La mer 46 : 65-75, 2009
Société franco-japonaise d'océanographie, Tokyo

Seasonal variation in fresh water residence time and its impact on the water quality at Hurun Bay, South Sumatera, Indonesia

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Abstract: To understand the characteristics and control mechanism of water quality at Hurun Bay, a seasonal variation in freshwater residence time was investigated based on a series of temperature, salinity, DIN (Dissolved Inorganic Nitrogen), TOM (Total Organic Matter), DIP (Dissolved Inorganic Phosphorus), DO (Dissolved Oxygen) and phytoplankton data observed during the period of 2004. The residence time of freshwater as indicator of the water exchange played an important role to control the water quality at Hurun Bay. Long freshwater residence time in both transition periods of Wet-Dry and Dry-Wet seasons has increased the DIN and TOM accumulation in the water column, and it stimulated phytoplankton bloom at Hurun Bay. This situation has caused the DO decrease due to fast decomposition of organic matter. The results recommend that in both transition periods, the aquaculture activity should be limited at minimum level to reduce the risk of fish mass mortality caused by the DO depletion due to the phytoplankton bloom and diseases appearance.

Keywords: *seasonal variation, fresh water residence time, water quality, Hurun Bay*

I. Introduction

Hurun Bay is a semi enclosed estuary situated at the western coastal area of Lampung Bay, southern coastal area of Sumatera and faces to the Sunda Strait (Fig.1). The environment within this area seems to be strongly influenced by monsoonal wind system that affects the variability of the meteorological and oceanographic conditions of Lampung Bay. There are two dominant monsoonal seasons, which drive the climate cycle in the study areas (as in all other Indonesian areas) named the dry and rainy seasons that occur during December to March and June to September, respectively. The rainy season is related to the northwest (NW) monsoon, while the dry season is related to the southeast (SE) monsoon. Among these seasons, there are two transition periods that also influence the circulation of the water mass within the study area; one is the period between wet and dry seasons (Trans. W-D) in April-May and another between dry and wet season (Trans. D-W) occurs in October to November. During the wet season, high air pressure over Asia and low air pressure over Australia are observed, allowing wet air transport (northwesterly wind) from the South China Sea to the Pacific Ocean across the Indonesian archipelago. Inversely, low air pressure over Asia and high air pressure over Australia drive the wind blowing from the southeast to the northwest (southeasterly wind) carrying the dry air from Australia and resulting in the dry season (BÜHRING, 2001;

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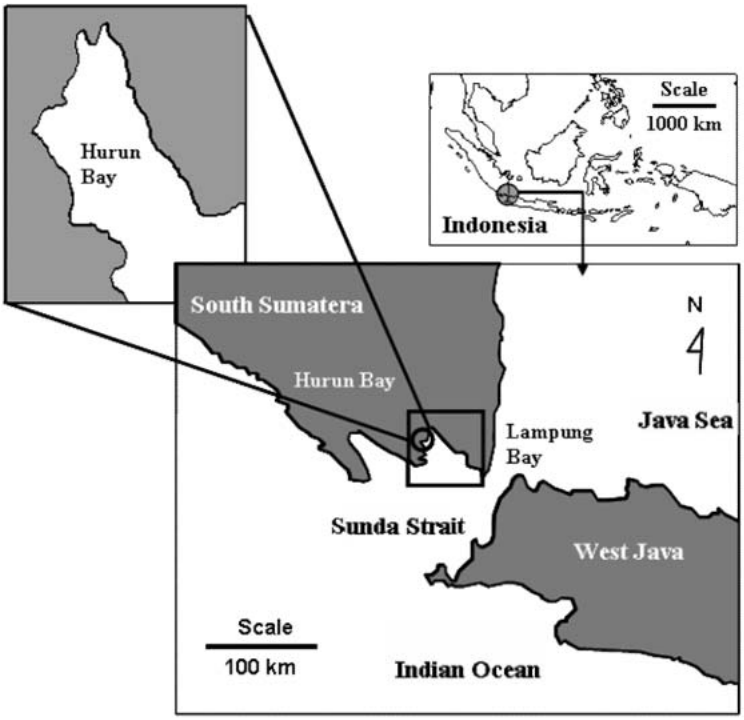

Fig.1. The location of Hurun Bay in the southern coastal area of Sumatera.

TOMASCIK *et al.,* 1997). Consequently, on the regional scale, the oceanic condition of Hurun Bay is highly influenced by water masses from the South China Sea, the Java Sea and the Indian Ocean that intrude through the Sunda Strait and spread in Lampung Bay (SACHOEMAR *et al.,* 2006; DAMAR, 2003; WIRYAWAN *et al.,* 1999).

GUO *et al.,* (2004) defines the residence time as the flushing time that determines the time where a pollutant moves through the bay (by action of freshwater discharge and tidal exchange). Information of the freshwater residence time in the bay is important to understand the mechanism of water exchange in reducing the water pollution in the bay (YANAGI, 1999a). Since Hurun Bay is considered to be an important water source to supply hatchery near the coast and the water body is utilized for growing of fish in the cage system, understanding the exchange process of the water mass that influences the water quality is important. Practical aquaculture will be easier to be managed if the information on the characteristics and behavior of marine ecosystem is available, though such information is very limited now at Hurun Bay. Hence, in the present study, the water exchange that is represented by the freshwater residence time will be evaluated to understand the mechanism of physical process that is considered to play an important role in the water quality variation at Hurun Bay as well as the monsoon, terrestrial and the anthropogenic activities.

2. Methods

2.1. Data Collections and Analysis

A series of temperature, salinity, DIN (Dissolved Inorganic Nitrogen), TOM (Total Organic Matter), DIP (Dissolved Inorganic Phosphorus), DO (Dissolved Oxygen) and phytoplankton parameters in wet season (mid-January and March), transition period of wet to dry season (Trans. W-D) of mid-April and May, dry season (mid-June, July, August and September) and transition period of dry to wet season (Trans. D-W) of mid-October and November were collected during the period of

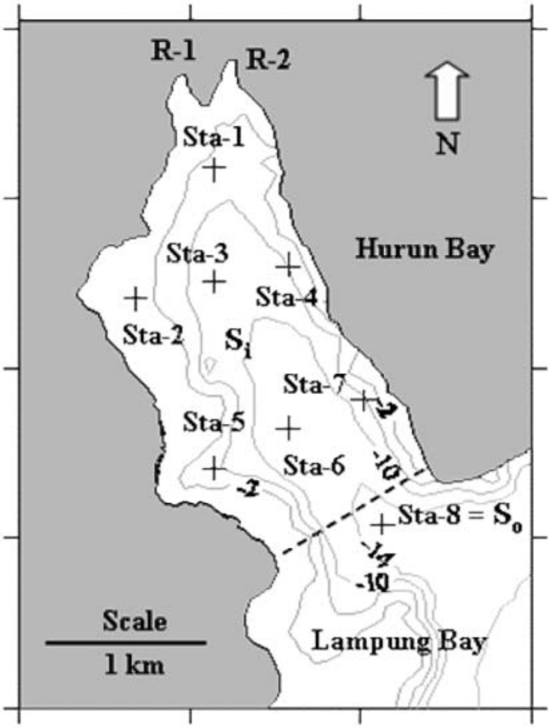

Fig.2. Sampling stations inside the bay (Stas.1–7) and outside the bay (Sta.8). Dashed line shows the boundary of the box. Numbers show the depth in meters.

2004. Water samples were taken by a Nansen bottle from the surface and 1 m above the bottom at eight stations of Hurun Bay (Fig.2). The water samples were then analyzed in the laboratory to measure TOM, DIN (nitrate, nitrite and ammonia) and DIP according to APHA (1979) standard method. Water temperature was measured directly in the field by using a water quality checker (YSI 55 Yellow Springs Instrument), dissolved oxygen (DO) by YSI 550 (Yellow Springs Instrument) and salinity by WTW 340i (Wissenschaftlich Technische Werkstatten, Germany), the nutrients were analyzed by using spectrophotometers (Spectronic 21D Milton and Spectro 2000 RS, Labomed). The phytoplankton was collected by filtering 50 l of the water sample of the surface layer using plankton net with the diameter of 30 cm and mesh size of 35 μm. Their abundance was then calculated by using Sedgwick Rafter Counting Cell, while the phytoplankton species was identified by YAMAZI (1982) identification guide.

In addition, the river discharge data from the two small rivers around Hurun Bay (R–1 and R–2 in Fig.2) were collected by measuring the speed of water flow, the depth and width of the rivers during the observation. The calculation results of the rivers discharge were then included in calculation of freshwater residence time in a box model analysis. To support this analysis, the meteorological data (precipitation and evaporation) for the period of 2004 were collected from the Indonesian Meteorological Agency for the Lampung region covering Hurun Bay. The depths of Hurun Bay are within a range of 2 to 21 m. All the data were then applied to analyze seasonal variation in freshwater residence time and its impact on the water quality of Hurun Bay

2.2. Box Model Analysis and Freshwater Residence Time

The analysis of freshwater residence time at Hurun Bay can be calculated by using box model analysis. Hurun Bay has a volume V of 35.2×10^6 m^3, sea surface area A_s of 3.4 km^2, cross sectional area at the sea boundary A_b of 12×10 m^2 and average depth H of 10.3 m (Fig.2). In this study, we assumed that the average of the water depth within the bay can represent the mean depth condition of the bay because the water masses from the inner and outer parts of the bay were exchanged only through the small area of the box boundary (dashed line) as shown in Fig.2.

