolution for the protection of the world's cultural and natural heritage and underlined the need to maintain the balance between natural and cultural goods.

In *Ethical Issues of the Fisheries*, FAO (2005) defined the ethics of fishing as values, rules, duties and virtues relevant to both the welfare of the human being and the good state of the ecosystem. Many studies conclude that artisanal fishery is more a way of life than a profession. Partners of the DIMPAT project "*DIMension PATrimoniale dans la définition de la durabilité des modes d'exploitation des ressources aquatiques*" (the heritage dimension in the definition of the sustainability of exploitation of aquatic resources) talk about "*local, maritime and continental fishing communities that are the holders of local culture and heritage, the richness and diversity of which have been nourished over centuries by external contributions of people, techniques and knowledge*" (Bernard *et al.*, 2012; Prouzet, 2014).

Thus, knowledge is fundamental in the definition of a new environmental governance through collective learning, crossing of scientific and traditional knowledge, plurality of value systems (not only based on economic value) and construction of shared common knowledge.

It is clear that governance as defined in the classical framework of sustainable development based on a so-called balance between the three spheres of interest: economic, social and environmental is a failure both socially and environmentally (Reid *et al.*, 2005; Rockström *et al.*, 2009; Prouzet *et al.*, 2019). As mentioned previously, the compromises for implementation of a sustainable development policy have too often been made at the expense of weak actors, i.e. those who live directly off the goods and services of Nature. However, it is these actors who often integrate into their culture (in the sense of knowledge and know-how) and their heritage, the cross-generational links that take future generations into account in the negotiation process *via* the transmission of knowledge and respect for Nature, a non-human actor very often absent from these negotiations. These traditional communities are also custodians of historical knowledge which is currently very often lacking for the definition of pristine references.

Charles (2011) proposed to develop cultural and human rights based-approaches to co-management and then considered each fishery in terms of its local characteristics and its social, economic and historical context. In that context, heritage is defined in such a way as to differentiate it from the notion of capital: one manages a capital to increase it, and one manages a heritage to transmit it to future generations (Prouzet *et al.*, 2020).

Unfortunately, the current vision remains too sectoral. Cultural practices as a support territories identity and local traditional knowledge of Nature are not sufficiently mobilised. It is here that the cultural dimension takes on its full meaning as a reflection on life in these natural and man-made spaces (Melin, 2011).

In 1996, Wackernagel and Rees (1996) defined *the ecological footprint* as the aggregate land area required for a given population to live in a sustainable manner. Melin (2011) proposed to add another less quantitative indicator measuring *the cultural footprint* of territories in order to assess the impact of cultural practices, beliefs and knowledge on the good or poor state of territories. The introduction of this new indicator makes it possible, in the long term, to encourage participative democracy and, first and foremost,

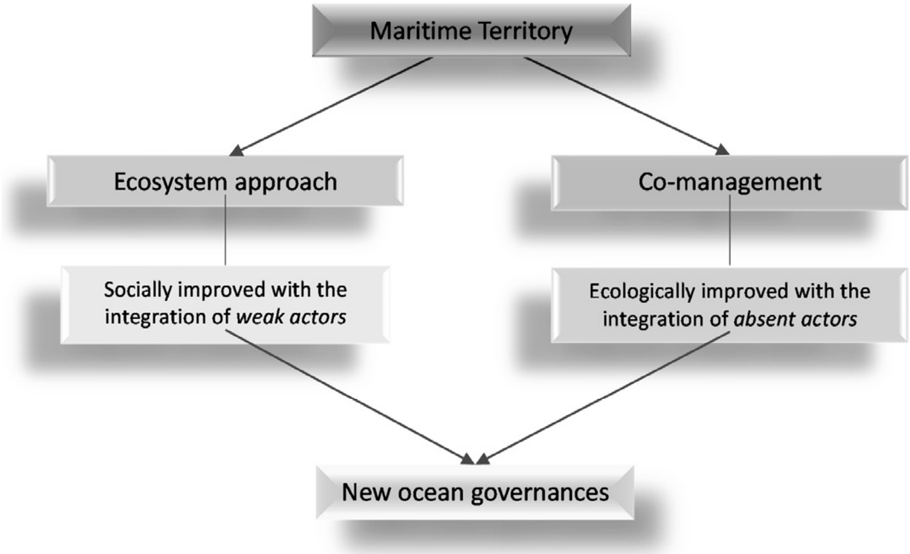

Fig. 15 Proposition of a framework to enhance new ocean governances (source: PROUZET *et al.* 2019).

to hear the voices of all the stakeholders directly concerned by environmental change.

Hence the idea of identifying maritime and non-maritime territories for the implementation of a genuine sustainable development policy, in order to better take into account this diversity of knowledges and practices that strengthen the cultural footprint (SÉBASTIEN, 2014) and by integrating differently the sectorial policies (HENOCQUE and KALAORA, 2014). It is this notion of maritime territory that is put forward by PROUZET *et al.* (2019) as a scale "combining an ecosystem approach socially improved with a co-management approach ecologically enhanced" (Fig. 15).

It is the aim of the project defined by the two Japanese-French Oceanographic Societies of France and Japan in 2018: "*Project Nature and Culture - on the five pillars of sustainable development and the five senses*". The objective of this project is to demonstrate through different examples of cooperation between France and Japan that it is possible to minimize our ecological footprint while enhancing our cultural footprint. The environments chosen for this project are also spaces of social and cultural expression that take into account the realities of the territory. For instance, a cooperation project between a certain site in the Seto Inland Sea (Japan) and the Arcachon Basin (France) has been outlined around the restoration of eelgrass beds and the diversity of oyster farming practices. More precisely, this project is undertaken with the Satoumi Research Institute, the Arcachon Basin Natural Marine Park, the Arcachon-Cap Ferret regional committee for Shellfish Aquaculture, New-Aquitania region and Europe and the two SFJOs. Another project on the eel is being developed and will focus on the restoration of the species and its habitats as well as its enhancement.

Here, the territorial scale is very important because it allows for the identification on a "human" scale of not only the goods and services of the natural ecosystems that make up the territory, but also the enhancement of local cultures and their territorial manifestations: handicrafts, leisure activities, product development, fishing activities, aquaculture, agriculture, gastronomy, museography... It also allows the proposal to be placed in a historical context that is nourished by the knowledges and skills of local communities, which are the fruit of an ancient and perennial practice of these natural and cultural environments.

As HENOCQUE and KALOARA (2014) pointed out, "good governance is first and foremost a matter of democracy, with a central question: how to ensure that Nature or non-human actors are integrated into the political community".

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Length-weight relationships and length-frequency analysis varying with seasons for fish community in the Luanhe River Estuary, Bohai Sea, northern China

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Abstract: The Luanhe River Estuary in the Bohai Sea in northern China is an important nursery and good fishing grounds for many marine organisms, including fish. Length-weight relationship (LWR) of fish is an important indicator for the proper fishing and management of fish populations. This study was conducted to obtain LWRs for fish species distributed there. From December 2016 to August 2017 at one-month intervals and from July 2016 to November 2017 at two-month intervals, using crab pots, trawl nets and bottom trawl nets, a total of 7,593 individuals belonging to 32 species in 20 families were obtained and their length and weight were measured. The most abundant species was *Chaeturichthys stigmatias* (N = 2,487). Length-weight relationships ($W = a \times L^b$) were obtained for the 17 fish species for which sufficient individuals were available for statistical analysis. Linear regression of log-transformed data was highly significant for all analysed species ($p < 0.05$), with LWR slope b values ranging from 2.57 for *Synechogobius ommaturus* to 3.66 for *Engraulis japonicus*. The b values of 50% of the total species ranged between 2.95 and 3.30. The LWR information could be used to manage fish stocks not only in the Luanhe River Estuary but also in other estuarine fisheries.

Keywords : *Luanhe river estuary, LWR, Bohai Sea, Xiangyun-wan*

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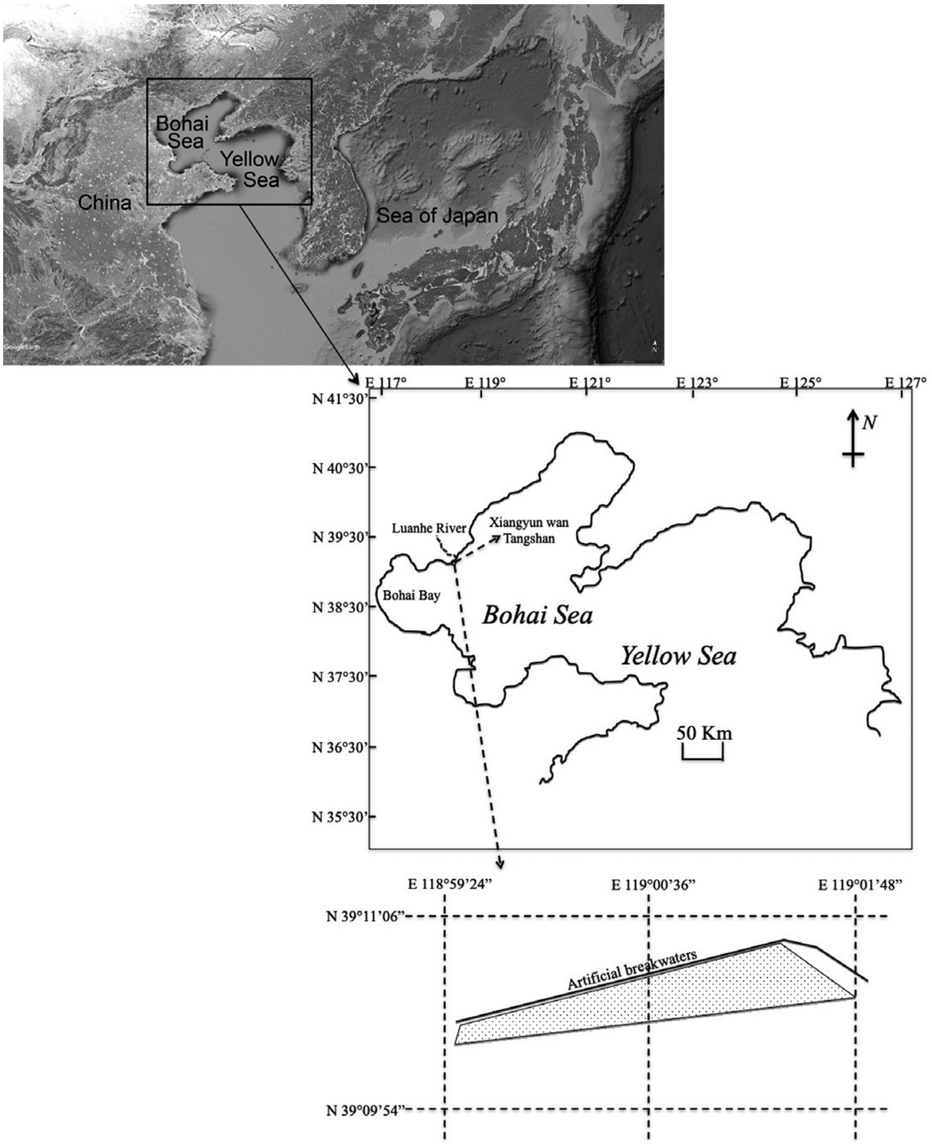

Fig. 1 Schematic map showing the survey area (dotted area in the bottom panel) in the northernmost part of Bohai Bay (middle panel), the Bohai Sea (top and middle panels), northern China (39° 11'06"-39° 09'54" N, 118° 59'24"-119° 01'48" E).

1. Introduction

Estuarine areas are extremely important areas in the life cycle of some fish species. These ecosystems provide food, shelter, and spawning grounds for varieties of marine organisms. The Luanhe River is a sediment-laden water course on the northern shore of Bohai Sea, China (GAO, 1981). The estuary of the Luanhe River is recognised as important feeding and breeding grounds for marine organisms and migratory species and is a famous fishing ground within Bohai Bay (WU, 1980; CHENG *et al.*, 1982; HU and

ZHAN, 1983; XU *et al.*, 1986).

The rational utilization of estuarine fisheries resources is necessary to build a sustainable society. Length-weight regressions (LWRs) are an important tool for the proper exploitation and management of fish populations (ANENE, 2005) because length and weight data for fish are needed to estimate growth rates, age structure, and other population dynamics (KOLHER *et al.*, 1995). This information is also commonly used in the ecosystem modeling approach (CHRISTENSEN and WALTERS, 2004) to calculate the production to biomass ratio (P/B) of different functional groups. Modeling should utilise the values of LWR of fish in the area of interest for modeling in order to estimate more accurate weights. In addition, LWRs allow life history and morphological comparisons among different fish species, or between fish populations from different habitats and/or regions (GONÇALVES *et al.*, 1997). Biological scientists often estimate fish weight in the field using LWR (MOREY *et al.*, 2003).

Prior to this study there was no LWR data available for fish species in the Luanhe River Estuary. This study aimed to provide information of the first LWR references for 18 fish species that could be used for the management of the Luanhe River fishery ground. The LWR data will be made available through the Fishbase Database (FROESE and PAURY, 2010), which can be used by other researchers in any countries.

2. Materials and methods

This study was carried out in the Luanhe River Estuary between longitude 118°59'24"-119°01'48" E and latitude 39°11'06"-39°09'54" N (Fig. 1). The estuary is subject to irregular, semidiurnal tides. The current study was conducted in 2016–2017 as part of a series of studies to assess the biological sustainable capacity of this area. Samples were collected at monthly intervals from December 2016 to August 2017 and at bimonthly intervals from July 2016 to November 2017. The fishing gear used for sampling included a crab pot, trammel net of various inner mesh sizes, and a bottom trawl. Trammel nets (50 m long and 1.3 m high) with mesh sizes of 2.0 cm, 3.3 cm, 3.5 cm, and 4.0 cm and an outer net mesh of 17.0 cm were used. The trammel nets of the four mesh sizes were continuously connected together, giving a total length of 200 m. The crab pot was 8 m long consisting of rectangular column traps measuring 20 cm long, 15 cm high and 15 cm wide, with a 10 cm sized mouth opening at the top of the trap (Fig. 2). Five crab pots were continuously connected together at the survey station, giving a total length of 40 m. They were set up and retrieved from the fishing grounds overnight. Trawl net was a mouth length of 2.5-m and a net length of 16 m with a mesh size of 3.5 cm. Trawling was carried out at a speed of 2 knots for 30 minutes.

Fig. 2 Photo of a fisherman deploying crab pots in the sea.

After sampling, fish samples were immediately transported to the laboratory in Hebei Provincial Research Institute for Engineering Technology of Coastal Ecology Rehabilitation. Specimens were identified to the species level.

Table 1. Seasonal variations (spring, summer, autumn, winter) of the number (unit: inds) and body length range (unit: cm) for 32 fish species caught in study area.

	Spring		Summer		Autumn		Winter	
	Number	*Range*	*Number*	*Range*	*Number*	*Range*	*Number*	*Range*
Synechogobius ommaturus	49	15.3–37.2	732	3.4–18.6	318	6.6–31.5	170	12.1–36.0
Tridentiger barbatus	20	3.0–10.8	20	4.2– 9.2			17	2.7–11.2
Tridentiger trigonocehalus	3	6.0– 8.7						
Tridentiger bifasciatus	3	6.7– 7.8					5	4.6– 9.2
Chaeturichthys stigmatias	13	9.0–14.1	1,265	2.7–16.7	616	4.1–17.5	593	4.4–18.7
Paratrypauchen microcephalus			37	4.0–12.4	7	4.5–10.1	3	6.7–10.3
Acanthopagrus schlegelii			1	8.1	5	11.3–17		
Zoarces elongatus	1	29.5						
Chirolophis japonicus	3	17.9–18.8	1	18.4				
Ernogrammus hexagrammus	4	10.0–12.6						
Johnius belangerii			418	2.7–12.6				
Lateolabrax maculatus			5	8.4–14.1			1	30.3
Hexagrammos agrammus	2	14.3–14.8	6	4 –10.5				
Hexagrammos otakii	207	6.0–28.1	107	6.5–19.4	7	8.9–11.8	13	9.6–19
Sebastes schlegelii	791	5.3–23.5	796	2.7–21.6	43	4.2–19.5	105	5.0–20.3
Trachidermus fasciatus	1	11.4	1	5.9			7	10.2–12.2
Platycephalus indicus	2	20.9–24.4	46	4.9–28.1				
Cociella crocodilus			14	5.0– 9.3	5	6.4– 7.4	3	6.4– 9.4
Cynoglossus joyneri	1	12.6	698	6.8–20	69	4.7–17.5	31	6.1–17.5
Kareius bicoloratus			6	7.0–13.9			1	16.2
Paralichthys olivaceus	3	12.2–16	4	15–22.5	15	9.2–21	4	9.5–16.6
Scophthalmus maximus			1	20				
Thrissa kammalensis			63	4.5–11.5	3	5 – 6.8		
Stolephorus indicus			3	8 – 9.6				
Engraulis japonicus			14	3.6– 8.6				
Sardinella zunasi			32	5.6–13.2				

Scientific names for each species were checked with Fishbase (FROESE and PAURY, 2010). The standard length (L) of each specimen was measured to the nearest 0.1 cm using a 30-cm ruler. Fish body weight for all specimens was weighed to the nearest 0.01 g using an electric balance (CR-5000WP, Custom, Japan).

LWRs (RICKER, 1973) were calculated using the equation $W = a \times L^b$. The relationship between the length and weight of the specimens per species was calculated by the least-square linear regression applied to logarithmic transformed data combined as the following equation (STERGIOU and MOUTOPOULOS, 2001):

$$\log W = \log a + b \log L,$$

where W is fish body weight (g), L is fish

Table 2. Descriptive statistics and estimated parameters of LWR for 17 fish species caught in the study area.

Family	Species	N	Length range (cm)	Weight range (g)	*a*	*b*	95%*CI*	R^2
Gobiidae	*Chaeturichthys stigmatias*	2,487	2.7–18.7	0.1– 51.6	0.0115	2.95	0.250	0.957
	Tridentiger barbatus	57	2.7–11.2	0.3– 43.1	0.0133	3.33	0.171	0.984
	Synechogobius ommaturus	1,269	3.4–37.2	0.7–264.8	0.0312	2.57	0.130	0.967
	Paratrypauchen microcephalus	47	4.0–12.4	0.2– 5.9	0.0047	2.90	0.225	0.942
Sciaenidae	*Johnius belangerii*	418	2.7–12.6	0.5– 36.5	0.0127	3.04	0.460	0.919
Hexagrammidae	*Hexagrammos otakii*	334	6.0–28.1	3.6–318.1	0.0146	3.05	0.117	0.961
Sebastidae	*Sebastes schlegelii*	1,735	2.7–23.5	0.4–395.6	0.0185	3.16	0.177	0.989
Platycephalidae	*Platycephalus indicus*	48	4.9–28.1	0.6–177.6	0.0044	3.11	0.261	0.956
	Cociella crocodilus	22	5.0– 9.4	1.5– 7.5	0.0093	2.94	0.165	0.895
Cynoglossidae	*Cynoglossus joyneri*	799	4.7–20	0.5– 52.5	0.0034	3.16	0.145	0.942
Paralichthyidae	*Paralichthys olivaceus*	26	9.2–22.5	8.8–182.7	0.0067	3.29	0.079	0.985
Engraulidae	*Thrissa kammalensis*	66	4.5–11.5	1.1– 18.8	0.0074	3.21	0.169	0.963
	Engraulis japonicus	14	3.6– 8.6	0.4– 9.4	0.0042	3.66	0.169	0.989
Clupeidae	*Sardinella zunasi*	32	5.6–13.2	2.2– 39.9	0.0048	3.49	0.068	0.976
	Konosirus punctatus	39	12.9–19.3	25.5– 95.7	0.0366	2.65	0.062	0.941
Syngnathidae	*Syngnathus acus*	14	12.5–22.7	0.3– 3.3	0.0000	3.62	0.144	0.904
Mugilidae	*Mugil cephalus*	113	5.1–51	2.95–1974.4	0.0123	3.07	0.095	0.998

Note: N is the number of samples, length range (cm), weight range (g), *a* and *b* are parameters of the LWR, 95% × *CI* (*b*) is the 95% confidence interval of *b*, and R^2 is the coefficient of determination.

standard length (cm), *a* is the initial growth coefficient and *b* is the growth coefficient. The statistical significance level of R^2 was estimated in LWR fitted by least-squares regression. Only extreme outliers attributed to errors in data collection were omitted from the analyses. Pearson's correlation coefficient analysis was applied to determine the relationships between fish standard length (cm) and fish body weight (g). A *p* value < 0.05 was considered significant.

The application of these regressions should be limited to the observed length ranges. These estimated parameters can be treated as mean annual values for the species in our study.

The 95% confidence interval (*CI*) of b was computed using the following equation:

$$CI = b \pm (1.96 \times SE),$$

where *SE* is the standard error of *b*.

3. Results and discussion

A total of 7,593 individuals belonging to 32 species (20 families) were recorded in this study (Table 1). The total number (unit: ind) and body length range (unit: cm) varying with seasons for 32 fish species caught in study area are described in Table 1. The species, family, sample size (N), length range (cm) and weight range (g), length-weight relationship parameters *a* and *b*, 95% *CI* for *b*, the coefficient of determination (R^2) are presented in Table 2. We analyzed length-category (mm) frequency with seasonal variations for fish species *Synechogobius ommaturus*, *Hexagrammos otakii* and *Chaeturichthys stigmatias* (Fig. 2). Linear regressions of log transformed data were significant ($P < 0.05$) for all analyzed species. The most abundant species sampled was *Chaeturichthys stigmatias* (N = 2,487). The best represented family was Gobiidae with 4 species recorded.

Table 3. Seasonal variations (spring, summer, autumn, winter) of estimated parameters of LWR for *Synechogobius ommaturus, Chaeturichthys stigmatias, Sebastes schlegelii* and *Cynoglossus joyneri* caught in the study area.

	Season	*a*	*b*	R^2
Synechogobius ommaturus	Spring	0.0001	2.46	0.936
	Summer	0.00002	2.90	0.912
	Autumn	0.000033	2.77	0.974
	Winter	0.00007	2.59	0.954
Chaeturichthys stigmatias	Summer	0.00001	3.10	0.910
	Autumn	0.000004	3.17	0.981
	Winter	0.000008	3.04	0.974
Sebastes schlegelii	Spring	0.00001	3.17	0.982
	Summer	0.00001	3.18	0.972
	Autumn	0.000011	3.19	0.993
	Winter	0.000012	3.16	0.996
Cynoglossus joyneri	Summer	0.000003	3.08	0.916
	Autumn	0.000004	3.05	0.977
	Winter	0.000001	3.23	0.966

The coefficients of determination (R^2) ranged from 0.95 to 1.00 for *Mugil cephalus, Sebastes schlegelii, Engraulis japonicus, Paralichthys olivaceus, Tridentiger barbatus, Sardinella zunasi, Synechogobius ommaturus, Thrissa kammalensis, Hexagrammos otakii, Chaeturichthys stigmatias, Platycephalus indicus*. On the other hand, R^2 values ranged from 0.90 to 0.95 for *Cynoglossus joyneri, Konosirus punctatus, Johnius belangerii, Syngnathus acus, Cociella crocodilus*, corresponding to a mean value of 0.957 (±0.03).

LWR slope (b) values ranged from 2.57 for *Synechogobius ommaturus* to 3.66 for *Engraulis japonicus*. The median value was 3.11 for *Platycephalus indicus*, although 50% of the values ranged from 2.95 to 3.30 for the complete data set. When $b = 3$, weight growth is isometric, and when the value of b differs from 3 ($b \neq 3$), weight growth is allometric. In terms of growth type, these results revealed that 3 species showed negative allometries ($b < 3$), 9 showed positive allometries ($b > 3$) and 5 showed isometric growth ($b = 3$). Most of the species generally presented positive allometric growth. *C. crocodilus* ($b = 2.94$), *C. stigmatias* ($b = 2.90$), *J. belangerii* ($b = 3.04$), *H. otakii* ($b = 3.05$), *M. cephalus* ($b = 3.07$) all displayed isometric growth. Various factors may be responsible for differences in parameters of LWR such as temperature, salinity, food (quantity, quality and size), sex, time of year and stage of maturity.

4. Conclusions

The data collected during this study represents an important contribution of base line data on the LWR of a number of fish species that were previously unavailable. It is important to point out that these LWR should be strictly limited to the length ranges used in the estimation of

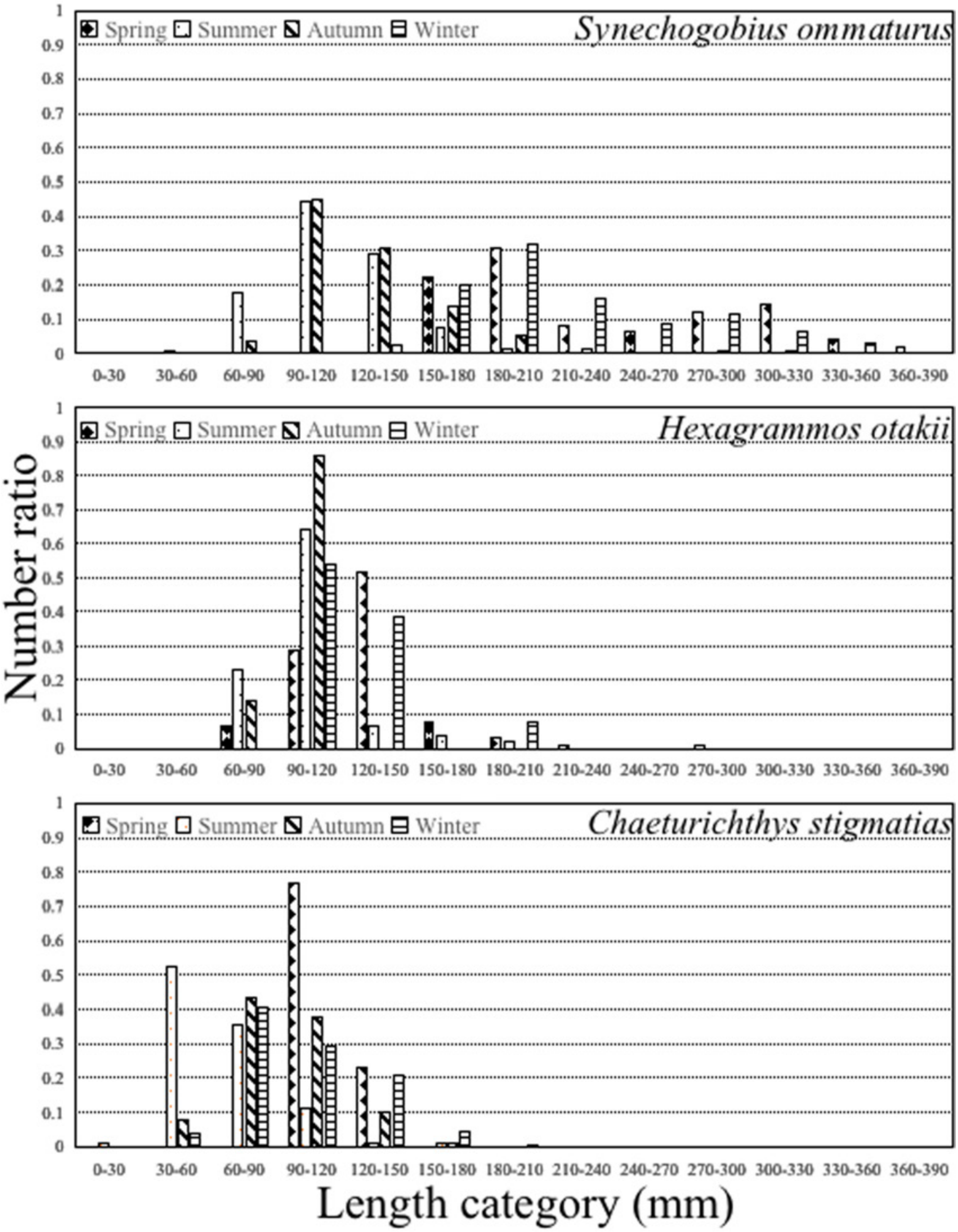

Fig. 3 Length-frequency with seasonal variations for fish species *Synechogobius ommaturus*, *Hexagrammos otakii* and *Chaeturichthys stigmatias*.

the linear regression parameters (PETRAKIS and STERGIOU, 1995). The results obtained in the current study will contribute to the knowledge of important fish populations in the Luanhe River Estuary and also assist fisheries scientists and managers in the future.

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Changes in thyroxine (T_4) concentrations in larval and juvenile marbled flounder, *Pseudopleuronectes yokohamae*

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Abstract: There are several reports on the dynamics of thyroid hormones during metamorphosis in flatfish, but there are limited reports on the post-metamorphic juvenile stage. In this study, we investigated changes in thyroxine (T_4), a thyroid hormone, from the larval to juvenile stages of the marbled flounder *Pseudopleuronectes yokohamae*. We found that the T_4 concentration from 20 days post-hatching (dph) (larval stage) to approximately 120 dph (juvenile stage) substantially increased in the juvenile stage. There was a local maximum T_4 concentration in the late developmental stage of juveniles. We also found considerable inter-annual variation in T_4 concentrations during this study (2015, 2016, 2018, and 2019). The findings of this study can be used to inform treatment options and management of flatfish seed production to ensure the health and quality of the fish produced

Keywords : *Pseudopleuronectes yokohamae, T_4 concentration, development, metamorphosis*

1. Introduction

Metamorphosis of flatfish is induced and regulated by two thyroid hormones, triiodothyronine (T_3) and thyroxine (T_4) (INUI *et al.*, 1995; CAMPINHO *et al.*, 2012; CAMPINHO, 2019). In many flatfish species, the level of T_4 increases considerably during metamorphosis (TAGAWA *et al.*, 1990; DE JESUS *et al.*, 1991; ARITAKI, 2013; SCHREIBER and SPECKER, 1998). During metamorphosis of flatfish, one eye starts migrating; its

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position becomes asymmetrical relative to the other eye. The skin pigmentation also becomes asymmetrical, with a dark upper side and a white underside. There are many reports on the morphological development of flatfish until the completion of metamorphosis (MINAMI, 1981a; 1981b; 1982). However, the marbled flounder *Pseudopleuronectes yokohamae* continues to develop morphologically even after metamorphosis is completed (I stage), and the juvenile stage is also divided into a J stage (post-metamorphosis) and K stage, according to the levels of skin pigment and lateral line development (FUKUHARA, 1988).

In marbled flounder seed production, juveniles often exhibit loss of fins, particularly the caudal fin, due to nipping. Owing to the fin damage, the fish are likely to contract bacterial infections (SUGIMOTO *et al*., 2007), and their swimming ability might be affected because of the decreased caudal fin area (UEKI *et al*., 2019). This nipping behavior was observed after metamorphosis and tended to increase during the juvenile stage. Salmonids are also known to exhibit nipping behavior, and the plasma T_4 level of masu salmon (*Oncorhynchus masou*) is negatively correlated with the frequency of nipping behavior (HUTCHISON and IWATA, 1997). Nipping behavior was reduced by treatment with T_4 in brown trout (*Salmo trutta*), steelhead trout (*Oncorhynchus mykiss*), and masu salmon (HUTCHISON and IWATA, 1998). If there is a negative correlation between T_4 concentration and nipping behavior, then large fluctuations in T_4 during the juvenile stage of the marbled flounder may affect nipping frequency. Understanding the dynamics of T_4 concentrations makes it possible to predict when aggression may increase, which is important for improving fish seed production techniques.

Most studies on the changes in T_4 concentration in flatfish are based on the developmental stages until metamorphosis, and there are few studies on changes in T_4 levels during the juvenile stage. As a preliminary approach to determine whether there are fluctuations in T_4 concentrations during the juvenile period, when nipping behavior increases, we examined the dynamics of T_4 from the larval to juvenile stages of marbled flounders. The findings will be used to inform treatment options and the management of flatfish seed production, to ensure the health and quality of fish produced.

2. Materials and methods

Marbled flounders that had been artificially fertilized and reared between 2015 and 2019 (except in 2017) at the Seed Production Research Laboratory, Futtsu Sea Farming Section, Chiba Prefectural Fisheries Research Center, Japan, were used as experimental animals. The fish were reared at a slightly fluctuating temperature (13–16 ℃) in 20–kL water tanks up to 50 days post-hatching (dph), and in 50–kL water tanks thereafter (after 50 dph).

In 2015, to characterize metamorphic progression, larvae were classified using the staging criteria listed in Table 1 (FUKUHARA, 1988). We sampled fish at different developmental stages: F (24 dph; pelagic larvae), G-H (24 dph; settling larvae), I (35 dph), J (48 dph), and K (122 dph). After 2016, samples were differentiated based on dph at intervals of 10 days for 20–70 dph, and at 10–30 days for 80–120 dph. The total number of fish sampled in each of the four years was 30, 83, 84 and 82, respectively.

Whole-body T_4 concentrations in larvae and juveniles were measured and analyzed at the Nikko Field Station, Fisheries Technology Institute, Japan. The T_4 contained in the frozen fish was extracted and measured mainly following the method described by KOBUKE *et al.*

Table 1. External features of *Pseudopleuronectes yokohamae* at different larval and juvenile stages: stage F-I, modified from FUKUHARA (1988); stages J and K, as described by FUKUHARA (1988).

Stage	Criteria
F	Eyes asymmetrical but not visible from the right
G	Eyes asymmetrical, left eye visible from right side but pupil not visible
H	Pupil of left eye visible from right side, but half of pupil not beyond ridge of head
I	More than half of pupil beyond ridge of head, completing metamorphosis
J	Body surface heavily covered with tiny melanophores in metamorphosed fish
K	Lateral line discerned clearly in 70-d old larvae, ocellated pigment patterns dispersed when juvenile is more than 20 mm standard length

(1987) and TAGAWA and HIRANO (1987). The frozen fish were minced, and then ice-cold 100% ethanol was added to the sample according to the size and homogenized with a homogenizer. The homogenate was decanted into an Eppendorf tube, and the tube and blade used for homogenization were washed with ice-cold ethanol. These rinses were added to the original homogenate. After centrifugation at 5,000 rpm for 10 min, the precipitate was re-extracted with ice-cold ethanol. Supernatants were combined and vacuum dried at 37 ℃. T_4 levels were measured using an enzyme immunoassay kit (Gen Way Biotech, San Diego, CA, USA). Optical density was measured with a microplate reader (SpectraMax 190, Nihon Molecular Devices, Tokyo, Japan). The measuring range of the standard was 3–250 ng/ml. The mean of the measured data was calculated and is hereafter referred to as the T_4 concentration.

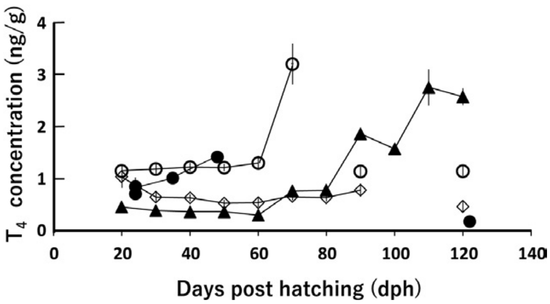

Fig. 1 Changes in the mean whole-body T_4 concentrations from larval to juvenile stages of the marbled flounder *Pseudopleuronectes yokohamae* (●, 2015; ○, 2016; ◇, 2018; ▲, 2019). Sample sizes of each stage or days post hatching (dph) were 6–12 individuals. Error bars indicate SEM.

3. Results

The changes in mean whole-body T_4 concentrations during the larval and juvenile stages are shown in Fig. 1. In 2015, the mean T_4 concentrations at stages F, G-H, I, J, and K were 0.71, 0.85, 1.01, 1.42, and 0.18 ng/g, respectively. The maximum T_4 concentration was observed in stage J. After 2016, the T_4 concentrations showed a considerable increase during the juvenile stage, increasing the most at 70 dph (2016) and 110 dph (2019) between 20 and 120 dph. Although the year-to-year fluctuation was large (Fig. 1), the maximum T_4 concentration in marbled flounders was observed after 70 dph, corresponding to the late juvenile stage (K stage) (FUKUHARA, 1988).

4. Discussion

Based on the changes in T_4 concentrations for each stage (F-K) in 2015, the post-metamorphosis J stage had the highest T_4 concentration. Based on the T_4 concentration of the marbled flounder up to 45 dph in a study by TAGAWA and KIMURA (1991), it was inferred that the T_4 concentration peaked at the post-metamorphosis stage. Therefore, we expected there to be a T_4 peak at the same stage during metamorphosis in this study. Many studies have reported that the peaks in T_4 concentration of other flatfish occurred before metamorphosis was complete (TAGAWA *et al.*, 1990; DE JESUS *et al.*, 1991; ARITAKI, 2013; SCHREIBER and SPECKER, 1998; EINARSDÓTTIR *et al.*, 2006; KLAREN *et al.*, 2008). However, the marbled flounder in our study showed a different trend to other flatfish, where T_4 concentrations increased in the post-metamorphic J stage but not in the metamorphosis completion stage (stage I).

The peak T_4 concentration in this study was 1.42 ng/g, which was lower than that reported in previous studies (e. g., Japanese flounder *Paralichthys olivaceus,* 12.2 ng/g (DE JESUS *et al.,* 1991) or 15 ng/g (TAGAWA *et al.,* 1990); brown sole *Pseudopleuronectes herzensteini,* 16.1–40.6 ng/g (ARITAKI, 2013); spotted halibut *Verasper variegatus* 2.3–15.9 ng/g (ARITAKI, 2013)). On the one hand, the difference between our results and those of past reports might be due to the difference in the measurement method used. The previous studies mainly used radioimmunoassay (RIA) for measurement, while non-radioactive enzyme immunoassay (ELISA) was used in the present study. On the other hand, this may also be due to interspecific differences, particularly differences in the thyroid to body weight ratios that are associated with different body types.

T_4 concentrations in 2016 were different from those in 2018 and 2019. The intra- and inter-assay errors in the measurement system used in this study were both within 10%, and a common sample was used as a reference to confirm the continuity of the measured values. However, the high value in 2016 exceeded the measurement error and was a continuous value. We considered that T_4 concentrations in 2016 compared to those of 2018 and 2019 were certain to represent a different trend.

In marbled flounder seed production, juveniles often exhibited caudal fin loss. Damage begins with a slight loss of the caudal fin, which then increases until the caudal fin area of some fish is reduced by more than half. In this study, we defined these as "seriously damaged fish." These fish are considered to exhibit reduced swimming performance (UEKI *et al.*, 2019). In a small-scale experiment conducted in 2018, 100% of the fish that were reared in a 100-L tank at the same stocking density as this study (2,500 individuals/m^2 bottom area) exhibited caudal fin loss by 70 dph, and 15% of these were seriously damaged (UEKI *et al.*, 2019). Furthermore, under the same rearing conditions as this study, the proportion of seriously damaged fish increased to approximately 39% after 102 dph (UEKI, 2020). These results indicate that nipping behavior increases during the juvenile stage. It is likely that nipping behavior increases when the T_4 concentration decreases after it peaks, which was reported in a previous study on masu salmon (HUTCHISON and IWATA, 1997). Future studies should investigate when nipping behavior increases, and whether the frequency of nipping changes after T_4 treatment.

In this study, we found that there was a local maximum T_4 concentration in the late developmental stages of juvenile marbled flounder, and that the annual fluctuations in T_4 concentrations in the larval and juvenile stages were large. To fully understand these fluctuations, future studies should increase the number of samples per test and shorten the sampling intervals, allowing for fine-scale changes in T_4 concentrations to be detected. Additionally, studies should aim to determine the concentrations before and after metamorphosis in other flatfish species, including the measurement of T_3 concentrations and their effects on fish physiology and behavior.

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Effect of environmental stressors on fish health – Possible action of controlled stress as a eustress in fish

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Abstract: Fish are exposed to various local and global environmental stressors (or stimuli), such as pollutants, chemicals, acute and chronic changes in temperature, and the subsequent increased chances of succumbing to infectious diseases are concerned. The exposure of organisms to stressors may result in a series of biochemical and physiological changes. At the living state, these changes are mediated by the neuroendocrine system. There is also a cellular stress response, which includes the induction of stress proteins, a family of heat shock proteins, following exposure to stressful situations. These stress responses in organisms can affect their general health. We observed the decrease in the redox state in response to heat shock or high doses of dietary antibiotics, oxytetracycline (OTC), in coho salmon (*Oncorhynchus kisutch*). The results indicate that both heat shock and the high doses of dietary OTC induce oxidative stress, which would enhance oxidation in fish. In addition to physical and chemical stress trials, we found that mild physiological stress by handling can affect the expression of growth-related genes in fish. In general, the word "stress" has a negative connotation and is likely to be considered undesirable. However, the effects of stress differ depending on the intensity of the stimulus, the condition of the recipient, etc. It is considered that there are two types of stress: eustress (positive or desirable stress) and distress (negative or undesirable stress). Accordingly, eustress provided by environmental stresses under control in aquaculture, are useful to accomplish the maintenance and improvement of farmed fish health as well as fish welfare.

Keywords : *environmental stressor, oxidative stress, eustress, distress, fish*

1. Introduction

The production of farmed fish has increased in inverse proportion to a global decline in ocean fishery stocks. About half of the world's fishery production is based on aquaculture which has the potential to reduce fishing pressure on

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threatened stocks (NAYLOR *et al.*, 2000, PAULY *et al.*, 2002, GARLOCK *et al.*, 2019). Global food demand has been increasing. Food from the sea is originated from capture fisheries and aquaculture, and represents 17% of the current global production of edible meat (COSTELLO *et al.*, 2020, FAO, 2020). In addition to protein, seafood is rich in functional polyunsaturated fatty acids and micronutrients, such as minerals, vitamins and carotenoids. Aquaculture is, therefore, important to be developed to support the increase of global food production. Global aquaculture production was estimated in 82 million tons of aquatic animals in 2018. At the time, aquatic animal farming was dominated by finfish (FAO, 2020). Aquaculture is supposed to become a major source of aquatic dietary proteins by 2050. Accordingly, it is important to develop methods to enhance the aquaculture production and to evaluate the impact of aquaculture on the environment.

Fish are exposed to various local and global environmental stressors (or stimuli), such as pollutants, chemicals, acute and chronic changes in temperature, and the chances of succumbing to infectious diseases may be increased subsequently (IWAMA *et al.*, 2006, NAKANO, 2016, AFONSO, 2020, NAKANO, 2020, NAKANO and WIEGERTJES, 2020, NAKANO, 2021a, 2021b, 2022, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016). The stress induced by environmental stressors in fish is thought to influence their fitness, productivity, health, and quality after catch. Therefore, the control of stress is considered to be very important in farmed fish. However, overall knowledge of stress response and protection against stress in fish is less comprehensive than that in mammals.

The objective of this article is to summarize knowledge concerning stress response to environmental stressors in fish. The possibility that controlled environmental stress might act as a eustress (positive or desirable stress) in fish is also discussed. (NIKI, 2007, OKEGBE *et al.*, 2012, KUPRIYANOV and ZHDANOV, 2014, AFONSO, 2020, NAKANO, 2021a, YAMAUCHI and SUTO, 2022).

2. Stress response in fish

Stress is likened to a dented rubber ball pushed with fingertips. The pressure (stimulus) of the external factor which causes the stress (dented state) is originally regarded as a stressor (BANNAI, 1994, NAKANO, 2021a). Stressors can be classified into three categories: (1) physical and chemical stress in response to detrimental temperature, ultraviolet rays, and radiation; (2) physiological stress caused by exercise, handling, and infection; and (3) psychological stress caused by intimidation and anxiety. The stress response can be divided into three phases, warning response, resistance, and exhaustion (IWAMA *et al.*, 2006, NAKANO, 2016, 2020, 2021a, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016).

The homeostasis of the organism is achieved through the formation of a network with the central nervous system as the control tower, the endocrine system for hormone secretion, and the immune system for biodefense (BARTON and IWAMA, 1991, SCHRECK, 1996, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016). In general, the exposure of fish to stresses may result in a series of biochemical and physiological changes. Although maintaining homeostasis should be a key process to cope with stress, these changes would be an important aspect of the adaptive response (IWAMA *et al.*, 2006, NAKANO, 2016, AFONSO, 2020, NAKANO, 2020, NAKANO and WIEGERTJES, 2020, NAKANO, 2021a, 2021b, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016).

The stress response to exogenous or endogenous stressors in fish has been divided into first,

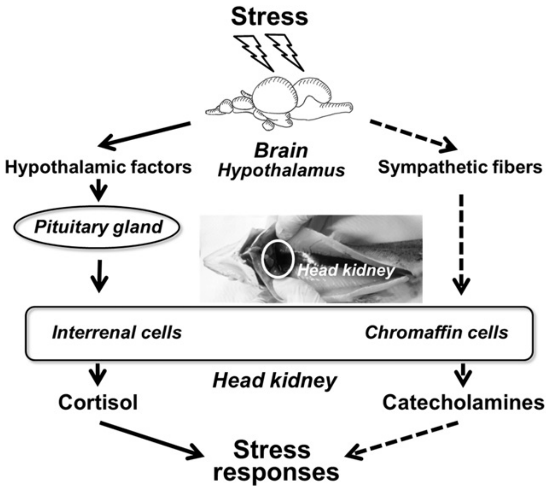

Fig. 1 Schematic view of the primary stress response, a neuroendocrine response, in fish. The solid and broken lines indicate hypothalamic-pituitary-interrenal cell (HPI) axis and hypothalamic-sympathetic-chromaffin cell (HSC) axis, respectively.

second, and third phases. The primary response represents the perception of an altered state and initiates a neuroendocrine reaction, resulting in the rapid release of stress-related hormones, such as catecholamines (dopamine, norepinephrine, adrenaline, etc.) and cortisol, into the blood circulation system through the two neuroendocrine pathways. Catecholamines and cortisol activate many metabolic pathways. The two systems shown in Fig. 1 are the hypothalamic-pituitary-interrenal (adrenal cortex in mammals) system (cortisol or HPA systems) and the sympathetic-chromaffin (adrenal medulla in mammals) system (adrenaline or SAM systems). The interrenal and chromaffin cells are present within the head kidney in fish. Hence, in fishes, the stress hormone cortisol is secreted from the head kidney (anterior portion of the kidney), which corresponds to the mammalian adrenal cortex and medulla. The magnitude of the stress hormone response depends on several factors including the type and degree of stresses, and fish species (BARTON and IWAMA, 1991, SCHRECK, 1996, BASU *et al.*, 2001, IWAMA *et al.*, 2006, NAKANO, 2020, 2021a, 2021b, GORISSEN and FLIK, 2016, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016, WINBERG *et al.*, 2016). The secondary stress response is composed of various biochemical and physiological adjustments associated with stress and these are mediated by several stress hormones. For example, the production of glucose from glycogen in response to stress provides fish with energy substrates to tissues in order to cope with the increased energy demand (BARTON and IWAMA, 1991, IWAMA *et al.*, 2006, NAKANO, 2020, 2021a, 2021b, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016). The tertiary stress response represents the reaction of the whole-organism associated with stress, including reduced growth, decreased reproduction, impaired immune system , and reduced survival (IWAMA *et al.*, 2006, NAKANO, 2016, 2020, 2021a, 2021b, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016).

In addition to the neuroendocrine stress response following exposure to stressful situations, there is a cellular stress response. At the cellular level, some stresses, such as the increased levels of temperature and hypoxia, and changes in salinity, may lead to the induction of a family of heat shock proteins (HSPs), which are highly conserved cellular proteins in all organisms, including animals and plants. Extensive studies on model species have revealed three major families of HSPs: HSP70, HSP90, and low molecular weight of HSPs. There is a constitutive production of these proteins known as a heat shock cognate, which is essential in various aspects of protein metabolism in unstressed cells in addition to the HSPs (RICHTER *et al.*, IWAMA *et al.*, 1998, BASU *et al.*, 2001, BASU *et al.*, 2002, DEANE *et al.*, 2004, KULTZ, 2005, IWAMA *et al.*, 2006, DEANE and WOO, 2011, CURRIE and SCHULTE, 2014, NAKANO, 2016, 2020, 2021a, HOCHACHKA and SOMERO, 2002, SOPINKA *et al.*, 2016). Accordingly, the levels of catecholamines, cortisol, and glucose in blood and HSPs in tissues are most widely used for monitoring stress in fish (BARTON and IWAMA, 1991, IWAMA *et al.*, 2006, NAKANO, 2020, 2021a, 2021b, SOPINKA *et al.*, 2016). However, most conventional methods for measuring stress, which employ anesthesia or tissue sampling by dissection, induce physical restraints. Recently, a new biosensor immobilized with glucose oxidase has been developed to measure blood glucose levels (WU *et al.*, 2015, WU *et al.*, 2019). This biosensor can nondestructively and noninvasively measure blood glucose levels in fish while swimming. Hence, this biosensor system could be useful for rapid, reliable, and convenient analysis of fish stress.

The stress response of the organism is an adaptation process that uses various functions of the whole body to deal with stress. Many reactions in organisms seem to be built on a delicate balance of anti-stress (defensive process) and stress (offensive process) responses. Hence, if this delicate balance in organisms is lost, the organisms will eventually fall ill (NAKANO, 2016, 2021a).

3. Effect of environmental stressors on fish health

3.1 Stress-related biomarker expressions upon heat stress

The physiological states of fish depend on the environmental temperature. Heat shock can lead to many kinds of changes in biological functions. Daily and seasonal temperature changes have an impact during the life of individual fish (BASU *et al.*, 2002, IWAMA *et al.*, 2006, CURRIE and SCHULTE, 2014). However, studies on the heat shock response in fish have primarily focused on the expression and characterization of HSPs as mentioned above (IWAMA *et al.*, 1998, IWAMA *et al.*, 1999, BASU *et al.*, 2001, BASU *et al.*, 2002, DEANE *et al.*, 2004, IWAMA *et al.*, 2004, IWAMA *et al.*, 2006, CURRIE and SCHULTE, 2014, NAKANO, 2020, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, SOPINKA *et al.*, 2016). The changes in the levels of redox-related biomarkers, such as glutathione (GSH) and lipid peroxide (LPO), in response to heat shock have been reported for coho salmon (*Oncorhynchus kisutch*), cold water fish species and one of the most valued aquaculture species (NAKANO *et al.*, 2014). The LPO levels in the plasma of stressed fish gradually increased after heat treatment. The total GSH levels in plasma temporarily decreased, but they returned to the basal levels by 17.5 h post-stress. The activities of superoxide dismutase (SOD), an important antioxidant enzyme, in the plasma of stressed fish increased significantly at 17.5 h post-stress compared with those in control fish, but returned to the basal levels at 48 h post-stress. The expression levels of hepatic GSH and HSP70 gradually increased after heat treatment. Similar changes in the levels of stress-related biomarkers in response to heat shock have been also observed in tropical rabbitfish (*Siganus guttatus*) (NAKANO *et al.*, 2011). The levels of stress-related markers in coho salmon were changed by thermal stress at the initial stage of heat treatment at 19℃, which was different from the reaction of rabbitfish. In rabbitfish, the expressions of stress-related markers by thermal stress took time and were changed at the later stage of heat treatment even at 34℃. Accordingly, the susceptibility to thermal stress might depend on several factors, such as fish species, breeding environment and life history. Cold water fish species such as coho salmon seem to be more susceptible to thermal stress, compared with

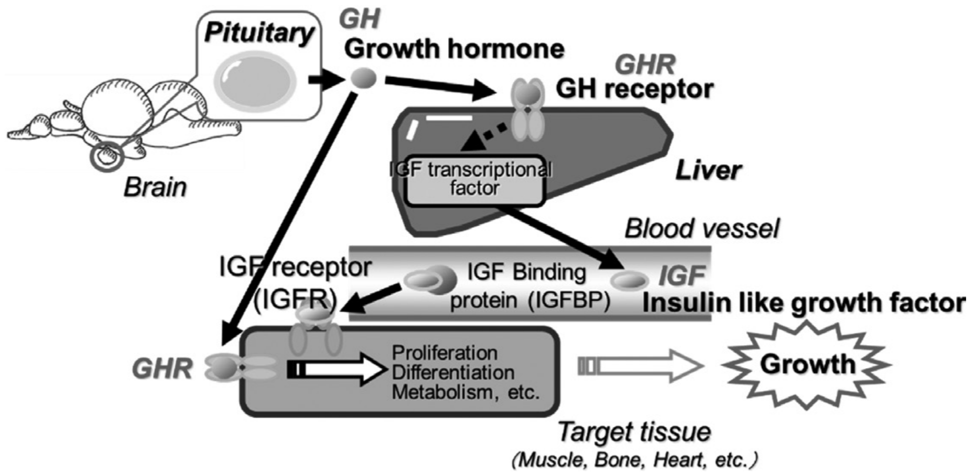

Fig. 2 Regulation of growth in fish. Growth in vertebrate including fish is regulated by the growth hormone (GH) secreted from pituitary gland and insulin-like growth factor (IGF) secreted from liver. The system responsible for regulation of growth in fish is called the GH-IGF axis. Growth is often influenced by a complex set of cellular, endocrine, and environmental factors.

tropical fish such as rabbitfish.

3.2 Stress-related biomarker expressions upon treatment with oxytetracycline

Oxytetracycline (OTC) is a broad-spectrum antibiotic (tetracycline family) with a bacteriostatic action against various gram-positive and gram-negative bacteria (BURRIDGE *et al.*, 2010, ZOUNKOVA *et al.*, 2011, YONAR, 2012). OTC is the antibiotic at the first choice to treat many bacterial diseases in farmed fish (BURRIDGE *et al.*, 2010, YONAR, 2012). However, high doses of OTC are known to cause side effects in fish and have detrimental effects on the environment. The expression of the stress-related biomarkers, such as GSH and HSP, in response to excessive doses of dietary OTC were determined for coho salmon (NAKANO *et al.*, 2018, 2022). The GSH levels in the liver, muscle, and stomach in OTC-fed fish were higher than those in OTC-unfed control fish. Plasma GSH levels in the OTC-fed fish were also higher than those in the control fish. Expression levels of HSP70 in liver, muscle, and stomach decreased following OTC administration. The OTC concentration in the tissues of the OTC-fed fish, such as coho salmon, has been reported to accumulate in the order of stomach > liver > skin > muscle at the end of the OTC feeding period for 42 days (ROGSTAD *et al.*, 1991, NAMDARI *et al.*, 1996).

Heat shock-induced thermal stress and OTC treatment are known to enhance the production of reactive oxygen species (ROS) in various tissuess (PETRENKO *et al.*, 1995, LESSER, 2006, HO *et al.*, 2013). Accordingly, the changes in the levels of multiple stress- and redox-related biomarkers observed in the above-mentioned studies suggest that thermal and chemical stressors might induce oxidative stress in fish (KAUR *et al.*, 2014, NAKANO, 2020, NAKANO *et al.*, 2018, 2022, NAKANO and WIEGERTJES, 2020).

3.3 Growth-related gene expressions upon physiological stress

As shown in Fig. 2, growth in fish is regulated to a large extent by growth-related systems, such as the liver-derived insulin-like growth factor (IGF)-1 in response to the binding of pituitary-secreted growth hormone (GH) to the GH receptor (GHR). The GH-IGF-1 axis in fish has a critical role in regulating growth (DEANE and WOO, 2009, REINECK, 2010, NAKANO, 2016, 2021). Coho salmon showed the changes in mRNA expression levels of *gh*, *ghr*, and *igf1* genes in response to acute physiological stress derived from a 2 min of chasing in the tank by a hand-held dip net followed by a 0.5 min aerial exposure after scooping with the dip net (NAKANO *et al.*, 2013). After exposure to handling stress, the mRNA levels of hepatic *igf1* transiently increased, then decreased 16 h post-stress, whereas those of *ghr* in the pituitary, liver, and muscle decreased gradually in response to the stress. However, the pituitary *gh* mRNA levels did not change during the treatment. These observations indicate that *gh*, *ghr*, and *igf1* responded differently to the stress. An acute physiological stress could mainly down-regulate the expressions of *ghr* and *igf1* in coho salmon. These results also suggest that neuroendocrine substances, such as cortisol and catecholamines, participate in stress response.

4. Eustress in farmed fish

It is thought that chronic stress accelerates aging and functional disorder of tissues, and that oxidative stress-induced damage plays an important role in this process. The physiological stress is often interpreted as having a negative impact on health. In fact, stress generally creates negative effects as we know. However, it has been recently suggested possible for animals and plants to manipulate eustress (positive or desirable stress) and to avoid distress (negative or undesirable stress) (NIKI, 2007, OKEGBE *et al.*, 2012, HIDEG *et al.*, 2013, KUPRIYANOV and ZHDANOV, 2014, AFONSO, 2020, YAMAUCHI and SUTO, 2022 NOAKES and JONES, 2016, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016). When the organism is exposed to stressors that induce distress, a functional physiological state is no longer maintained. However, when the organism is exposed to stressors that induce eustress, it acquires a qualitatively different physiological state, while it still maintains homeostasis. The eustress is one of the hormesis effects of toxicants: the toxicant has a benefit on the organism when it ingests under a certain threshold concentration, but the excessive amount of the toxicant becomes toxic on the organism (NIKI, 2007). It is known that ROS-induced severe oxidative stress leads to oxidative damage *in vivo*. However, a moderate level of oxidative stress promotes altered cellular functions, giving rise to benefits on animal health (MILISAV *et al.*, 2012, GORRINI *et al.*, 2013).

It is thought that the redox balance in fish exposed to various environmental stressors, such as heat shock and antibiotics, is shifted to the oxidizing direction, which may induce oxidative stress *in vivo* (NAKANO *et al.*, 1999, KAUR *et al.*, 2014, NAKANO *et al.*, 2014, NAKANO *et al.*, 2018, 2022, NAKANO, 2020, NAKANO *et al.*, 2020, NAKANO and WIEGERTJES, 2020). Many stresses derived from various environmental stressors are those of oxidative, suggesting that the antioxidants are effective as an antistress supplement to cope with the environmental stress (NAKANO and WIEGERTJES, 2020, NAKANO, 2020, 2021a, 2021b). Accordingly, manipulation of controlled stress treatment, such as mild physiological or thermal treatment, and use of adequate concentrations of antioxidative supplements could be employed as eustresses to improve the health of farmed fish (Fig. 3) (NAKANO *et al.*, 1995, NAKANO *et al.*, 1999,

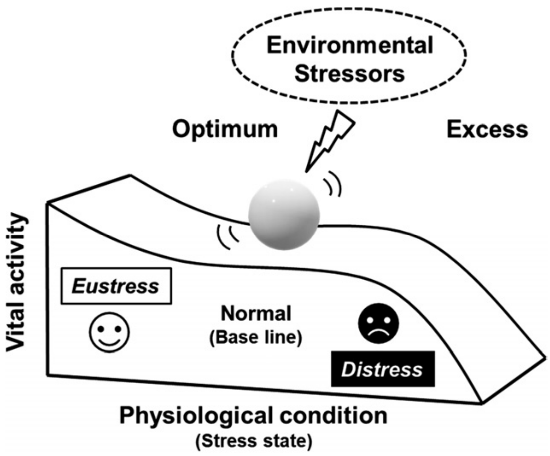

Fig. 3 Schematic view of altered physiological conditions with different stress states in response to environmental stressors in fish body. The physiological condition of fish body is like a ball. Environmental stressors can affect the condition and vital activity of fish body.

NAKANO *et al.*, 1999, NAKANO *et al.*, 2004, NIKI, 2007, DEANE and WOO, 2009, OKEGBE *et al.*, 2012, NAKANO *et al.*, 2013, NAKANO *et al.*, 2014, WU *et al.*, 2015, NAKANO *et al.*, 2018, AFONSO, 2020, NAKANO, 2020, NAKANO and WIEGERTJES, 2020, CERQUEIRA *et al.*, 2021, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016).

5. Conclusions and perspective

Aquaculture is thought to be the fastest growing food production technology in the world. Aquacultural production will continue to grow rapidly (FROEHLICH *et al.* 2018, GARLOCK *et al.*, 2019). Seafood contains various kinds of health-related functional components that are rare in land-based animal and plant foods. Hence, seafood is believed to contribute to global food and nutrition security (GOLDEN *et al.*, 2016, HICKS *et al.*, 2019, COSTELLO *et al.*, 2020). Although the sources of stress in aquaculture are variable, it has been found that most of them induced in fish is oxidative (NAKANO, 2016, 2020, NAKANO *et al.*, 2018, 2022, NAKANO and WIEGERTJES, 2020, NAKANO, 2021a). When fish falls ill due to stress, it is often difficult for the fish to be completely cured, and the quality and the value of the product derived from the fish are decreased. Not only routine management but also adequate and time-consuming treatment to cope with detrimental effects of stresses are required for farmed fish. The concept to employ eustress in aquaculture has the potential to provide innovative technology to keep fish health and to establish fish welfare (CONTE, 2004, BERGQVIST and GUNNARSSON, 2013, SCHRECK and TORT, 2016, SNEDDON *et al.*, 2016, AFONSO, 2020, BARRETO *et al.*, 2021, FRANKS *et al.*, 2021, NAKANO, 2021, YAMAUCHI and SUTO, 2022). Additionally, there is a line of increasing evidence that aquaculture-based food contributes to a more environmentally sustainable production of animal proteins, compared with that of land-based livestock animals (NAGASAKI, 1996, FROEHLICH *et al.* 2018, GARLOCK *et al.*, 2019). Increased aquaculture production is important to supply animal proteins on a global scale. Aquaculture is known to require less feed crops and land space referring to country-level aquatic and terrestrial data (NAGASAKI, 1996, FROEHLICH *et al.*, 2018). Aquaculture-based food production is expected, therefore, to contribute to the achievement of the United Nations' Sustainable Development Goals (SDGs) and the blue revolution (FROEHLICH *et al.* 2018, GARLOCK *et al.*, 2019, COSTELLO *et al.*, 2020, FARMERY *et al.*, 2021, JACOB-JOHN *et al.*, 2021).

Further studies will reveal the contribution of stress management including eustress and distress to the promotion of health and welfare of farmed fish and the improvement of aquaculture system.

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A practical survey with vertical-longline for characterizing vertical fish species distributions on Hachirigase Sea Hill, Sea of Japan: A case study assuming a complement for echosounder-based fish stock assessment

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Abstract: Accurate estimation of fish stocks is crucial for the sustainable use of fishery resources in offshore sea hills. However, bottom trawling is not practical for estimating fish stocks in areas with bumpy or rocky seabed topography. Although quantitative stock surveys using echosounders are effective, the identification of fish species from echograms remains a challenge. This study investigated the efficacy of vertical longlining in identifying fish species distributions near the seabed during an echosounder survey around Hachirigase Sea Hill in the Sea of Japan in June 2006. Seven species were caught at 7 of the 8 stations, resulting in a CPUE (inds./10-minute longlining) of 1.15. Threeline grunts and red lizardfish were the most abundant species, accounting for 43.7% and 37.0% of the CPUE, respectively. Threeline grunts were caught between the seafloor and 9 m above the seafloor, while red lizardfish were caught only in a narrow layer between the seafloor and 3 m above the seafloor. A significant difference in height above the seafloor was revealed between the two species. The study found that vertical longlining could complement echosounder-based surveys and may be an effective approach to determining the abundance of fish on a sea hill where trawl surveys are difficult.

Keywords : *acoustic survey, sampling gear, sampling method, sea hill*

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1. Introduction

Located on the continental shelf of the Sea of Japan, Hachirigase Sea Hill off Mishima Island, Japan, is an important spawning and nursery ground supporting coastal fisheries (Fig. 1). However, fishers are concerned that unplanned and illegal fishing is devastating fish resources in this area (e.g. HAMANO and UCHIDA, 2000). The accurate estimation of fishery resources is essential for their sustainable use and conservation (HAMANO and NOMURA, 2002).

The undulating rocky seabed at Hachirigase Sea Hill prevents the surveying of fish stocks using trawls. The area is accessible by an unusual trawl, with strong synthetic net fibers, large rubber bobbins, metal discs along the footrope, and precise electronic positioning systems; however, it destroys the habitat (KOSLOW *et al*., 2001). We previously applied an acoustic monitoring method to assess the distribution and abundance of fish in this area (TANOUE *et al*., 2008; HAMANO *et al*., 2015). This method still requires the identification of fish species detected in echograms (e.g. VILLAR *et al*., 2021), such as through *in situ* surveys, for the accurate estimation of fish abundance (SIMMONDS and MACLENNAN, 2005).

In waters with bumpy terrain such as rocky reefs, sampling can be accomplished through fishing with longlines or rods (MCCLATCHIE *et al*., 2000); for example, *Tamanawa* (Japanese name), a type of longlining, is a fishing method wherein one main line connected to floats (buoys) at regular intervals is spread out over the sea surface with many branch lines suspended vertically in the water, allowing for the assessment of the relative density and vertical distribution of fish near the seabed (MAEDA *et al*., 1982; ARIMOTO *et al*., 1983).

In addition, the simple fishing method known as vertical longlining employs one main line with multiple branch lines attached at intervals that is vertically suspended in the sea so that one end reaches the seafloor. This method enables prompt casting and recovery of the fishing gear for real-time sampling of fish detected by an echosounder. In surveys using quantitative echosounders to estimate the biomass of alfonsino, *Beryx splendens,* around a seamount, this vertical-longline method has been used to identify fish species (KOMATSU *et al*., 2002). This study examines the characteristics of fish species distributions using vertical-longline on Hachirigase Sea Hill.

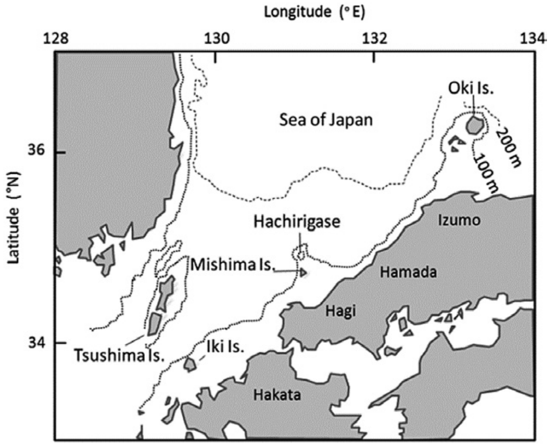

Fig. 1 Hachirigase Sea Hill, one of the most important offshore natural reef fishing grounds on the continental shelf southwest of the Sea of Japan.

2. Materials and methods

On 21 and 22 June 2006, we conducted vertical-longline sampling of fish on Hachirigase Sea Hill aboard a fishing boat (6.08 tons). The survey period was limited to daytime on two consecutive days in consideration of possible changes in fish behavior between daytime and nighttime and to ensure concurrency of the observations (SIMMONDS et al., 1992; TANOUE *et al*., 2007).

We used a 50-kHz echosounder (FCV-291,

Furuno Electric Co., Ltd.) equipped on the boat to measure fish echoes and their depths (TANOUE *et al.*, 2007; TANOUE *et al.*, 2013a). Vertical-longline fishing methods can be classified into two techniques: longlines operated through handling of the main line and longlines deployed with attached floats called *tarunagashi* (drifting barrels) in Japanese. In this survey, the former method was used to catch fish displayed on the echosounder, which reduced the risk of lost gear. Lost gear causes various problems, including ghost fishing (e.g. RUITTON *et al.*, 2019).

In vertical-longline fishing, fish are caught on a line deployed by hand, without the use of floats or fishing rods. To investigate fish species distributions by depth, we attached 10 branch lines (length: 0.375 m; diameter: 0.285 mm; load capacity: 5 kg) to the main line (diameter: 0.375 mm) at intervals of 1.5 m. A 187.5-g weight was attached to the end of the main line. The species and size selection (e. g. HOVGÅRD and LASSEN, 2000; YAMASHITA *et al.*, 2010), and fish catch (e.g. PORSMOGUER *et al.*, 2015) vary depending on the hook. In this study, it was important that fish distributed on the hill were caught without selection, so we decided to use the following hook based on the results of a preliminary survey (e.g. HAMANO *et al.*, 2001; HAMANO and NOMURA, 2002).

Circle hooks (called *nemuri-bari* or *mutsu-bari* in Japanese) with a curved shape (gap: 7 mm; height: 16 mm) were used as fishing hooks (e.g. PRPMJINDA *et al.*, 2008) and attached to the branch lines. In addition to the fishing lures that fishermen normally use in the field, boiled mysids were also used as bait to catch species that are less dependent on sight in order to reduce the selectivity of fish species as much as possible (e. g. KAWAMURA *et al.*, 1970; WOLF and CHISLETTE, 1974; KAWAMURA and TAMURA, 1990).

We set eight sampling stations across the hill

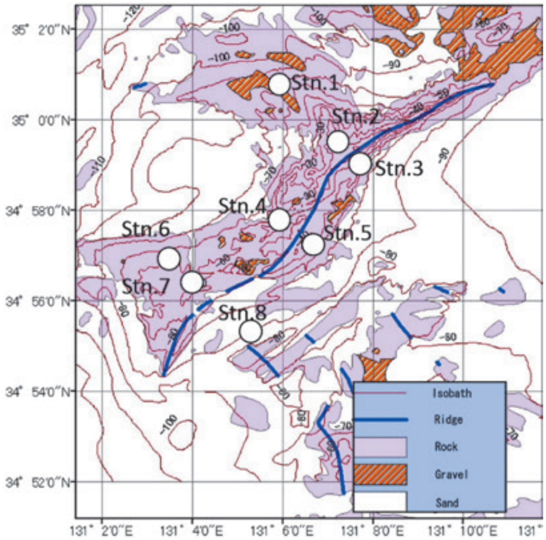

Fig. 2 Sampling stations (open circles) on Hachirigase Sea Hill in June 2006.

and allocated 10 minutes for catching fish with a vertical longline at each station (Fig. 2). If more than one fish was caught in a 10-minute fishing session with a vertical longline, the sampling time at that station was extended by 10 minutes. This extension was repeated until no more fish were caught. The catch per unit effort (CPUE: individuals/10-minute longlining) of vertical-longline fishing was defined as the number of fish caught divided by the number of 10-minute fishing sessions.

3. Results and discussion

We caught 7 species at 7 of a total of 8 sampling stations and during 18 of a total of 27 sampling times, resulting in a CPUE of 1.15. The proportional contribution to the CPUE for each fish species was 43.7% for threeline grunt (*Parapristipoma trilineatum*), 37.0% for red lizardfish (*Synodus ulae*), and less than 5% each for the other species, including cherry bass (*Sacura margaritacea*), bottom perch (*Apogon semilineatus*), filefish (*Thamnaconus modestus*), John dory (*Zeus faber*), and rockfish (*Sebastes inermis*). In this study, as only one type of hook was used and the size was constant, we did not correct CPUE due to differences in these variables. Although it is very difficult to eliminate species selectivity completely by hook, we caught fish species that are expected to be distributed in the Hachirigase, which has been confirmed by market research and underwater camera surveys (e.g. HAMANO *et al.*, 2001; HAMANO and NOMURA, 2002; FUJIWARA *et al.*, 2018). Thereafter, we discuss the distribution of the main catches of threeline grunt and red lizardfish.

Threeline grunt is a commercially harvested species that swims in schools (SUZUKI *et al.*, 2003; KOMATSU *et al.*, 2011; TANOUE *et al.*, 2013b), is benthopelagic (FROESE and PAULY, 2021), and inhabits rocky coastal seafloor areas, which are important fishing grounds for this species. The mean fork length of the threeline grunts (n = 13) caught at six sampling stations (Stns. 2–7) in a rocky area with bottom depths < 60 m was 28.3 ± 4.7 (mean ± standard deviation) (range: 19.4–34.0) cm, and mean body weight was 440.8 ± 191.9 (range: 119.3–646.8) g. The red lizardfish is demersal and lives on coastal reef flats with sandy or rocky bottoms (FROESE and PAULY, 2021). The mean fork length of red lizardfish (n = 12) collected at five stations in rocky and sandy areas (Stn. 4–8) was 17.0 ± 2.5 (range: 13.0–23.0) cm and the mean body weight was 47.5 ± 31.0 g with a range of 24.9 to 144.2 g.

According to KAWANO (1997), the fork lengths of 2, 3, 4, 5, 6 and 7-year-old threeline grunts on the Sea of Japan side of Yamaguchi Prefecture were estimated to be 18.4, 22.8, 26.2, 28.9, 31.1 and 32.0 cm, respectively. In addition, the mean and deviation fork length of the threeline grunts caught in this study were almost the same as the threeline grunts inhabiting the coast of Hagi City, including Hachirigase reported by KAWANO

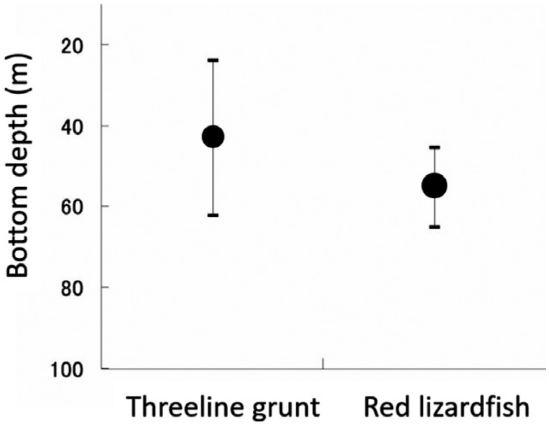

Fig. 3 Mean bottom depths (closed circles) at which threeline grunts and red lizardfishes were caught with a vertical-longline on Hachirigase Sea Hill in June 2006. Bars indicate standard deviations.