Spatially averaged data at stations 1–7 are the representative value inside the box, and the averaged data at Stas.R–1 and R–2 and that at Sta.8 represent the rivers and the sea, respectively. The box model analysis (GORDON *et al.*, 1996; YANAGI, 1999a) is applied to the bounded area of Hurun Bay (Fig. 2) using the average data observed during the wet season (January and March), the transition period of W-D (April and May), the dry season (June, July, August, September) and the transition period of D-W (October and November) in 2004.

The freshwater entering the bay mainly comes from the discharge of two rivers (R–1 and R–2) with the annual average of 2.68×10^6 m^3/month (Fig.3). The highest river discharge

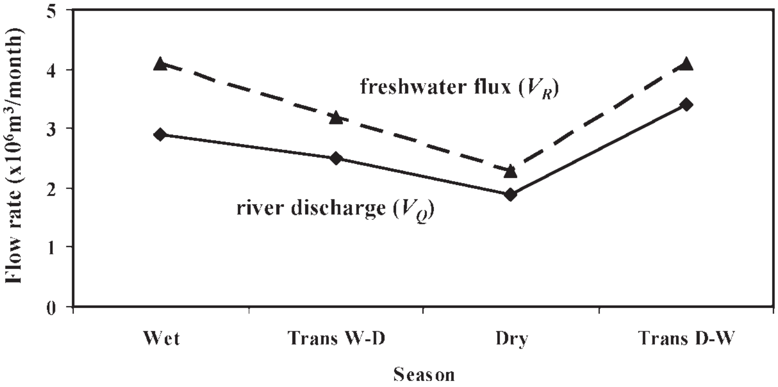

Fig.3. Seasonal variations in river discharge (V_Q) and freshwater flux (V_R) from the box.

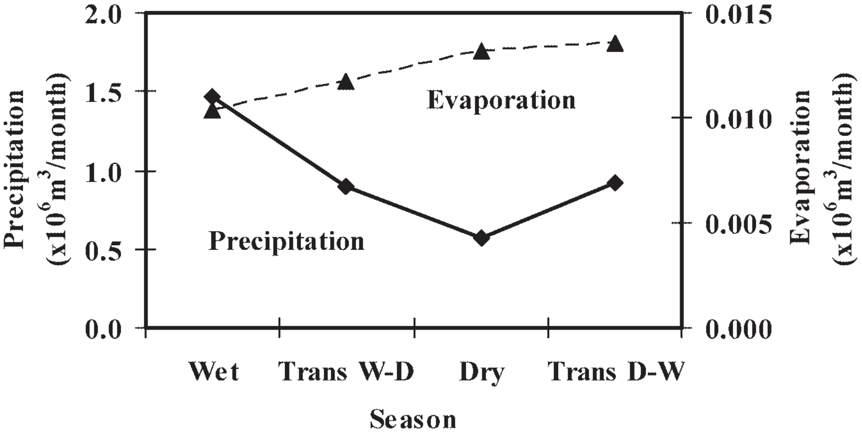

Fig.4. Seasonal variations in precipitation and evaporation in 2003–2005 at Hurun Bay (Source : Indonesian Meteorological Agency).

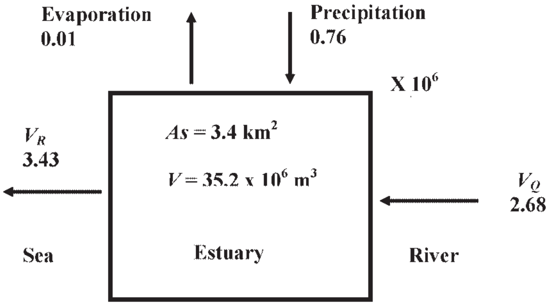

Fig. 5. Annually averaged freshwater budget at Hurun Bay.

was in the transition period of D-W (3.4 × 10^6 m^3/month) and the lowest was in the dry season (1.9 × 10^6 m^3/month). If the ground water discharge and variation of the mean sea level may be assumed to be zero and the atmospheric budget (precipitation-evaporation) is considered, the freshwater flux through the open boundary of Hurun Bay V_R is calculated. According to the meteorological data in 2004, precipitation and evaporation are estimated to be 1.5 and 0.010 × 10^6 m^3/month for the wet season, 0.9 and 0.012 × 10^6 m^3/month for Trans. W-D, 0.6 and 0.013 × 10^6 m^3/month for the dry season, 0.9 and 0.014 × 10^6 m^3/month for Trans. D-W, respectively (Fig.4). Hence, the freshwater export (V_R) from the box to the outside of the bay was largest in the wet season and smallest in the dry season (Fig.3). Because the evaporation level was insignificant, the amount of the freshwater flux to the bay was mainly governed by precipitation (Fig.4). The annual average of freshwater budget at Hurun Bay (Fig.5) with V_R is 3.43 × 10^6 m^3/month.

Temporal variability of salinity in the box (S_i) and outside the box (S_o) (Fig. 6), indicates

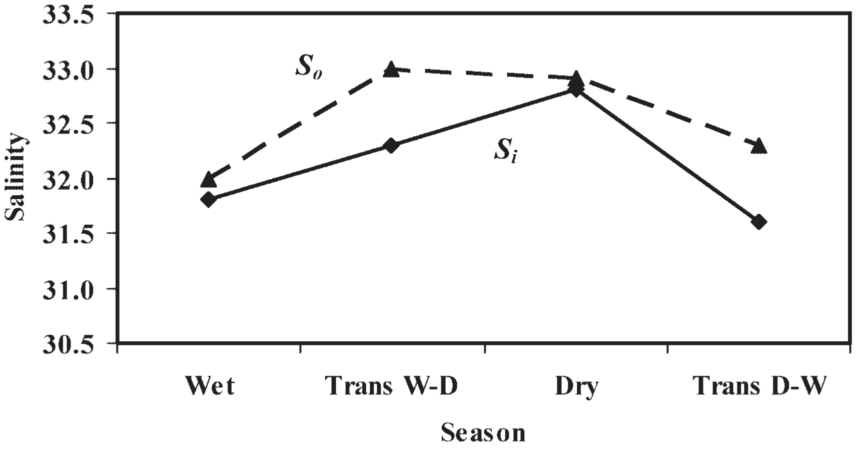

Fig. 6. Seasonal variations of salinity inside of the bay (S_i) and these outside of the bay (S_o).

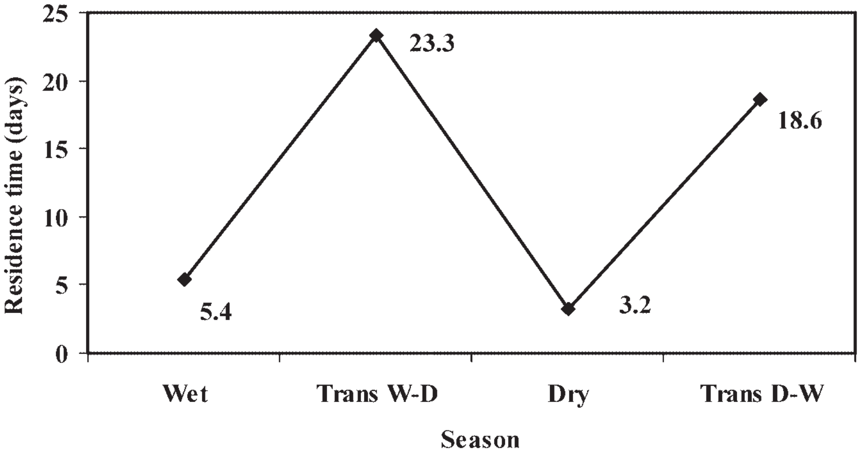

Fig. 7. Seasonal variations in freshwater residence time at Hurun Bay.

the strong monsoonal effect of the river discharge, precipitation and the water mass exchange within and around the bay. Large river discharge (Fig. 3) and precipitation (Fig.4) in the wet season results in low salinity in the box S_i (31.8) and low salinity gradient between S_i and S_o (0.2), while in the dry season the strong intrusion of water mass from the open sea and low river discharge are responsible for high salinity in the box of S_i (32.8) and low salinity gradient between S_i and S_o (0.1). On the other hand, the combined effect of moderate river discharge and intrusion of water mass from the open ocean in both transition periods of W-D and D-W resulted in high salinity gradient between S_i and S_o (0.7). This situation indicates that the water exchange was large in both wet and dry seasons compared to that during the transition periods of W-D and D-W. To confirm these phenomena, the residence time of freshwater in the bay was estimated by using the calculation method of YANAGI (1999b) and BURANAPRATHEPRAT *et al.*,. (2002) as follows :

$$\tau_f = V_f / V_R, \qquad (1)$$

$$V_f = (S_o - S_i) V / S_o, \qquad (2)$$

where τ_f is the residence time of freshwater, V_f is the standing stock of freshwater in Hurun Bay.