(1997). Additionally, the fork length of the captured red lizardfish was as wide as the threeline grunts. Some reports (e. g. ERZINI *et al.*, 1996; KATAYAMA and FUJIMORI, 2018) have shown that the hook width selectivity curves of longlines are much wider than typical curves, such as those of gillnets. In addition, as red lizardfish have a large mouth and swallow bait, the tendency to select the size of the catch (ERZINI *et al.*, 1997) was moderate.

Threeline grunts and red lizardfishes were sampled at sites with bottom depths of 43.3 ± 19.3 and 55.5 ± 10.0 m, respectively (Fig. 3). No significant difference in the bottom depth of the sampling sites where these fishes were caught was found between the two species (Mann-Whitney U test, $p > 0.05$). Threeline grunts, a benthopelagic species, were caught between the seafloor and 9 m above the seafloor, whereas red lizardfishes, a demersal species, were caught only in a narrow band between the seafloor and 3 m above the seafloor (Fig. 4). The mean heights from the seafloor where threeline grunts

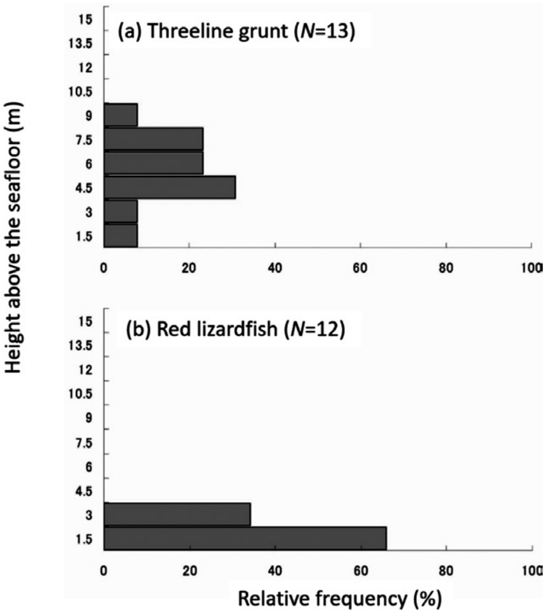

Fig. 4 Sampling frequencies of threeline grunts (a) and red lizardfishes (b) by height above the seafloor on Hachirigase Sea Hill in June 2006.

(n = 13) and red lizardfishes (n = 12) were caught were 5.5 ± 2.0 and 2.0 ± 0.7 m, respectively. A significant difference was found between the two fish species in height from the seafloor (Mann-Whitney U test, $p < 0.01$).

Our surveys revealed that the dominant species below a height of 9 m from the seabed in rocky areas shallower than 60 m in the fish echoes observed from Hachirigase Sea Hill was an important commercial fish in that area, threeline grunt. When investigating threeline grunts in June using an echosounder, surveying was most efficient around noon, when the fish do not move (TANOUE *et al.*, 2013b). We predicted catch, based on information from a preliminary survey, but cross-checking by underwater visual censes (e. g. RUITTON *et al.*, 2000) and environmental DNA (e.g. SATO *et al.*, 2021) are also important for verification.

This study shows that the vertical-longline sampling is effective for characterizing vertical fish species distributions on a sea hill where trawl surveys are difficult. If fish species can be assigned to fish echoes using criteria based on height-specific contribution to total CPUE, the accuracy of fish stock estimation is expected to improve.

Acknowledgments

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Safe seas through safe fishing work
– Research to understand and improve fishers' work –

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Abstract: In the context of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), the author's efforts over the past decade on the occupational safety of Japanese fishers and the possible challenges over the next decade were reviewed and discussed. Few studies have been conducted on the occupational safety in Japanese fisheries. As one of the few leading experts in the field, the author's work may provide a broad overview of the efforts on the occupational safety of fishers in Japan. The author conducted surveys on the workload of fishers on small-bottom trawlers and other fishing boats. Based on the survey results, some possible solutions have been proposed, such as the utilization of a workbench or work-assistive suit. Field surveys were also conducted to determine why fishers do not necessarily wear life jackets. Corresponding to the author's efforts, national efforts for fishers' occupational safety have gradually improved over the past decade, resulting in safety seminars for fishers; further, laws and regulations concerning the wearing of a life jacket have been amended. To ensure the occupational safety in the fishing industry in Japan, infrastructure to support long-term efforts for fishers' occupational safety is needed.

Keywords : *fishers' work, occupational safety, work posture, life jacket*

1. Introduction

Although the fishery is an important industry in Japan, it has the third-highest occupational accident rate among industries (MINISTRY OF HEALTH, LABOR AND WELFARE OF JAPAN, 2020). The number of Japanese fishers declined steadily to around 150,000 in the 2010s, which is a quarter of that in the 1970s (FISHERIES AGENCY OF JAPAN, 2018a). Furthermore, nearly 40% of fishers are aged 65 years or older. Although the Japanese population is declining and aging, the fishing industry is weakening at a disproportionately greater rate. According to a comparison of the populations of fishers in France and Japan, the population declined in both countries; however, Japan surpassed France in rapid decline and a high aging rate (TAKAHASHI and LE ROY, 2020). This finding highlights the seriousness of the decline in the fishing industry in Japan.

Occupational safety issues in the fishing

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industry might cause this weakening, along with the decline in fish catches and the deteriorating economic situation. To revive the Japanese fishing industry, it is important to develop a safe working environment. In this study, I will review work concerning occupational safety in Japanese fisheries and discuss a plan for the next ten years, in line with the United Nations Decade of Ocean Science for Sustainable Development (2021–2030).

First, I illustrate my research efforts on fishers' occupational safety and related national efforts in Japan. I will naturally cover some of the research on the occupational safety of Japanese fisheries in the last decade by looking back on the series of my work due to a lack of specialized researchers in Japan. Next, I summarize the national efforts on work safety that have been gradually enhanced in the last decade. Based on these findings and efforts, the steps required to ensure fishers' occupational safety are discussed.

2. Research efforts to improve work in the fishing industry

There are many accidents associated with fishing in Japan. However, when I started my study twenty years ago, there was little knowledge about the actual dangers involved in fishing and the extent of these dangers. The Japan Coast Guard compiled statistics on fishers' occupational injuries in marine accidents and the Ministry of Health, Labor, and Welfare of Japan on occupational accidents. However, these statistical materials do not address the specific work of fishers, and we do not know the resulting burdens on fishers' bodies. From a preventive perspective, it is necessary to understand the day-to-day work life of fishers. Therefore, I observed fishers at their work and then analyzed them for quantitative characterization. I then examined measures that could be undertaken to reduce risk.

2.1 Understanding and improving the actual work in the fishing industry

To observe the actual work involved in fishing, I boarded various fishing boats nationwide and recorded their activities. By applying ergonomic techniques to my findings, I analyzed the work involved and the extent of the burden exerted by each type of work on the fisher's body. The Ovako Working-posture Analyzing System (OWAS) (KARHU *et al.*, 1977; STOFFERT, 1985; KANT *et al.*, 1989), one of the most common and simple methods, was used to analyze the workload. In the OWAS method, the demand for work improvement is evaluated by combining the categorized postures of the three body parts (upper body, upper limbs, and lower limbs) and the weight handled by a worker (Fig. 1). Demand is classified into a four-level index, called the Action Category (AC) (Table 1). Analyses of several cases of small bottom trawling fisheries (e.g., TAKAHASHI, 2009; 2013; 2015; TAKAHASHI *et al.*, 2012a), one of the major coastal fisheries in Japan, revealed that most time was spent sorting fish. In addition, according to analyses using the OWAS method, the physical burden during the fish sorting tasks was often classified as AC2 (slightly harmful) or AC3 (distinctly harmful). Further, these tasks place a high burden on the musculoskeletal system of fishers (Fig. 2).

Based on these findings, improvement measures are proposed. The effect of a workbench, a classic and simple measure, on improving the forward leaning postures of the worker's upper body was verified. (TAKAHASHI *et al.*, 2017). An assistive suit was proposed as an advanced measure to reduce the burden on the lower back while working in a leaning posture. The effect of a prototype work-assistive suit on

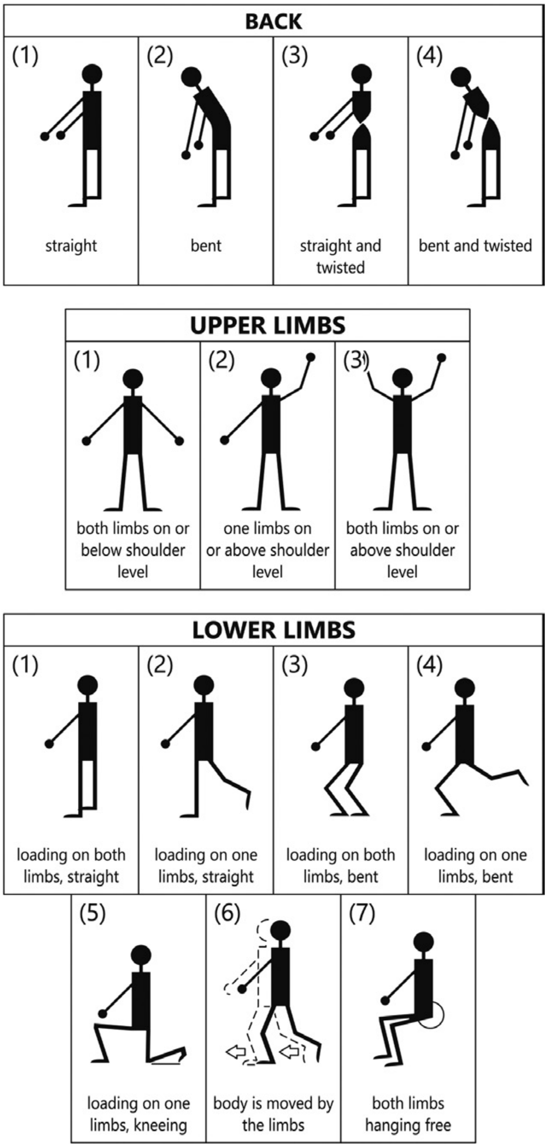

Fig. 1 Classified work postures used in the Ovako Working-posture Analyzing System (OWAS) method (drawn by the author based on Karhu *et al.*, 1977). In the OWAS method, a work posture is evaluated by the combination of the postures of back (upper body), upper limbs, and lower limbs.

fishing was verified by an indoor experiment using electromyography (Fig. 3) (Takahashi *et al.*, 2021). A similar approach is being explored in other types of fisheries, including fisheries in other countries, to expand our knowledge of the subject, which will be the basis for improving working conditions and occupational safety.

Table 1. Action Categories (AC) used to judge the physical burden and improvement demand in the Ovako Working-posture Analyzing System (OWAS) method (based on Kant *et al.*, 1990).

Action Category (AC)	Judgment (physical burden and improvement demand)
AC1	normal posture: NO ACTION REQUIRED;
AC2	the load of the posture is slightly harmful: actions to change the posture should be taken IN THE NEAR FUTURE;
AC3	the load of the posture is distinctly harmful: actions to change the posture should be taken AS SOON AS POSSIBLE;
AC4	the load of the posture is extremely harmful: actions to change the posture should be taken IMMEDIATELY.

2.2 Understanding the reasons why fishers do not wear life jackets

Not a few fishers do not wear life jackets despite the availability of essential work safety equipment on board. I asked some fishers to use and compare different jackets in their lines of work. There are a wide variety of work styles, and the suitability of jackets varies with the type of work (Takahashi *et al.*, 2020). In other words, one possible reason why fishers do not wear jackets is that they do not select a jacket suitable to their work. In addition, life jackets were worn out because of heat in most areas, except

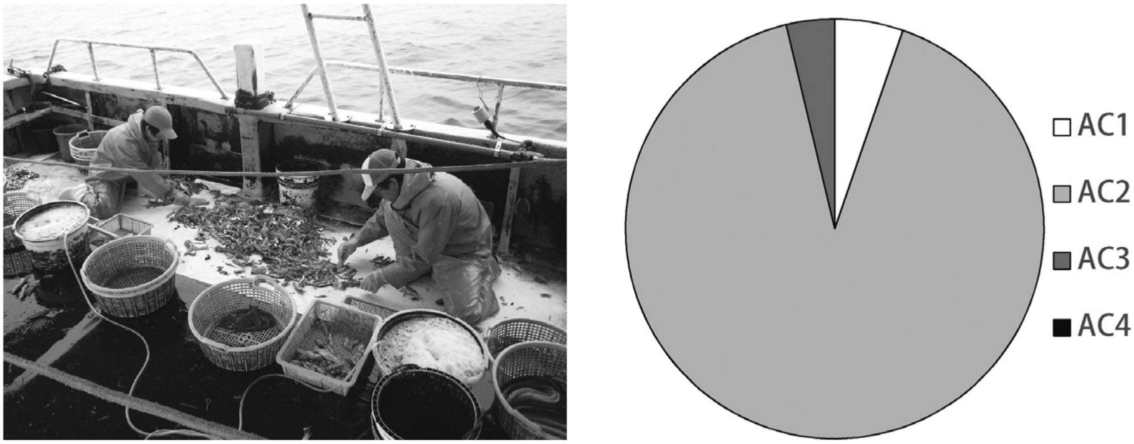

Fig. 2 Example of work posture analysis by the Ovako Working-posture Analyzing System (OWAS) method (Data from TAKAHASHI *et al.*, 2012a). Two crew members were engaged in catch-sorting tasks with their upper bodies leaning forward and kneeling in this case. About 95% of the work postures in the task were judged as AC2 of the OWAS method (i.e., slightly harmful), and actions to change the posture should be taken in the near future.

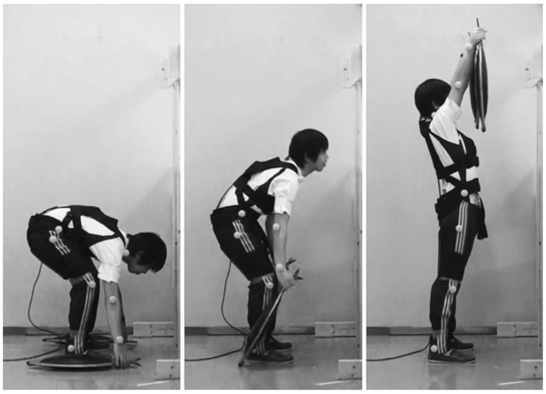

Fig. 3 Experiment to verify the effect of a work-assistive suit on fish unloading task from fish hold. An indoor experimental system was constructed because the actual fish hold was too narrow to perform the experiments. The effect was quantitatively verified by observing the difference in myoelectric potential of the muscle around the lower back depending on whether a work-assistive suit is worn. See TAKAHASHI *et al.* (2021) for details.

in the northern region of Japan. Alternatively, fishers in some kinds of fisheries, such as gill-netting, avoided using life jackets for fear of being caught in fishing gear. Based on the results of this study, a life jacket recommendation guide for different work environments was created and introduced on the website of the Fisheries Agency of Japan (FISHERIES AGENCY OF JAPAN, 2018b). This knowledge should be enhanced for many types of fisheries to enable the dissemination of suitable jackets according to the type of work.

2.3 Efforts to prevent falling on fishing boats

Falling on fishing boats is one of the most common accidents in the Japanese fishing industry. The deck of a fishing boat is usually slippery because of seawater on the floor and the swaying caused by ocean waves; sometimes, there are structural level differences and things left on the deck, such as fishing gear, which makes it easy to fall. I am working on multiple approaches to reduce accidents associated with falling down.

The first approach is to investigate the work

Fig. 4 A fisher taking the physical fitness test to diagnose his risks for falling down (right-side person on the photograph). The test is composed of three different trials: 5 m balance walk, two step walk, and standing on one leg; each trial provides information on balance, hip flexibility, and leg strength.

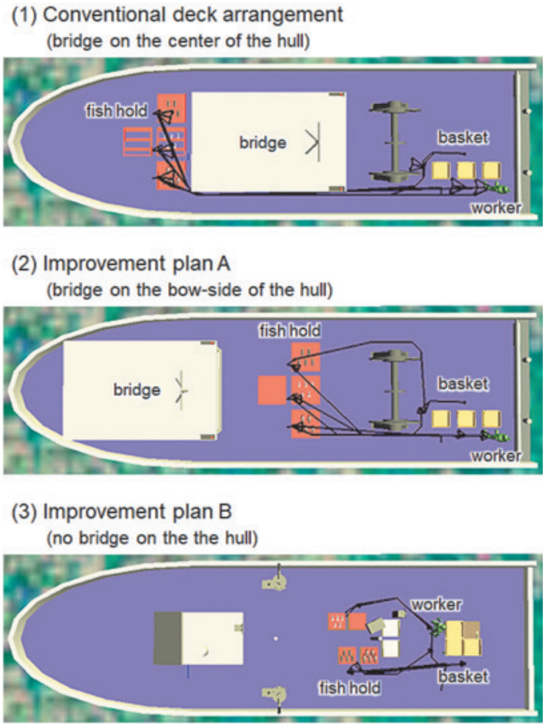

Fig. 5 Workflow analysis on a small trawl fishing boat (the figure quoted from TAKAHASHI *et al.* (2012b)). Three deck arrangements were reproduced virtually on a computer software, and the differences in the workflow lines (black lines) among the arrangements were evaluated. See TAKAHASHI *et al.* (2012b, 2021) for details.

and situation of fishing boats in the same way as in the survey mentioned above and to encourage work improvements that can mitigate hazards of falling down.

The second approach is to understand and improve fishers' physical fitness levels to prevent falling-down accidents. A method to assess the risk of falling through physical fitness tests was developed to reduce occupational accidents in a steel mill (NAGARA *et al.*, 2007). I am trying to apply the tests to understand and decrease fishers' falling risks (Fig. 4). I would like to introduce the test results of another study.

The third is the improvement of workflow lines on the deck of a fishing boat. As mentioned above, the conditions of the deck itself can create tripping hazards. Thus, minimizing passengers' walking on the deck prevents falling. The deck arrangement of a coastal trawling fishing boat was reproduced virtually on a computer, and the changes in the workflow lines were examined based on the difference in deck arrangements (Fig. 5) (TAKAHASHI *et al.*, 2012b; 2021). The simulation of the catch-transporting task on a coastal bottom trawler showed that the workflow lines were significantly shortened by placing the bridge on the bow-side to consolidate the work area on the stern deck. It is difficult to try multiple deck plans on a real fishing boat; however, various deck arrangements can be examined in virtual space without any risk to fishers.

3. Recent national efforts to secure fishers' occupational safety

National efforts have also increased the occupational safety of fishers in Japan. The author has been involved as a practitioner, lecturer, and committee member in most cases, as discussed below.

In 2013, a project funded by the Fisheries Agency of Japan was initiated to secure a safe work environment for fishers. The main objective of the project was to hold seminars for fishers nationwide and facilitate their learning of basic occupational safety. To date, more than 5,000 fishers have attended seminars. Although the project has a scale not large enough to reach all fishers, it is steadily contributing through the dissemination of knowledge on safety in fishing work.

The Fisheries Agency of Japan prepared a casebook called the Safety Inspection Manual as part of the project (National Fisheries Worker Securing and Training Center, 2021). The manual is intended to encourage fishers and persons concerned with the fishing industry to discuss their occupational safety and measures for improvement. The manual is a collection of slides that briefly introduce topics related to occupational safety with photographs and illustrations. The manual is expected to help disseminate knowledge on occupational safety to fishers.

In 2016, life jackets were discussed in a joint meeting held by the Ministry of Land, Infrastructure, Transport, and Tourism and the Fisheries Agency of Japan. It was decided that all fishing boat passengers would be required to wear life jackets.

In 2020, the Ministry of Agriculture, Forestry, and Fisheries of Japan hosted an expert meeting on new occupational safety measures in some industries, including fisheries. As a result, a norm and a check sheet were created for each industry, summarizing the occupational safety issues that business operators must consider.

4. Discussion

Over the last decade, knowledge of fishers' work and the associated problems has gradually been accumulated by aspiring individual efforts, including the author. National efforts are underway to address these problems. It is important to establish a simple and effective method of occupational safety, convey information to fishers all over the country, and continue these efforts until occupational safety is established. The most salient concern is that no permanent research organization or department is responsible for occupational safety in the Japanese fishery industry. Projects and research on fishers' occupational safety are under time constraints; in principle, long-term continuity is not guaranteed. An infrastructure that enables the continuity of long-term projects must be established. I hope that the system for the occupational safety of fishers will improve in the next decade to establish a safe working environment.

Acknowledgements

The surveys introduced in this review were completed through the kindness and cooperation of fishers and other relevant parties. I am grateful to my colleagues for their extended support during this study. Some of the surveys were conducted under a public project funded by the Fisheries Agency of Japan.

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Mini-Symposium on our scientific contribution to the Decade of Ocean Science

The 18th Japanese-French Oceanography Symposium entitled "Oceanography for future we want: transformation of our society for sustainable development with the changing sea" has been prepared to commemorate the 60th anniversary of the Japanese-French Oceanographic Society (SFJO) of Japan. The symposium aims to share new discoveries obtained through cutting-edge oceanographic research between participants from Japan and France, to serve to better transform human society for sustainable development and better adapt it to current changes in the ocean, marine and coastal environments. "The UN Decade of Ocean Science for Sustainable Development (UNDOS) aims to achieve a sustainable "the Ocean We Want" by 2030 through the work of research institutes and scientists from around the world working together over the next decade. The UNDOS outlined seven Decade Outcomes: a clean ocean, a healthy and resilient ocean, a predicted ocean, a safe ocean, a sustainably harvested and productive ocean, a transparent ocean and an inspiring and engaging ocean. The 18th Japanese-French Oceanography Symposium was organised in response to a common concern with the UNDOS: the need to transform society in order to overcome the crisis facing the oceans and to create a sustainable world. This web-based symposium "Mini-Symposium on our scientific contribution to the Decade of Ocean Science" featured six talks by six speakers from each of France and Japan (Table 1). Each of them corresponds to one of Decade Outcomes that is closely related to the content of each talk and present it in that order. The presentations were given in the order of the Decade Outcomes.

The mini-symposium was organised via the web on 19 October 2021 from 16:00 to 20:00 (CET). The presentations help to improve the understanding of the oceans among a wider audience and help to build a society that can appreciate the oceans. The abstracts presented to the mini-symposium are listed below the programme. This mini-symposium was supported by the Japanese-French Oceanographic Society France, *le Service pour la Science et la Technologie (SST) de l'Ambassade de France au Japon, la Fondation Franco- Japonaise Sasakawa,* the Japan Agency for Marine-Earth Science and Technology, the Japanese Society of Fisheries Science, the Japanese Society of Fisheries Oceanography, the Oceanographic Society of Japan and the Japanese National Committee of the UN Decade of Ocean Science for Sustainable Development.

Table 1. Programme of the mini-symposium on our contribution to the Decade of Ocean Science.

Time (JST)	Title	Speaker	The Ocean We Want for a sustainable future is represented by seven Decade Outcomes
16：00～16：20	Plastics contamination in the coastal areas around Japan	Hisayuki ARAKAWA	1. A clean ocean
16：20～16：40	Environmental conservation of the Seto Inland Sea, Japan	Kuninao TADA	1. A clean ocean
16：40～17：00	Marine biodiversity in the Mediterranean, in the era of global warming	Charles-François BOUDOURESQUE	2. A healthy and resilient ocean
17：00～17：20	Diversity of polydorid species (Polychaeta: Spionidae) in the English Channel (France) and on the Pacific Coast of Tohoku District (Japan)	Jean-Claude DAUVIN	2. A healthy and resilient ocean
17：20～17：40	Toward prediction of interaction between Coastal Circulation and the Kuroshio	Kiyoshi TANAKA	3. A predicted ocean
17：40～8：00	Influence of global warming on spatial distribution of *Sargassum horneri* in northwestern Pacific	Teruhisa KOMATSU	3. A predicted ocean
18：00～18：20	How frequently can we observe winds and waves for safer maritime transport?	Kaoru ICHIKAWA	4. A safe ocean
18：20～18：40	Safe seas through safe fishing work	Hideyuki TAKAHASHI	4. A safe ocean
18：40～19：00	Sustainable development and responsible exploitation. As an example, the management and exploitation of diadromous species in the context of Small-Scale Fisheries	Patrick PROUZET	5. A sustainably harvested and productive ocean
19：00～19：20	Ecosystem-Based Management approach applying to Artificial Reefs assessment: a case study of network analysis in Capbreton, France	Jessica SALAÜN	5. A sustainably harvested and productive ocean
19：20～19：40	Failure of bivalve foundation species recruitment in a context of extreme heat wave event	Franck LAGARDE	5. A sustainably harvested and productive ocean
19：40～20：00	Observing the deep and sharing the invisible: a nascent case study in the South Pacific, New Caledonia	Yves HENOCQUE	6. A transparent ocean

Abstracts presented to the mini-symposium on the on our contribution to the Decade of Ocean Science

Plastics contamination in the coastal areas around Japan

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1. Objectives

One desirable outcome of the UN Decade of Ocean Science for Sustainable Development is the "clean ocean" (https://en.unesco.org/ocean-decade). If a "clean ocean" is defined as an ocean of clear water, we want to have as few particles as possible in the seawater. In recent years, it has been reported that artificial plastic particles are increasing in the ocean. These floating particles gradually become damaged, and are known as microplastics (hereinafter MPs) when they are 5 mm or less in length (ANDRADY, 2011). Contamination by MPs is thought to have an adverse effect on various organisms living in the ocean (GALL and THOMPSON, 2015). For this reason, surveys have been conducted all over the world, from which is understood that MPs are distributed globally in the ocean. It has been reported that concentrations of MPs are higher in East Asian waters than elsewhere (ISOBE *et al.*, 2015). Distribution of MPs in the coastal waters of Japan needs investigation. This study examined the concentration distribution of plastic litter and MPs in East Asian waters, and especially in the coastal areas of Japan.

2. Survey of macro-plastic litter in Japan

A survey of marine plastic litter in Japan has been conducted since around 2014 and is carried out by observers on vessels passing through the survey areas. Plastic food packaging litter is widely distributed along the Japanese coast. Plastic bags are also widely distributed throughout Japanese waters, and numbers are locally elevated off the east coast of the Tsugaru Strait. Styrofoam and plastic bottles are extremely high near the Tsushima Strait.

3. MPs survey in Japan

The marine MPs survey was started at the same time as the litter survey. The detection method was to collect particles from the sea surface using a neuston net, to extract plastic-like particles in the laboratory, and to determine the polymer type by Fourier Transform Infrared Spectroscopy. The MPs on the sea surface were widely distributed along the coast of Japan, at an average concentration of 3.7 pieces m^{-3}. This concentration was very high compared with other sea areas in the world (ISOBE *et al.*, 2015), and the average concentration of MPs in Tokyo Bay was 3.98 pieces m^{-3}. The concentration varied greatly depending on the location and season (NAKANO *et al.*, 2021).

4. Survey of small MPs in Japan

The neuston net (mesh opening: 350 μm) was mainly used in the MPs survey, and so MPs smaller than 350 μm were not collected. For this reason we created double neuston nets, comprising two nets of 350 μm and 50 μm mesh, and investigated small MPs (hereinafter SMPs) in the open ocean (off the Tokai coast) and inner bay (Tokyo Bay). The concentration of SMPs was 1,000–5,900 pieces m^{-3} in the open ocean and about 3,000 pieces m^{-3} in the inner bay.

5. Discussion

In recent years, the Japanese Ministry of the Environment and Japanese universities have investigated the concentration distribution of marine plastic litter, MPs (> 350 μm) and SMPs (< 350 μm) off the Japanese coast. Gradually, progress is being made in our understanding of plastics pollution in the sea area. It is difficult to compare research data because unified methods of collecting and analysing MPs have not yet been established. In particular, no appropriate survey method has been established for SMPs. Development of methods of detecting SMPs must continue. In the future, data not only on the origin and distribution of MPs of various sizes in sea areas, but also of pollution on the beach, seabed, and organisms must be accumulated.

Acknowledgements

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Changes in nutrients and their effects on fisheries after the introduction of land-based nutrient loading regulations in the Seto Inland Sea since 1973: A review

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1. Objectives

The Seto Inland Sea is the largest enclosed sea in Japan (Fig. 1). The sea is well known as beautiful landscape including about 600 islands. This sea is also an industrially developed area and about 30 million people live in the coastal area. This sea was heavily eutrophicated during 1960s and 1970s. After that, the water quality gradually improved. Here, we review the change of water quality for about the last 40 years in this sea. We will discuss the nutrient decrease, focusing on Harima Nada, the eastern part of the Seto Inland Sea based on information obtained during our previous study. Our study is in line of with the basic policy of the "14 Life Below Water" of SDGs, "Conserve and sustainably use the oceans, sea and marine resources for sustainable development". Also, in this year, "United Nations Decade Ocean Science for Sustainable Development" has started. We also conduct this research in accordance with the "Ocean decade".

2. Previous eutrophication and its environmental conservation in the Seto Inland Sea: Background of the present environmental problem

During high economic growth since the 1960s, the Seto Inland Sea became heavily eutrophicated due to serious water pollution by industrial effluent and urban wastewater. At that time, red tides often occurred. To resolve the situation, the Law for Conservation of Environment of Seto Inland Sea was enacted in 1973. Since 1973, the industrial effluent and urban wastewater were regulated by a Total Pollution Load Control System under this law. After that, the number of red tide occurrences decreased from 300 times to 100 times per year and then it is now constant under 100 times. Whereas the water quality has improved, recent seaweed (*Nori*) bleaching due to lack of nutrient has often occurred and *Nori* culture in this sea was heavily damaged despite the water quality improvement. Fish catches have also gradually decreased.

3. The nutrient dynamics in Harima Nada

The nutrient concentrations (NO_3, NH_4, and PO_4) have apparently decreased since 1970s, as has dissolved inorganic nitrogen (DIN: NO_3 + NO_2 + NH_4) (Fig. 2). However, total nitrogen (TN) and phosphorous (TP) concentrations have not apparently decreased, although TN and TP loadings to the sea were reduced 40% and 61%, respectively, from 1979 to 2009 by implementing a Total Pollution Load Control System. It suggested that the decrease of nutrient concentrations could not be explained by only reducing of TN and TP loading. To maintain the appropriate nutrient condition, we need to know the mechanism of nutrient circulation and nutrient behavior. The nutrient concentrations of this sea water should be decided by the balance of nutrient income and outgo at three sites (Fig. 3a). Those are the freshwater inflow from the river, the interface between the coastal sea and open ocean or adjacent sea, and the interface between the bottom sediment and bottom water. In three sites, we monitored the upward

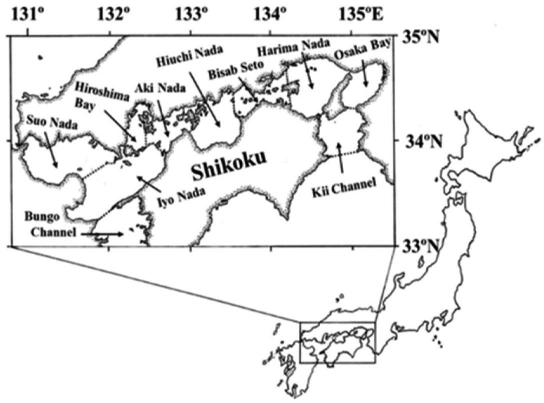

Fig. 1 Location of the Seto Inland Sea.

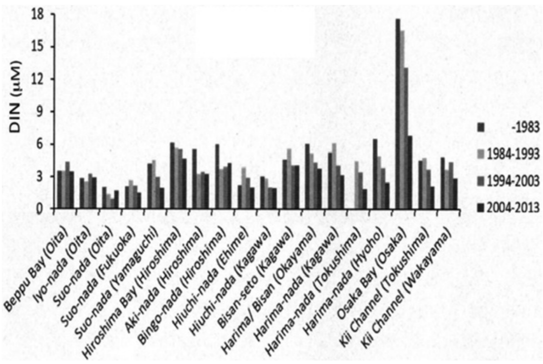

Fig. 2 Average DIN concentrations for every 10 years in each sea area (ABO *et al.*, 2018).

nutrient flux across the overlying water-sediment interface. In Harima-nada, it was estimated that nutrient flux from bottom sediment during summer was larger than nutrient inflow from the river by 3.2 times (TADA *et al.*, 2014). To know the nutrient dynamics, we are trying to reveal the budget of the nutrient cycle in the water column, including the primary production of phytoplankton, organic matter settling fluxes, decomposition of settling matter in the bottom layer, and nutrient upward flux from bottom sediments (Fig. 3b).

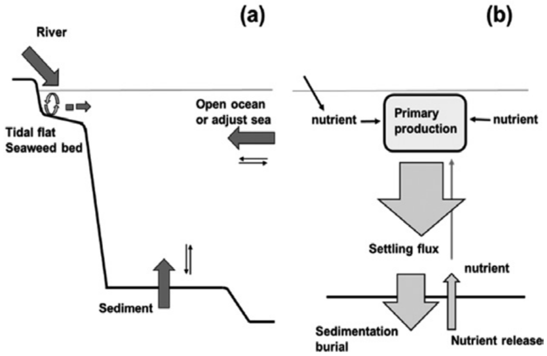

Fig. 3 Nutrient Dynamics (a) and material cycle in a coastal sea water.

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Marine biodiversity in the Mediterranean, in the era of global warming

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The Mediterranean is a semi-closed temperate to locally warm sea. It is a hotspot of species, functional and ecosystem diversity, characterized by a high rate of endemism and a number of unique ecosystems. Between 12,000 and 17,000 marine species have been reported in the Mediterranean. Only one species is totally extinct and less than ten are extinct in the Mediterranean but still present elsewhere. In contrast, many species are functionally and/or regionally extinct. The progressive arrival of a thousand non-native species has in fact considerably increased the epsilon species diversity of the Mediterranean, contrary to the naive beliefs of some environmentalists. Several of the emblematic ecosystems of the Mediterranean (e.g. the seagrass *Posidonia oceanica* meadow, the dune-beach-banquette ecosystem, the *Lithophyllum byssoides* algal rim and the coralligenous) are currently in decline. Finally, the functioning of ecosystems (relative abundance of key species, carbon and nutrient flows, food webs, and interactions between ecosystems) has been profoundly altered. The causes of these effects on biodiversity are various; the three main ones are overfishing, biological invasions and coastal development. Global warming is beginning to play a role, which will increase significantly over the course of the 21st century, but it is currently far behind other human-induced causes. The concern over the growing and irreversible effects of global warming is totally justified; but the underestimation of other threats is based on reasons which may be political or related to human perceptions and science funding, and which are discussed here.

Diversity of polydorid species (Polychaeta: Spionidae) in the English Channel (France) and on the Pacific Coast of Tohoku District (Japan)

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The polydorid (Annelida, Spionidae) contains nine genera: i. e. *Amphipolydora*, *Boccardia*, *Boccardiella*, *Carazziella*, *Dipolydora*, *Polydora*, *Polydorella*, *Pseudopolydora*, *and Tripolydora*, with each of them having a modified fifth chaetiger. Identification of polydorids remains problematic due to numerous confusions of species and their unknown distribution: i.e. several introduced species around the world ocean. Moreover, many polydorid species are known for their boring into calcareous substrates, and have been reported to inhabit various types of living and non-living calcareous structures including mollusc shells, corals and coralline algae. They cause grave damage to their calcareous hosts, and polydorid infestation is considered as a serious problem in aquaculture especially for oyster culture. Successive inventories have reported polydorids in the English Channel (FAUVEL, 1927; DAUVIN *et al.*, 2003; RUELLET, 2004). There are some reports describing polydorids from the Pacific coast of Tohoku District, Japan (SATO-OKOSHI, 1999; 2000; ABE *et al.*, 2020). Species Richness in both areas is compared and discussed. Moreover, in March 2018, French-Japanese collaboration led to the collection of polydorid species from the shells of feral and cultured oysters *Crassostrea gigas* (THUNBERG, 1793) along the western coast of Normandy, France. Some species were also extracted from coralline algae and other calcareous substrates. Eight species were recorded from four polydorid genera: *Boccardia, Boccardiella, Dipolydora* and *Polydora*. The two species *Polydora hoplura* Claparède, 1868 and *Dipolydora giardi* (Mesnil, 1893) were previously known in Normandy, along with another member of the genus *Dipolydora* that has not been identified to the species level. *Boccardia proboscidea* Hartman, 1940, *Boccardiella hamata* (Webster, 1879) and *Polydora websteri* Hartman in Loosanoff & Engle, 1943 represent new records in Normandy, while both *Boccardia pseudonatrix* Day, 1961 and *Polydora onagawaensis* Teramoto, Sato-Okoshi, Abe, Nishitani & Endo, 2013 are new species for European waters. We point out that collaboration with polychaete specialists to study well-known seas such as the English Channel would allow us to discover new species, expanding the list of species actually present. This study also highlights the need to continue this partnership further identify which polychaete species infest English Channel oysters.