3. Results and Discussion

The calculation result shows that the residence time of freshwater in Hurun Bay was

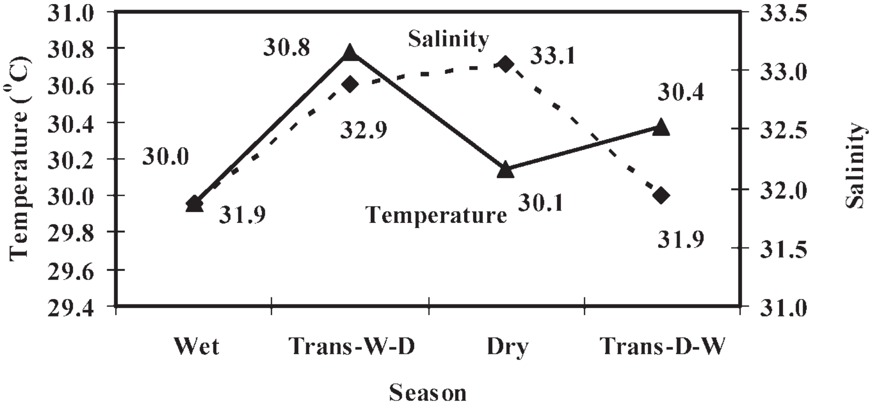

Fig. 8. Seasonal variations in water temperature and salinity observed at Sta. 8 in Hurun Bay.

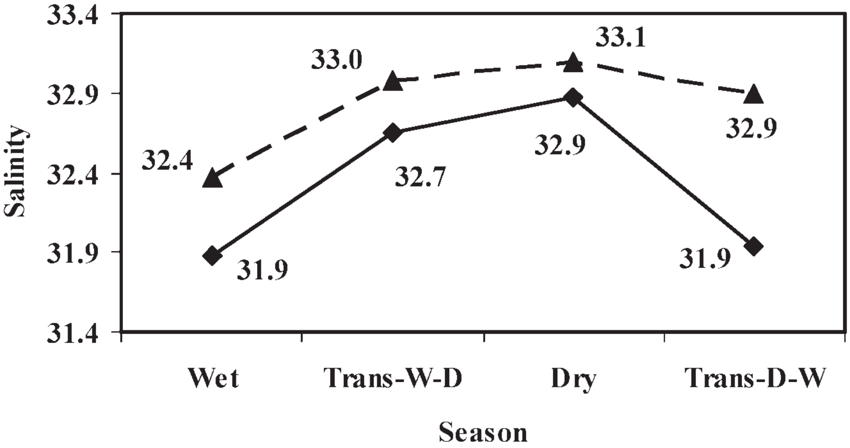

Fig.9. Seasonal variations of vertical distribution in water salinity at the surface and bottom layer in Hurun Bay.

within the range of 3.2 to 23.3 days (Fig. 7). In the wet and dry seasons, the residence time of freshwater was shorter than that in the transition periods of W-D and D-W, that is, 5.4 days in the wet season and 3.2 days in the dry season. While in the transition periods of W-D and D-W they are 23.3 days and 18.6 days, respectively. This means the water exchange in Hurun Bay is weak during the monsoon transition period. Since the water circulation is low, the water quality within the bay might be disturbed. The monsoonal system as driving force of meteorological and oceanographic variability seems to have played an important role in the water exchange within this area. During the wet (northwest monsoon) and dry (southeast monsoon) seasons, the northwesterly and southeasterly winds were steady and strong compared to those in both transition periods of W-D and D-W. Such local wind variability seems to influence the water circulation in Hurun Bay and Lampung Bay. In the southeast monsoon (Dry season), the upwelling occurrence in the coastal area of south Java penetrates the cold and high salinity water mass into Hurun Bay, as recorded at Sta. 8 (Fig. 8). While in the northwest monsoon (Wet season), the cold and low salinity water mass of the Java Sea and the South China Sea.

This situation suggests that the different wind direction in the wet and dry seasons has influenced the water exchange through the different mechanism of the water circulation. In both wet and dry seasons, the water column was well stratified and promoted the gravitational forces in classic estuarine circulation in

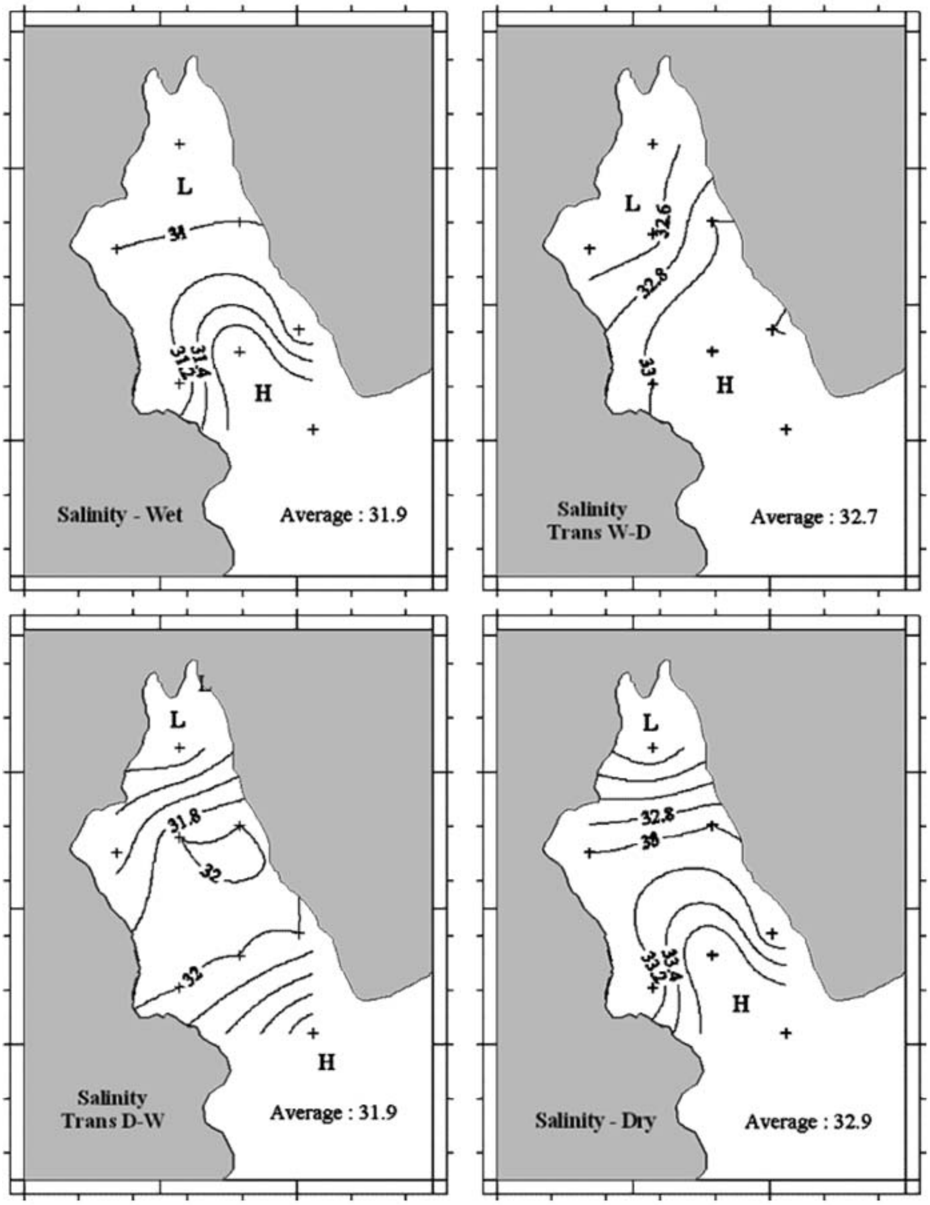

Fig.10. Seasonal and spatial variations in sea surface salinity at Hurun Bay.

Hurun Bay, where the upwelling and precipitation play important roles in generating water exchange and their circulation. These phenomena were also supported by vertical salinity distribution at the surface and bottom layers, and their horizontal distribution as shown in Fig 9 and 10. Variability of sea surface salinity indicates the strong correlation with the precipitation as shown in Fig.4, where high precipitation has caused decreasing salinity in the bay. Large river discharge during the period of wet, transition period of W-D and D-W has influenced on the salinity distribution in the bay. Low salinity water in the upper part of the bay during these periods was wider than that in the dry season, while high salinity