Toward prediction of interaction between Coastal Circulation and the Kuroshio

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1. Objectives

We are currently conducting a research project designed to investigate interaction between coastal circulation and the Kuroshio current. The goal of our project is to present a clear vision for future ocean science in bays and estuaries adjacent to the Kuroshio, meeting the expected outcome of the UN Decade of Ocean Science, especially for "A Predicted Ocean". To achieve this goal, we have three objectives: development of numerical simulation, establishment of sustainable in situ observation, and collaboration with stakeholders. Background and progress of the project is introduced in this paper.

2. Background

Coastal circulation off the south coast of Japan interacts strongly with the Kuroshio current. For example, after being detached from the Kuroshio current, meso- and submesoscale disturbances with momentum are often captured into small bays, where they drive local peculiar coastal circulation (Fig. 1). This example indicates that understanding and prediction of the interaction between coastal circulation and the Kuroshio current are necessary to achieve a healthy, safe, and resilient ocean for sustainable development including improved forecasts of regional weather and climate and better management of regional fisheries and aquaculture.

We are in an age when high-resolution ocean

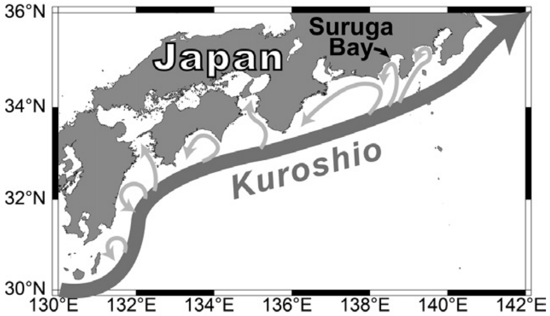

Fig. 1 Schematic of the Kuroshio current and coastal circulation off the south of coast of Japan.

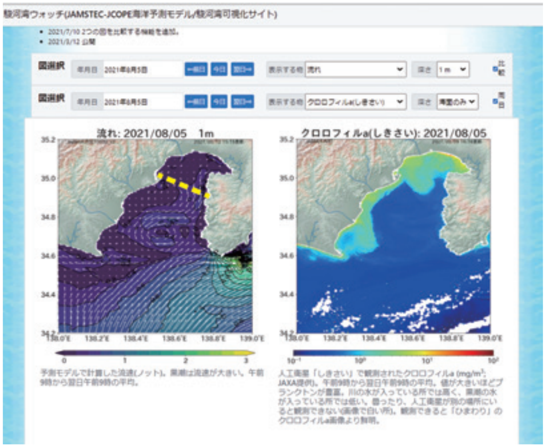

Fig. 2 Open website of JCOPE model. Left: forecasted surface currents. Right: forecasted surface chlorophyll.

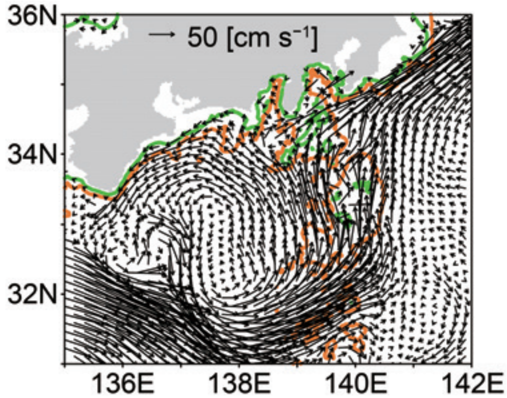

Fig. 3 Surface currents in MRI.COM model.

circulation models have started simulating the meso- and submesoscale disturbances directly. Moreover, in situ observation has recently become easier to perform using ordinary fishing boats or commercial ships, because observational instruments have been downsized. It should be noted that in coastal seas, there are usually few research boats or ships equipped with advanced observational instruments. Therefore, we have developed a project that performs numerical simulation using state-of-the-art ocean circulation models and in situ observation using ordinary fishing boats and a commercial ship to study the interaction between coastal circulation and the Kuroshio current around Suruga Bay off the south coast of Japan (Fig. 1). A key point is that the numerical simulation is validated by the in situ observations.

3. Results

Two types of numerical models with variational data assimilation are used: JCOPE model with a terrain following (s-) coordinate system has been developed by JAMSTEC (Japan Agency for Marine-Earth Science and Technology). MRI.COM model with a geopotential (z-) coordinate system has been developed by JMA (Japan Meteorological Agency). Both the models successfully reproduce complex circulation systems between the south coast of Japan and the Kuroshio, including daily variations of winds, river discharge, and tides (Figs. 2 and 3).

Two types of in situ observation are ongoing. An ADCP (acoustic Doppler current profiler) mounted on the bottom of a commercial ferry (Fig. 4) is measuring velocity profiles on a transect across Suruga Bay every day (dashed line in Fig. 2). Moreover, mooring observation (Fig. 5) has been performed to record time

Fig. 4 The ferry "Fuji", on the bottom of which an ADCP is mounted.

series of temperature, salinity, and velocity with shorter time intervals at a few fixed positions in the bay.

4. Discussion

To achieve our project goal, synergistic collaboration with stakeholders such as local fishers and shipping agencies is essential. This is because frequent observations with high spatial and temporal resolution cannot be made without their support. In other words, there are usually few research boats or ships in most of the coastal seas. At the same time, there are many fishery problems that cannot be solved without state-of-the-art ocean science, because seawater circulation has a crucial influence on fishing grounds. In these points our project meets the goal of the UN Decade of Ocean, developing a sustainable ocean science.

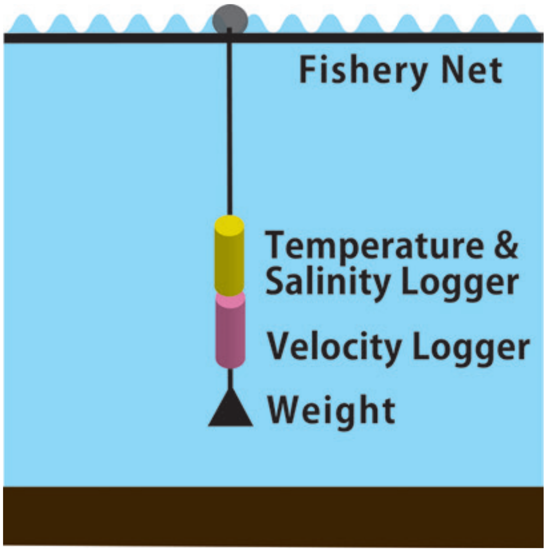

Fig. 5 Schematic of mooring system equipped with a fishery net.

Acknowledgements

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Influence of global warming on spatial distribution of *Sargassum horneri* in northwestern Pacific

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1. Introduction

Seaweed and seagrass beds are one of the most important primary producers in coastal areas and provide a habitat for many organisms, and their ecosystem services per unit area are estimated to be about ten times those of tropical forests (COSTANZA *et al*., 2014). Large seaweeds and seagrasses spend a long period of their life history as anchorage and are not able to move actively. The effects of ocean warming on benthic organisms that live fix on hard substrates are clearly visible as changes in their distribution areas. KOMATSU *et al*. (2014) estimated changes in the distribution of *S. horneri* based on surface water temperature data for 2050 and 2100 estimated under the A2 scenario of IPCC (2000), which assumes high economic growth and regional identities. However, the spatial resolution was coarse (1.1° longitude and 0.55° latitude) and made coastal water temperatures problematic. Thus, predictions of surface water temperatures with higher spatial resolution were desired.

Institute of Applied Mechanics of Kyushu University (RIAM) has been developing a model, DREAMS, for estimating future water temperature distributions in the northwest Pacific Ocean with high spatial resolution. Using the surface water temperature in 2100 calculated by DREAMS, we estimated the future geographical distribution of *S. horneri*, which is the most widespread and biomass-rich species in northwestern Pacific and important species forming floating rafts in the East China Sea (e.g. KOMATSU *et al*., 2008; MIZUNO *et al*., 2014). We also examine the impact of global warming on the relationship between yellowtail juveniles that use *S. horneri* floating rafts as a habitat.

2. Water temperature distribution data

The model DREAMS_B (HIROSE, 2011) with a high spatial resolution of longitude 1/4° x latitude 1/5° is used to calculate the future ocean environment in the Northwest Pacific Ocean under the RCP8.5 high reference scenario (a scenario in which the maximum possible amount of greenhouse gas emissions is assumed to continue until 2100). Based on the results, we used the surface temperatures in 2000 and 2100 as estimates for August, the month with the highest surface temperatures, and February, the month with the lowest surface temperatures. Based on this range of maximal and minimal water temperatures in the coastal zone in which *S. horneri* could grow, we estimated the coastal area where the *S. horneri* can grow based on the surface water temperatures in 2100.

3. Growth temperature range of *Sargassum* horneri and its distribution in 2000

On the Sea of Japan coast, *S. horneri* grows as far south as Amakusa Peninsular in Nagasaki

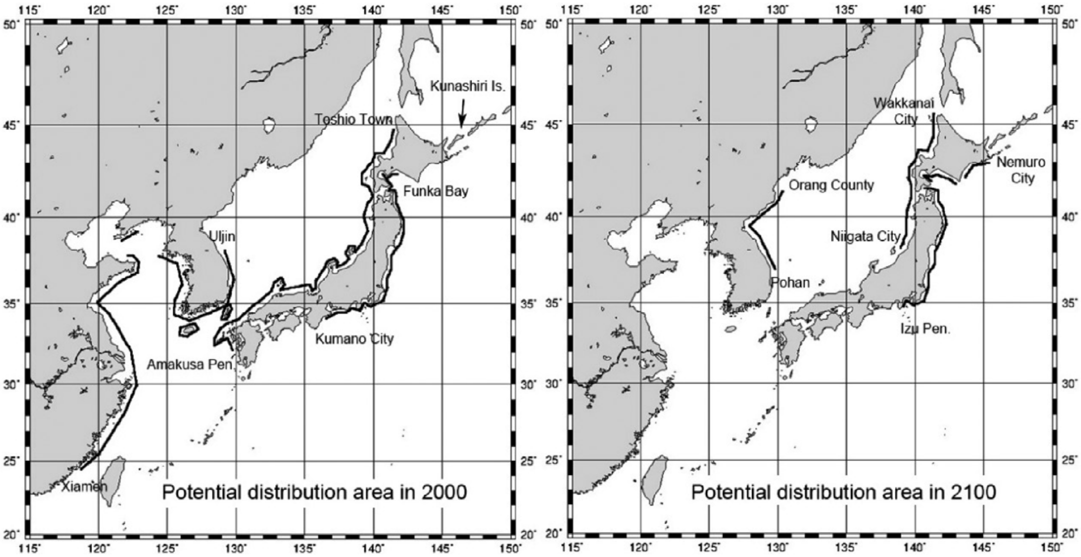

Fig. 1 Map showing potential geographical distributions of *Sargassum horneri* (solid line) in 2000 (left panel) and 2100 (right panel).

and as far north as Teuri in Hokkaido Prefecture, while on the Pacific coast, it grows as far south as Mie Prefecture in Kii Peninsular and as far north as Kunashiri Island (UMEZAKI, 1984). We tuned Umezaki's north and south ends of *S. horneri* distributions according to our field surveys. On the East China Sea - Sea of Japan side along the Japanese coast, the distribution of *S. horneri* ranged from Amakusa Peninsula in Kyushu in the south to near Teuri Island in Hokkaido in the north, and on the Pacific side along the Japanese coast, from Kumano City in Mie Prefecture in the south to Funka Bay in Hokkaido in the north. According to the geographical distributions of *S. horneri*, sea surface temperature (SST) in February, which is the coldest month of the year, in the coast where *S. horneri* grows is 15℃ at the highest and 4℃ at the lowest in East China Sea - Sea of Japan side and 14℃ at the highest and 4℃ at the lowest in the Pacific side of Japan. The SST in August, which is the highest month of the year in the coast where *S. horneri* grows is 28℃ at the highest and 22℃ at the lowest in East China Sea - Sea of Japan side, and 28℃ at the highest and 20℃ at the lowest in the Pacific side of Japan. Based on these results, the potential distribution range of *S. horneri* was estimated to be around Xiamen, Fujian Province in the south and Uljin, Korea on the east coast of Korean Peninsula in the north along the Eurasian coast (Fig. 1).

4. Predicted distribution of *Sargassum horneri* in 2100 and impact on yellowtail juveniles

Based on the predicted water temperatures in February and August of 2100, we estimated the potential distribution range of *S. horneri* (Fig. 1). Along the Eurasian coast, Sea of Japan and Pacific coast of Japan, the potential geographical distribution of *S. horneri* was estimated to move northward. Maximum water temperatures in summer were the main factor limiting the distribution of *S. horneri* in these areas.

According to YAMAMOTO *et al.* (2007), the optimum SST for yellowtail spawning in East China Sea is 19–21°C. In February and March 2100, the surface temperature range of 19–21°C in East China Sea was 122–124°E, 27–28°N in February and 125–129°E, 31–33.8°N in March. There is no possibility for 20-day-old yellowtail juveniles to encounter *S. horneri* in East China Sea (Fig. 1).

How frequently can we observe winds and waves for safer maritime transport?

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1. Introduction

Observations of offshore sea states are difficult since the ocean is wide and far from lands where people are living. In general, however, timescales of most oceanic variations are long, so any observations are significant even if they are intermittent. Especially, recent progress of numerical models and data assimilation techniques enables us to forecast oceanic conditions from limited observational data.

However, atmospheric conditions govern sea surface winds, and sea surface waves forced by them. Therefore, their timescales are often smaller than the other oceanographic variations. This also means that assimilation of a single measurement can improve the numerical model only for a small adjacent time and location. To improve accuracy of long-term forecast of the model for offshore winds and waves, therefore, we need denser observations. This would be a critical problem for safe offshore marine transport. In other words, selections of safe and economic ship routing would strongly depend on observation density of observe offshore winds and waves. In this presentation, we discuss how often we can observe offshore winds and waves by various methods.

2. Winds

The most essential method to observe offshore winds is in situ measurements by ships. Although locations of observations are limited to ship routes, this method can provide temporally continuous observations. Nevertheless, this method could be strongly biased, since no observations are available when wind conditions are severe, which would be critical for forecasting safe marine transport. Meanwhile, moored buoys and surface drifters can provide continuous in situ observations outside the ship routes. However, their locations are significantly limited comparing to the vast size of oceans, since their maintenance and deployment costs are too high to cover wide areas.

Satellite observations are the most practical method of observing global winds. Various types

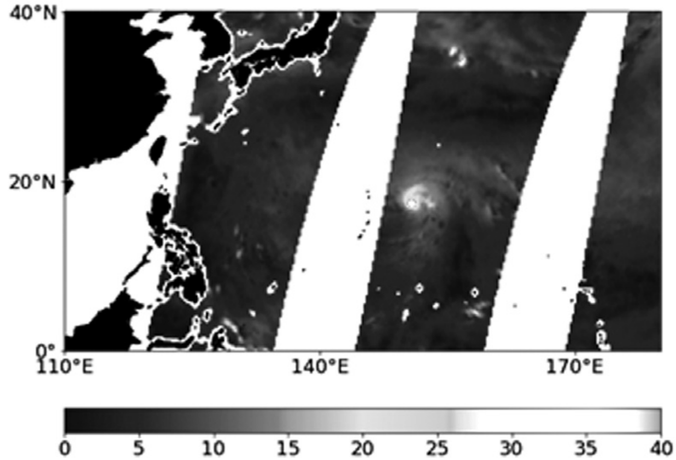

Fig. 1 Wind speed distribution (ms^{-1}) in the afternoon on 29 August 2018 (by JAXA AMSR2 sensor).

of sensors on satellites can estimate sea surface wind speeds, but most of them indirectly measure the amplitude of short-wavelength wind waves that respond to local wind speed. Within a short period, global distribution of wind speeds can be measured (Fig. 1), and these observation data will be available soon after they are downlinked to ground stations. By combining several sensor records, offshore wind speeds at an arbitrary point can be observed several times in a day, which are now essential inputs for wind forecasting.

3. Waves

Unlike winds, quantitative measurements of waves by ships are difficult since a sailing ship generates additional waves around herself. Therefore, buoys and surface drifters become an essential in situ method for observing offshore waves, which shows that locations of *in situ* wave observations are significantly limited. Furthermore, no satellite sensors other than altimeters can provide a direct estimation of wave heights, or amplitude of swells. Although satellite altimeters cover global ocean, they cannot provide horizontal two-dimensional coverages, as in Figure 1; observation points of altimeters are confined along tracks just below the satellites. Thus, observations of offshore wave heights are significantly intermittent both in time and space. These sparse observations are not commonly used in practical numerical wave model estimations.

Recently, a new method has been proposed to observe wave heights by ships. As shown in Figure 2, GNSS signals reflected at the sea surface are received together with direct signals. Since the reflected signals travel longer distance than the direct signals, the distance between sea surface and the antenna can be estimated from this difference (GNSS Reflectometry, or GNSS-R). More frequent observations of offshore wave heights could be possible by using such GNSS-R methods.

Acknowledgements

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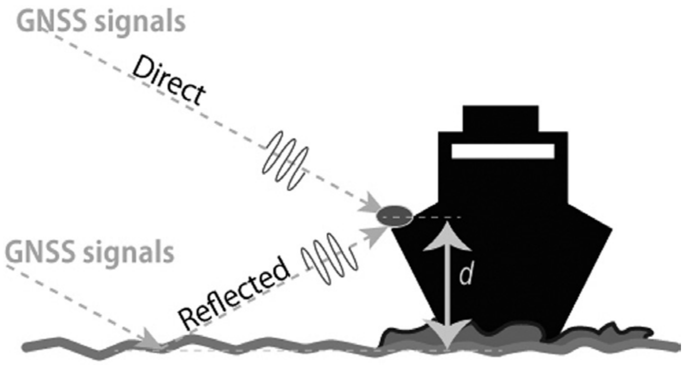

Fig. 2 Concept of GNSS-Reflectometry.

Safe seas through safe fishing work

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1. Introduction

Fishery is a dangerous industry in Japan. Fishery stands third when considering the highest occupational accident rate by industry (MINISTRY OF HEALTH, LABOUR AND WELFARE OF JAPAN, 2020). The number of Japanese fishers is declined steadily to around 150 thousand in the 2010s—a quarter of that in the 1970s (FISHERIES AGENCY OF JAPAN, 2018). Furthermore, nearly 40% of fishers are 65 or older. While the Japanese population is declining and aging, but fishers are weakening at a greater rate. The fact that fishery is still a dangerous industry might be a cause of the weakening, along with the deterioration of fish catches and the economic situation. To revive the Japanese fishing industry, it is important to develop a safe working environment. In this presentation, I have illustrated my research efforts on fishers' work safety and related national efforts in Japan. Based on the findings, the steps required for ensuring fishers' work safety have been discussed.

2. Efforts to understand the actual labor situation in the fishing industry

Fishing has always been considered dangerous in Japan. However, when I started my study twenty years ago, there was little knowledge about the actual dangers involved in fishing and their extent. To observe the actual work involved in fishing, I boarded various fishing boats nationwide and recorded their work. By applying ergonomic techniques to my findings, I analyzed the kind of work involved and the extent of burden exerted by each kind on the fisher's body. In small trawls, one of the popular fisheries in Japan, a lot of time was spent on fish sorting, during which there was a heavy physical burden on the lower back of fishers (e. g. TAKAHASHI, 2015). Based on these findings, improvement measures were also proposed (e.g. TAKAHASHI *et al.*, 2017). As an advanced measure, an assistive suit was proposed to reduce the burden on the lower back while working in leaning postures (TAKAHASHI *et al.*, 2021). I am trying to apply this approach to other fisheries, including fisheries in other countries, to expand my knowledge.

Not a few fishers do not wear life jackets despite the availability of essential work safety equipment on board. I asked some fishers to use and compare different jackets in their line of work. There is a wide variety of work styles, and the suitability of jackets varies with the type of work (TAKAHASHI *et al.*, 2020). This knowledge should be applied to other fisheries to enable the dissemination of suitable jackets according to the type of work.

3. Recent national efforts to secure fishers' occupational safety

Parallel to my research, national efforts have also been gradually increased for fishers' occupational safety in Japan. I have been involved as a committee member in major cases as discussed below:

In 2013, a project funded by the Fisheries Agency of Japan was initiated to secure a safe work environment for fishers. The main objective of the project is to hold seminars for fishers nationwide and facilitate their learning of basic occupational safety. More than 5,000 fishers have attended the seminars to date. Although the project is not large enough to reach all fishers, it is steadily contributing to disseminate the knowledge of safety in fishing work.

In 2016, life jacket use was discussed in a joint meeting held by the Ministry of Land, Infrastructure, Transport and Tourism and the Fisheries Agency of Japan. It was decided that, in principle, all passengers of fishing boats would be required to wear life jackets.

In 2020, the Ministry of Agriculture, Forestry, and Fisheries of Japan hosted an expert meeting on new occupational safety measures in some industries, including fisheries. A norm and a check-sheet were created for each industry, summarizing work safety issues that business operators must consider.

4. Discussion

Over the last decade, knowledge of fishers' work and the problems associated therein has gradually accumulated. National efforts are being made to address the problems. It is important to establish a simple and effective method of occupational safety, distribute it to fishers all over the country, and continue these efforts until occupational safety is established. Infrastructure that enables the continuity of long-term projects must be built. I hope that the working environment of fishers will improve significantly in the United Nations Decade of Ocean Science for Sustainable Development (2021–2030).

Acknowledgements

The surveys introduced in this presentation were realized by the kindness and cooperation of fishers as well as other relevant parties. I am grateful to my colleagues for the support extended to me during this study. Parts of the surveys were carried out under a public project funded by the Fisheries Agency of Japan. I would like to thank Editage (www.editage.com) for English language editing.

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Sustainable development and responsible exploitation. As an example, the management and exploitation of diadromous species in the context of Small-Scale Fisheries

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Abstract

Defined in a report of the World Commission for Environment and Development (1988), the Sustainable Development is positioned at the convergence of 3 areas of equal interest: economy, social and environment. The definition and the implementation of a sustainable development policy is a negotiation process among actors with different powers from an economic and social point of view. Some are strong, others weak or absent. Some are directly concerned for their social and economic future by the productivity of the natural environment while others are not. Some are never present at the negotiation table such as future generations and the Nature itself.

The definition of a sustainable development policy is based on different principles such as: Precautionary principle (Article 15 of the Earth Summit declaration in 1992); Principle of prevention; Polluter-pays principle. In France, the Precautionary principle is included into the French Constitutionality Corpus in 2005 but, with some modifications by comparison with the initial definition. In particular, the notions of "economically bearable cost" and "effective and proportionate measures" have been added. So, in most cases, the environmental sphere is disregarded when socio-economic interest is at stake

and the equilibrium between the 3 components: economic, social and environmental of the sustainable development is not respected.

In that context, the sustainable exploitation of aquatic living resources is more and more difficult to achieve in accordance with the Maximum Sustainable Yield, the level of which continues to decline with the degradation of continental, estuarine and coastal environment under the pressure of many anthropogenic factors. It is particularly the case for diadromous fisheries (but many fisheries of coastal fish species are in the same situation) the future of which is seriously affected by a sectoral legislation that focuses its attention, for the sake of convenience, mainly on the regulation of fisheries and less on the decrease of the footprint of many uses that greatly affect the productivity of the natural environment.

It is the reason why the communities of fishers prefer to speak of responsible exploitation rather than sustainable exploitation particularly with regard to small scale fisheries. The responsible exploitation is more than a simple fishing activity, it includes: production of fish in the respect of fishery legislation in order to minimize the footprint of the fishery, environmental watch to participate in the management of the aquatic living resources and its habitats, whistle-blower to draw attention of public authorities to the risk of irreversible environmental damages.

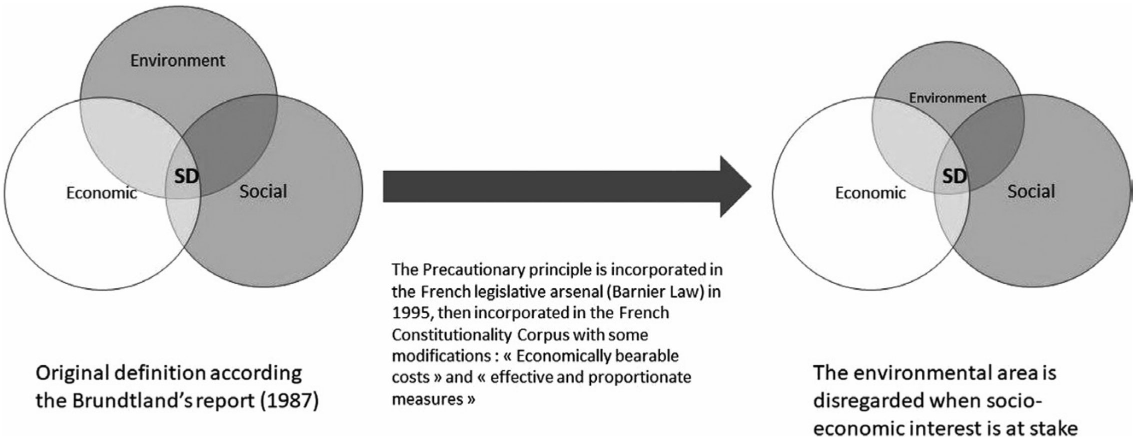
A more socio-ecosystem based approach is needed. Many studies conclude that small scale fisheries and generally artisanal fishing is more a way of life than a profession. It is essential to recognize the diversity, complexity and dynamics of this kind of activities. This is possible at the scale of the territory for the implementation of a genuine environmental governance, the fourth component of the sustainable development and to take into account a fifth component, the culture in the sense of knowledge and know-hows as the expression of intergenerational solidarity.

Contents

4. Conclusion: Need to introduce culture as the fifth dimension of the sustainable development.

As early as 1972, the UNESCO General Convention adopted a convention for the protection of the world's cultural and natural heritage and underlined the need to maintain the balance between natural and cultural goods. This agreement was further confirmed by the Earth summit in Rio in 1992: in addition to the ecological footprint, it was essential to introduce the notion of a cultural footprint.

It is clear that governance as defined in the classical framework of sustainable development based on a so-called balance between the three spheres of interest: economic, social and environmental is a failure both socially and environmentally. As mentioned previously, the compromises for the implementation of a sustainable development policy have too often been made at the expense of weak actors, i. e. those who live directly off the goods and services of Nature. Yet



it is these actors who often integrate into their cultures (in the sense of knowledge and know-how) and their heritage, the cross-generational links that take future generations into account in the negotiation process via the transmission of knowledge and respect for Nature, a non-human actor very often absent from these negotiations.

As an example: The project Nature and Culture developed by the two SFJOs.

Ecosystem-Based Management approach applying to Artificial Reefs assessment: a case study of network analysis in Capbreton, France

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For more than fifty years, Artificial Reefs (ARs) have been deployed in France to answer world decrease of harvested fish stocks. The main objective of these structures is to sustain artisanal fisheries and enhance fish's biomasses. However, despite of the ARs worldwide deployment and the increasing research on their design, performance and management, the

understood of their effectiveness regarding the production and protection still remain a point of interest for scientists and managers. As known in Japan under the name "Sato-umi", ARs are one of the main tools used to manage and support biodiversity for a "win-win" interaction between human activities and ecosystems. But there is a lack of feedback and long-term monitoring, that raises several questions regarding their, both, social and ecological benefits. Network analysis is useful to address diverse ecological, social, economic, management questions, but at our knowledge few studies combine social and ecological in a single analysis. Understanding link between social and ecological network helps in the establishing of Ecosystem-Based Management for sustainable use of marine resources. By coupling social and ecological network analysis in a single study, we aim to provide holistic results in order to contribute and enrich Ecosystem-Based Management. We've applied network analysis on French AR's located in Capbreton in the southern part of the Bay of Biscay, Atlantic French coast; manage by an environmental association named "Atlantique Landes Récifs" for more than twenty years. In this aim, provide social and ecological analysis, we will firstly present our results to identify the stakeholders' objectives throughout Actor Network Theory tool and reveal the social-ecological process guiding AR's project development. Then we apply the network analysis framework to reveal the keys stakeholders and define the strongest links between them. We've found that local stakeholders support effective ARs management by relying on a large social network. Thus, this web of actors has been enhanced by time and integrate various scales of stakeholders, from local to international, for instance with Japanese researchers through SFJO colloquium. Our network analysis approach allows to enrich social aspect with ecosystems indicators, using ecological trophic modelling. This analysis highlights interactions between species at different trophic levels as they are based on the quantification of flows of energy and matter in ecosystems. Coupling with Before-After Control Impact (BACI) approach, the trophic analysis could provide effective overview to assess artificial structure net benefits on the marine ecosystem, such as low influence on fish assemblage. The comparison of the ecosystem state before and after a range of five to twenty years of ARs deployment by using a trophic modelling and *in situ* data is an innovative approach that has only been experimented in Laizhou Bay (China). Our results shown that ARs stakeholders' involvement and collaboration supports ensure their long-term protection of biodiversity and an effective AR's management. This social-ecological approach provides an integrated framework with an operational and innovative method.

Failure of bivalve foundation species recruitment in a context of extreme heat wave event

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Abstract: Bivalves are important regulator of coastal lagoons providing a wide range of ecosystem services, but these environments are very sensitive to climate change. Here, we present the ecological cascade of an extreme heat wave until the recruitment failure of a bivalve foundation species, the oyster *Crassostrea gigas*. Results show evidence that high salinity and temperature modified largely the planktonic community with a shift on small-sized taxa. These trophic changes had no impact on food accumulation by oyster larvae, but act on the metamorphosis process where the development of gills by young juveniles could not be adapted to these small particles. The result is a recruitment failure of oysters and the stimulation of annelid development, a trophic and space competitor, more adapted for the ingestion of small particles. This new knowledge prove that the ecological limits of oyster larvae are narrower than the physiological limits in this context of marine heat waves.

Observing the deep and sharing the invisible: a nascent case study in the South Pacific, New Caledonia

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France (IFREMER) and Japan (JAMSTEC), through their long collaboration history, agreed to develop and run in common the first deep sea observatory in the South Pacific, around New

Caledonia. Besides its scientific and technological aspects, the project will give much importance to local and regional stakeholders engagement with overarching principles such as the convergence on common goals, effective communication, co-production of information and knowledge, and the need for innovation.

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Transcript of Natural Science Lecture on "Transforming our society facing the changing sea - Microplastics in the ocean -" organised by *Maison franco-japonaise* and Japanese-French Oceanographic Society of Japan on 23 October 2021

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Abstract: Japanese-French Oceanographic Society of Japan had planned to hold the 18th Japanese-French Oceanography Symposium in 2020 to celebrate its 60th anniversary. However, this was postponed due to the COVID-19 pandemic. In 2021 a web-based symposium was available, and the 18th Japanese-French Oceanography Symposium was held between 19–23 October 2021. In order to disseminate the results obtained by the exchanges between French and Japanese researchers working on oceanography and fisheries science at this symposium to the public, *Maison franco-japonaise* and Japanese-French Oceanographic Society of Japan organised a public symposium on the theme of "Transforming our society facing the changing sea - Microplastics in the ocean -" with the co-organiser the *Société franco-japonaise des Techniques Industrielles* (SFJTI) as the Natural Science Lecture Series of *Maison franco-japonaise* on 23 October 2021. This paper outlines the reasons for choosing this theme for the lecture, the basic knowledge of the microplastics issue and the summary of each presentation. Presenters were Dr François Galgani of Ifremer, Dr Katsunori Fujikura of JASMTEC, Dr Sylvain Agostini University of Tsukuba, Ms Cristina Barreau of Surfrider Foundation Europe, two high school students and Teacher Mr Takashi Inoue of Sanyo Gakuen Juniro and Senior High School and Professor Tadahisa Iwata of SFJTI/the University of Tokyo.

Keywords : *social transformation, microplastics, 60th anniversary of Japanese-French Oceanographic Society of Japan, Decade of Ocean Science*

1. The 60th anniversary symposium of the Japanese-French Oceanographic Society

The Japanese-French Oceanographic Society was founded in April 1960. In 1984, a sister society on the French side was established, the Japanese-French Oceanographic Society France, at the instigation of Hubert-Jean Ceccaldi, Professor at *Ecole pratique des hautes Etudes* and then French President of the *Maison franco-*

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japonaise. Since 1984, the two Japanese-French Oceanographic Societies have organised Japanese-French Oceanography Symposium, in principle, at intervals of one to three years, alternating between Japan and France. The 18th Japanese-French Oceanography Symposium was planned to be held in Tokyo in 2020, the 60th anniversary of the founding of the Japanese-French Oceanographic Society of Japan. However, it was postponed due to the COVID-19 pandemic, and the symposium was held from 18 to 23 October 2021 using the web, with the support of the *Maison franco-japonaise*, the French Research Institute on Japan at *Maison franco-japonaise* (*L'Institut français de Recherche sur le Japon à la Maison franco-japonaise*), Japanese-French Oceanographic Society of France, Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), Japan, Science and Technology Department, Embassy of France in Japan, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), The Japanese Society of Fisheries Science, The Japanese Society of Fisheries Oceanography, The Oceanographic Society of Japan, Japanese National Committee for the UN Decade of Ocean Science for Sustainable Development and the *Fondation Sasakawa franco-japonaise*.

The symposium organising committee discussed the theme of the 18th Japanese-French Oceanography Symposium. The symposium organising committee then turned its attention to the declaration of the 72nd UN General Assembly in 2017 on the UN Decade of Ocean Science for Sustainable Development (2021–2030) ("the Decade of Ocean Sciences") in its comprehensive resolution on the ocean (Fig. 1). This Decade of Ocean Science states that a special international focus will be placed on achieving the Sustainable Development Goals, in particular SDG 14, and other ocean-related goals for the decade 2021–2030. The UN Decade of Ocean Science has seven goals, or "seven oceans", as societal outcomes. One of these is a "clean ocean" in which pollution sources are identified, reduced, and eliminated (Fig. 1 below).

Today's oceans are facing changes in the marine environment due to global warming, plastics from land-based sources entering the oceans through rivers and small plastic fragments entering the marine food chain, and anthropogenic impacts such as land reclamation, pollution and eutrophication of the oceans. In order to realise and keep a marine environment of sustainable, rich and clean oceans, human society must change its ways. Therefore, the theme of the 18th Japanese-French Oceanography Symposium was set as "Oceanography for future we want: transformation of our society in the changing sea" and the symposium was positioned as part of the United Nations Decade of Ocean Science, which will begin in 2021. An application was submitted to the Japanese National Committee of the UN Decade of Marine Science for the 18th Japanese-French Oceanography Symposium as an activity of the UN Decade of Ocean Science, which was officially approved.