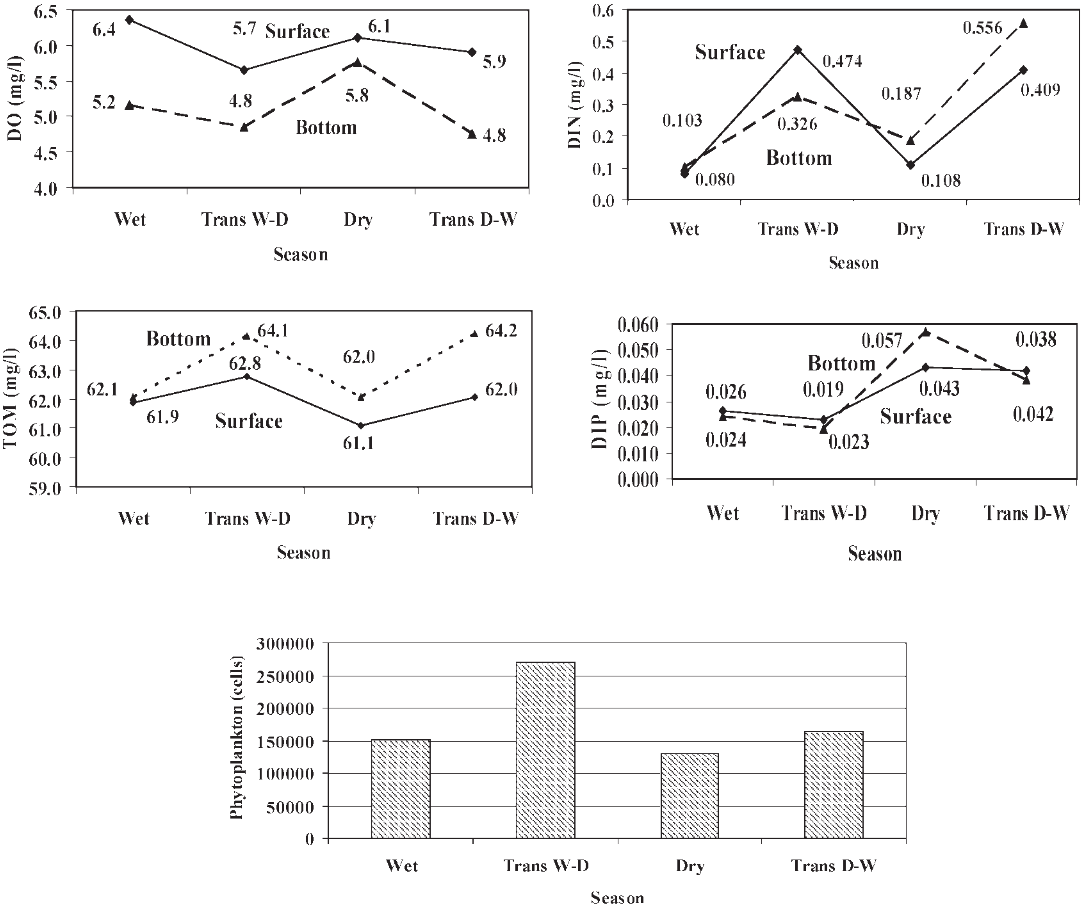

Fig.11. Seasonal variations in DO,DIN, TOM, DIP and Phytoplankton at Hurun Bay.

water was intruded into the bay during the period of dry season.

3.2. DO, DIN, TOM, DIP and Phytoplankton

The impact of the seasonal variability of the fresh water residence time on the water quality was seen on the DO, DIN, TOM and phytoplankton abundance. In the wet and dry seasons, DO in the surface and bottom layers were higher than those in the transition periods of W-D and D-W. DO at the surface layer in the wet and dry seasons were 6.4 and 6.1 mg/l, respectively (Fig.11), while in the bottom layer, DO was 5.2 mg/l in the wet season and 5.8 mg/l in the dry season. In the transition periods of W-D and D-W, DO at the surface layer was 5.7 and 5.9 mg/l, respectively, and that in the bottom layer was 4.8 mg/l. Low DO in the transition periods of W-D and D-W seems to be associated with the weak of water exchange during these periods in response to the long freshwater residence time. On the contrary, when the freshwater residence time, is short in the wet and dry seasons, the DO is high (Figs.7 and 11). Since DO concentration depends on temperature and salinity, we calculate DO saturation using observed temperature and salinity. The results are shown in Table 1, where DO concentration and DO saturation were low in transition seasons. These suggest that the long residence time in transition seasons results in high water temperature and low dissolved oxygen concentration, and low DO saturation due to large and long consumption of DO by organic matter in transition seasons. The variability of the ocean dynamics and the

Table 1. Seasonal variations of mean average water temperature (oC), salinity, DO concentration (mg/l) and DO saturation (%) derived from sea surface and bottom layer in Hurun Bay during period of 2004.

Season	Temperature (oC)	Salinity	DO concentration (mg/l)	DO saturation (%)
Wet	30.0	32.2	5.8	91.6
TransW-D	30.5	32.9	5.3	83.9
Dry	30.0	33.0	6.0	94.4
TransD-W	30.5	32.4	5.4	85.1

water circulation in Hurun Bay associated with the monsoonal system seem to have influenced on the DO variability. Hence, during the monsoon transition periods, the aquaculture activity should be limited to minimize the risk of fish mass mortality due to the depletion of the DO within this region.

The influence of the freshwater residence time on the water quality was also seen in the variability of DIN and TOM as shown in Fig. 11. Unlike the DO variability that has a negative correlation with the freshwater residence time, the DIN and TOM variabilities have positive correlations with the freshwater residence time. When the freshwater residence time was long, i.e. in the transition periods of W-D and D-W, DIN and TOM were high and the opposite in the wet and dry seasons. This means that the long freshwater residence time increases DIN and TOM in the water body of the bay, particularly in the area where the aquaculture activity is high at Hurun Bay. The spatial variability of DIN (Fig. 12) shows that DIN concentrations near Stas. 2 (outlet hatchery) and 8 (fish cage) were relatively high in all seasons and their concentrations increase in the transition periods of W-D and D-W. Increasing DIN concentration in both transition periods might be due to low water exchange as response to long freshwater residence time. DIN was released from the reservoir of hatchery and fish cage, being accumulated in the stagnant water mass of the bay, and conversely for the short freshwater residence time, the pollutant will be pushed away soon. Increased DIN in both transition periods of W-D and D-W seems to have stimulated phytoplankton bloom as shown in Fig.11. The population of phytoplankton species in Hurun Bay for the period of 2004 was dominated by *Alexandrium, Chaetoceros, Dinophysis, Nitzschia, Pseudo-nitzschia, Pyrodinium, Protoperidinium and Noctiluca* with more than 20% from total phytoplankton population identified.

Moreover, the temporal variability of DIP shown in Fig. 11 shows an insignificant seasonal variation in Hurun Bay. This means that DIP was not the main factor of the environmental loading at Hurun Bay and not critical for eutrophication. Since the water body in Hurun Bay is used for the aquaculture activity, nitrogen is a dominant factor for the environmental loading in the coastal area of Hurun Bay. This is consistent with results by previous researchers (DUFF, 1987; HAMMO, 1987; WALDICHUK, 1987; WILDISH *et al.,* 1990; SOLEY *et al.,* 1994; WU *et al.,* 1994; WU, 1995; LUPATSCH and KISSIL, 1998).

4. Conclusion

The monsoonal system has strongly affected on the water exchange in Hurun Bay and influenced the water quality. Long freshwater residence time during both transition periods of W-D and D-W has increased the DIN and TOM accumulation in the water body. Consequently it stimulated phytoplankton bloom and caused the decrease of DO concentration. At least there are two factors that influence the variability of freshwater residence time at Hurun Bay, being associated with the monsoonal system. The first is the precipitation and the water circulation in the Java and South China Seas in the wet season (northwest monsoon), and the second is the water mass penetration from the southern coastal area of Java due to the upwelling occurrence in the dry season (southeast monsoon). During these seasons, the water circulation was more active being stimulated by relatively strong northwesterly

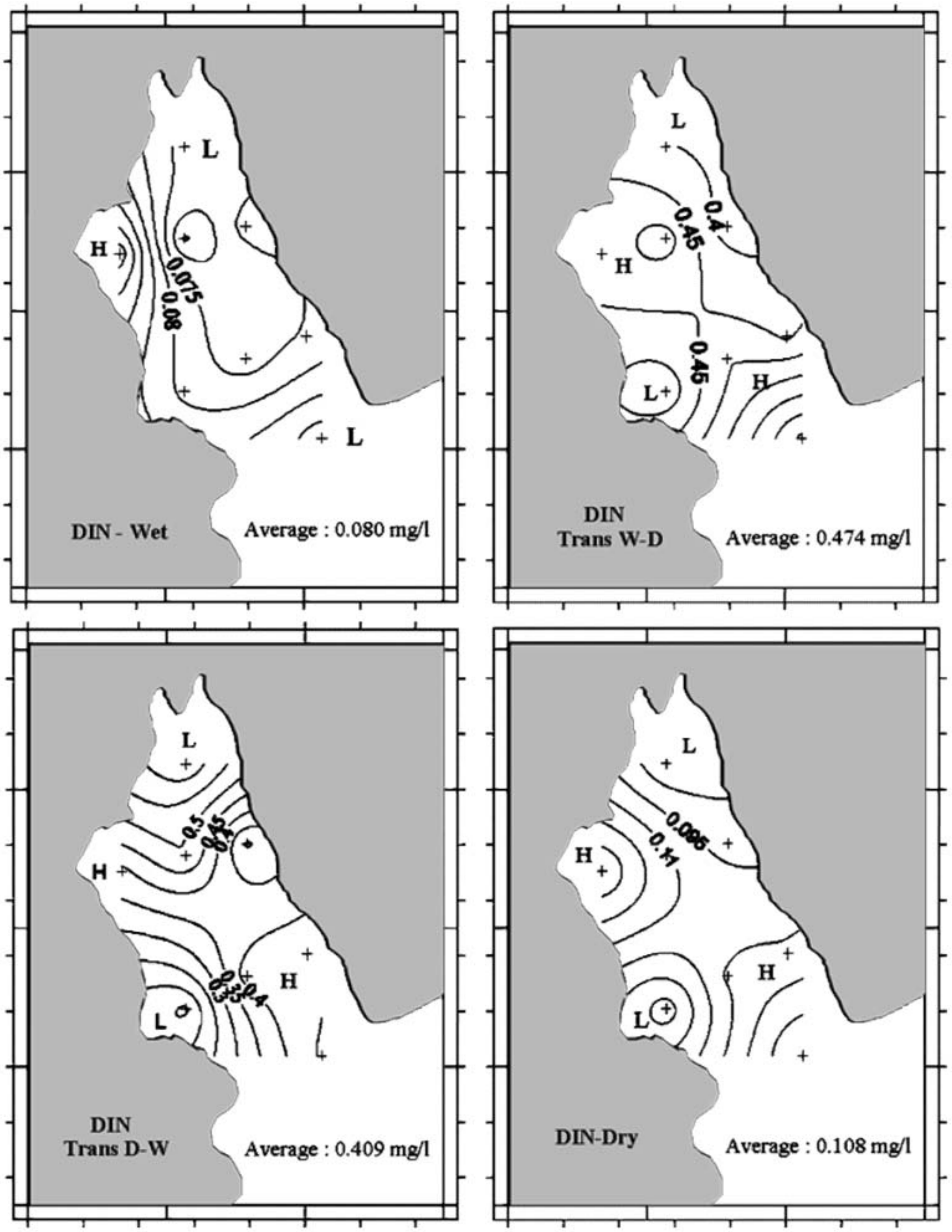

Fig.12. Seasonal and spatial variations in sea surface DIN at Hurun Bay.

and southeasterly winds over the ocean surface, but in both transition periods the wind was weak and so was the water circulation.

By understanding the characteristic variability of freshwater residence time in relation to the water quality in Hurun Bay, the aquaculture activity within this region could be managed properly toward sustainable utilization. In both monsoonal transition periods, the aquaculture activity should be limited to reduce the risk of fish mass mortality caused by the DO depletion and fish diseases due to the blooming of undesired phytoplankton.

Acknowledgment

The authors wish express sincere thanks to the National Sea Farming Development Centre, Ministry of Marine and Fisheries Affair (BBL-LAMPUNG) and Agency for the Assessment and Application of Technology (BPPT) for their support on this study.

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Received April 17, 2008
Accepted September 26, 2008

La mer 46 : 77-84, 2009
Société franco-japonaise d'océanographie, Tokyo

Describing Cetacean Habitat in Australian Waters

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Abstract: An understanding of habitat has been acknowledged as a priority for cetacean science in Australian waters. Global reviews suggest that the definition of cetacean habitat should be relatively broad and include multiple variables and factors, yet also tailored to both species and region . It has also been noted that variables and factors need to be measured at a scale that matches the appropriate process, phenomena, pattern and scale at which the given variables operate. In Australia, cetacean habitat research to date has focussed primarily on small coastal species, covers a restricted geographic range, and includes a limited number of factors such as water depth, sea surface temperature and migratory pathways. Specific habitat–related information is available for less than a quarter of the known Australian cetacean species. The investigation of cetacean habitat in Australian waters should be undertaken in a broad and quantitative manner as effective habitat protection and associated threat mitigation serves as key and timely tools in cetacean conservation efforts.

Keywords: *Australia, cetacean, habitat, environmental variables*

1. Introduction

Describing and understanding habitat is consistently noted as a necessary and meaningful component of cetacean science (BANNISTER *et al.* 1996, REEVES *et al.* 2003, HOYT 2005). Cetacean habitat is often defined in terms of critical behaviours such as breeding, foraging and migration yet is sometimes expanded to include those parts of the distributional range that are important for day–to–day survival and reproductive fitness (HARWOOD 2001, HOYT 2005). Habitat of cetaceans is typically described by measurement of environmental, spatial, and temporal variables as well as those factors that may influence distribution in the immediate marine environment of a given species. A review of cetacean studies revealed that some of the common variables used to describe cetacean habitat include water temperature, salinity, dissolved oxygen, turbidity, habitat type, water depth, distance from shore, and topography (GASKIN 1968, KENNEY 1990, BALLANCE 1992, BAUMGARTNER 1997, WILSON *et al.* 1997, ALLEN *et al.* 2001, HASTIE *et al.* 2002, INGRAM and ROGAN 2002, JAQUET and GENDRON 2002, BRAGER *et al.* 2003, MILLER 2003, TYNAN *et al.* 2005, CRIBB 2006, PARRA *et al.* 2006, AZEVEDO *et al.* 2007). From this review it was also evident that cetacean habitat studies differ in the given combinations of variables measured, the scales and methods of quantification, and the analytical techniques and inferences invoked. These differences are in part due to the various ways in which cetacean habitat is measured, geographic region, research technique, time frame, objectives and intended application of the given study, and determination of what constitutes habitat for a given cetacean species (HARWOOD 2001, HOYT 2005, REDFERN *et al.* 2006).

In a comprehensive review of Australian cetaceans, BANNISTER *et al.* (1996) listed general habitat characteristics (water depth, water temperature, latitude, and prey type) for forty–three cetacean species. However, more detailed information about many of these species was evidently lacking as the status of half of these

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species was classified1 as 'No Category Assigned due to insufficient information' (Table 1) (BANNISTER *et al.* 1996). This particular classification may be due to lack of information in regard to population, habitat or perhaps both. A more recent national report focusing only on smaller whales and dolphins (ROSS 2005) provided similar results. More specifically, most species (26 out of 33) did not have a change in conservation status from that designated in BANNISTER *et al.* (1996) (Table 1). Conservation status designations and habitat types for Australian cetaceans are also contained in the IUCN listings (www.iucnredlist.org accessed in July 2008) yet again this information does not differ significantly from the findings of BANNISTER *et al.* (1996) and ROSS (2005) (Table 1).

BANNISTER *et al.* (1996) emphasized that effective cetacean conservation in Australian waters is intrinsically related to protection of appropriate habitat and associated ecosystems, and that the identification of key habitats was an important component of this objective. Given these noted priorities this current paper briefly investigates how cetacean habitat has been described, quantified and applied in terms of conservation and management in Australian waters.

2. Methods

Studies relating to cetacean habitat in Australian waters were collated from published and unpublished reports, database searches and direct approaches to researchers. Each study was examined on an individual basis to determine how habitat had been defined and quantified. Two criteria were used to determine whether a given study was subsequently included in our results section. Firstly, the given study had to include a variable that had a potential effect on description of habitat. This premise meant that any environmental, biological, physical, chemical, spatial or temporal factor related to habitat could potentially be considered as a habitat variable. In addition, factors that drove movement were also listed here due to their inherent influence on distribution and consequent habitat used by cetaceans. Examples of factors influencing movement included migration pathways, avoidance of areas of high boat traffic and attraction to areas of increased feeding opportunity. Secondly, when a study was deemed to include a habitat-related variable it was then confirmed whether the variable had been directly quantified during the course of the study. A variable was considered quantified if it was directly measured via in-situ field measurements (e.g., water temperature, salinity and turbidity), referenced from in-field GPS locations via remote sensing or detailed reference maps (e.g., distance from shore, chlorophyll *a* concentration and water depth), classified via a pre-determined criteria (e.g., distinct habitat types such as seagrass or bare sand substrate), or counted in a consistent manner (e.g., number of boats in a given area over a specific time frame).

The above criteria precluded inclusion of studies that referred only to location or population bounds rather than a habitat related component of these factors. However, special consideration was given to studies in which feeding, breeding, migration and calving were observed as these behaviours could potentially be correlated with a given habitat, and therefore deemed important drivers of spatial and temporal distribution. In some instances it was found that although variables were measured according to study design no analysis of these variables was reported. These studies were therefore excluded. Numerous studies discussed the implications of their findings in relation to habitat, yet if these factors were not specifically measured during the study they were omitted also. Each study was considered on an individual basis yet it is possible there are omissions due to interpretation as well as difficulty in sourcing all relevant studies. Hence, this paper is not presented as an exhaustive listing of cetacean habitat studies in Australia but rather a discussion and analysis of how habitat has been defined and quantified in this region. Selected studies were tabulated and categorized according to species studied, location of study, and habitat variables measured.