The symposium consisted of a web-based poster session from 18–21 October 2022 and a core-time discussion between presenters, a web-based mini-symposium with participants on 21 October, with four research presentations each by Japanese and French researchers on the web on 19 October 2022 and the commemorated symposium "60 years of Japanese-French cooperation in oceanography" organised by the Japanese-French Oceanographic Societies of Japan and France, the *Maison franco-japonaise* and the French Institute for Research on Japan at the *Maison franco-japonaise* on 20 October 2022. In order to disseminate the results of the 18th

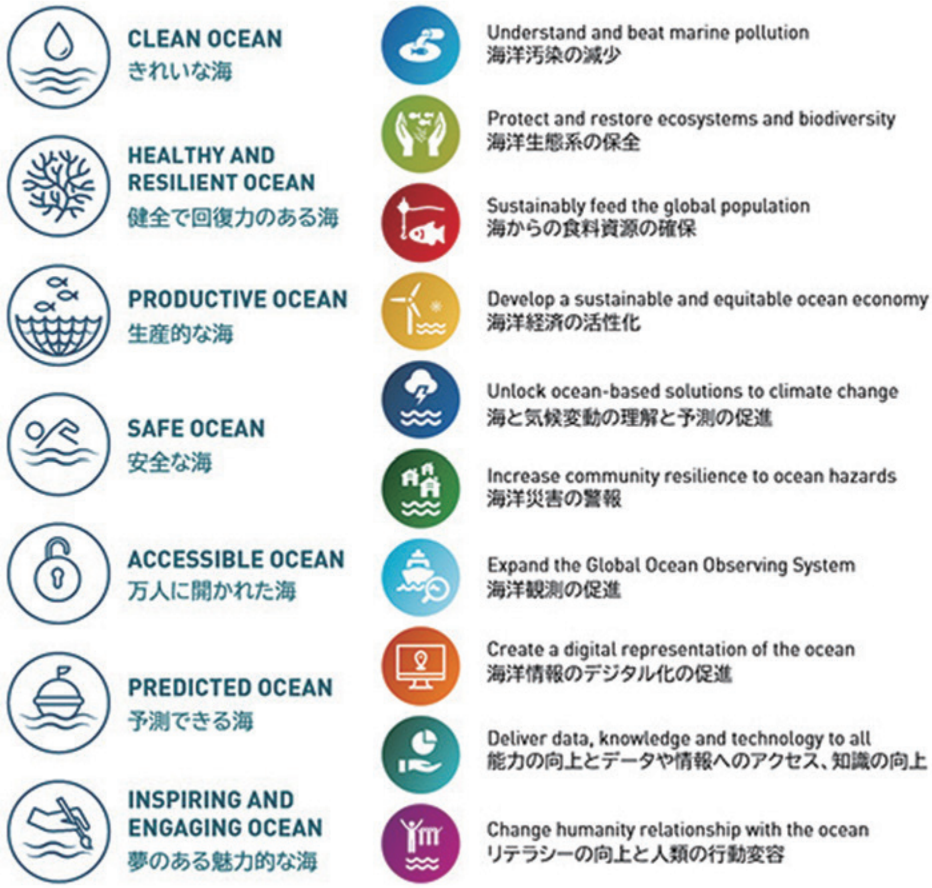

Fig. 1 Logo for the UN Decade of Ocean Science (top: source https://www.oceandecade.org/ja/) and the seven societal goals (bottom left) and ten challenges (bottom right) (see below: https://www.spf.org/opri/newsletter/500_1.html? latest=1)

Japanese-French Oceanography Symposium to the public on the final day on 23 October 2021, the organising committee consulted with Professor Atsushi Miura, Chairperson of the Scientific and Cultural Committee of the Maison franco-japonaise, Professor Sunao Sawada, Vice Chairperson of the same committee, and other people. As a result, it was decided that on 23 October 2022, as part of the Natural Science Lecture Series organised by the *Maison franco-japonaise*, the *Maison franco-japonaise* and the Japanese-French Oceanographic Society of Japan presented the results of the academic exchanges at the Japanese-French Oceanography Symposium to the public.

2. SDG 14 and marine microplastics

Each SDG has several targets: target 14.1 of SDG 14 is "By 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution." (Fig. 2). In addition, a large proportion of marine litter is plastic. Target 14.1, mentioned above, has global indicators, which raise (a) indicators of coastal eutrophication and (b) the density of plastic litter,

Fig. 2 English logo for Target 14. 1 of SDG 14 (source: https://www.future-creation-support.com/2017/05/29/sdgs-goal14/)

Fig. 3 Microplastics (Source. https://www.wbsj.org/activity/conservation/law/plastic-pollution/article/2021-05-06/)

making marine plastics an important topic (https://unstats.un.org/sdgs/metadata/files/Metadata-14-01-01.pdf accessed on 10 February 2022). Plastic is a general term for natural and synthetic resins among organic polymeric materials, which are mainly made from petroleum, show viscous fluidity when heated and can be moulded into a predetermined shape. They are not decomposed by micro-organisms, are stable in air and water, do not decompose or dissolve, and are lightweight. This makes them very convenient for human life. Since the 1970s, the mass consumption of plastics on land has rapidly increased and much of the plastics used has reached the sea. However, most of the plastics that reach the sea does not return from the sea to land.

Plastics are broken down into smaller pieces by ultraviolet radiation, heat and waves, but it is not easily decomposed by micro-organisms. Therefore, they do not enter the material cycle of bio-elements such as carbon, phosphorus, nitrogen and other elements that make up the bodies of living organisms and remains in the ocean in the form of microplastics. Microplastics are defined as plastics with a diameter of 5 mm or less (Fig. 3). Furthermore, when microplastics are further fragmented, they become nanoplastics (< 1 μm). Although it has become clear that nanoplastics are diffusing into the atmosphere as well as the oceans and that their extremely small nature allows them to pass through cell membranes and enter living tissues and organs, little is known about their danger to humans. This is mainly due to the fact that they are too small to be easily measured.

Various chemical substances are originally added to plastics when they are manufactured and processed, such as dyeing agents, flame retardants for fire prevention, plasticisers for softening and UV absorbers to give them the properties required for their intended use. These chemicals are referred to as "additives". Additives, together with their degradation products they produce, contain many substances that are harmful to the human body. For example, bisphenol A (BPA), which is used as a raw material for polycarbonate, and phthalic acid additives used as plasticisers have endocrine-disrupting effects (also called environmental hormones) that can cause cancer and impair reproductive functions even at low concentrations and are harmful persistent organic pollutants (POPs). Polybrominated diphenyl ethers (PBDEs), brominated flame retardants used as flame retardants, are also well known as one of the POPs and are thyroid disruptors and neurotoxic. The degree to which additives leach in the ocean depends on the additive's molecular weight and instability, environmental conditions such as pH and temperature, and the permeability of the plastic polymer. If the additive is highly hydrophobic, it will stay in the plastic without leaching much and move with the plastic. As plastics are highly hydrophobic, they attract various types of lipophilic and persistent organic pollutants in seawater and adsorb them onto the plastic. For example, POPs, which are toxic and harmful chemicals such as DDT and PCBs, are accumulated in the animal's body as lipoidal materials once eaten by animals. In other words, although the plastics themselves may be discharged from animal bodies, the chemical components adsorbed on them are absorbed and accumulated in the bodies of animals that eat the plastics. Furthermore, POPs are thought to be concentrated and accumulated in fish and shellfish through the food chain and taken up by the human body that eats them (Fig. 4). At moment, there may be little to concern, but if plastic pollution progresses further, it is feared that it will have a negative impact on marine ecosystems and human health. We are currently faced with oceans that are becoming increasingly polluted with microplastics, and we need to change the way our society works to overcome this problem.

The Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), an independent group of scientific experts advising the UN system on the scientific aspects of marine environmental protection, has developed a new programme on microplastics with a review aimed at comprehensively mapping existing knowledge, aligning it according to guidelines and identifying the extent to which research has not been carried out on marine microplastics and chemical components related to the microplastics. A workshop organized by United Nations Educational, Scientific and Cultural Organization-Intergovernmental Oceanographic Commission (IOC) in Paris in June 2010 brought together experts from industry, academia, NGOs and policymakers to examine plastic particles as a persistent, bioaccumulative and toxic transport vector in the ocean. In 2012, GESAMP created Working Group 40 (WG40), a working group to study 'Sources, dynamics and impacts of plastics and microplastics in the marine environment'. Dr François Galgani, Director of the Corsica branch of the French Research Institute for Exploitation of the Sea (Ifremer), a member of the Japanese-French Oceanographic Society of France, has been working on this issue from the beginning and is the co-chair for microplastics of the third phase of WG40, which began in 2018. Another major

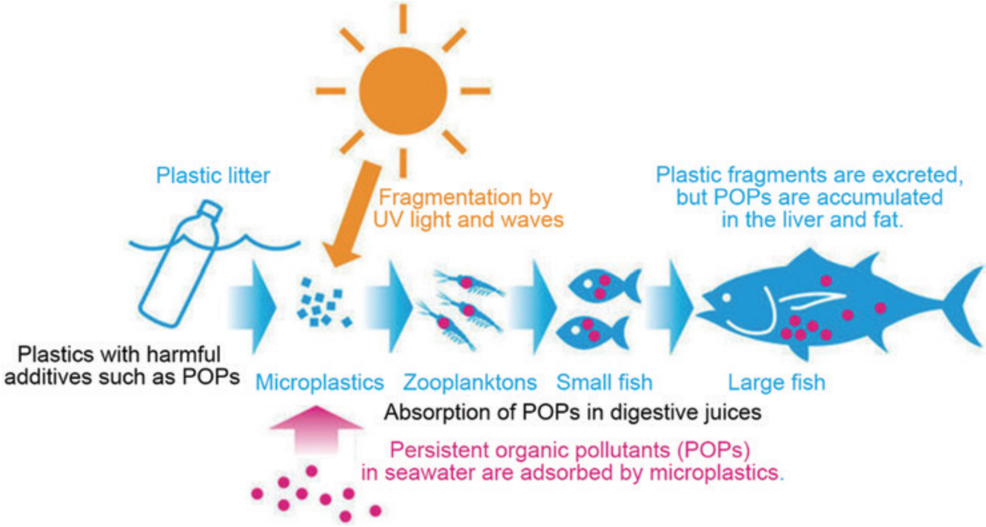

Fig. 4 Plastics with harmful additives become microplastics and absorb harmful persistent organic pollutants (POPs) in the sea. Zooplanktons mistake microplastics for food, east them to take up the POPs. Zooplanktons are eaten by small fish. Larger fish eat the small fish that have accumulated POPs to accumulate higher concentrations of POPs (Figure from the Ocean Sweep Association: https://www.atpress.ne.jp/news/277287, partly modified).

motivation for organising this symposium was the fact that several core members of the Japanese-French Oceanographic Society conduct research on marine microplastics and are key researchers in this field in Japan.

Countries have national borders, and oceans have exclusive economic zones and territorial waters. However, as air and sea water move across national borders, the problem of marine plastics in seawater or floating on the sea surface cannot be dealt with by one country alone but must be solved through cooperation between countries that share a common destiny. Therefore, in consultation with Professor Tatsuya Maruyama, a member of the Scientific and Cultural Committee of the *Maison franco-japonaise*, and Professor Mitsuru Yamazaki, an associate member of the same committee, we decided to invite people who are researching microplastics in Japan and France to give presentations and discuss the issue of microplastics in the ocean together with the symposium participants. The theme of this Japanese-French Science Lecture was decided as "Transforming our society facing the changing sea - Microplastics in the ocean -" organised by the *Maison franco-japonaise* and the Japanese-French Oceanographic Society of Japan and co-organised by the Japanese-French Society of Industrial Techniques.

3. Structure of the symposium

The presentation (Table 1) featured a keynote address by Dr François Galgani of Ifremer, one of the first researchers in the world to address this issue. For the content, see Dr Galgani's article in this issue. The pictures of plastic waste accumulating on the beautiful Mediterranean seabed were shocking. Next, Dr Katsunori Fujikura of the Japan Agency for Marine-Earth

Table 1 Programme of the Japanese-French Science Lecture on "Transforming our society facing the changing sea - Microplastics in the ocean -" on 23 October 2021.

(14：45–15：00)	Zoom connection test	Secretariat
15：00–15：05	Introduction	President Professor Teruhisa Komatsu (SFJO Japan)
15：05–15：35	Oceans of plastics	Dr François Galgani (Ifremer Bastia)
15：35–16：05	Approaching of the missing plastics	Dr Katsunori Fujikura (JAMSETC)
16：05–16：35	Tara Jambio Mission Microplastics: science, education, art and sharing	Dr Sylvain Agostini (Shimoda Marine Research Centre, University of Tsukuba)
16：35–17：05	The fight against microplastic pollution of the ocean: from citizen action to the development of standards	Mme Cristina Barreau (Surfrider Foundation Europe)
17：05–17：35	Towards a solution to the marine litter problem in the Seto Inland Sea: Practical steps to make the problem a "Personal matter"	Mr Takashi Inoue, teacher (adviser) and two students (Sanyo Gakuen Junior & Senior High School Geography and History Club)
17：35–18：05	Development of plastics that degrade in the ocean and future prospects	President Professor Tadahisa Iwata (Japanese-French Society of Industrial Techniques/the University of Tokyo)
18：05–18：35	General discussion	Moderator Professor Mitsuru Yamazaki (Academic and Cultural Projects Committee, *Maison franco-japonaise*)
18：35–18：40	Closing remarks	President Professor Teruhisa Komatsu (SFJO Japan)

Science and Technology (JAMSTEC), who is working to find out the whereabouts of plastics in the sea, explained the current situation. The samples analysed included microplastic samples collected by Mr Kojiro Shiraishi, a Japanese yachtsman who participated in the Vendée Globe, a solo, port-free, round-the-world yacht race from 8 November 2020, in a location that is not normally open to observation. Assistant Professor Sylvain Agostini of Shimoda Marine Research Centre, University of Tsukuba, is a leader of the project of the Japanese Association of Marine Biology (JAMBIO), a network of Japanese coastal experimental stations belonging to universities supported by the Tara Ocean Foundation surveying the distribution of microplastics around the stations and raises awareness of the public. He presented the surveys on microplastics and awareness-raising activities for the public through artistic activities and public participation events. One unique activity is through the art, in which students at Tokyo University of the Arts also participated. Ms Cristina Barreau of Surfrider Foundation Europe working to raise awareness of the plastics problem and change environmental policy in Europe and France presented how important public participation and political commitment is to solve the problem of marine plastics. She gave examples of concrete activities and results in Europe. Symposium participants recognised that environmental activities in Japan also need to be committed to the policy-making process. A presentation was given by two second-year high school students from the Geography and History Club of Sanyo Gakuen Junior and Senior High

School and their advisor, Teacher Mr Takashi Inoue, on the efforts of the club to study plastic waste collected by trawl nets and washed up on island beaches in the Seto Inland Sea, and to raise public awareness of the need to keep plastic out of the environment. Unique initiatives included efforts to show the relationship between the lives of people living in the town and plastics collected from the sea at a product display in a shopping centre so that people who are not interested in environmental issues can understand the relationship, and activities to find out where plastic waste can be found in the town. Finally, Professor Tadahisa Iwata, President of *Société franco-japonaise des Techniques industrielles* (SFJTI: the Japanese-French Society of Industrial Techniques), who is researching bioplastics that degrade in the sea at the University of Tokyo, introduced the current status of his research and future prospects, focusing on his own research results. There was also an interesting report on how biodegradable plastics actually change in the deep sea. Based on these reports, a lively discussion was held on how we can overcome the microplastic problem and survive if we change our society, in a general debate chaired by Professor Mitsuru Yamazaki, a member of the Scientific and Cultural Projects Committee. One notable outcome was the large number of high school students and their teachers who attended the event as a result of an appeal to many high schools by Professor Mitsuru Yamazaki. These are the people who will be responsible for the SDG issues in the future, or the teachers who will educate such students, and it can be said that this symposium led to the development of the core members of the next generation who will achieve the SDGs.

4. Epilogue

A student from the Sanyo Gakuen Senior High School Geography and History Club, who attended the symposium, suggested that they would like to exchange their experiences on activities concerning plastics with high school students in France who are working on the marine plastic issue. Members of the Japanese-French Oceanographic Society of France searched for a high school in France that was engaged in such activities, and found that students at *Paul Bousquet - Lycée de la mer* (Paul Bousquet Marine High School) in Sète on Étang de Thau, a brackish lake in the Mediterranean Sea, were working to solve the marine plastic problem. The Japanese-French Oceanographic Societies of Japan and France are currently building bridges with the supervisory teachers of the two high schools. If the exchange between the two schools progresses, the two Japanese-French Oceanographic Societies of France and Japan are considering that tow high school students present the results of the exchange at the 19th Japanese-French Oceanography Symposium scheduled for 23–27 October 2023 in Caen, Normandy. It is a great achievement that this symposium has paved the way for the next generation of Japanese-French exchanges towards the implementation of SDG 14. In the future, the Japanese-French Oceanographic Society of Japan hopes to continue to work together with the *Maison franco-japonaise* towards the implementation of the SDGs.

Acknowledgements

We were not able to bring everyone together at the *Maison franco-japonaise* in Tokyo for this symposium as everyone had wanted. However, about 100 participants from France and Japan were connected via the web. This symposium could not have been possible without the cooperation and support of many parties, especially the *Maison franco-japonaise*. I would like to express my deepest gratitude to the members of the Scientific and Cultural Committee of the *Maison franco-japonaise* for their efforts in making this symposium possible, in particular to Professor Atsushi Miura, Chair, Professor Sunao Sawada, Vice Chair, Professor Tatsuya Maruyama, Professor Mitsuru Yamazaki and Ms Eriko Takeda and Ms Nami Aosawa in charge of projects at the Secretariat. I would also like to thank the simultaneous interpreters and Ms Tomoko Honda of the Secretariat of the Japanese-French Oceanographic Society of Japan for their great help in organising the symposium smoothly. I would like to thank them here. We also acknowledge to the Japanese-French Society of Industrial Techniques for co-hosting the symposium, and Dr Kazufumi Takayanagi, Professor Yuji Tanaka, Professor Yasuyuki Koike and Ms Tomoko Honda, Secretary of the Japanese-French Society of Oceanography of Japan, for their comments on the manuscript. Finally, I sincerely thank to the supports of Japanese-French Oceanographic Society of France, Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), Japan, Science and Technology Department, Embassy of France in Japan, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), The Japanese Society of Fisheries Science, The Japanese Society of Fisheries Oceanography, The Oceanographic Society of Japan, Japanese National Committee for the UN Decade of Ocean Science for Sustainable Development and the *Fondation Sasakawa franco-Japonaise*. Without the supports, the symposium was not able to be relalised.

Appendix

The followings are the abstracts of Natural Science Lecture on "Transforming our society facing the changing sea - Microplastics in the ocean -" organised by *Maison franco-japonaise* and Japanese-French Oceanographic Society of Japan on 23 October 2021 are listed below. Appendix 1 and 2 are abstracts in French and Japanese, respectively.

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プラスチックの海

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年間 800 万トン以上のプラスチックが海に流れ込み，1 秒間に約 15 トンものプラスチックが海に流れ込んでいます。これは残念ながら，都市部からの大量の投入，河川や沿岸の利用，下水処理場からの排出，観光業，船舶の航行や漁業活動による海上の発生源，無秩序な投棄などが原因となっています。自然現象による大量の流入も重要であり（ハリケーン，津波など），世界のいくつかの地域では考慮する必要があります。プラスチック廃棄物は，長距離を輸送されることができます。重要なのは，プラスチック汚染の 95 %以上が海底で発見されているということです。量，分布，劣化，影響などの点で，我々の現在の知識はまだ限られています。海水の循環は，海でのプラスチックの運命を左右する最も重要な要因です。プラスチック大陸と呼ばれることもある海洋の収束域での蓄積が報告されているほか，最近では海底，特に峡谷でのプラスチック廃棄物の大量堆積に関する報告が数多く見られます。

近年，多くの国で実施されているプラスチック汚染レベルの定期的なモニタリングにより，この汚染の進行についての理解が深まっています。ほとんどの場合，発生源に近い地域では経年変化は見られませんが，より遠い地域（極地，海洋島）に移ると，近年，著しい増加が見られます。プラスチックの断片化に起因するマイクロプラスチックが海洋堆積物中に蓄積することは，深海域の持つ重要性を裏付けているようです。

プラスチック汚染の影響は多岐にわたりますが，主な問題は，放置された漁具（網など）で多くの種が窒息すること，ほぼすべての種が破片やマイクロプラスチックを摂取すること，汚染物質や添加物が放出されること，破片に付着した種が長距離輸送されることなどです。また，漁業や観

A

B


Fig. 1　砂浜（A），浮遊物（B），海底のいずれにおいても，プラスチックごみの断片化によって生じるマイクロプラスチックは，海洋におけるプラスチック汚染の重要な部分を占めています。世界の一部の地域では 1km^{2}あたり 6400 万個以上の粒子密度に達しており，この問題は海洋汚染の大きな課題の一つとなっているようです。

光への経済的影響も非常に大きいです。最後に，デブリ*による船舶の航行上の問題（デブリへのプロペラの絡みつき，浮遊するコンテナ）や，健康への影響のリスク（マイクロプラスチックの摂取，海岸での怪我）について，管理者は深刻な問題と考えています。

今回の発表では，プラスチック汚染の科学的な問題だけでなく，海上での汚染のモニタリングに関する作業や，国際的な機関やイニシアチブによるさまざまな削減戦略（予防，教育，回収・リサイクル，洗浄，水処理など）についても議論します。この問題は地球規模の越境的な問題であるため，様々な関係者（経営者，政治家，科学者，NGO，産業界，一般市民）の関与が必要となっています。

（*通常は海底に堆積した物を意味しますが，この言葉の後に，問題の具体例として浮遊するコンテナを含んでいるため，ここでは，プラスチックの大型のゴミという意味と解釈されます）

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行方不明のプラスチックを追う
(Approaching for the Missing Plastics)

藤倉克則
海洋研究開発機構

プラスチックは，安い，軽い，丈夫，さまざまな形にできる，硬軟自在といったすぐれた特性を持っていて，今や生活に欠かせない材料です。しかし，この便利なプラスチックが，適切に処理されなかったために海に大量に流れ込み，このまま何もしなければ深刻な海洋汚染を引き起こすことが心配されています。プラスチックは太陽光の紫外線や波で細かくはなりますが，生物に影響がないくらいまで化学的に分解されるには，どれくらい膨大な時間がかかるのかわかりません。

海のプラスチックが引き起こす問題としては，海洋生物が餌と間違って食べてしまうこと，漁具などに絡みついてしまうことなどはよく耳にします。他にも人の生活環境汚染，船の航行障害，観光業への影響など数え上げたら枚挙にいとまがありません。なかでも，最も懸念されることの一つが，海洋生物への化学汚染です。5 mm 以下の小さなプラスチックはマイクロプラスチックと呼ばれますが，小さなプラスチックほど海洋生物に大きな影響を及ぼすこともわかりつつあります。海洋生物のなかには，水中の粒子を吸い込んで餌としているものもたくさんいますから，小さなプラスチックほど生物に取り込まれやすくなります。プラスチックは海を漂う間に有害な物質を吸着する性質があり，また，プラスチック自身も製品化する時にさまざまな化学物質が使われます。これらは海洋生態系の食物連鎖のなかで生物濃縮により濃度が高くなり，それを食べる人間への影響も心配されています。

海洋プラスチック問題を完全に解決するには，①プラスチックを流出させないこと，②生物へ影響を与えずに海からプラスチックを取り除くこと，③環境中に流出したとしても生物へ影響を与

Fig. 1 1999 年，相模湾の水深 1344 m で見られる大量のレジ袋

えないレベルにまで短時間に分解される材料を使うことが理想です。この理想に向けさまざまな取り組みが現在進行中ですが，いずれもまだまだ時間がかかりそうです。それどころか，私たちは現在，海のどこにどれだけプラスチックがあるのか，海洋生物や人間にどのような影響を及ぼすのかも正確には把握できておらず，科学的な情報集めが世界中で進められています。

毎年 1,000 万トンのプラスチックが海に流入し，これまでに流入した分を合わせると，外洋の表層に約 4500 万トンのプラスチックが浮いています。しかし，これまでの調査結果から科学的に説明できるのは，そのうちの数十万トン分のみで，残りはどこに行ったのかわかりません。これは The missing plastics（行方不明のプラスチック）と呼ばれ，海のどこにどれだけプラスチックがあるのかを把握するには解明しなくてはならない課題です。おそらく，①深海底に沈む（Fig. 1），②

未調査海域に大量にある，③水中に漂っている，④小さくなりすぎて見つからない，といった可能性がありそうですが，私たちは①と②に注目して研究を進めています。

プラスチックの材質はポリエチレン PE やポリプロピレン PP といったように何十種類もあります。材質によって浮くものもあれば沈むものもありますし，また添加されている化学物質が異なります。そのため，プラスチックの分布や生物への影響を知るためには，プラスチックの材質を判別して，大きさ，量，形などを計測する必要があります。この分析はとても手間がかかり，特にマイクロプラスチックでは大変な作業になります。そこで，私たちはマイクロプラスチックを素早く正確に計測する技術開発にも取り組んでいます。The missing plastics の知見は，簡便なマイクロプラスチックの分析技術で加速して集積されると思います。

海は広大で研究機関が調査できる範囲はわずかです。一方，海には莫大な数の船舶が走っています。これらの船舶で海洋プラスチックに関するデータを集めることができれば，海洋プラスチックの分布実態は飛躍的に理解が進むことは間違いありません。また，SDGs の動きも踏まえ，さまざまなセクターによる環境問題解決に向けた貢献への意識が高まってきています。そこで，私たちはまず，ヨットを使った海洋プラスチックの採集をヨットレースに参加する方々と協同で行いました。具体的には，日本とパラオ間のヨットレースと，世界一過酷なヨットレースと言われるヴァンデ・グローブ（Vendée Globe）で試験的にマイクロプラスチックの採集と分析を行いました。このような動きは未調査海域における海洋プラスチックの分布情報を提供することになるでしょう。

この講演会では，私たち海洋研究開発機構が取り組んでいる The missing plastics（行方不明のプラスチック）研究と，それを支える取り組みについて紹介します。

Tara-Jambio マイクロプラスチック ミッション :科学，教育，芸術，共有

シルヴァン・アゴスティーニ
筑波大学下田臨海研究センター・Tara Océan Japan

タラ・オーシャン・ファウンデーション（Tara Ocean Foundation）は，海のための組織です。著名な研究機関との連携により，オープンで高度な科学研究を展開しています。この科学的専門知識を用いて，一般市民，特に若い世代の意識を高めるとともに，政治的意思決定者をも動員しています。世界各地で行われている科学的探検により，すでに国際的な活動を行っているこの財団は，その活動を拡大しており，2017 年には「タラ オセアン ジャパン（Tara Océan Japan）」が設立されました。タラ オセアン ジャパンは，Jambio（マリンバイオ共同推進機構）ネットワークと協力して，日本の沿岸海域におけるプラスチック汚染を調査する初の科学プロジェクトを実施しています。Jambio ネットワークは，日本の国立大学が所有する 23 の臨海実験所をつなげています。日本の海岸線のさまざまな生態系や，研究に必要なインフラに，科学者たちが直接アクセスできるようになっています（Fig. 1）。

プラスチックを大量に消費する日本は，マイクロプラスチック汚染のホットスポットと認識されている海域に位置しています（Isobe *et al.*, 2015）。日本の海で観測された高濃度のマイクロプラスチックは，亜熱帯域から日本沿岸を流れる黒潮が

運んできたマイクロプラスチックと局所的に流入したマイクロプラスチックが主な原因であると考えられています。しかし，沿岸地域のプラスチック汚染に関するデータはまだ十分ではありません。さらに，これらの地域の堆積物のプラスチック汚染に関するデータはほとんどないため，海岸からのマイクロプラスチックの鉛直方向の流出流入に関するモデルの開発には限界があります。そして，プラスチックやマイクロプラスチックは寿命が長いため，生物を長距離に運ぶことができます。このプラスチックの漂流筏の効果は，生態系や養殖，私たちの健康にも影響を与えます。そのため，海岸で発見されたプラスチックにどのような種類のマクロ・ミクロの生物が存在するかを調査することが重要です。Tara-Jambio プロジェクトは，日本の沿岸水域および堆積物におけるマイクロプラスチック汚染，プラスチックによって運ばれる微生物種の構成，この汚染が沿岸生態系に与える潜在的な影響を調査し，プラスチック汚染および海洋生物多様性を脅かす気候変動などの環境問題に対する一般の人々の認識を高めることを目的としています。

「タラ・ジャンビオ・マイクロプラスティック・ミッション（Tara Jambio Microplastic Mission）」プロジェクトは 2019 年に開始され，その間，タラ・オセアンが実施した様々なミッションで使用された国際基準やプロトコルに基づいて研究プロトコルが開発されました。これにより，プロジェクトで得られたデータを文献で入手可能なデータと比較することができます。プロジェクトで得られたすべてのデータは，科学界の利益のために誰もがアクセスできるようになります。2020 年と 2021 年の 2 回の採集調査を実施し，岡山大学，広島大学，島根大学，九州大学，名古屋大学，筑波大学，東北大学，北海道大学の臨海実験所の協力を得て，九州から北海道まで 10 カ所以上を調べました。それぞれの場所で，臨海実験所付近の河口，湾，湾外，海岸の海水や堆積物中のマイクロプラスチックを採取し，臨海実験所ごとに 100 以上のマイクロプラスチックのサンプルを取得するとともに，地域の生物多様性（底生生物とプランクトン）や環境条件（CTD，TEP 濃度など）を調査しました。筑波大学下田臨海実験センターでは，2020 年 7 月から毎月，同じサンプリング方法でモニタリングを行っています。現在，サンプルの分析を行っていますが，観測結果は，海洋表層の海水や海底の堆積物にかかわらず，すべてのサンプルに粒子，繊維，フィルムなどさまざまな種類のマイクロプラスチックが存在していることを示しています。

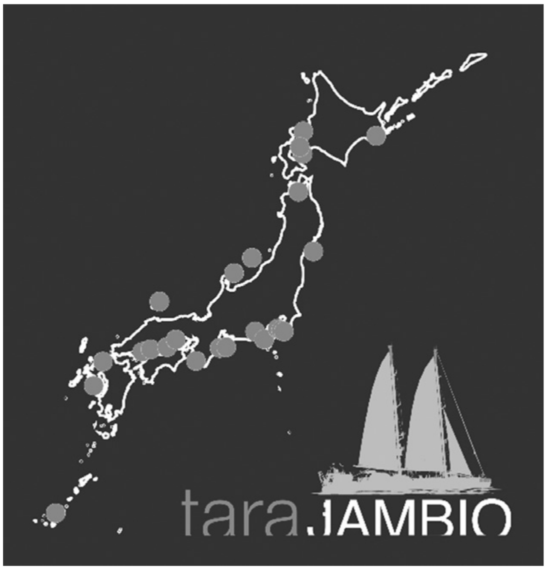

Fig. 1　「Tara-Jambio マイクロプラスチック ミッション」計画の下で本研究で使用した Jambio ネットワークに参加する大学附属臨海実験所（赤丸）

サンプリングキャンペーンは，啓蒙活動の機会にもなりました。ビーチクリーンアップ，ビーチや調査船上でのサンプリング，シンポジウムなど，あらゆる年齢層の一般の方々を対象としたイベントを開催しています。タラの精神に基づき，科学者はアーティストと協力し，海の重要性を市民に認識してもらえる作品を制作するためにキャンペーンに参加しています。東京芸術大学の日比野教授が企画したこのサイエンスとアートのコラボレーションでは，東京芸術大学の学生が現場調査で下田沖の海洋生物多様性とマイクロプラスチッ

ク汚染を調べました。

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海洋におけるマイクロプラスチック汚染への対策：市民活動から基準設定まで

クリスティナ・バロー
Surfrider Foundation Europe

数年前から，科学界は，マイクロプラスチックの汚染が河川や海洋環境のどこにでもあると警告しています。調査によると，マイクロプラスチックは海のあらゆる場所に侵入しています。海面に浮かんでいるもの，堆積物の中にあるもの，氷の中にあるもの，海底にあるものなどがあります。北極海のように文明から遠く離れた地域でも，この汚染と無縁ではありません。

海洋環境への残留性に加え，生態系への影響も問題となっています。マイクロプラスチックは大変小さいため，摂取する可能性のある種や海洋生物が非常に多く，食物網全体の汚染につながります。マイクロプラスチックは，環境中にすでに存在する残留性有機汚染物質（POPs）を吸着・濃縮するとともに，病原体や有害な生物の輸送手段としても機能します。マイクロプラスチックは，特定の生物種の成長と繁殖を妨げ，生態系の不可逆的な汚染を引き起こします。

マイクロプラスチック汚染は海だけの問題ではありません。私たちが吸う空気，飲む水，食べるものの中にもマイクロプラスチックの存在が確認されていますが，一般の人々にはまだ知られていないのです。

海洋環境と海洋環境の利用者の保護を目的とした団体である Surfrider Foundation Europe は，一次マイクロプラスチックおよび二次マイクロプラスチックを発生源で削減するための多分野に関係するプログラムを開発しました。サーフライダーは，この目に見えない汚染に対する市民の意識を高め，他のステークホルダー（関係者）との対話を促進することで，市民を行動計画の中心に据えています。環境中のマイクロプラスチックに関するデータや，特定の製品の組成に関するデータの取得には，参加型科学とデジタルツールを用いて市民が参加しています。市民を動員することで，国と欧州の両方のレベルで公的な意思決定者に異議を唱え，長期的に汚染を防ぐための拘束力のある対策を採用するよう促すことが可能になります。それと同じように，イメージを大切にする経済界は，消費者の要求にも敏感です。

このプレゼンテーションでは，見えないものを見えるようにして，水生環境におけるマイクロプラスチックの生産と拡散に関わるすべての関係者の意識を高めるために，協会が利用できるさまざまな意識向上の手段と呼びかけの方法について紹介します。意思決定者や民間企業だけでなく，現場での市民活動が中心的な役割を果たしていることを示します。

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瀬戸内海の海洋ごみ問題の解決に向けた「自分事」化の実践への挑戦

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はじめに

瀬戸内海は日本初の国立公園であり，風光明媚な多島美が広がり，多種の魚介類に恵まれる。しかし，大量の海洋ごみによる漁獲量の減少や景観美を損ねるなど深刻な影響が及んでいる。これら瀬戸内海の海洋ごみ問題の解決に向けて，2008 年より山陽学園中・高の地歴部の生徒が，海底ごみや島嶼部の海岸漂着ごみの回収活動と，発生抑制のための啓発活動に取り組んだ。啓発活動をする際に感じた課題を解決することで，より効果的な啓発効果を得られる実践に挑戦した。

啓発活動の問題点

海洋ごみを取り巻く課題には，回収量を大きく上回る発生量があり，その原因が日常生活にある。地歴部の啓発活動は，メディアからの情報発信，学会等の学術活動，体験学習会・展示会・出張講座の開催など多岐にわたる。多くの啓発活動は事前の申込制である。参加者は高齢者が多く，問題に対する意識が高く，行動に移している人が多いことがアンケート調査から明確となった。啓発活動の効果があることは確かであるが，効果の広がりを疑問に感じた。啓発イベントへ参加できない人や問題に対する意識が低い人など，問題を他人

事としている人への啓蒙・啓発が本来必要ではないだろうか。そこで，問題を「自分事」として捉え，解決に向けて意識と行動の変化を促せる啓発活動の実践に挑戦した。

「日常生活」・「地域」から訴え掛ける実践

海洋ごみ問題の「自分事」化のキーワードは「日常生活」と「地域（足元）」である。申込者の参加が多い啓発活動をより効果的なものにするためには，日常生活の中で不特定多数が多く利用する商業施設で訴え掛けである。スーパー等の商業施設では大量にプラスチック製品が販売され，ビニールに包装されている。また，リサイクルポストが設置され，ペットボトル等の再資源化が活発である。つまり，経済活動と環境保全の交差点ではないだろうか。喉か乾いて購入したペットボトルの飲料水は大切に扱うが，飲み干した後はごみとなり，正しい廃棄への意識は高いとは言えない。商業施設では買い物客に対して，訴え掛けを行うだけではなく，回収した海洋ごみの展示を商品棚の傍に構え，購入品と海洋ごみとの繋がりの理解を促した。

地域では啓発活動をする際に，その地域の用水路調査を実施した。地域の足元の様子の理解は意外と進んでいない。海洋ごみ問題は決して沿岸域だけの問題にしてはいけない。用水路の調査結果は地図にして「見える化」することで，地域の足元のごみの実態と，用水路から海へと繋がることの理解を促した。用水路マップはその後も地域の清掃活動に活用されるなど，一過性の取り組みではなく継続的・発展的な実践となった。

海洋で分解する生分解性プラスチックの開発と将来展望

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はじめに

現在，海洋マイクロプラスチック問題に代表されるように，非生分解性プラスチックの廃棄物による環境汚染が地球規模の解決すべき重要な課題となっています。その解決策の一つとして，環境中の微生物によって水と二酸化炭素にまで完全に分解される「生分解性プラスチック」の開発が望まれています。