Table 1. Conservation status of cetacean species found in Australian waters

Species	IUCN (2006)	Bannister et al. (1996)	Ross (2005)
Eubalaena australis	LR/cd	V	
Balaenoptera acutorostrata	LR/nt	NCA (a)	
Balaenoptera acutorostrata bonaerensis		S	
Balaenoptera borealis	EN	V	
Balaenoptera edeni	DD	NCA (a)	
Balaenoptera musculus	EN	EN	
Balaenoptera musculus brevicauda		NCA (a)	
Balaenoptera physalus	EN	V	
Megaptera novaeangliae	VU	V	
Caperea marginata	LR/lc	NCA (b)	
Delphinus delphis	LR/lc	NCA (b)	*
Globicephala macrorhynchus	LR/cd	NCA (b)	*
Globicephala melas	LR/lc	NCA (b)	*
Grampus griseus	DD	NCA (a)	*
Lagenodelphis hosei	DD	NCA (a)	*
Lagenorhynchus cruciger	LR/lc	NCA (b)	*
Lagenorhynchus obscurus	DD	NCA (a)	*
Lissodelphis peronii	DD	NCA (b)	NCA (a)
Orcaella heinsohni			
Orcinus orca	LR/cd	NCA (c)	NCA (b)
Peponocephala electra	LR	NCA (a)	NCA (b)
Pseudorca crassidens	LR/lc	NCA (a)	NCA (b)
Sousa chinensis	DD	K	*
Stenella attenuata	LR/cd	NCA (a)	*
Stenella coeruleoalba	LR	NCA (a)	*
Stenella longirostris	LR	K	*
Steno bredanensis	DD	NCA (a)	*
Tursiops aduncus	DD		NCA (a)
Tursiops truncatus	DD	NCA (a)	NCA (b)
Phocoena dioptrica	DD	NCA (a)	*
Kogia breviceps	LR/lc	NCA (a)	NCA (b)
Kogia sima	LR/lc	NCA (a)	*
Physeter macrocephalus	VU	K	
Berardius arnuxii	LR/cd	NCA (b)	*
Hyperoodon planifrons	LR/cd	NCA (b)	*
Indopacetus pacificus		NCA (a)	
Mesoplodon bowdoini	DD	NCA (a)	*
Mesoplodon densirostris	DD	NCA (a)	*
Mesoplodon ginkgodens	DD	NCA (a)	*
Mesoplodon grayi	DD	NCA (b)	*
Mesoplodon hectori	DD	NCA (a)	*
Mesoplodon layardii	DD	NCA (b)	*
Mesoplodon mirus	DD	NCA (a)	*
Tasmacetus shepherdi	DD	NCA (a)	*
Ziphius cavirostris	DD	NCA (b)	*

* Conservation status is the same as Bannister *et al.* (1996)

IUCN categories： Extinct *EX*, Near Threatened NT, Extinct in the Wild, *EW*, Least Concern *LC*, Critically Endangered *CR*,, Data Deficient *DD*, Endangered *EN*, Not Evaluated *NE*, Vulnerable *VU*

Bannister et al. (1996) and Ross (2005) conservation status categories： Endangered *EN*, vulnerable *V*, insufficiently known *K*, No category assigned because of insufficient information *NCA* (*a*), No category assigned, but possibly secure *NCA* (*b*), No category assigned, but probably secure *NCA* (*c*)

3. Results

Twenty–four cetacean habitat studies were further analyzed for their method of habitat description (Table 2). Most of these studies were reported from Western Australian and Queensland waters, with bottlenose dolphins (*Tursiops* sp.) being the most frequently studied species. In total, research involving nine different species were noted to have incorporated quantitatively defined habitat variables, specifically: southern right whale (*Eubalaena australis*), sei whale (*Balaenoptera borealis*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), Indo–Pacific humpback dolphin (*Sousa chinensis*), common bottlenose dolphin (*Tursiops truncatus*), Indo–Pacific bottlenose dolphin (*Tursiops aduncus*) and the Australian snubfin dolphin (*Orcaella heinsohni*). The habitat variables measured within these studies included: water depth, sea surface temperature, salinity, dissolved oxygen, turbidity, pH, phytoplankton biomass, distance to land, distance to freshwater, Euclidean distance to habitat type, bathymetry and thermal fronts. In addition, factors deemed to drive distribution included human influences (the presence of tourism vessels, aquaculture and fisheries), migratory routes and calving areas, and the presence of both predators and prey. In several cases, additional analyses into home range, seasonal movement, residency, genetics and site fidelity were investigated concurrently.

4. Discussion

Despite strong recommendations from national reviews (Bannister *et al.* 1996, Ross 2005) cetacean habitat has only been considered on a relatively limited basis within cetacean research projects conducted in Australian waters. A greater understanding of cetacean distribution, behaviour and migration patterns' in the context of their habitat and environment would not only provide insight into the ecology and life history of a given species, but would also enable more effective ecosystem protection and mitigation of potential threats. This current lack of information presents an obstacle towards cetacean conservation efforts in Australia.

However, some exceptions are apparent. In far north Queensland environmental correlates (distance to land, distance to river mouth, and water depth) were examined in relation to the spatial distribution of Australian snubfin (*Orcaella heinsohni*) and Indo–Pacific humpback dolphins (*Sousa chinensis*) (Parra *et al.* 2006). Findings from this work indicated that both of these species demonstrated a preference for near–shore, estuarine waters. In discussion the authors noted that these same areas were subject to potentially threatening fishing nets and therefore suggested regulation of such activities in those near–shore, estuarine waters that had been identified as important cetacean habitat. In Shark Bay, Western Australia, behavioural studies on Indo–Pacific bottlenose dolphin (*Tursiops* sp.) populations documented reactions such as changes in spatial positioning within groups and irregular swimming behaviour in response to boat traffic (Bejder *et al.* 2006a). Although the level of boat traffic could not be correlated with the relative occurrence or absence of a response, a complementary study inferred that the cumulative impact of boat traffic over the longer–term could be linked to changes in overall population numbers (Bejder *et al.* 2006b) and therefore a change in habitat used by these impacted individuals. In response to these findings, the scientific committee of the International Whaling Commission recommended protection of these populations (IWC 2006). Consequently the Western Australian government reduced the number of tourism licenses operating in proximity to this population of bottlenose dolphins (IWC 2007).

The quantification of appropriate factors and variables to describe cetacean habitat presents unique challenges as it necessarily requires the measurement of factors such as changing prey fields, modulating species assemblages, and dynamic marine ecosystems. These oceanographic processes and properties can vary on distinctive spatial and temporal scales, and may be intermittently independent or correlated with one another (Ricklefs 1993, Garrison 1998, Redfern *et al.* 2006). Additional variables such as boat traffic and

Table 2. Examples from Australian cetacean studies of quantified environmental variables and factors measured in relation to species' distribution.

Common name	Location	Environmental habitat variables	Reference
Common bottlenose dolphin, Indo-Pacific humpback dolphin	Moreton Bay, QLD	Water depth, distance from shore	Corkeron (1990)
Irrawaddy dolphin	QLD coast	Distance to land, freshwater	Parra *et al.* (2002)
Humpback whale	Hervey Bay and Whitsundays, QLD	Sea surface temperature, depth, GPS location, calving areas, migrational routes	Forestell *et al.* (2003)
Snubfin dolphin, Indo-Pacific humpback dolphin	Cleveland Bay, QLD	Sea surface temperature, location to habitat type, bathymetry	Parra (2005)
Bottlenose dolphin	Port Adelaide, SA	Water depth, water temperature, total dissolved solids, dissolved oxygen, turbidity, pH, distribution according to habitat type	Cribb (2006)
Snubfin dolphin, Indo-Pacific humpback dolphin	Cleveland Bay, QLD	Water depth, Euclidean distance to habitat type (reef, seagrass, dredged channel)	Parra (2006)
Snubfin dolphin, Indo-Pacific humpback dolphin	Cleveland Bay, QLD	Distance to land, river mouths, water depth	Parra *et al.* (2006)
Bottlenose dolphin	Bunbury, WA	Water depth, temperature, turbidity/visibility, presence of vessels, home ranges, seasonal movement, residency, site fidelity, demography	Smith (pers. com.)
Southern right whale	Doubtful Island Bay, WA; Warrnambool, VIC; Head of Bight, SA Australian calving grounds	Distance from shore, position long-shore, depth, slope, substrate, breeding status, group type, behaviour, exposure, sinuosity, substrate, tidal range	Pirzl (pers. com.)
Pygmy blue whale	Bonney Upwelling, SA	Coastal upwelling, krill presence	Gill (2002)

Common Name	Location	Variable defining distribution	Reference
Bottlenose dolphin	Moreton Bay, QLD	Presence of predators	Corkeron *et al.* (1987)
Humpback whale	Stradbroke Island, QLD	Migrational routes	Paterson (1991)
Bottlenose dolphin	Tangalooma, QLD	Presence of feeding station	Orams (1995)
Various species	Shark Bay, Ningaloo Reef and Exmouth Gulf, WA	Sea surface temperature, abundance and distribution	Preen *et al.* (1997)
Bottlenose dolphin	Shark Bay, WA	Reproductive success, water depth, temperature	Mann *et al.* (2000)
Humpback whale	WA coast	Temporal and geographic movements according to migration	Jenner *et al.* (2001)
Bottlenose dolphin	Shark Bay, WA	Prey abundance, shark presence	Heithaus and Dill (2002, 2006)
Humpback whale, Southern right whale, blue whale, fin whale, sei whale	National	Aggregation areas for calving, resting, feeding, migratory pathways	Department Of The Environment And Heritage (2005 a,b,c)
Bottlenose dolphin	Shark Bay, WA	Aquaculture presence	Watson-Capps and Mann (2005)
Bottlenose dolphin	Shark Bay, WA	Vessel effect on abundance	Bejder *et al.* (2006b)
Bottlenose dolphin	Shark Bay, WA	Use of habitat in relation to vessel exposure	Bejder *et al.* (2006a)

Note: Irrawaddy dolphin listed by Parra *et al.* (2002) would now be described as a snubfin dolphin (Beasley *et al.* 2005) construction may also have an impact on cetacean distribution, as do individual factors such as species, age–class, geographic location and conservation status. Given this complexity and flexibility it is appropriate that the definition and measurement of cetacean habitat be considered in an open and objective way and on a case–by–case basis to ensure all necessary factors have been accounted for. However, it is also imperative that investigations into cetacean habitat be quantified in such a manner as to allow appropriate inferences and management advice to be rendered if required.