本講演では，生分解性プラスチックの定義と期待される用途，当研究室における海洋分解性繊維やマイクロビーズなどの開発状況と海洋分解性，さらには今後の展望について紹介します。

生分解性プラスチックとは

生分解性プラスチックとは，「使用中は通常のプラスチックと同じように使用でき，使用後は自然界において微生物が関与して低分子化合物，最終的に水と二酸化炭素にまで完全に分解されるプラスチック」と定義されています（Fig. 1)。したがって，生分解性プラスチックは，環境保全に貢献するという観点で環境にやさしいプラスチックであり，生分解するという機能に大きな意味があることから，原料が石油であるのか，再生産可能な植物バイオマスであるのかは関係ありません。

環境にやさしいプラスチックとして多くの方が誤解していることですが，植物成分からつくられる「バイオマスプラスチック」は，プラスチックの原料を石油から植物成分に替えているだけなので，全てのバイオマスプラスチックが「生分解性」という機能を持っているわけではありません。生分解性プラスチックとバイオマスプラスチックは同じように思われていますが，生分解性プラス

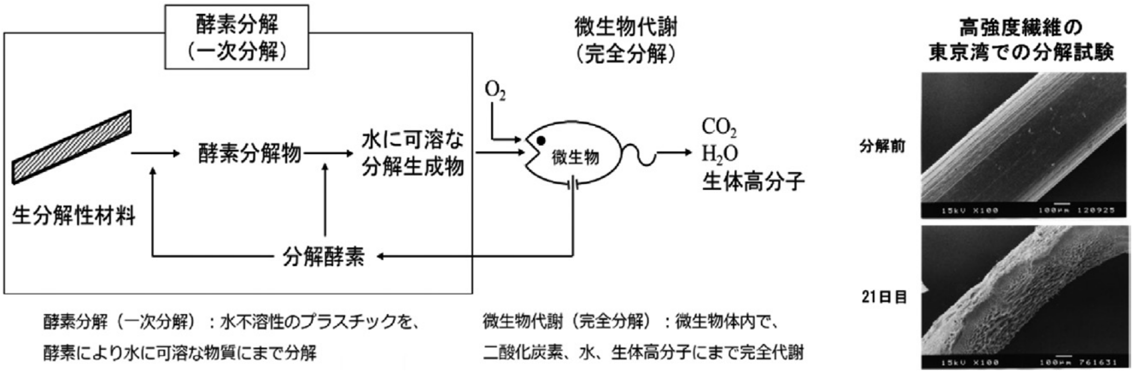

Fig. 1　生分解性プラスチックの分解機構（酵素分解と微生物代謝）と一例

Table 1. 生分解性プラスチックに期待される用途

分　野	用　途	
自然環境中で利用される分野	農林水産用資材	多目的フィルム、農薬・肥料用の徐放性被覆材、移植用苗ポット、釣り糸、漁網、ノリ網など
	土木・建設用資材	荒地・砂漠の緑化用保水素材、工事用の保水シート、土のう袋、植生ネットなど
	野外レジャー用品	ゴルフ、釣り、マリーンスポーツなどの使い捨て製品
	水処理用資材	沈殿剤、分散剤、洗剤
有機廃棄物のコンポスト化に有用な分野	食品容器包装資材	生鮮食品用のトレー、ファーストフードの容器、弁当箱など
	衛生用品	紙おむつ、生理用品など
	日用品、雑貨類	ごみ袋、使い捨てのコップなど

チックは「生分解」という機能を持ったプラスチックで，バイオマスプラスチックは「バイオマス」からつくられるプラスチックのことであり，全く違うコンセプトのプラスチックです。

生分解性プラスチックに期待される用途

生分解性プラスチックは「生分解」することに意義があります。よって，生分解性プラスチックの利用用途としては，農林水産用資材，野外レジャー用品など環境中で使用され，全てを回収することが困難な自然環境中で利用される分野と，食品包装用資材や日用品・雑貨類などの分別回収は難しいが，きちんと回収してコンポスト分解させることが望ましい分野の2つが考えられます（Table 1）。

高強度・高伸縮性を兼ね備えた海洋分解繊維の開発

現在問題となっているマイクロプラスチックは，数ミリ角のプラスチックです。今後さらに問題となるのは，衣料の洗濯により排出されるミクロンオーダーの繊維くず，化粧品や歯磨き粉などに入っているナノ粒子（スクラブ，研磨剤）など，目に見えない本当の意味でのマイクロプラスチックやナノプラスチックです。

我々は最近，強いだけでなく，2〜3倍に伸び縮みする，高強度・高伸縮性の生分解性繊維の開発に成功しました（Fig. 2）。この繊維は大人の力でも切れない十分な強さを有しています。この繊維は海洋分解性のみならず，生体吸収性も有するため，釣り糸や漁網などにはもちろん，手術用縫合糸などの医療材料への展開も期待されています。

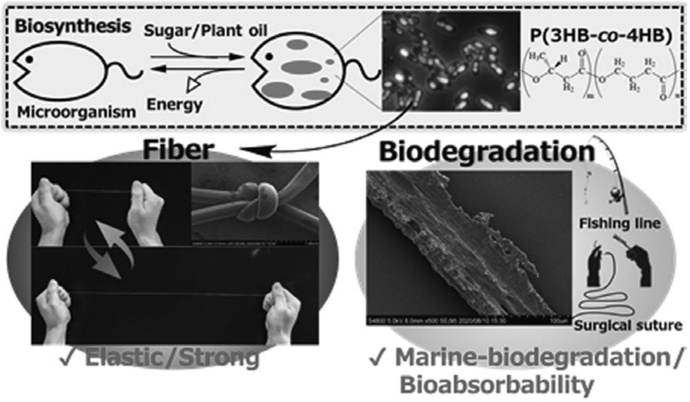

Fig. 2 微生物産生ポリエステルの伸縮性繊維と海洋分解性

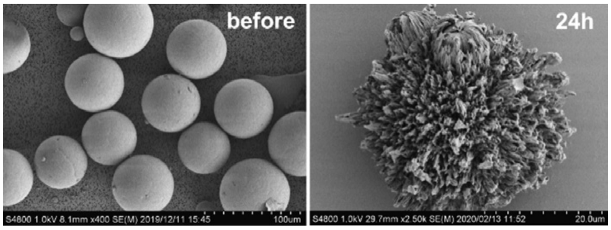

Fig. 3 マイクロビーズと生分解性

最近演者らは，微生物産生ポリエステルから海水で分解する微粒子の開発にも成功しました (Fig. 3)。

当日は，様々な研究開発の状況と今後の展望についてもご紹介したいと思います。

Océans de plastique

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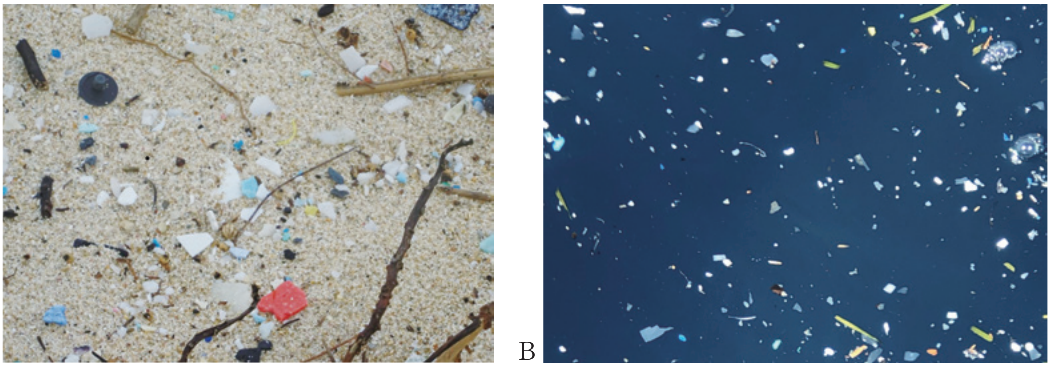
Plus de 8 millions de tonnes de plastique entrent dans les océans chaque année, soit environ 15 tonnes par seconde. Cela est malheureusement possible en raison d'apports massifs issus des zones urbanisées, des fleuves et de l'utilisation du littoral, des rejets de stations d'épuration, en raison du tourisme, en raison de sources maritimes liées au trafic des navires ou des activités de la pêche, et en raison de rejets ou décharges incontrôlées. Les apports massifs liés aux évènements naturels sont également important (ouragans, tsunamis, etc.) et doivent être pris en compte dans certaines régions du monde. Les déchets de plastiques peuvent être transportés sur de longues distances. Il est important de noter que l'on retrouve plus de 95% de la pollution plastique sur les fonds marins. Nos connaissances actuelles de la situation restent limitées pour ce qui concerne les quantités, leur distribution, leur dégradation et leurs impacts. La circulation des eaux marines et le facteur le plus important qui régit le devenir du plastique en mer. Des accumulations ont été décrite dans les zones de convergence océanique, parfois appelées continent de plastique, et depuis peu, de nombreuses descriptions d'accumulation massive de déchets plastiques sur les fonds, notamment dans les canyons, ont été décrites dans la littérature.

Les suivis réguliers du niveau de la pollution plastique mis en place récemment dans de nombreux pays permettent de mieux comprendre l'évolution de cette pollution. La plupart des travaux dans les régions près des sources ne montrent pas de changement au cours du temps mais un transfert vers les zones les plus éloignées (zones polaires, íles océaniques) où ont été constatées des augmentations significatives au cours des dernières années. L'accumulation des microplastiques, issus de la fragmentation du plastique, dans les sédiments marins semble comfirmer l'importance des zones profondes.

Les impacts de la pollution plastique sont nombreux et concernent principalement l'étouffement de nombreuses espèces dans les engins de pêche abandonnés, l'ingestion de débris et microplastiques pour pratiquement toutes les espèces, le relargage de contaminants ou d'additifs, et le transport sur de longues distances d'espèces fixées sur le débris. Par ailleurs, et sur le plan économique, l'impact sur la pêche et sur le tourisme sont très significatifs. Enfin, L'importance des débris pour la navigation (emmêlements des hélices dans les débris, conteneurs flottants, et les risques d'impacts sur la santé (ingestion de microplastiques, blessures sur les plages) sont des sujets considérés comme sérieux par les gestionnaires.

Dans cette présentation, nous discutons les enjeux scientifiques de la pollution plastique, mais également les travaux concernant le suivi de cette pollution en mer ainsi que les différentes stratégies de réduction mises en place par les institutions et initiatives internationales (prévention, éducation, collecte et recyclage, nettoyage, traitement des eaux, etc.). L'implication des



A B

Fig. 1 *Sur les plages (A), flottants (B) ou sur les fonds, les microplastiques, issus de la fragmentation des débris plastiques, constituent une part importante de la pollution plastique des océans. Avec des densités atteignant plus de 64 millions de particules par km2 dans certaines régions du globe, ce problème apparait comme l'un des enjeux majeurs de la pollution du milieu marin*

différents acteurs (gestionnaires, politiques, scientifiques ONGs, industrie, public) est devenue une nécessité car il s'agit d'un problème global et transfrontalier.

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La chasse aux plastiques disparus

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Le plastique est aujourd'hui un matériau indispensable dans notre vie quotidienne car il est bon marché, léger, solide, peut être façonné de nombreuses façons et est flexible. Toutefois, on craint que ce plastique utile, s'il n'est pas éliminé correctement, ne se retrouve dans les océans et ne provoque une grave pollution si rien n'est fait. Le plastique est décomposé en petits morceaux par les rayons ultraviolets et les ondes du soleil, mais on ne sait pas exactement combien de temps il faudra pour qu'il se décompose chimiquement au point de ne plus affecter les organismes vivants.

Nous entendons souvent parler des problèmes causés par le plastique dans la mer, comme le fait que la faune marine le consomme par erreur comme nourriture ou qu'il s'emmêle dans les engins de pêche. D'autres plastiques présents dans la mer entraînent une pollution des conditions de vie, nuisent à la navigation des navires et affectent l'industrie du tourisme. Ces problèmes sont trop nombreux pour être tous mentionnés. L'une des principales préoccupations est la pollution chimique de la vie marine. Les plastiques de moins de 5 mm sont appelés microplastiques, mais il est de plus en plus évident que plus le plastique est petit, plus son impact sur la vie marine est important. Plus le plastique est petit, plus il a de chances d'être absorbé par les organismes marins, dont beaucoup se nourrissent des particules présentes dans l'eau. En dérivant dans la mer, le plastique absorbe des substances nocives, et divers produits chimiques sont utilisés lorsqu'il est transformé en produit de consommation. La concentration de ces substances dans la chaîne alimentaire des écosystèmes marins augmente par bioaccumulation, et l'on s'inquiète de l'impact sur les humains qui les consomment.

Une solution complète au problème des plastiques marins impliquerait idéalement : (1) aucun déversement de plastique ; (2) l'élimination du plastique des océans sans affecter les organismes vivants ; et (3) l'utilisation de matériaux qui se décomposent rapidement au point de ne pas affecter les organismes vivants s'ils sont libérés dans l'environnement. Un certain nombre d'initiatives sont actuellement en cours pour atteindre ces idéaux, mais elles prendront toutes du temps. En fait, nous ne savons même pas exactement combien de plastique il y a dans les océans et comment il affecte la vie marine et les humains, et des informations scientifiques sont recueillies dans le monde entier.

Chaque année, 10 millions de tonnes de plastique pénètrent dans la mer et, si l'on ajoute ce qui est entré jusqu'à présent, ce sont environ 45 millions de tonnes de plastique qui flottent à la surface de la haute mer. Cependant, seules quelques centaines de milliers de tonnes peuvent être expliquées scientifiquement par les découvertes faites jusqu'à présent, et nous ne savons pas où est passé le reste. C'est ce que l'on appelle les plastiques manquants, et c'est un défi qui doit être relevé si nous voulons comprendre où et combien de plastique se trouve dans la mer. Il y a plusieurs possibilités : (1) il coule au fond de l'océan (Fig. 1), (2) il est trouvé en grande quantité dans des zones non étudiées, (3) il

Fig. 1 Un grand nombre de sacs plastiques vus à une profondeur de 1344 m dans la baie de Sagami en 1999.

dérive dans l'eau, ou (4) il est trop petit pour être trouvé. Nous concentrons nos recherches sur (1) et (2).

Il existe des dizaines de types différents de matières plastiques, comme le polyéthylène PE et le polypropylène PP. Selon le matériau, certains flottent, d'autres coulent et d'autres encore contiennent différents produits chimiques. Par conséquent, afin de déterminer la distribution des plastiques et leur impact sur les organismes vivants, il est nécessaire d'identifier la matière plastique et de mesurer sa taille, sa quantité et sa forme. Cette analyse prend beaucoup de temps, surtout pour les microplastiques. Les connaissances manquantes sur les matières plastiques seront accélérées et intégrées par une simple technique d'analyse des microplastiques.

La mer est si vaste que les instituts de recherche ne peuvent en étudier qu'une petite partie. D'autre part, il y a un nombre énorme de navires en mer. Si nous pouvons collecter des données sur les plastiques marins à partir de ces navires, nous pourrons sans aucun doute améliorer considérablement notre compréhension de la distribution des plastiques marins. À la lumière des ODDs, on prend de plus en plus conscience de la nécessité pour les différents secteurs de contribuer à la résolution des problèmes environnementaux. Nous avons donc commencé par travailler avec les participants à la course de voiliers pour collecter les plastiques marins à l'aide de leurs voiliers. Nous avons collecté et analysé des microplastiques à titre d'essai pendant la Japan-Palau Yacht Race et le Vendée Globe, la course de voiliers la plus difficile au monde. Une telle initiative permettrait d'obtenir des informations sur la répartition des plastiques marins dans les eaux non surveillées.

Dans cette conférence, nous présenterons la recherche sur les plastiques manquants que nous menons à l'Agence japonaise pour la science et la technologie marine et terrestre (JAMSTEC) et les initiatives qui la soutiennent.

(Ce texte a été traduit en français à partir du texte japonais par Mr Katsunori Fujikura. La responsabilité de la traduction incombe à la Société franco-japonaise d'Océanographie du Japon.

Tara-Jambio Mission Microplastique: Science, Education, Art et Partage

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La fondation Tara océan est un organisme consacré à locéan. Elle développe une science ouverte et de haut niveau en collaborant avec des instituts de recherche renommés. Elle utilise cette expertise scientifique pour sensibiliser le grand publique et surtout les jeunes générations, mais aussi mobiliser les décideurs politiques. Déjà d'envergure internationale de part les expéditions scientifiques menées à travers le monde, la fondation étend ces activités et Tara Océan Japan a été crée en 2017. Pour son premier projet scientifique, Tara Océan Japan s'associe avec le réseau Jambio pour étudier la pollution plastique dans les eaux côtières japonaises. Le réseau Jambio connecte 23 des stations marines appartenant aux universités nationales japonaises. Il donne à la communauté scientifique un accès direct aux divers écosystèmes des côtes japonaises et aux infrastructures nécessaires pour conduire leur recherche (Fig. 1).

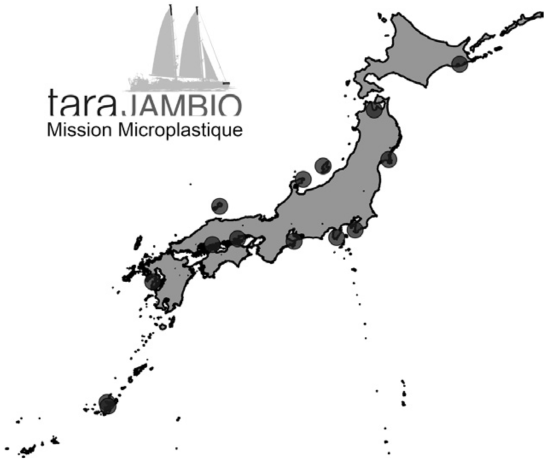

Fig. 1 Location des stations marines indiquées oar des cercles noirs appartenant aux réseau Jambio et utilisé dans le cadre du projet "Tara-Jambio Mission Microplastique".

Le Japon, un grand consommateur de plastique, est situé dans un zone océanique reconnue comme un hotspot pour la pollution microplastique (Isobe et al., 2015). Les hautes concentrations en microplastiques observées dans les eaux japonaises ont en grande partie été attribuées aux flux locaux et aux microplastique portés par le courant Kuroshio qui a pour origine l'Asie du Sud-Est et longe les côtes japonaises. Cependant, les données sur la pollution plastiques dans les zones côtières sont encore insuffisantes. De plus il nexiste que très peu de données sur la pollution plastique des sédiments dans ces zones, ce qui limite le développement de modèles sur les flux verticaux de microplastiques qui proviennent des côtes. Enfin, de part sa longue durée de vie, le plastique et microplastique sont capables de transporter des organismes sur de longues distances. Cet effet de radeau peut avoir un impact sur les ecosystèmes, l'aquaculture et notre santé. Il est donc important d'étudier quelles espèces aussi bien de macro- et microorganismes, sont présentes sur les plastiques trouvés aux larges de nos côtes. Le projet Tara-Jambio a donc pour but d'étudier la pollution en microplastique dans les eaux et sediments des côtes japonaises, la composition des espèces microbiennes transportées par le plastique, l'impact potentiel de cette pollution sur les écosystèmes côtiers, et, enfin, de sensibiliser le public à la pollution plastique et les défis environnementaux comme le changement climatique qui menacent la biodiversité marine.

Le projet Tara Jambio Mission Microplastique a commencé en 2019, année pendant laquelle les protocoles de recherche ont été développés sur la base des standard internationaux et des protocoles utilisés pendant les différentes missions menées par Tara Océan. Cela permettra de comparer les données obtenues pendant le projet aux données accessibles dans la littérature. Toutes les données obtenues pendant le projet seront accessible pour tous au bénéfice de la communauté scientifique. Deux campagnes déchantillonnages ont été menées en 2020 et 2021 avec plus de dix locations étudiées de Kyushyu à Hokkaido, avec la collaboration des stations marines des universités de Okayama, Hiroshima, Shimane, Kyushyu, Nagoya, Tsukuba, Tohoku et Hokkaido. À chaque location, le microplastique dans les eaux et sédiments d'un estuaire, une baie et hors de la baie, et enfin sur des plages à proximité des différentes stations marines, ont été échantillonnés, accumulant plus d'une centaine échantillons de microplastique et autant pour étudier la biodiversité locale (benthique et planctonique) et les conditions environnementales (CTD, TEP concentration, etc.). Enfin un effort de monitoring est en cours à la station marine de Shimoda de l'Université de Tsukuba, où le même protocole déchantillonnage est suivi tout les mois depuis Juillet 2020. Les échantillons sont maintenant en cours d'analyses mais les premières observations montrent la présence de microplastiques de divers types : particules, fibres et films, dans tout les échantillons quils soient d'eaux de surfaces ou de sédiment.

Les campagnes déchantillonnages ont été aussi loccasion de mener des campagnes de sensibilisation. Des événements destinés au grand public de tout ages ont été organisés avec des nettoyages de plages, des échantillonnages sur les plages ou a bord des bateaux de recherches et des symposiums. Dans lesprit Tara, les scientifiques impliqués collaborent avec des artistes, qui participent à léchantillonnage dans le but de produire des œuvres qui pourront sensibiliser le public sur limportance de locéan. Cette collaboration science-art organisée par Prof Hibino de l'Université d'Art de Tokyo, a aussi permis a des etudiants de cette universités detudier la biodiversité marine et la pollution microplastique aux larges de Shimoda lors dune mission de terrain.

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Lutte contre la Pollution microplastique de l'Océan : de l'action citoyenne à l'élaboration des normes

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Depuis quelques années la communauté scientifique nous alerte sur l'omniprésence de la pollution microplastique dans les cours d'eaux et le milieu marin. Les études révèlent en effet, que les microplastiques ont envahi tous les compartiments de l'Océan : on les retrouve flottant en surface, dans les sédiments, dans les glaces ou tapissant les fonds océaniques. Même les zones éloignées de toute civilisation comme les eaux arctiques n'échappent pas à cette pollution.

En plus de leur persistance dans l'environnement marin, se pose alors la question de leurs impacts sur les écosystèmes. De part leur taille, les espèces et organismes marins susceptibles de les ingérer sont très nombreux menant ainsi à une contamination de l'ensemble des réseaux trophiques. Les microplastiques adsorbent et concentrent des polluants organiques persistants (POP) déjà présents dans le milieu et peuvent servir de moyens de transport à des espèces pathogènes et nuisibles. Les microplastiques perturbent la croissance et la reproduction de certaines espèces et causent une pollution irréversible sur les écosystèmes.

La pollution microplastique ne concerne pas seulement lOcéan puisque leur présence a été mise en évidence dans l'air que nous respirons, l'eau que nous buvons ou des aliments que nous consommons, pourtant elle reste encore méconnue du grand public.

Surfrider Foundation Europe, association de protection de l'environnement marin et des usagers a développé un programme multisectoriel pour réduire à la source les microplastiques aussi bien primaires que secondaires. Surfrider a placé au cœur de son programme d'action les citoyens en les sensibilisant à cette pollution invisible et en favorisant le dialogue avec les autres parties prenantes. Les citoyens participent notamment à l'acquisition de données sur les microplastiques aussi bien dans l'environnement que dans la composition de certains produits via les sciences participatives et l'utilisation des outils numériques. La mobilisation citoyenne permet d'interpeler les décideurs publics tant au niveau national qu'européen et de les encourager à adopter des mesures contraignantes afin de prévenir durablement la pollution. De la même manière, les acteurs économiques soucieux de leurs images, sont sensibles aux revendications des consommateurs.

Dans cette présentation, nous exposerons les différents moyens de sensibilisation et d'interpellation à disposition de lassociation pour rendre visible l'invisible et ainsi favoriser une prise de conscience de l'ensemble des acteurs impliqués dans la production et dissémination des microplastiques dans les milieux aquatiques. Nous montrerons le rôle central de l'action citoyenne aussi bien sur le terrain qu'auprès des instances décisionnaires et du secteur privé.

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Le défi de la mise en pratique de l'approche "affaire personnelle" pour résoudre le problème des déchets marins dans la mer intérieure de Seto.

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Introduction

La mer intérieure de Seto est le premier parc national du Japon. Elle offre des paysages d'une grande beauté et une grande variété de fruits de mer. Cependant, la grande quantité de déchets marins a eu un impact sérieux, réduisant la quantité de poissons capturés et endommageant la beauté du paysage. Afin de résoudre le problème des déchets marins dans la mer intérieure de Seto, les élèves du club de géographie et d'histoire du collège et du lycée Sanyo Gakuen participent depuis 2008 au ramassage des déchets sur le fond marin et des déchets échoués sur la plage des îles, ainsi qu'à la sensibilisation à la nécessité de réduire la quantité de déchets produits. Le club a été mis au défi de mettre en œuvre des pratiques qui seraient plus efficaces en matière de sensibilisation en relevant les défis qu'il estimait devoir relever pour y parvenir.

Problèmes liés aux activités de sensibilisation

Les problèmes liés aux déchets marins

incluent le fait que la quantité de déchets générés dépasse largement la quantité collectée, et que cela est dû à notre vie quotidienne. Les activités de sensibilisation du club de géographie et d'histoire couvrent un large éventail de sujets, notamment la diffusion d'informations par les médias, les activités académiques telles que les conférences, et l'organisation d'événements d'apprentissage pratique, d'expositions et de conférences sur site. Beaucoup de ces activités nécessitent une inscription préalable. L'enquête par questionnaire montre clairement que les participants sont principalement des personnes âgées, qui sont plus conscientes des problèmes et plus susceptibles d'agir. Il est clair que les activités de sensibilisation sont efficaces, mais nous nous sommes interrogés sur la propagation des effets. Nous pensons qu'il est nécessaire d'éduquer ceux qui ne sont pas en mesure de participer aux événements de sensibilisation et ceux qui ne sont pas conscients de la question. Nous nous sommes donc lancés le défi de créer une campagne de sensibilisation qui encouragerait les gens à considérer le problème comme une affaire personnelle et à changer leurs attitudes et leurs comportements pour le résoudre.

Pratique pour faire appel à la "vie quotidienne" et à la "communauté"

Les mots clés pour faire du problème des déchets marins une "affaire personnelle" sont "vie quotidienne" et "communauté". Afin de rendre plus efficaces les activités de sensibilisation, qui impliquent souvent la participation de nombreuses personnes, nous devrions faire appel aux personnes dans les centres commerciaux utilisées par de nombreuses personnes dans leur vie quotidienne. Dans les centres commerciaux tels que les supermarchés, de grandes quantités de produits en plastique sont vendues et emballées dans du plastique. En outre, des postes de recyclage ont été mis en place et le recyclage des bouteilles en plastique et d'autres matériaux est très actif. En d'autres termes, les centres commerciaux peuvent être l'intersection de l'activité économique et de la protection de l'environnement. Les gens prennent bien soin de l'eau en bouteille qu'ils achètent parce qu'ils ont soif, mais une fois qu'ils ont bu toute l'eau, la bouteille va à la poubelle et la sensibilisation à son élimination correcte n'est pas élevée. Dans les centres commerciaux, nous n'avons pas seulement interpellé les acheteurs, mais nous avons également installé des présentoirs de déchets marins collectés à côté des rayons pour les encourager à comprendre le lien entre leurs achats et les déchets marins.

Dans la communauté, nous avons réalisé une enquête sur les canaux d'irrigation dans la zone où nous menions nos activités de sensibilisation. Il est surprenant de constater que peu de progrès ont été réalisés pour comprendre ce qui se passe sous les pieds de la communauté. Le problème des déchets marins ne devrait jamais se limiter aux zones côtières. Les résultats de l'enquête sur les canaux d'irrigation ont été cartographiés et rendus "visibles" afin de promouvoir la compréhension de la situation réelle des déchets sous les pieds de la communauté et du lien entre les canaux d'irrigation et la mer. La carte des canaux a ensuite été utilisée pour des activités locales de nettoyage, il ne s'agissait donc pas d'une initiative ponctuelle mais d'une pratique continue et en développement.

(Ce texte a été traduit en français à partir du texte japonais par Mr Takashi Inoue La responsabilité de la traduction incombe à la Société franco-japonaise d'Océanographie du Japon.)

Développement et perspectives d’avenir des plastiques biodégradables qui se décomposent dans la mer

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Introduction

Aujourd’hui, la pollution environnementale causée par les déchets plastiques non biodégradables est un problème mondial important à résoudre, comme l’illustre le problème des microplastiques marins. L’une des solutions à ce problème est le développement de plastiques biodégradables, qui peuvent être entièrement dégradés en eau et en dioxyde de carbone par les micro-organismes présents dans l’environnement.

Dans cet exposé, je présenterai la définition des plastiques biodégradables et leurs applications prévues, le développement de fibres et de microbilles dégradables en milieu marin dans notre laboratoire, leur dégradabilité en milieu marin et les perspectives d’avenir.

Que sont les plastiques biodégradables ?

Les plastiques biodégradables sont définis comme "des plastiques qui peuvent être utilisés de la même manière que les plastiques normaux pendant leur utilisation, mais qui sont complètement dégradés dans la nature par des micro-organismes en composés de faible poids moléculaire et finalement en eau et en dioxyde de carbone" (Fig. 1). Les plastiques biodégradables sont donc écologiques du point de vue de leur contribution à la préservation de l’environnement, et peu importe que la matière première soit du pétrole ou de la biomasse végétale renouvelable, car la fonction de biodégradation est d’une grande importance.

On croit souvent à tort que tous les plastiques issus de la biomasse sont (not negative) biodégradables, car ils sont fabriqués à partir de plantes et non de pétrole. Les plastiques issus de

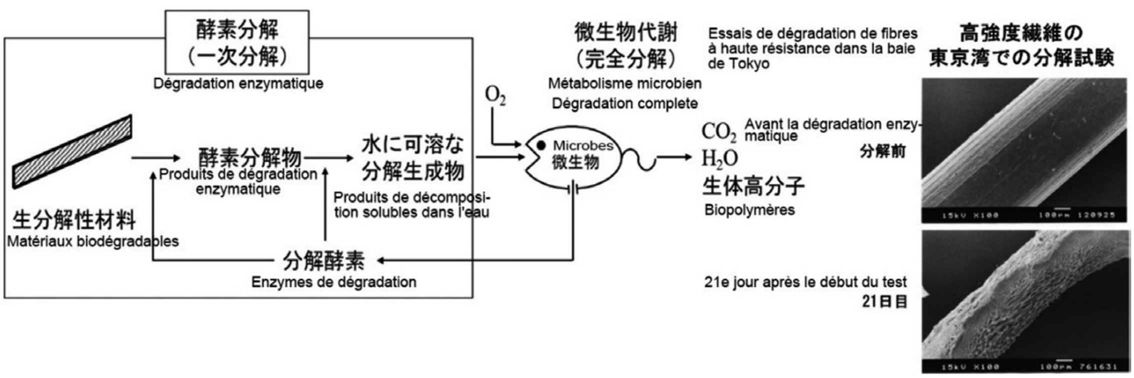

Fig. 1 Un exemple du mécanisme de dégradation des plastiques biodégradables

Tableau 1. Applications potentielles des plastiques biodégradables

Secteurs	Utilisations	
Secteurs d'utilisation dans l'environnement naturel	Matériaux pour l'agriculture	Films à usages multiples, revêtements à libération lente pour les pesticides et les engrais, pots de semis pour la transplantation, lignes de pêche, filets de pêche, filets à algues, etc.
	Matériaux pour le génie civil et la construction	Matériaux de rétention d'eau pour le verdissement des terrains vagues et des déserts, feuilles de rétention d'eau pour la construction, sacs de sable, filets de végétation, etc.
	Produits de loisirs de plein air	Produits jetables pour le golf, la pêche, les sports marins, etc.
	Traitement de l'eau	matériaux de sédimentation, dispersants, détergents
Secteurs utiles pour le compostage des déchets organiques	Matériaux d'emballage alimentaire	Plateaux de produits frais, conteneurs de restauration rapide, boîtes à lunch, etc.
	Produits d'hygiène	Couches jetables, produits sanitaires, etc.
	Articles ménagers et divers	Sacs poubelles, gobelets jetables, etc.

la biomasse ne sont pas tous biodégradables. On pense souvent que les plastiques biodégradables et les plastiques issus de la biomasse sont identiques, mais les plastiques biodégradables sont des plastiques qui sont biodégradables, tandis que les plastiques issus de la biomasse sont des plastiques fabriqués à partir de la biomasse, ce qui est un concept complètement différent.

Applications potentielles des plastiques biodégradables

Il est important de noter que les plastiques biodégradables sont "biodégradables". Il existe donc deux applications possibles pour les plastiques biodégradables : celles utilisées dans l'environnement naturel, où il est difficile de collecter tous les matériaux, comme les matériaux pour l'agriculture, la sylviculture et les pêcheries, et les produits de loisirs de plein air ; et celles où il est difficile de les collecter séparément, comme les matériaux d'emballage alimentaire, les produits de première nécessité et les biens divers, mais où il est souhaitable de les collecter et de les composter (Tableau 1). Il existe deux secteurs possibles (Tableau 1).

Développement d'une fibre marine dégradable à haute résistance et haute élasticité

Les microplastiques qui posent actuellement des problèmes sont des plastiques qui ne font que quelques millimètres de côté. À l'avenir, les microplastiques et les nanoplastiques deviendront encore plus problématiques, car ils sont invisibles au sens propre du terme, comme les déchets de fibres d'ordre micrométrique provenant du lavage des vêtements et les nanoparticules (agents de frottement et de polissage) présentes dans les cosmétiques et le dentifrice.

Nous avons récemment réussi à mettre au point une fibre biodégradable à haute résistance et à haute élasticité, qui est non seulement solide, mais peut également s'étirer et se contracter deux à trois fois (Fig. 2). Les fibres sont suffisamment solides pour résister à la force d'un adulte. Comme cette fibre est non seulement dégradable en milieu marin, mais aussi bioabsorbable, elle pourrait être utilisée pour les lignes et les filets de pêche ainsi que pour les matériels médicaux tels que les sutures chirurgicales.

Récemment, nous avons également réussi à

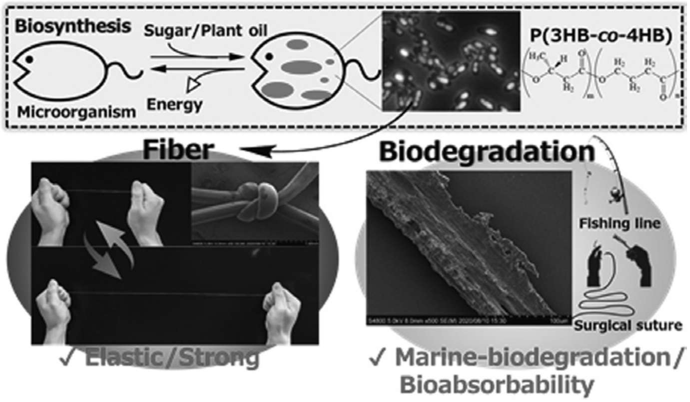

Fig. 2 Fibres extensibles et dégradabilité marine des polyesters produits par des microorganismes

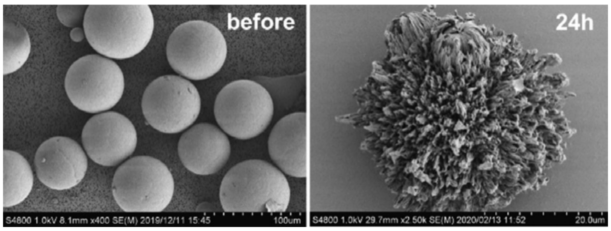

Fig. 3 Microbilles et biodégradabilité

développer des microparticules à partir de polyesters microbiens qui se dégradent dans l'eau de mer (Fig. 3).

Lors de cette journée, nous présenterons également l'état d'avancement de nos différentes activités de recherche et de développement ainsi que nos perspectives d'avenir.

(Ce texte a été traduit en français à partir du texte japonais par Prof Tadahisa Iwata. La responsabilité de la traduction incombe à la Société franco-japonaise d'Océanographie du Japon.)

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Poster Session of the 18th Japanese-French Oceanography Symposium

The poster session of the 18th Japanese-French Oceanography Symposium was held online from 18 October 2021 to 21 October 2021. The core time for the poster session was 16:00-16:50 on 21 October 2021. The number of poster presentations was 12. Abstracts of the poster presentations are as follows.

Horizontal distribution of concentration and composition of microplastics in sediments of Otsuchi Bay, Japan

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INTRODUCTION

The amount of waste plastic discharged into the ocean is estimated between 4.8 and 12.7 million tons per year (JAMBECK *et al.*, 2015)[1]. It was considered about 47.4% of these plastics were degraded into fine pieces (microplastics, hereinafter referred to as MPs) less than 5 mm in diameter (LEBRETON *et al.*, 2017)[2].

In particular, the number of MPs drifting in the Japanese coastal waters was estimated 1,720,000 pcs km^{-2}, which was 27 times higher than the global average (ISOBE *et al.*, 2015)[3]. Previous studies have indicated that 73% of missing MPs accumulated on the seabed as sediments (MATSUGUMA *et al.*, 2017)[4]. However, our knowledge about MPs contamination in sediments is still insufficient in coastal areas of Japan. The influence of river water on the behavior of MPs is also unclear.

In order to solve the above problems, we observe the horizontal distribution of MPs concentrations and composition in sediments on the sea floor in Otsuchi Bay, one of small ria bays in Sanriku on the Pacific coast of Tohoku, Japan.

METHODS

The survey was conducted in March 2021 by a research vessel of boat of the International Coastal Research Center, AORI, Univ. Tokyo at the three stations in Otsuchi Bay. The seabed sediments were sampled by a G. S. type core sampler (ASYURA) at each station. The sediment cores were sliced onsite into 5 cm intervals and stored in a dark, cold chamber.

The MPs concentration was measured with reference to MASURA *et al.* (2015)[5]. Approximately 10 g (wet weight) of the sample from 0–5 cm layer was separated into a beaker. Next, 300 mL of NaI solution adjusted to a density of 1.6 g cm^{-3} was poured into the beaker and stirred. The sample was left to stand for 24 h and the supernatant was then collected. This density-separation operation was repeated three times. After that, the collected supernatant was passed through a sieve with mesh size of 10 μm, and the particles in the supernatant were collected. The particles remaining on the sieve were washed with distilled water. Next, 20 mL of 30% hydrogen peroxide was added to the sample, and the mixture was heated at 60 ℃ for 3 days to remove impurities. Finally, pure MPs were collected on a PTFE filter (25 mm diameter, 0.45 μm pore diameter) by vacuum filtration.

The sample was analyzed by FTIR-microscope (Thermo Fisher Scientific Nicolet iN10). The measured spectrum was compared with the spectrum of a standard plastic registered in advance (polyethylene, polypropylene, polystyrene, polyamide and polyvinyl chloride) to determine the composition of the particles in the sample (MATSUGUMA *et al.*, 2017)[4]. The spectrum and size of the MPs particles was measured by an analytical software, OMNIC.

RESULTS AND DISCUSSION

The concentrations of seabed sediments at Sta. 1, 2 and 3 in March 2021 were 13.6 ± 9.8, 1.7 ± 0.6, 2.6 ± 0.3 pcs g-1 DW, respectively. The MPs concentration at Sta. 1 was significantly higher than that of Sta.2 (Kruskal-Wallis test, $p < 0.05$). The size ranges (average particles size ± standard deviation) of MPs were 353.1 ± 161.5, 269.5 ± 95.6, and 163.7 ± 31.1 μm, respectively. There were no significant differences among stations in terms of the average MPs particle size (Kruskal-Wallis test, $p > 0.05$).

The MPs concentration in sediment in Otsuchi Bay indicated to be higher toward the inner part of the bay which is located on the estuary of the Otsuchi River. This result is consistent with WANG *et al.*, (2021)[6], who found that MPs concentration of 145 pcs g^{-1}DW on the estuary part of Tokyo Bay was higher than 53.3 pcs g^{-1}DW on the mouth side of the bay. The results might be explained by that the deposition of particles containing MPs is likely strongly affected by the enhanced outflow of the Otsuchi River in estuary, especially during the period of heavy rains.

Another possible explanation is influences of inflow of the offshore water into the bay. The bottom water originated from The Tsugaru Warm Current or the Oyashio Current flows counterclockwise along the coast of the bay during autumn to spring in Otsuchi Bay (ISHIZU *et al.*, 2016)[7]. It is necessary to study the seasonal change of MPs distribution in order to clarify the influence of the circulation in Otsuchi Bay.

CONCLUSION

We clarified the horizontal distribution of MPs concentration and composition in seafloor sediments in Otsuchi Bay. The MPs concentration of 13.6 ± 9.8 g^{-1} DW on estuary side was higher than the 1.7 ± 0.6 g^{-1} DW on coastal side. There was no difference in the average particle size of MPs at observation points. These results suggest that the settlement of MPs may affected by the river discharge or inflow of the offshore waters into Otsuchi Bay.

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Interdiurnal variation of chlorophyll-a and transition of dominant phytoplankton observed at the Yodo River estuary, JAPAN

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Keywords: interdiurnal variation, diatom, dinoflagellate, mole ratio, Yodo River

INTRODUCTION

Osaka Bay located in West Japan is the semi-enclosed bay. Large amounts of nutrients are loaded from the Yodo River and are released from the bottom. Diatom dominates usually in the Yodo River estuary, but other various phytoplankton species also appear. The year-to-year variation of dominant phytoplankton species in 1990s was analysed[1]. On the other hand, since the minimum interval of the field observations of red tide is one week, the transition of species at the shorter time and its reasons are indistinct. The field observation was carried out at the Yodo River estuary to clarify the interdiurnal variation of dominant phytoplankton species and the marine environment. And the reason of the transition was discussed.

OBSERVATION

The field observation was carried out from June 29 to July 14, 2004 for 16 days[2]. CTD was installed at the Yodo River estuary. Water depth of the site is about 12 m, and the depth of CTD around 1.5 m. The time series of water temperature, salinity, chlorophyll-*a* (chl.*a*) concentration, dissolved oxygen saturation, and light intensity were obtained every 10 minutes. The vertical profile of the same parameter at the site were obtained every 0.1 m by another CTD once a day at almost every day. Seawater was also sampled at the three depths, the sea surface, 7 m and 1 m above the bottom, and dissolved inorganic nitrogen (DIN), phosphorous (DIP) and silicate (DSi) concentrations, chl.a concentration

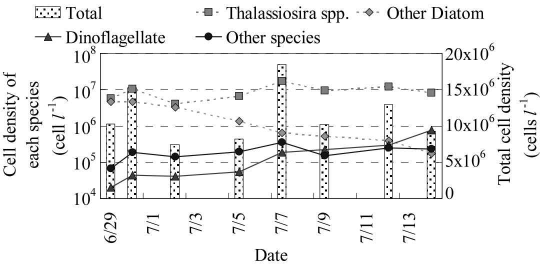

Fig. 1 The transition of the cell density in the sea surface of the site.

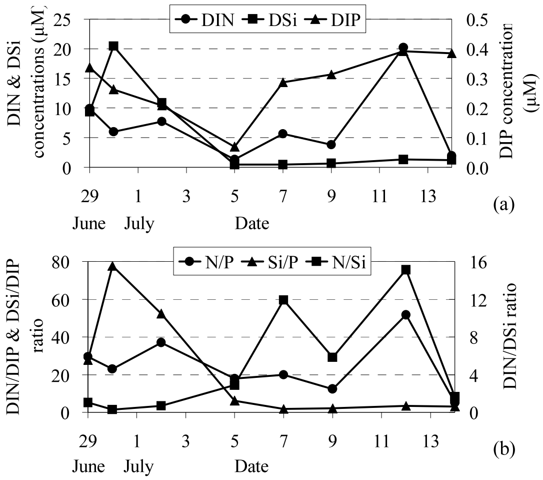

Fig. 2 The temporal variation of nutrient concentrations (a) and the ratios (b).

and cell density of phytoplankton were analysed. General meteorology parameters, air temperature, solar radiation and so on, and tidal height were recorded every minute at Fukae campus of Kobe University.

RESULTS AND DISCUSSION

Figure 1 shows the transition of the cell density of each species and total in the sea surface of the site. Variation of the total cell density agreed with chl.a concentration. *Thalassiosira spp.* dominated throughout the period. On the other hand, other diatom species decreased, and dinoflagellate and other species increased in later period. Figure 2 shows the temporal variation of nutrient concentrations and the ratios. All nutrient decreased toward July 5, but DIN and DIP concentrations recovered. DSi concentration continued the low condition after July 7. From the results based on nutrient concentrations and those mole ratio, the growth of all species was limited by DIP before 2 July. Diatom has advantage in this case because it can grow under the lower DIP concentration. After that, nutrient which limits the growth of diatom changed to DSi due to the decrease of DSi concentration. Then DIP and DIN concentration increased in favour of dinoflagellate. This is the reason of increase of dinoflagellate in the later period.

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ACKNOWLEDGMENTS

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Impact of basin soil on river water quality in salmon breeding rivers in the *Nemuro* region of *Hokkaido*

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INTRODUCTION

Salmon (*Oncorhynchus keta*) that live in the *Hokkaido-Nemuro* region spawn in the upper reaches of rivers. When the fry hatch, they descend to the Bering Sea and grow. After growing, it has the property of returning to the upper reaches of the river.

Salmon fishing has been practiced in the *Nemuro* region since the 1700s. Even today, salmon fishing is a major industry in the *Nemuro* region.

The *Nemuro* region of *Hokkaido* was a deciduous broad-leaved forest zone until the 1800s. After World War II, the region was developed as a grassland dairy area. As a result, most of the river basin became grassland. On the other hand, deciduous broadleaf forest remains around the river.

It has been pointed out that such changes in the river environment have reduced the forest rate in the river basin and increased the artificial nitrogen input. It has been pointed out that the river water quality is changing due to such changes in the river basin environment.

It has been pointed out that the concentration of nitrate nitrogen, potassium, calcium, and aluminum in river water increased due to the fact that most of the river basin became grassland. It has been pointed out that aluminum is toxic to juvenile salmon.

Therefore, the purpose of this study was to investigate the factors that affect the aluminum concentration in river water.

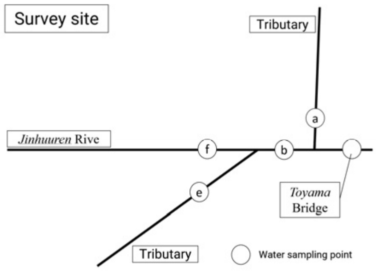

Table 1 Land use of survey site

point	Basin area ha	Basin grassland ratio %
Toyama Bridge	1543.1	60.0
a	226.7	68.1
b	1534.2	60.2
f	–	–
e	35.7	60.5

Table 2 Results of river water quality and soil chemistry

	river	soil	
	T-Al	ex-Ca	T-C
point	mg/l	mg/100gsoil	%
Toyama Bridge	71.0	–	–
a	22.5	204.8	10.0
b	123.4	–	–
f	69.2	198.7	9.4
e	214.1	150.0	10.0

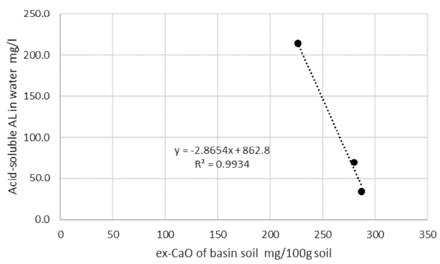

Fig. 1 Relationship between soil exchangeable calcium and total aluminum in river water

METHODS

The site where the test was conducted is near the *Toyama* Bridge on the *Jinhuuren* River (latitude 43.3 ° north, longitude 145.2 ° east). The basin area is 1543.1 ha. Every year, the *Betsukai* Fisheries Cooperative releases juvenile salmon at the *Toyama* Bridge. In May and August 2019, water was sampled at two locations on the *Toyama* Bridge and the main stream of the *Jinhuuren* River, and two tributaries, and water quality was analyzed. In October 2019, soil was collected at 35 locations in the grassland upstream of the *Toyama* Bridge, and soil chemistry was analyzed.

RESULTS AND DISCUSSION

As the exchangeable calcium content of basin grassland soil increased, the aluminum concentration in river water tended to decrease (Table 2). In addition, a negative correlation was found between soil exchangeable calcium and the aluminum concentration in river water. These things have the same results as previously reported. This suggests that the soil exchangeable calcium concentration may be a factor influencing the aluminum concentration in river water at the site where the test was conducted.

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Contamination of marine Echinoderms by radiocesium released during the Fukushima Daiichi Nuclear Power Plant accident.

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INTRODUCTION

The Great East Japan Earthquake and tsunami that struck on 11 March 2011 caused a severe accident at Fukushima Dai-ichi Nuclear Power Plant (FDNPP), owned by the Tokyo Electric Power Company (TEPCO)[1]. The total amount of ^{137}Cs directly discharged into the sea was estimated to be approximately 3.5 PBq[2]. Radioactive cesium was detected from marine biota collected in the waters off Fukushima Prefecture and its vicinity immediately after the FDNPP accident[3]. Our study reports on regional dispersion trends of radiocesium in marine echinoderms caught from coasts of Fukushima Prefecture and ecological half-lives (T_{eco}) in selected species. The purpose of this study was to determine how the radiocesium contamination of echinoderms from the FDNPP accident changed over time. To achieve this, T_{eco} of radioactive cesium in echinoderms were investigated over the period from 426–2726 days after the accident.

METHODS

Six species (*Mesocentrotus nudus, Echinocardium cordatum, Luidia quinarian, Distolasterias nipon, Astrocladus coniferus and*

Asterias amurensis) of Echinoderm samples were collected from three locations (Yotsukura, Ena and Hirono Thermal Power Plant) in Fukushima near FDNPP. After collecting samples, brought to the laboratory and processed. Then Germanium Semiconductor spectrometer (GMX Series Coaxial HP Ge Detector) was used to measure the radiocesium in echinoderms. The measurement time was 7200 sec for each sample. Concentrations of radiocesium in different species of echinoderms were measured and then the T_{eco} values of radiocesium were calculated. The following formulas were used to calculate T_{eco} of radiocesium in echinoderms.

$$1/\ T_{eco} = 1/\ T_{eff\ (in\ situ)} - 1/T_{p}$$

Where, T_{eff} and T_p denote effective half-life and physical half-life of radiocesium, respectively.

RESULTS AND DISCUSSION

As shown in Fig. 1, the ^{137}Cs and ^{134}Cs concentrations (converted to log scale) in echinoderm samples tended to decrease over time (426–1175 days after the FDNPP accident). Both radionuclides (^{137}Cs and ^{134}Cs) concentrations were much higher in *E. cordatum* (318 and 165 Bq/kg-ww, respectively) at Yotsukura station approximately 500 days after the FDNPP accident. In contrary, radiocesium concentrations were much lower in *A. coniferus* (4.25 Bq/kg-WW) and *L. quinaria* (4.45 Bq/kg-WW) at Yotsukura station.

In the case of Ena station, both of ^{137}Cs and ^{134}Cs concentrations were higher in *E. cordatum* (289 Bq/kg-WW and 161 Bq/kg-WW, respectively) and lower in *M. nudus* (respectively, 3.55 Bq/kg-WW and 2.08 Bq/kg-WW). At Hirono Thermal Power Plant station, ^{137}Cs concentrations were much higher in *M. nudus* (63.7 Bq/kg-WW) and lower concentrations were observed in *A. amurensis* (4.21 Bq/kg-WW).

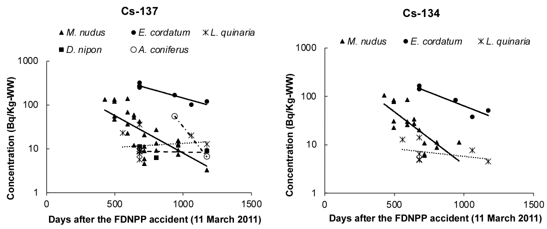

Fig. 1 Spatial and temporal changes in the ^{137}Cs and ^{134}Cs concentrations in different echinoderms collected from Yotsukura station in Fukushima Prefecture after the FDNPP accident. Solid and dashed lines represent statistically significant and insignificant regression slopes, respectively. Data below the detection limit are excluded.

Ecological half-lives of ^{137}Cs (T_{eco}) in different echinoderms were also estimated using those collected samples from three areas. T_{eco} of ^{137}Cs in *M. nudus* and *E. cordatum* were 176 days and 358 days, respectively, and T_{eco} values of ^{134}Cs in *M. nudus* and *E. cordatum* were respectively 170 days and 333 days at Yotsukura station. At Ena station, T_{eco} of ^{137}Cs and ^{134}Cs in *M. nudus* were 358 days and 136 days respectively.

CONCLUSION

It is concluded that variations of spatial environment and food habit may affect on the ecological half-life (T_{eco}) of radiocesium but the mechanism is not clear. So, it would be useful to carry out further analysis of concentration factors and food uptake amounts of various species to improve our understanding of how echinoderms ingest and eliminates radioactive cesium.

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Shell pigments in cultured abalone

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INTRODUCTION

Pigments in the algae upon which abalone feed are thought to color the abalone shell, so the food on which abalone feed can be deduced from analysis of the pigments present in the shell. In this study, pigments were analyzed in the shells of cultured Ezo abalone (*Haliotis discus hannai*), whose feeding environment was known during rearing, to investigate the relationship between the pigment composition detected and the food on which the abalone had fed.

METHODS

The experiments were performed on *H. discus hannai* of mean shell length 30 mm. They were reared firstly on nursery boards covered predominantly by the green alga *Ulvella lens*, and then by feeding with artificial feed. These shells had a characteristic green colour (referred to in the industry as 'green mark') derived from the artificial feed. In preparation for pigment analysis, any matter adhering to the shells was removed by brushing the surface. The shells were then ground in a blender (Wonder blender, Osaka Chemical, Osaka). Lipid-soluble and water-soluble pigments were extracted from the ground shells and analysed by high performance liquid chromatography (HPLC; Shimadzu, Kyoto). Lipid-soluble pigments, such as chlorophyll and xanthophyll, were analysed by the method of ZATATA *et al.* (2000); and water-soluble pigments, such as phycobiliprotein, by the method of ZOLLA *et al.* (1999).

RESULTS AND DISCUSSION

Many pigments detected in the shells were also detected in abalone feed. The major pigments detected in the shells were 19'-butanoyloxyfucoxanthin (But), Chlorophyll *a* (Chl *a*), Chlorophyll *b* (Chl *b*), β-carotene (β -Car), Fucoxanthin (Fuco), 9'-cis-neoxanthin (Neo), Siphonaxanthin (Siphx), Violaxanthin (Viola), and Zeaxanthin (Zea).

Chl *a* and β-Car are pigments found naturally in most plants, including green algae. The nursery boards (to which *U. lens* was attached) contained (in addition to Chl *a* and β-car) Chl *b*, Neo, Siphx, Viola, and also Antheraxanthin (Anthera), Lutein (Lut) and Prasinoxanthin (Proasino). These pigments are contained in green algae. It is considered that Neo, Siphx, and Viola detected in the shells were derived from the pigments of *U. lens*. Viola, Anthera, and Zea are pigments related to protecting plants from photooxidative damage (HAVAUX and NIYOGI 1999), changing from Viola to Anthera to Zea, or Zea to Anthera to Viola, depending on the light conditions. Therefore, it is deduced that Zea detected in the shells was derived from *U. lens*.

From the artificial feed fed to the abalone, derivatives of both Chl *a* and Chl *c* were detected and are considered to be degradation products arising during the thermal drying process prior to measurement (See, for example, Nosan Corporation, https://www.nosan.co.jp/business/fodder/progress.htm). In addition to these Chl derivatives, Fuco and Lut were detected and it is considered that Fuco detected in the shell is derived from pigments in the artificial feed.

In addition to Chl *a* and β-car, Chlorophyll c_2, Chlorophyll c_1, Fuco, and Diadinoxanthin were detected in the culture seawater. These are pigments contained in Bacillariophyceae (diatoms). Alloxanthin, present in Cryptophyta, was also detected in the seawater, suggesting the presence of both diatoms and Cryptophyta in the ambient seawater. Diatoms (which are planktonic and unable to swim) are common in seabed deposits. Therefore, some of the Fuco detected in the seawater may be derived from diatoms deposited to the bottom of water tank and attached to the nursery boards.

Prasino from the nursery boards, Lut from the nursery boards and in artificial feed, and Chl *a* and Chl *c* derivatives found in artificial feed were not detected in the she lls It may be that the latter derivatives were not detected as pigments in the shells because of further degradation. Prasino and Lut were found in lower concentrations than those of chlorophyll pigments, so they may have been beyond the level of detection in the shells, or for some reason do not accumulate in the shell.

The maximum absorption wavelengths of the water-soluble pigments analysed by HPLC were in the range 550–610 nm, so they were considered to be phycocyanin and phycoerythrin-like pigments from the spectrum. These pigments were retained by cyanobacteria and red algae and appear to be derived from the artificial feed.

Overall, it is considered that these results confirm the hypothesis that the "green mark" of abalone shells is indeed derived from coloured pigments in the algal feed, which include various lipid-soluble and water-soluble pigments.

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Effect of naphthalene on phytoplankton

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INTRODUCTION

Chemical substances, such as aromatic hydrocarbons, are known to become more toxic to aquatic organisms when their structure is altered by light (mainly ultraviolet light) and their water solubility increases. This phenomenon is called phototoxicity. While photosynthetic organisms are known to have various photoprotective mechanisms, such as the xanthophyll cycle, to protect them from photooxidative damage in response to excessive light exposure, the combination of high light intensity and chemicals may affect the toxicity or the response of phytoplankton. In this study, three phytoplankton species of differing pigment composition were exposed to naphthalene under different light conditions and investigated for effects on growth and the xanthophyll cycle.

METHODS

Three concentrations (0.05, 0.5, and 5.0 ppm) of naphthalene were administered to three species of phytoplankton: the diatom *Phaeodactylum tricornutum* (Phylum Bacillariophyta, Class Bacillariophyceae), *Pycnococcus provasoli* (Phylum Chlorophyta, Class Prasinophyceae), and *Phormidium* sp. (Phylum Cyanobacteria, Family Oscillatoriaceae). Control preparations contained no naphthalene. All preparations were exposed to white (200 μmol m^{-2} s^{-1}), red (200 μmol m^{-2} s^{-1}, wavelength 625 nm), green (200 μmol m^{-2} s^{-1}, wavelength 530 nm), or intense white light (2000 μmol m^{-2} s^{-1}). Growth was measured by Chl *a* analysis with high performance liquid chromatography (HPLC; Shimadzu, Kyoto, using a short column) every 24 h for 72 h (14 light :10 dark cycle).

To test for short term reactions, naphthalene (15 ppm to *Phaeodactylum*, and 30 ppm to *Pycnococcus*) was administered under dark conditions, followed rapidly by exposure to white light (200 μmol m^{-2} s^{-1}), or intense white light (2000 μmol m^{-2} s^{-1}). Control preparations contained no naphthalene. After 0 min (dark), 5 min, 15 min, 30 min, and 1 h, changes were measured in the composition of pigments involved in the xanthophyll cycle. Pigment profiles were measured by HPLC (Zapata *et al.* 2000).

RESULTS AND DISCUSSION

Phytoplankton growth was inhibited with increasing naphthalene concentration under all light conditions. Growth of the diatom and the prasinophyte showed the largest inhibition under strong white light, while that of the cyanobacteria was most strongly inhibited under red light. The wavelengths affecting these three phytoplankton species differed presumably because of their differing pigment profiles. Unlike diatoms and prasinophytes, cyanobacteria contain phycocyanin, which has a wavelength of maximum absorption in the red (620 nm): this may explain the observed susceptibility to damage by red light in *Phormidium* sp.

The phytoplankton xanthophyll cycle responded fastest where naphthalene addition and intense light coincided.

CONCLUSION

Previous studies have focussed on structural changes to chemical substances during phytoplankton toxicity tests. However, the experiments conducted here focussed on photodamage within the phytoplankton itself. The results showed clearly that the combined effects of photodamage caused by strong light in the presence of a chemical substance increased the toxic effect. In addition, because different taxonomic groups of phytoplankton possess different pigments, the wavelength of maximum photodamage differed accordingly.

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Length-weight relationships for 17 fish species in the Luanhe River Estuary, Bohai Sea, northern China

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INTRODUCTION

Estuarine areas are extremely important areas in the life cycle of some fish species. These ecosystems provide food, shelter, and spawning grounds for varieties of marine organisms. The Luanhe River is a sediment-laden water course on the northern shore of Bohai Bay, China[1]. The estuary of the Luanhe River is a famous fishing ground and nursery area for marine organisms within Bohai Bay. This area is recognized as an important feeding and breeding location for migratory species[2–5].

Length-weight regressions (LWR) are an important tool for the proper exploitation and management of fish populations[6]. Length and weight data for fish are needed to estimate growth rates, age structure, and other population dynamics[7]. This information is commonly used in the ecosystem modeling approach[8] to calculate the production to biomass ratio (P/B) of different functional groups, taking into account that for more precise weight estimates it is advisable to make use of local values. In addition, LWR allow life history and morphological comparisons between different fish species, or between fish populations from different habitats and/or regions[9]. Biological scientists often estimate fish weight in the field using LWR[10].

Prior to this study there was LWR data available for fish species in the Luanhe River Estuary and this study provides the first LWR references for 17 fish species from this area. This study aimed to provide information that could be used for the management of the Luanhe River fishery grounds. The LWR data will be made available through the Fishbase Database[11], so that they

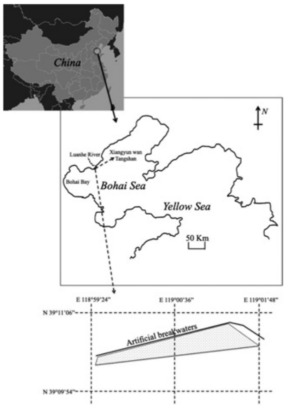

Fig. 1 Schematic map showing the survey area in the northernmost part of Bohai Bay, the Bohai Sea, China.

can be used by other researchers.

METHODS

This study was carried out in the Luanhe River Estuary between longitude E 118° 59'24"-119° 01'48" and latitude N 39° 11'06"-39° 09'54" (Fig. 1). Samples were collected at monthly intervals from December 2016 to August 2017 and at bimonthly intervals from July 2016 to November 2017. The fishing gear used for sampling included a crab pot, trammel net of various inner mesh sizes, and a bottom trawl. The standard length (L) of each specimen was measured to the nearest 0.1 cm using a 30 cm ruler. Fish body weight for all specimens was weighed to the nearest 0.01 g using an electric balance (CR-5000WP, Custom, Japan).

RESULTS AND DISCUSSION

A total of 7354 individuals belonging to 17 species (11 families) were recorded in this study. Linear regressions of log transformed data were highly significant ($P < 0.05$) for all analyzed species. The most abundant species sampled was *Chaeturichthys stigmatias* (N = 2483). The best represented family was Gobiidae with 4 species recorded.

The coefficients of determination (R^2) ranged from 0.95 to 1.00 for *Mugil cephalus, Sebastes schlegelii, Engraulis japonicus, Paralichthys olivaceus, Tridentiger barbatus, Sardinella zunasi, Acanthogobius ommaturus, Thrissa kammalensis, Hexagrammos otakii, Chaeturichthys stigmatias, Platycephalus indicus.*

LWR slope (b) values ranged from 2.572 for *Acanthogobius ommaturus* to 3.6581 for *Engraulis japonicus*. The median value was 3.114 for *Platycephalus indicus*, although 50% of the values ranged from 2.9451 to 3.2965 for the complete data set.

CONCLUSION

The data collected during this study represents an important contribution of base line data on the LWR of a number of fish species that were previously unavailable. It is important to point out that these LWR should be strictly limited to the length ranges used in the estimation of the linear regression parameters[14]. The results obtained in the current study will contribute to the knowledge of fish populations in the important Luanhe River Estuary and also assist fisheries scientists and managers in the future.

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Shipboard observations of the physical marine environment at the mouth of Otsuchi -Funakoshi Bay, Sanriku Coast

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INTRODUCTION

Otsuchi Bay is one of ria bays of Sanriku Coast, Pacific coast ranging 600 km in the northern Japan, and is known for intrusion of cold bottom water from the open ocean[1]. It is also known that baroclinic current structures composed of inflow at lower (upper) layer and outflow at upper (lower) layer occur at flood (ebb) tide[2]. Nutrients and dissolved oxygen that are necessary for active aquaculture in the bay are maintained by the inflow of bottom water from open ocean. We surveyed the physical marine environment, that is, water property and current, to reveal the unknown movement of open-ocean water between the bay and the open ocean.

METHODS

We conducted shipboard observations at the mouth of both Otsuchi and Funakoshi Bays by R/V Yayoi (12 tonnage) of International Coastal Research Center, AORI, on 20 July 2015, 12 July 2016, and 29 June 2018 (Fig. 1). In every observation, we operated towed ADCP (V-fin) for sufficient measurement of the bottom currents[3] (Photo 1) as well as CTD and shipboard ADCP of R/V Yayoi. Tidal phases at observations were flood tide in 2015, ebb tide in 2016, low tide in 2018.

RESULTS AND DISCUSSION

Eastward velocity component (u) at the thick

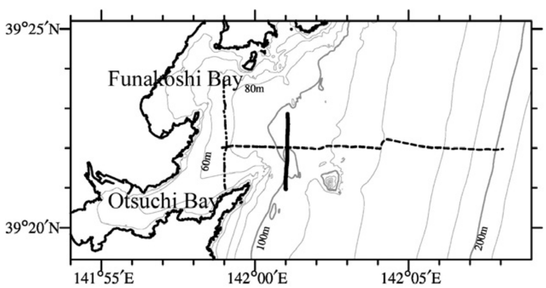

Fig. 1 Observation area and V-fin lines in 2015 (thick line), 2016 (broken line), 2018 (dot line).

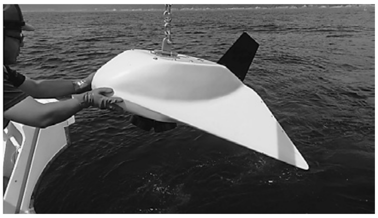

Photo 1. V-fin at the start of towing.

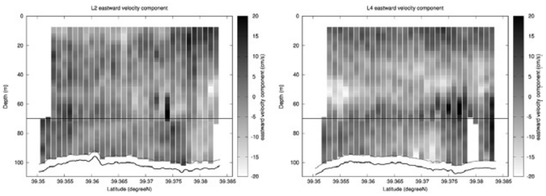

Fig. 2 Eastward velocity component (u) sections at the first half (left) and just before the end (right) of flood tide on 30 July 2015. U above and below 70 m depth are measured by shipboard ADCP and V-fin, respectively.

line of Fig. 1 in 2015 shows inflow below 30 m depth and outflow in the upper particularly at the north at flood tide. Before end of flood tide, the inflow below 60 m depth weakens. It implies the tidal change has time lag between above and below 60 m depth. ADCP results at the dot line of Fig. 1 in 2018 was too complex to interpret due to low tide as well as low echo intensity that implies low concentration of tiny particles in water (not shown).

We tried east-west observation across isobaths towing V-fin along the broken line of Fig. 1 in 2016 and succeeded in measuring offshore bottom current over the continental shelf during ebb tide (Fig. 3).

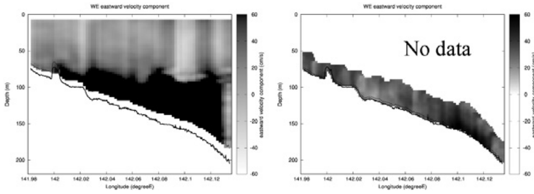

Fig. 3 Eastward velocity component (u) sections during ebb tide on 12 July 2016. Left and right panels are from shipboard ADCP and V-fin, respectively.

CONCLUSION

We confirmed the circulation pattern of the outflow and inflow in the lower layer at ebb and flood tides, respectively. However, the circulation pattern is more complex below 60 m depth at the bay mouth probably due to the time lag between the bottom and the middle depth.

We plan further accumulation of water-property and current data while considering the possibility of mooring observation for investigating temporal variability.

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Changes in thyroxine (T_4) concentrations in larval and juvenile marbled flounder *Pseudopleuronectes yokohamae*

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INTRODUCTION

The metamorphosis of flatfish is regulated by thyroid hormone (INUI *et al.*, 1994). Thyroid hormone levels rise during the climax of metamorphosis (TAGAWA *et al.*, 1990; DE JESUS *et al.*, 1991). The morphological development of marbled flounder *Pseudopleuronectes yokohamae* continues after the climax stage of metamorphosis (G-H Stage), and the K stage, where the lateral line is identified, occurs 70 days post hatching (dph) (FUKUHARA, 1988). The levels of thyroxine (T_4), one of the thyroid hormones, fluctuates notably during the metamorphosis of flatfish (TAGAWA *et al.*, 1990). There are limited reports of changes in T_4 levels during the juvenile stage since the post-climax of flatfish. This study investigates the dynamics of T_4 from the larval to juvenile stages of marbled flounders.

METHODS

Marbled flounder artificially fertilized and reared between 2015 and 2019 (except 2017) at the Seed Production Res. Lab., Futtsu Sea Farming Section, Chiba Prefectural Fisheries Research Center, were used as experimental animals. In 2015, we sampled fish at different developmental stages: F stage (24 dph; pelagic larva), G-H stage (24 dph), I stage (35 dph), J stage (48 dph), and K stage (122 dph) based on FUKUHARA (1988). After 2016, samples were differentiated based on dph at intervals of 10 days for 20–70 dph and 10–30 days for 80–120 dph. The total number of specimens for four years were 30, 83, 84, 82, respectively. Whole-body T_4 concentrations in larvae and juveniles were measured and analyzed at the Nikko Field Station, Fisheries Technology Institute. Frozen fish were minced and extracted mainly following the method (KOBUKE *et al.*, 1987; TAGAWA and HIRANO, 1987) and the T_4 concentration was measured by ELISA.

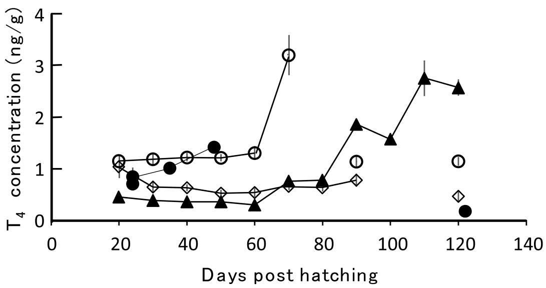

Fig. 1 Changes in the mean whole-body T_4 concentrations from larva to juvenile of marbled flounder *Pseudopleuronectes yokohamae*. (●, 2015; ○, 2016; ◇, 2018; ▲, 2019). Error bars indicate SEM.

RESULTS AND DISCUSSION

The changes in mean whole-body T_4 concentrations during the larval and juvenile stages are shown in Fig. 1. In 2015, the mean T_4 concentrations at stages F, G-H, I, J, and K were 0.71, 0.85, 1.01, 1.42, and 0.18 ng/g, respectively. The maximum T_4 concentration was observed in stage J. After 2016, the T_4 concentrations showed a considerable increase during the juvenile stage, increasing the most at 70 dph (2016) and 110 dph (2019) between 20 and 120 dph. Although the year-to-year fluctuation was large (Fig. 1), the maximum T_4 concentration in marbled flounders was observed after 70 dph, corresponding to the late juvenile stage (K stage) (FUKUHARA, 1988). Based on the T_4 concentration of the marbled flounder up to 45 dph in a study by TAGAWA and KIMURA (1991), it was inferred that the T_4 concentration peaked at the post-metamorphosis stage. In our study, T_4 concentrations increased in the post-metamorphic J stage but not in the metamorphosis completion stage (stage I).

In marbled flounder seed production, caudal fin loss by nipping is observed during the juvenile stage. Plasma T_4 levels of masu salmon are negatively correlated with the frequency of nipping behavior, and T_4- treated masu salmon, brown trout and steelhead trout show a reduction in nipping behavior (HUTCHISON and IWATA, 1998). It is likely that nipping behavior increases when the T_4 concentration decreases after it peaks, which was reported in a previous study on masu salmon (HUTCHISON and IWATA, 1997). Future studies should investigate when nipping behavior increases, and whether the frequency of nipping changes after T_4 treatment.

CONCLUSION

In this study, we investigated changes in thyroxine (T_4), a thyroid hormone, from the larval to juvenile stages of the marbled flounder. We found that the T_4 concentration from 20 days post-hatching (dph) (larval stage) to approximately 120 dph (juvenile stage) substantially increased in the juvenile stage. There was a local maximum T_4 concentration in the late developmental stage of juveniles. We also found considerable inter-annual variation in T_4 concentrations during this study .