The importance of habitat has been recognized by conservation initiatives that strive to progress protection mechanisms for cetaceans, their habitats and associated ecosystems (HOYT 2005, SOUTH AUSTRALIAN DEPARTMENT OF ENVIRONMENT AND HERITAGE 2006). Furthermore, there is global scientific support for recommendations regarding threat mitigation in instances of incomplete species understanding (REEVES *et al.* 2003, CMS 2006). Given these noted concerns it is necessary to place priority on quantifying habitat in cetacean research studies. It is therefore timely and necessary that in Australian waters useful investigations into cetacean habitat are prioritized, and in instances of limited baseline knowledge a risk–averse approach to habitat protection and threat mitigation is progressed.

Acknowledgements

The authors would like to thank M. BOSSLEY, P. BRAKES, W. FERRELL, E. HOYT and M. SIMMONDS for providing comment on an earlier draft of this paper.

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Received: August 13, 2008
Accepted: October 22, 2008

La mer 46 : 85–96, 2009
Société franco-japonaise d'océanographie, Tokyo

Cephalic Appendage Motion during Swimming of a Calanoid Copepod, *Subeucalanus crassus* (Giesbrecht, 1888)

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Abstract: The swimming behavior of *Subeucalanus crassus* was observed by video equipment, with focus on 3-dimensional motions of the cephalic appendages. High-speed recordings showed that only the rotation of the 2nd antennae (A2) and the mandibular palp (MP) contributed to propulsion for typical swimming, jerky swimming, and hovering. During typical swimming, both appendages rotated at a frequency ranging 70–80 Hz with the maximum rotation angle of 90°. During hovering, the frequency of appendages ranged 60–70 Hz with the maximum rotation angle of 45°. Sinking was accomplished by horizontal spreading of the motionless 1st antennae, A2 and the MP, while being pulled posteriorly by gravity. Previous observations of *S. crassus* behaviors from Australian and off Georgia waters could not be confirmed by the present observation on *S. crassus* from Sagami Bay suggesting that the latter represents a different species or a behaviorally differentiated population.

Keywords: *Eucalanidae, hovering, swimming, sinking, cephalic appendages*

Introduction

Copepods are the most abundant metazoan plankton in the ocean and their behaviors are fundamentally important for their existence in the food chain and ecosystem interactions. JIAN *et al.* (2002) compiled an overview of copepod species behaviors and general propulsionary appendage usage. Species specific or taxon specific behaviors and methods for feeding and swimming are important for prey detection, predator avoidance, and mate recognition (JIAN *et al.*, 2002; LOWNDES, 1935; STRICKLER, 1982).

The family Eucalanidae have a world-wide distribution (BOLTOVSKOY, 1999; BRADFORD-GRIEVE, 1994; LANG, 1965) and were used for some of the first feeding studies (ESTERLY, 1916) and repeatedly used for optical recording studies (ALCARAZ *et al.*, 1980; PAFFENHÖFER and LEWIS, 1989; PAFFENHÖFER *et al.*, 1982; STRICKLER, 1982, 1985) taking advantage of their large and robust bodies. *Subeucalanus crassus* has exhibited the following basic behaviors in the laboratory, while unrestrained: swimming to the surface, then sinking to the bottom, jagged and backward swimming, and remains suspended in the water for prolonged periods of time (STRICKLER, 1982). Previous behavioral studies on tethered *S. crassus* have concentrated on feeding currents (JIANG *et al.*, 2002) and prey selection (ALCARAZ *et al.*, 1980; PAFFENHÖFER *et al.*, 1982; PRICE and PAFFENHÖFER, 1986). However, the role of appendages involved in achieving different propulsionary or feeding methods has not been well addressed.

LOWNDES (1935) observed the motions of the cephalic appendages of various calanoid copepods such as *Calanus finmarchicus* and *Diaptomus gracilis*. He took particular notice of the 2nd antennae (A2) and how it rotates from a vertical position to a horizontal position. Recent 3-dimensional analyses have focused on the appendages used during feeding, such as the 1st maxilla (M1), 2nd maxilla (M2) and maxilliped (MX) (STRICKLER, 1984), and

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the 3-dimensional flow field around a copepod have examined (FIELDS and YEN, 1993; JIANG *et al.*, 2002). However, despite the availability of advanced optical technology, recent studies have not examined 3-dimensional movements of the A2 and the MP, which are involved in prey capture, ingestion and locomotion by creating currents.

For better understanding of the feeding behavior of copepods, the present study aimed to re-examine the swimming behaviors of *S. crassus* with particular reference to the movements of the cephalic appendages as propulsionary or food collecting apparatuses, using a simple high-speed camera set up. In this paper, the precise movements of the cephalic appendages, particularly the A2 and the MP during swimming are re-described.

Methods

Collection and Culture

During cruises on the training and research vessel Seiyo Maru of Tokyo University of Marine Science and Technology, female *S. crassus* were collected year round at a fixed station (35° 00' N 139° 20' E) in Sagami Bay, Japan. Vertical tows from 300 m depth were conducted during the daytime with a NORPAC net (45 cm diameter with 330 μm mesh), and copepods were sorted live with pipettes and stored in 1 L or 125 mL containers filled with cooled surface seawater. The containers were kept in insulated coolers and maintained at approximately 10℃. On land, copepods were maintained at 15℃ and re-sorted into glass containers, 1 animal per 250 mL of filtered seawater (Whatman GF/F), and fed a mixed diet of flagellates, *Isochrysis galbana* and *Tetraselmis* sp. (both less than 5 μm in diameter) and diatoms, *Chaetoceros* sp. (approximately 10 μm in width per individual cell), *Coscinodiscus wailesii* (160–350 μm in diameter), *Eucampia zodiacus* (approximately 15 μm width per individual cell), and *Thalassiosira weissflogii* (approximately 13 μm in diameter per individual cell).

Non-tethered filming and calculations

Non-tethered copepods were placed in a 1 L rectangular acrylic container (20.5×12.5×4.5 cm), in a 15℃ room in filtered seawater, under room light conditions. Copepods were filmed with and without food against a white background with an ordinary video camera (NVGS500, Panasonic, Japan). Eye observations were made on a daily basis for newly caught animals for a period of 7 days. Filming and observations of free swimming animals were made with the lens axis parallel to the horizon. Prey items were gently pipetted into the experimental chamber and evenly distributed by gentle pipetting. Concentrations were not recorded, as our purpose was to observe the feeding behavior. Prey items were added singly and as various mixtures to encourage the copepods to alter their behavior. Copepod feeding and food selection observations will be published elsewhere. Swimming and sinking velocities were calculated by importing the video data into the Adobe Professional Video Collection software where a grid of 1 mm lines was superimposed on the image to measure the ani mals' velocities. Only clear images of copepods swimming or sinking for at least 1 s in a linear line were used. The time in seconds was provided from the date/time stamp of the original recording device.

Tethered filming and calculations

Adult female copepods were kept overnight in the experimental room, without food. Copepods were then tethered to a hair by fast acting adhesive (Aron alfa, TOA, Japan). Wild grizzly bear hair of approximately 1 cm in length was used after being washed and rinsed with deionized water, and then acetone. One end of the hair was glued to the dorsal side of the copepods carapace and the opposite end was glued to a piece of gold wire, with a diameter of 1 mm; which was connected to the rod of a micromanipulator (UB-K, Kanetec, Japan). The tether for *S. crassus* was similar to that as described by ALCARAZ *et al.* (1980), although the tether was only attached to the dorsal cephalosome.

Previous observations used dog hair as the tether (ALCARAZ *et al.*, 1980; BUNDY and PAFFENHÖFER, 1996; COWLES and STRICKLER, 1983; PAFFENHÖFER *et al.*, 1982). However pet hair was found to be inadequate for this study as it was too brittle and copepods quickly died, probably from the release of a contaminant into the water. An assortment of wild Canadian animal hairs were tried with a variety of problems; hairs being too flexible or brittle, too narrow or thick. Canadian grizzly bear (Arctoidea; *Ursus arctos horribilis*) hair was found to be adequate for tethering. Grizzly hair, approximately 200 μm in diameter is strong, sturdy, and is flexible enough that the copepod could jump and was slowly returned back to the focal position with minimal stress.

A high-speed digital video camera (Fastcam-net from Photron, Japan) was mounted on top of a dissecting microscope (SZX12, Olympus, Japan) with light provided by a Cold Spot fiber optic (PCS-UMX250, NPI, Japan). Tethered copepods were kept in a 550 mL ($14.5 \times 9.0 \times 6.0$ cm) rectangular acrylic container of filtered seawater for a minimum of 1 hour before digital recording. All instruments used for filming were placed on a 1 - cm thick black-painted iron plate with stabilizing mat to reduce vibrations. Animals were rotated around the behavior of interest at approximately 5° increments by micromanipulator to allow repositioning of the copepods without jarring or shaking. The process was repeated for each new position observed, and the animal was rotated until the limit of the equipment had been reached. Digital images were examined using the Adobe Professional Video Collection and the Adobe Premium Creative Suite. The appendage rotation frequency (Hz) was calculated by analyzing 1 s of high-speed video recordings.

S. crassus general body schematic, appendage structure, tether construction, notational and directional terms used for figures and photos are shown in Fig. 1. All the appendages have hairs or spines (setae) on them, which have only been drawn on the A2 and MP. The setae are covered with even smaller, finer hairs (setules), only included on the A2 exopod for reference.