Eustress (Good Stress) and Distress (Bad Stress) in Fish

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Keywords: thermal stressor, oxidative stress, eustress, distress, fish

INTRODUCTION

The production of farmed fish has increased due to the worldwide decline of ocean fisheries stocks. It is known that almost half of the world's fishery production is currently based on aquaculture[1]. Thus, appropriate monitoring and evaluation methods for impact and risk of aquaculture on the environment need to be considered[1, 2]. Fish are exposed to various local and global environmental stressors, such as pollutants and acute changes in temperature, and the chances of succumbing to infectious diseases may be increased as a result[3,4]. Accordingly, the stress induced by environmental stimuli in fish is thought to influence their fitness, productivity, and health. In the present study, we examined the changing patterns of stress and growth-related biomarkers in response to a thermal stress in tropical rabbitfish *Siganus guttatus*. The results on rabbitfish were compared with those obtained previously in temperate coho salmon *Oncorhynchus kisutch*[5].

METHODS

Animal experiment: The fish (approx. body weight, 43 g) which were reared at the facility of Sesoko station, TBRC, Univ. Ryukyus, were divided into groups. One group was undisturbed used as a control; the others were exposed to heat shock (+ 10℃ for 2 h). Measurements: Lipid peroxides (LPO) were determined as thiobarbituric acid reactive substances. Total glutathione (GSH) levels were measured by a glutathione reductase-recycling method. Heat shock protein 70 (HSP70) levels were determined by immunoblotting. The levels of growth hormone (*gh*) and insulin-like growth factor (*igf1*) mRNA expressions in the tissues were determined by real-time quantitative PCR (qPCR).

RESULTS AND DISCUSSION

Although the plasma LPO levels in rabbitfish were almost the same for all sampling periods, they increased significantly in coho salmon at both 17 h and 48 h post stress[5]. In rabbitfish, GSH decreased gradually and reached its lowest value at 48 h post stress. On the other hand, GSH in coho salmon decreased tentatively at 2 h post stress after which it then increased[5]. HSP70 expression in the liver of both fish species increased at about 17 h post stress[5].

Pituitary *gh* mRNA expression in rabbitfish gradually increased following heat stress treatment. On the other hand, *gh* mRNA expression in coho salmon pituitary increased at 2 h post stress but returned to control levels at 17 h and 48 h post stress. Hepatic *igf1* mRNA in rabbitfish increased, reaching its highest value at 17 h post stress before decreasing. On the other hand, *igf1* mRNA in coho salmon liver gradually decreased following thermal stress treatment.

The level of stress-related markers in coho salmon have been changed by stress at initial stage, compared with rabbitfish. These results suggest that temperate fish species such as coho salmon is subject to thermal stress. The changing patterns of markers also suggest that severe thermal stressors can induce oxidative stress in fish. It is known that oxidative stress leads to oxidative damage *in vivo*. However, a moderate level of oxidative stress might modulate important cellular functions[6]. The possibilities of using eustress (good stress) and avoiding distress (bad stress) for animals has been discussed[7,8]. When the organism is exposed to stimuli that induce distress, a functional physiological state is no longer maintained. However, when the organism is exposed to stimuli that induce eustress, it enters a qualitatively different physiological state, but still maintains homeostasis[8]. Hence, manipulation of appropriate stressor such as moderate thermal treatment and handling stress might be useful to control and improve the health of fish as a eustress[9]. Further studies are needed to reveal the relationships between the oxidative stress, fitness, and health of farmed fish.

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Characteristics of fish species distribution revealed by the surveys of vertical longline and echosounder in Hachirigase Sea Hill, Japan Sea

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INTRODUCTION

The Hachirigase Sea Hill off Mishima Island, Japan, is located in the continental shelf of Japan Sea and is an important spawning and nursery ground to support coastal fisheries. However, fishers concern unplanned/illegal fishing activities are devastating fish resources. Thus, accurate estimates of fisheries resources are needed to use them as a sustainable way. The undulating reefs of Hachirigase Sea Hill prevent us from fish stock surveys using trawl. We applied an acoustic monitoring method to assess the distribution and stocks of fish in this area. This method requires to identify the species of the fishes on the echogram by in situ survey for accurate estimation of the fish abundance. This study examines characteristics of fish species distribution using vertical longline sampling to identify fish species corresponding to fish echoes observed in the Hachirigase Sea Hill.

METHODS

On 21 and 22 June 2006, we conducted vertical longline sampling of fish in Hachirigase Sea Hill on board a fishing boat (6.08 tons). We used the 50 kHz echosounder (FCV-291, Furuno Electric Co., Ltd.) equipped with the ship to measure fish echoes and depths. We set 8 sampling stations over the hill and allocated 10 minutes to catch fish with a vertical longline at a station. If a fish was caught, the sampling time for this station was extended by 10 minutes each time until no more fish were caught. In vertical longline fishing, fish were caught by hanging a line by hand, without the use of floats and fishing rods. To investigate the fish species distributions by depth, we attached 10 branch lines (length: 0.375 m; diameter: 0.285 mm; load capacity: 5 kg) to the main line (diameter: 0.375 mm) at intervals of 1.5 m. A 187.5 g weight was attached to the end of the main line. Circle hooks (called as "nemuri-bari" or "mutsu-bari" in Japan) with a curved part (gap: 7 mm; height: 16 mm) were used as fishing hooks attached to the branch lines. Fishing lures or boiled mysids were used as fishing baits. Catch per unit effort (CPUE: inds/10-minute longlining) of vertical longline fishing was defined as the number of catches divided by the number of sampling times.

RESULTS AND DISCUSSION

We caught 7 species at 7 stations out of a total of 8 sampling stations and in 18 times out of a total of 27 sampling times, resulting in 1.15 CPUE. The ratios of the fish species in CPUE were 43.7 % of threeline grunt (*Parapristipoma trilineatum*), 37.0% of red lizard fish (*Synodus ulae*) and less than 5% of species, cherry bass (*Sacura margaritacea*), bottom perch (*Apogon semilineatus*), filefish (*Thamnaconus modestus*), John dory (*Zeus faber*) and rockfish (*Sebastes inermis*), respectively. Fork length of the grunt (n = 13) caught at six sampling stations (rocky area) of Stn. 2 to Stn. 7 (less than 60 m in bottom depth) were 28.3 ± 4.7 cm (mean ± SD) and body weight were 440.8 ± 191.9 g. Fork Length of red lizard fishes (n = 12) at five stations (rocky and sandy area) of Stn. 4 to Stn. 8 were 17.0 ± 2.5 cm and body weigh were 47.5 ± 31.0 g. For the grunts and red lizard fishes, the sampling bottom depths were 43.3 ± 19.3 m and 55.5 ± 10.0 m, respectively. There was no significant difference in the average bottom depth of the sampling areas where these fishes caught (Mann-Whitney U, $P > 0.05$). Grunts, benthopelagic fish, were caught in the layer between the sea bottom and 9 m above the sea bottom, whereas red lizard fishes, demersal fish, were caught in the narrower layer only between the sea bottom and 3 m above the sea bottom. The mean heights from the sea bottom where grunts (n = 13) and red lizard fishes (n = 12) were caught were 5.5 ± 2.0 m and 2.0 ± 0.7 m, respectively. There was a significant difference in the average height of the two fish species (Mann-Whitney U, $P < 0.01$).

CONCLUSION

Our surveys revealed that the dominant species distributed below the height of 9 m above the sea bottom in the rocky area shallower than a depth of 60 m, where distributions of fish echo was observed in Hachirigase Sea Hill, was the grunt, which the most important commercial fish there. From the above, it is expected that the method, which assigns fish species to the fish echoes according to the standard set based on the ratio of CPUE by height, will lead to improvement in the accuracy of fish abundance estimation. This study shows that the combination of echosounder and vertical longline is effective in determining the abundance of fish in the sea hill where trawl surveys are difficult.

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New technologies to improve bycatchmitigation in industrial fisheries

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INTRODUCTION

For many years, tremendous effort has been dedicated to developing new industrial tuna fisheries while their adverse impacts on threatened marine species has received relatively little attention. In tuna fisheries bycatch is its major anthropogenic threat to marine megafauna in general, particularly sharks. Research on the development of gear technology for bycatch reduction and potential mitigation measures helped tuna Regional Fisheries Management Organizations adopt bycatch reduction management measures. Despite the urgency in investigating and implementing mitigation measures in fisheries, there are still a number of burgeoning questions inherent in the process: (1) Do we know enough about the capture process? (2) How to better assess the efficacy of mitigation measures in practice? (3) Why mitigation measures are not always transferable? (4) What should we study to innovate effective mitigation measures? and (5) Which tools should we develop in the future? This study presents a history of the development of the techniques and facilities for studying tuna and marine megafauna behaviour and reviews research on the development of mitigation measures for pelagic longline and tropical purse seine, and proposes new perspectives integrating recent technological breakthroughs based on investigations on bycatch behaviours especially sharks and fishing gear dynamics. Lastly, this study highlights new discoveries on fish sentience and their other capabilities recently revealed.

METHODS

By reviewing the literature on the development of mitigation measures it appears that effective methods or promising concepts to avoid capture of unwanted species or/and methods to reduce bycatch mortality arose from four main types of approach: a) shark biology and sensory physiology, b) aggregating behaviour of various species under natural or man- made FADs, c) fishing gear behaviour and marine creatures interactions during the fishing process and d) habitat use.

RESULTS AND DISCUSSION

What is missing in our understanding of fish capture and escape processes?

Basically, the efficiency of a measure is evaluated based on data collected by scientists. However, various interactions with fishing gears, different from capture, are generally not observed and remain cryptic. Moreover, no study has tested the responses of sharks and other prey using the same experimental procedures. In other words, results of the experiments were never fully duplicated or extended on other species. This could be the reason why the transfer of a successful mitigation measure from one region to another did not always occur. Understanding species' behaviours especially during capture is essential for formulating further bycatch reduction approaches and to assess the effectiveness of mitigation measures.

New tools to investigate bycatch behaviour and fishing gear dynamics

- *Longline and mini AUVs: platform of observation*

Instrumented pelagic longline gear could be used to investigate specific animal behaviours, to evaluate a suite of prognostic environmental and operational factors determining the effectiveness of candidate mitigation measures. Furthermore, it requires designing a comprehensive system of "monitored" fishing gear to assess gear dynamics while fishing and the effectiveness of candidate mitigation measures during specific experiments (e.g., hook tests of a different shape or size, bait test, etc…).

- *Visual inspection of DFADs and in the purse seine*

The mini AUV could be used to approach and inspect deployed DFADs and to observe at different spatial and temporal scales the occurrence, density and location of pelagic organisms and to monitor the free swimming schools of pelagic species during purse seining operation. Visual inspection could be done using its embedded camera but multiple cameras can be added to record the whole environment. Sonar could be used to assist the drone to track tunas (large swim bladder) to analyze their movements near the DFAD.

- *Computer simulation and analysis of fishing gear geometry and dynamics*

The recent development of numerical simulations of the three-dimensional dynamics of fishing nets has brought new insights on purse seine capture processes and perspectives for the development of technical mitigation measures.

CONCLUSION

All the technological innovations proposed will help scientists exploring the mechanisms of interactions of all animals with fishing gears, the causes of differing responses among individuals and species, allowing an understanding of potential adverse effects of the fishing gear on unwanted individuals and how these could be reduced. In the light of the results, simplified technological transfers to fishers could be envisaged giving them the ability to monitor their fishing operations and to make adjustments to maximise catch and avoid or reduce mortality of bycatch.

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資　料

第61巻第3・4号掲載欧文論文の和文要旨

小松輝久：日仏海洋学会創立60周年記念シンポジウム："海洋学における日仏協力の60年"

本稿では，1960年に設立された日仏海洋学会の創立60周年を記念したシンポジウムについて紹介する。COVID-19のパンデミックにより，60周年記念シンポジウムは2021年に延期され，ウェブを通じてバーチャルに開催された。シンポジウムでは，海洋学・水産学分野における日仏の歴史的な交流を振り返り，未来を展望した。第1部では，1958年のフランスの深海調査潜水艇（バチスカーフ）FNRS III の日本訪問，1960年代の日本産カキ稚貝のフランスへの輸出，日仏海洋開発小委員会の設立と活動など，両国の科学・技術の交流と協力の重要な場面が紹介された。また，今後の協力計画である，日仏の海洋対話で決まったニューカレドニア周辺の海山の調査協力や，日仏の知識やノウハウを交換する「自然と文化プロジェクト」などが紹介された。第2部では，日仏海洋学会の創立60周年を記念して，海洋学・水産学に関連する学会や組織からの祝辞が紹介された。日仏海洋学会は，日仏間の海洋・水産学の交流に貢献された方々を表彰した。仏日海洋学会副会長からは，日仏海洋学会への祝辞の後，日仏海洋学会創立60周年の記念メダルが小松輝久会長に手渡された。（〒108-8477　東京都港区港南4-5-7 東京海洋大学海洋資源環境学部海洋環境科学科環境測定学研究室内 日仏海洋学会事務所　*連絡先著者：小松輝久　Tel/FAX：+81-3-5463-0467　E-mail: cymodocea@gmail.com）

小松輝久[1, 2]*・Hubert-Jean CECCALDI[3]：なぜバチスカーフ FNRS III は日本に来たか。海洋学における日仏協力の始まり

本稿では，1958年5月に潜水艇 FNRS III がなぜ日本に来航し，日仏の科学者が共に日本海溝を調査したのか，その概要を紹介する。1953年にトゥーロンで進水した FNRS III は，当時世界で最も先進的な潜水艇であった。日本で深海調査を行っていた東京水産大学の佐々木忠義教授は，1956年1月から7ヶ月間，パリ海洋研究所に滞在した。そこで，バチスカーフ・カリプソ運航委員会委員長であるパリ国立自然史博物館・海洋研究所のルイ・ファージュ教授と出会うことになる。佐々木教授の説得の結果，ファージュ教授はこの潜水艇を日本へ送ることを約束した。佐々木教授は日本の他の団体と共に，FNRS III を日本で受け入れる準備を行った。1958年5月に日本に到着した潜水艇は，日本海溝とその周辺に潜降し，貴重な成果を上げた。これを契機として，1960年4月，海洋学および水産学の分野における日仏協力の発展と深化を目的に，日仏海洋学会（SFJO）が日本に設立された。以来，SFJO は，海洋学および水産学の分野における日仏間の協力関係を促進し，交流を深めている。

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小池康之[1)]*・小松輝久[1, 2)]：フランスにおけるカキの大量斃死と三陸産種ガキのフランスへの輸出を契機とした，水産学分野における日仏交流

1960年に日仏海洋学会（SFJO）が設立され，フランスとの海洋学に関する協力が始まった。1960年代後半，フランスで養殖されていたカキが病気で大量に死亡し，カキ養殖の存続が危ぶまれる事態になった。そこでフランスの研究者は，SFJO 会員である東北大学の今井丈夫教授に，病気に強い三陸カキをフランスに輸出できないか打診した。今井教授を中心とする研究チームは，検疫や病理検査を行い，三陸産のシングルシードのカキ1万トンをフランスに輸出することに成功した。この輸出により，フランスのカキ養殖業は危機を脱した。その後，

日仏協力は水産学にも及び，1984 年に仏日海洋学会が設立された。2011 年 3 月 11 日，三陸沖で大津波が発生し，養殖施設が壊滅的な被害を受けた。その直後，仏日海洋学会，フランスの牡蠣養殖業者，その他のフランスの団体から，三陸のカキ養殖業者によるカキ稚貝提供のお礼として，彼らを支援したいと日仏海洋学会に連絡があった。これらの団体と日仏海洋学会は，三陸の県水産試験場や県漁協に顕微鏡やプランクトンネットなど，カキの種苗採集に不可欠な機材を寄贈した。本稿では，このような水産科学に関する日仏の交流について概説する。

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戸谷 玄[1)]*：日仏海洋開発専門部会の発足とその後

本稿では，1974 年に締結された日仏科学技術協力協定に基づき設置された「日仏海洋開発専門部会」の創設とその後の活動について概説する。1974 年 7 月，日仏科学技術協力合同委員会において，フランス側がオキアミの採捕と利用，魚病学，マンガン団塊に関心を示した。1975 年 4 月，日仏海洋開発専門部会の第 1 回会合が開かれ，日本側は潜水技術，海岸開発・海洋構造物，海洋観測機器に関心を示した。同年 10 月の第 2 回会合では，クロマグロの養殖や海洋エネルギーについて日仏両国で議論が行われた。近年は，継続プロジェクト，新規プロジェクト，終了プロジェクトの報告が行われるとともに，海洋研究，海洋技術・研究基盤，海洋資源，海洋バイオテクノロジー，深海生態系，沿岸生態系，社会生態系を主要テーマとして専門部会は拡大している。海洋開発における日仏の協力推進において，日仏海洋開発専門部会は重要な役割を担っている。

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François GALGANI：プラスチックの海

人工高分子（プラスチック）の世界生産量は年間 4 億トンを超え，海洋はプラスチック汚染の影響を最も受ける地域の一つとなっている。この海洋におけるプラスチックの分布は，人間の活動によって影響を受けている。プラスチック汚染は，世界中の海岸，地表，そして 90％以上が海底に見られる。プラスチックは海中でマイクロプラスチックやナノプラスチックに劣化し，工業用ペレットや一次マイクロプラスチックとともに，サイズ，形状，色，化学組成，密度が異なる異質な粒子群を形成する。海洋ごみとマイクロプラスチックが引き起こす影響の範囲については，ほとんど知られていない。最も重要なものとしては，生物の絞殺，生物による摂取，汚染物質の放出，種の長距離輸送などがある。循環型経済，リサイクル，水質浄化，選択的洗浄，教育などに基づく削減対策に加え，世界的な取り組み（国連環境総会，G7，G20）により，各国がより良い環境状態を実現するための管理措置を講じる枠組みを確立している。しかし，環境的，社会的，経済的，そして人間の健康にとって，リスクは依然として高い。

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Cristina BARREAU*・Clément MORENO：市民参加：海洋保護への推進力

海洋ゴミは，世界中の海や海岸線に影響を及ぼす地球規模の環境問題である。毎年 800 万トン以上のプラスチックが海に流入し，世界の海の表層に少なくとも 24 兆 4 千億個のプラスチック粒子が存在すると推定されている。これらのプラスチックは，海面や堆積物，海氷，海底表面に見られる。1990 年以来，サーフライダー・ファウンデーション・ヨーロッパは，海洋ごみとの闘いをその活動の最前線に据えている。サーフライダーは，海洋汚染への理解を深め，海洋環境に流入するゴミの量を減らし，海洋環境と人間への影響を低減するために活動している。NGO であるサーフライダーの活動は，この課題の根本的な原因となる問題に取り組むために，人々の意識を高め，科学的研究を刺激し，政治的行動を開始することから始まる。地域社会と市民が活動プログラムの核心であり，市民参加はその中心である。市民は，海洋ゴミの特徴，分布，輸送経路，野生生物と人間への潜在的な影響に関するデータを収集し，残されている疑問に答えるだけでなく，政策の立案にも参加する。サーフラ

イダーは，警告者，専門家，変革の担い手として，市民，科学者，意思決定者の間の対話を促進する。
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荒川久幸[1)]＊・中野知香[2)]・内田圭一[1)]：日本沿岸海域のプラスチック汚染

日本沿岸の海水，海底，海岸におけるプラスチックごみ，マイクロプラスチック（350μm 以上，5mm 未満），小型マイクロプラスチック（350μm 未満）の濃度と分布について記述した文献をレビューした。食品包装用プラスチックやポリエチレン製レジ袋は日本の海岸に広く分布している。東シナ海の海域では，発泡プラスチックやペットボトルの濃度が高い。海面のマイクロプラスチックは日本沿岸に広く分布し，日本沿岸海域のマイクロプラスチックの濃度は世界の他の地域と比較して非常に高い。東京湾において，350μm メッシュの内網と 50μm メッシュの外網からなるダブルニューストンネットを用いて，小型マイクロプラスチック（＞ 50μm，＜ 350μm）およびマイクロプラスチック（＞ 350μm，＜ 5mm）の定量調査を行った。小型マイクロプラスチックの濃度は，マイクロプラスチックの約 10 倍であった。マイクロプラスチックの定量に用いられている従来の技術は，プラスチック濃度を過小評価する可能性がある。
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多田邦尚[1, 2)]＊・中國正寿[1)]・山口一岩[1)]・一見和彦[1, 2)]：瀬戸内海における陸からの栄養塩負荷削減（1973 年）実施以降の栄養塩濃度変化とその水産業への影響

瀬戸内海の栄養塩濃度減少と水産業への影響について議論した。瀬戸内海は 1960 年代にはじまった高度経済成長期に，著しく富栄養化が進行した。当時は，赤潮が多発し，魚類養殖にも大きな被害が及んだ。近年，水質が劇的に改善した。陸からの全窒素・全リン（TN，TP）負荷量はそれぞれ 40%，60% 削減され，海水中の栄養塩濃度は明らかに低下した一方で，TN，TP 濃度には顕著な低下がみられない。栄養塩濃度減少は単純に陸上からの負荷削減だけがその要因ではなく，海底堆積物からの栄養塩溶出も重要であると考えられた。しかしながら，水質の改善にも関わらず，漁獲量は徐々に減少してきた。植物プランクトンの基礎生産量はこの栄養塩濃度減少に応答しておらず，また，動物プランクトン量の変動については，それを解析できるデータがない。漁獲量減少の原因については不明である。栄養塩濃度減少は，その原因のひとつであると考えられるが，埋め立て，藻場・干潟の減少，地球の温暖化，漁獲圧もすべて漁獲量減少の原因として考えるべきである。
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Charles-François Boudouresque[1)]＊・Aurélie Blanfune[1)]・Thomas Changeux[1)]・Gérard Pergent[2)]・Michèle Perret-Boudouresque[1)]・Sandrine Ruitton[1)]・Thierry Thibaut[1)]：地中海における地球温暖化時代の海洋生物多様性

地中海は半閉鎖性の温帯海域で，局地的に温暖な海である。地中海は，種，機能，生態系の多様性のホットスポットであり，固有種が多く，ユニークな生態系が多数存在することが特徴である。地中海には 12,000 から 17,000 の海洋生物種が報告されている。完全に絶滅した種は 1 つだけで，地中海において，ある場所で絶滅したが他の場所にはまだ存在する種は 10 以下である。一方，多くの種が機能的または地域的に絶滅している。一部の環境保護主義者の甘い考えとは裏腹に，1,000 種もの外来種が徐々に流入してきたことで，地中海のイプシロン種多様性は実際かなり高まっている。地中海を象徴するいくつかの生態系（砂丘-ビーチ-バンケット生態系，*Lithophyllum byssoides* 帯状藻場，海草 *Posidonia oceanica* 藻場，岩礁性ヒバマタ目藻場，サンゴ礁など）は現在減少傾向にある。つまり，生態系の機能（鍵種の相対的豊度，炭素と栄養塩類の流れ，食物網，生態系間の相互作用）は，大きく変化している。このような生物多様性への影響の原因は様々であるが，沿岸開発，乱獲，外来種の侵入の 3 つが主な原因となっている。地球温暖化もその一翼を担い始めており，21 世紀中に顕著に増加す

ると考えられるが，現在のところ，他の人為的な原因には遠く及ばない。地球温暖化の進行する影響や不可逆的影響に対する懸念は全く正当なものである。しかし，他の脅威の過小評価は，政治的，あるいは人間の認識や科学研究の資金に関連する問題に由来しており，ここではそれについて考察する。

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Jean-Claude Dauvin[1)]＊・大越和加[2)]・大越健嗣[3)]・阿部博和[4)]：英仏海峡および東北地方太平洋岸における polydorids 多毛類（多毛綱：スピオ科）の種の豊富さに関する研究

英仏海峡の polydorids 多毛類はこれまでにも多くの多毛類目録で報告されており，日本の東北地方太平洋岸でも polydorids 多毛類を記述する報告がいくつかある。両地域の種の豊富さ（species richness）を比較し，考察した。さらに，2018 年 3 月，日仏共同研究により，フランス・ノルマンディー地方西海岸沿いで野生と養殖のマガキ *Crassostrea gigas*（Thunberg, 1793）の殻から polydorids 多毛類を採取することに成功した。また，石灰藻や他の石灰基質からもいくつかの種が得られた。*Boccardia, Boccardiella, Dipolydora, Polydora* の 4 属に属する 8 種が記録された。ノルマンディーでは，*Polydora hoplura* Claparède, 1868 と *Dipolydora giardi*（Mesnil, 1893）の 2 種が知られており，さらに *Dipolydora* 属の 1 種が種レベルで同定されていないことが判明している。*Boccardia proboscidea* Hartman, 1940, *Boccardiella hamata*（Webster, 1879）および *Polydora websteri* Hartman in Loosanoff & Engle, 1943 はノルマンディーにおける，*Boccardia pseudonatrix* Day, 1961 および *Polydora onagawaensis* Teramoto, Sato-Okoshi, Abe, Nishitani & Endo, 2013 はヨーロッパ海域における新記録種である。多毛類の専門家と協力して英仏海峡のような有名な海を調査すれば，新種を発見することができ，実際に存在する種のリストを増やすことができることを示している。英仏海峡のカキにどのような多毛類が侵蝕しているのかを特定するために，このパートナーシップをさらに継続することが必要であることを、本研究は明らかにした。

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Jean-Claude Dauvin[1)]＊・Aurélie Foveau[2)]・Manon Jean[1)]：カキ養殖台上に設置したコンクリートブロックに定着したタナイス類 *Zeuxo holdichi* Bamber, 1990 の生活環と個体群動態に関する最初の研究成果（英仏海峡東部地域，セーヌ湾）

タナイス類の *Zeuxo holdichi* は英仏海峡のフランス側の潮間帯や浅瀬に多く生息し，カルバドス沿岸では非常に高い豊度で確認されている．潮間帯のカキ養殖台（海底から 0.5m）の上に人工ブロックを設置し，底生のコロニー形成実験を 1 年間行い，*Z. holdichi* の豊度と個体群動態を調査した．隔月のサンプリングにより，コロニー形成は急速で，4ヶ月で 2,000 individuals per m^2の豊度に達することが示された．9 月末と 11 月初旬に 2 つのピークが観察され，豊度は 21,000 individuals per m^2を超えた。アロメトリー測定の結果，頭胸部の長さが個体の全長を推定する良い指標となることが示された。個体群は主に 5.35mm までの雄雌成体からなる。抱卵雌は 6 月中旬から調査終了まで存在し，8-10 月に多く出現する。卵の数は 5 から 89 個で，1 つの育房に平均 24 個の卵が存在する。雌の平均サイズは 3.5mm，平均的な雌雄比は 4.28 である。これらの生活特性を考慮すると，*Z. hodichi* は新しい硬い基質に迅速にコロニーを形成する高い能力を有している。

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奥村裕[1)]＊・増田義男[2)]・鈴木矩晃[3)]・色川七瀬[4)†]・片山亜優[4)]：2012年から2013年の女川湾における植物プランクトン群集について

女川湾で2012年1月～2014年2月にかけて，植物プランクトンの群集組成を調べた。Chl. *a* 量は冬から春にかけて高い傾向にあり，珪藻が保持するFuco量も似た傾向を示したことから，春季ブルームは主に珪藻によるものと考えられた。6月にはChl. *b* 量が高い傾向にあり，ピコプラシノ藻が増加していた。出現割合は平均2%にも満たないが，ラン藻は，夏に出現する傾向があった。ピコプラシノ藻とラン藻は貝類の捕食サイズより小さいため，餌料効率が低く，貝類の餌料としては適さない。渦鞭毛藻が保持する色素のPerid量と，下痢貝毒原因プランクトンのディノフィシス属は経時的に不規則な変化をしていた。また，クリプト藻の中ではディノフィシス属の間接的に餌料となる種が優占していた。そのため，女川湾はディノフィシス属の増殖にとって適した環境になっていると考えられた。ハプト藻の中では，*Phaeocystis* sp.が優占していた。毒性を持つ種も存在するため，引き続き観察が必要と考えられた。HPLCによる色素分析とNGSによる遺伝子解析を組み合わせることで，貝類の餌料環境を把握するのに必要な植物プランクトンの季節変動を網羅的に把握できた。

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Patrick Prouzet[1)]＊・Marie Lecomte[2)]・Johanna Herfaut[3)]・Lise Mas[4)]・Nathalie Porcher[5)]：持続可能な開発と責任ある開発　小規模漁業における遡河性魚種の管理と利用を例として

持続可能な開発政策は，関係者間の交渉の産物である。ある者は強く，ある者は弱く，あるいは存在しない。自然環境の生産性が，自分たちの社会的・経済的未来に直接関わる人もいれば，そうでない人もいる。また，将来の世代や自然そのもののように，交渉のテーブルに決してつかない者もいる。予防原則は，2005年にフランスの憲法に盛り込まれたが，いくつかの修正が加えられている。特に，「経済的に負担可能なコスト」と「効果的かつ相応の措置」という概念が追加された。水生生物資源の持続的利用は，最大持続生産量（Maximum Sustainable Yield）に従って行われることがますます困難になっており，その水準は，多くの人為的要因の圧力による大陸，河口，沿岸環境の悪化に伴って低下し続けている。漁業コミュニティが「持続可能な開発」よりも「責任ある開発」について話すことを好む理由は，このためである。そこで，より社会・生態系に基づいたアプローチが必要である。このアプローチは，真の環境統治（持続可能な開発の第4番の要素）を実施し，世代間の連帯の表現としての知識とノウハウという意味での文化という第5の要素を考慮するため，地域スケールでのみ可能である。

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中国北部の渤海にある灤河河口域は，魚類を含む多くの海洋生物にとって重要な保育場となっており，好漁場でもある。魚類の体長-体重関係（LWR）は，個体群を適切に漁獲し管理するための重要な指標である。そこで，灤河河口域に分布する魚類のLWRの取得を目的として本研究を実施した。2016年12月から2017年8月までは1ヶ月間隔で，2016年7月から2017年11月までは2ヶ月間隔で，カニカゴ，トロール網，底曳網を用いて，20

科 32 種に属する合計 7,593 尾の個体を採集し，それらの体長（L），体重（W）を測定した。最も多くの個体が得られた種は *Chaeturichthys stigmatias*（N = 2,487）であった。統計解析に十分な個体が得られた 17 魚種の長さ-体重関係（LWR，$W = a \times L^b$）が得られた。対数変換したデータの線形回帰は，すべての分析種で非常に有意であった（$p < 0.05$）。LWR の傾き b 値は *Synechogobius ommaturus* の 2.57 から *Engraulis japonicus* の 3.66 までであった。17 種全体の 50% の種の b 値は 2.95 から 3.30 の間であった。LWR の情報は，灤河河口域だけでなく，他の河口域の漁場における魚類資源の管理に利用できるだろう。

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柴田玲奈[1)]*・石樢賢一[2)]・植木誠[3)]・阿部倫久[4)]・矢田崇[4)]：マコガレイ *Pseudopleuronectes yokohamae* 仔稚魚におけるチロキシン（T_4）の変化

マコガレイ *Pseudopleuronectes yokohamae* の仔魚期から稚魚期にかけての甲状腺ホルモンの一種であるチロキシン（T_4）の変化を調べた。孵化後 20 日齢（浮遊期）から約 120 日齢（稚魚期）における T_4 濃度は，稚魚期において大きく上昇することが認められ，稚魚の発育段階後期で極大値を持つことが示唆された。また本研究中において，T_4 濃度の年変化は大きいことが示された。

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中野俊樹[1)]*・竹村明洋[2)]・落合芳博[1)]・Luis O.B. Afonso[3)]：魚類の健康における環境ストレスの影響ー魚類におけるコントロールされたストレスのユーストレス（良いストレス）としての可能性

魚類は，汚染物質や水温変化などローカルとグローバルな因子が複合した環境ストレスを受ける。生物がストレスを受けると一連の生化学的および生理学的な変化が生じ，この生体レベルのストレス反応（応答）を神経内分泌系が支配している。細胞レベルでは，ストレスにより熱ショックタンパク質と呼ばれる一群のストレスタンパク質が誘導される。そしてストレスは生物の健康状態に大きく影響する。ギンザケ（*Oncorhynchus kisutch*）における熱ショックまたは養殖現場で汎用される抗生物質オキシテトラサイクリンの投与が体内で酸化ストレスを誘発し，生体内酸化を促進することを明らかにした。さらに，ハンドリングによるマイルドな生理学的ストレスが，魚類の成長関連遺伝子の発現に影響を与えることも認めている。生体に対するストレスの影響は，ストレスの強さや受ける側の生理状態などにより異なることから，ストレスには，「ユーストレス（良いストレス）」と「ディストレス（悪いストレス）」の 2 種類があると考えられる。従って，養殖現場でもコントロールされた環境ストレスはユーストレスとして働き，養殖魚の健康の維持と改善および福祉にとり有益であると期待される。

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田上英明[1)]＊・三谷勇[2)]・日下崇[3)]・毛利雅彦[4)]・濱野明[4)]・小松輝久[3, 5)]：八里ヶ瀬海丘における立縄による魚類鉛直分布の実用的調査：魚群探知機による魚群資源量推定の補完を想定した事例研究

沖合海丘における水産資源の持続的な利用には，魚類資源量の正確な推定が不可欠である。しかし，海底地形が凸凹していたり，岩が多い地域では，底引き網を用いた魚類資源の推定は現実的ではない。魚群探知機を用いた定量的な資源量調査は有効であるが，エコーグラムから魚種を同定することは容易ではない。本研究では，2006 年 6 月に日本海の八里ヶ瀬海丘周辺で行われた魚群探知機調査において，海底付近に分布する魚種の特定に立縄が有効かどうかを検討した。8 地点中 7 地点で 7 種が捕獲され，CPUE（10 分間操業当たり個体数）は 1.15 となった。イサキとアカエソが主な漁獲種であり，それぞれが CPUE に占める値は 43.7%，37.0%であった。イサキは海底から海底上 9m の間で捕獲され，アカエソは海底から海底上 3m の間の狭い層でのみ捕獲され，両種間で海底からの高さに大きな差があることが明らかになった。本研究により，立縄は魚群探知機を用いた調査を補完することができ，トロールによる調査が困難な海丘の魚類資源量を把握するための有効な手法となる可能性が示された。

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髙橋秀行：安全な漁業による安全な海－漁師の仕事を理解し，改善するための研究－

日本では漁業の作業研究はほとんど行われておらず，著者はその数少ない研究者の一人である。したがって著者のこれまでの約 10 年の研究をとりまとめれば，日本における漁業の作業研究の経緯を大凡把握することができ，また次の 10 年に取り組むべきことを考えるヒントになるだろう。そこで本稿では著者の一連の研究をレビューすることを目的とした。小型底びき網漁業を中心にいくつかの漁業における作業負担を調査し，得られた結果から作業台やアシストスーツの活用などを改善策として提案した。また漁業者が救命胴衣を着用しない理由に迫る現地調査も行った。著者の活動と同期するように，漁業の作業安全に関する国家的な取組もこの 10 年で徐々に発展し，漁業者向けの安全講習会の実施や，救命胴衣着用に関する規則の改正が行われた。漁業者の作業安全を確保するには，これらの取組を一時的なものとせず，長期的に支える仕組みを整備する必要がある。

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小松輝久：2021 年 10 月 23 日開催，日仏会館・日仏海洋学会主催自然科学講座「変わりゆく海に臨む社会変革―海洋マイクロプラスチック問題を巡って―」の記録

日仏海洋学会は，2020 年に創立 60 周年を記念した「第 18 回日仏海洋学シンポジウム」を開催する予定であったが，コロナ禍のため延期となっていた。2021 年にはウェブ上でのシンポジウムが可能となり，2021 年 10 月 19 日から 23 日に第 18 回日仏海洋学シンポジウムを開催した。このシンポジウムで海洋学や水産学に携わる日仏の研究者が交流して得た成果を広く市民に知ってもらうために，日仏会館と日仏海洋学会は，日仏工業技術会（SFJTI）の共催を得て，2021 年 10 月 23 日に公開シンポジウム，日仏科学講座「変わりゆく海に臨む社会変革－海洋マイクロプラスチック問題を巡って－」を開催した。本稿では，講演会のテーマを選んだ理由，マイクロプラスチック問題の基礎知識，発表内容の概略を紹介する。発表者は，Ifremer の François Galgani 博士，JASMTEC の藤倉克則博士，筑波大学の Sylvain Agostini 博士，Surfrider Foundation Europe の Cristina Barreau 氏，山陽学園中学・高等学校の高校生 2 人と井上貴司教諭，SFJTI/ 東京大学の岩田忠久教授であった。

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