Taxonomic verification of *S. crassus* was based on the re-description of *Eucalanus crassus* by MORI (1937) and confirmed against the integumental pore signatures from the Atlantic (FLEMINGER, 1973) and New Zealand waters (BRADFORD-GRIEVE, 1994). The *S. crassus* from Sagami Bay was also covered with small spinules reported on those from New Zealand by BRADFORD-GRIEVE (1994).

Results

Non-tethered Swimming Modes

The copepods, during swimming, oriented vertically with the A1 spread outward, which is characteristic of calanoid copepods (LOWNDES, 1935). "Swimming" in the present paper is defined as the active movements of the copepod relative to the water. Swimming was further subdivided into the following four swimming modes. 1) Typical swimming: active and smooth propulsion through the water. 2) Hovering: extremely slow linear upward swimming. 3) Jerky swimming: active shift of location by the urosome movement. 4) Escape: active, sudden, short-lived, erratic propulsion. Sinking was excluded from swimming modes as it was the passive downward movement due to gravity, with no movements of body parts or appendages. Sinking was done by spreading the A1, A2 and MP out much like a parachute allowing gravity to pull the animal downwards. Once the appendages were spread, no appendages were observed to actively move and the urosome was positioned dorsally.

In filtered seawater without food, copepods showed repeated linear sinking and swimming, as well as random smooth looping patterns, which was also included in typical swimming. During linear swimming and sinking sessions of six individuals, swimming speeds of 0.43-0.90 cm s^{-1} and sinking speeds of 0.48-1.60 cm s^{-1} were observed. Typical swimming mode was used to swim to the surface, as was verified by eye and video recordings by use of the A2, and MP. Looping speeds were observed by eye to be quick, but could not be measured due to the a nimals' 3-dimensional motions and our methods. The urosome was positioned dorsally for both typical swimming and sinking, but its movements could only be observed by eye when the animal moved linearly. Any of the small diatom species (*Chaetoceros* sp., *E. zodiacus* and *T. weissflogii*) added to the chamber media resulted in the copepods swimming mode to change. There was no difference between the feeding modes of copepods fed single diatom species and those fed mixtures of more than

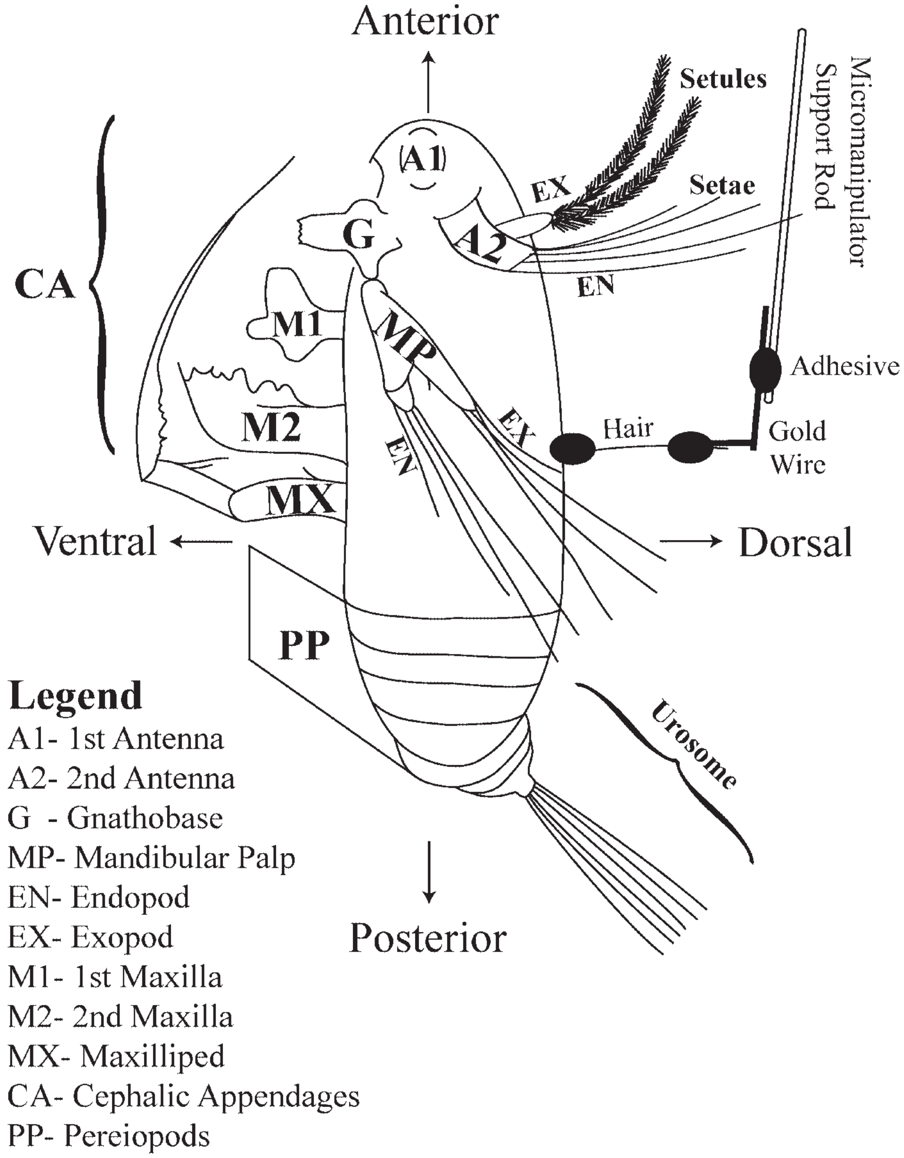

Fig. 1. The basic schematic of a female *Subeucalanus crassus* in a typical tethered position, with general appendage placement, tether construction, direction and notation legend. Diagram is not to scale.

one species. When the diatoms had been found by the copepod, the animals switched from typical swimming mode to the hovering mode and remained within the food area by maintaining a constant slow speed of 0.14 cm s^{-1}. Only when fed the large diatom *C. wailesii*, which sank when introduced, did the copepod swim to the surface in a jerky manner. The jerky swimming was attributed to the dorsal-ventral flicking of the urosome, which was easily observed by eye. The A2 and MP behaved in the same way as observed for typical swimming. The main propulsion for typical swimming, hovering and jerky swimming were observed to be created by the movement of the A2 and MP.

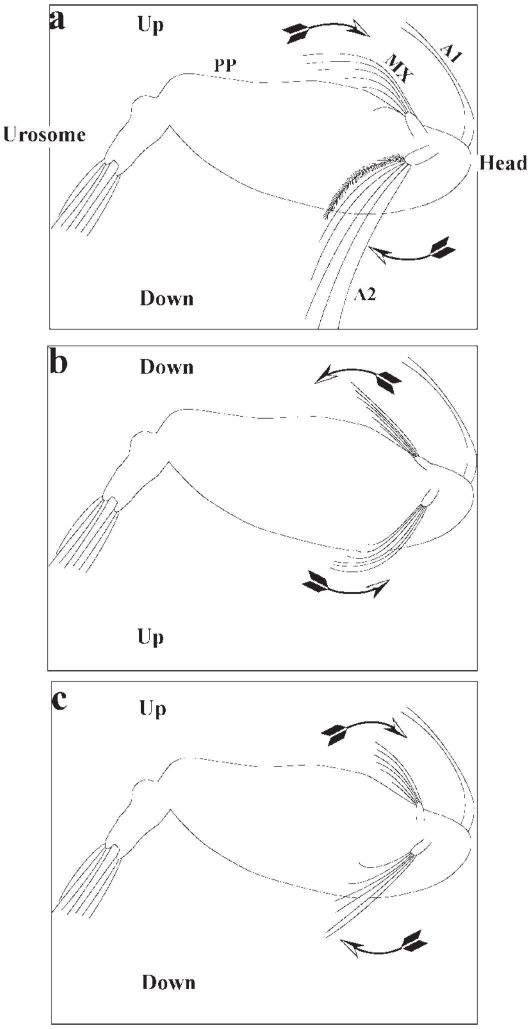

Fig. 2. Left side of a female *Subeucalanus crassus* typical swimming schematic sketches, when unfed. The animal is tethered horizontally, lying on its side with the filming lens axis at a 45° angle to the body. The arrows indicate the appendage stroke direction for the 2nd antennae (A2) and the mandibular palp (MP). See text for details.

Tethered Swimming Modes

High speed video images showed two distinct movements of the cephalic appendages, which corresponded to "typical swimming" and "hovering." At first there seemed to be no noticeable difference between typical swimming and hovering. The urosome was positioned dorsally during both of these swimming modes. The present description of the cephalic appendages is limited to the A2 and the MP, as the M1, M2 and MX were not observed to contribute to swimming modes, but become active during prey capture and ingestion, which will be published elsewhere. The left and right A2 and MP rotated in the same elliptical motion during typical swimming and hovering modes, and their endopods and exopods moved through the water much like oars on a row boat.

Typical Swimming Mode

Typical swimming was observed when the copepod was tethered and unfed with a stroke-frequency range of the A2 of 70-80 Hz, where only the A2 and MP were found to move. The animal was positioned with the left side of the cephalic appendages slanted 45° towards the lens axis while the body was parallel to the horizon. This position allowed the left side appendages to remain in focus. From sequential digital images recorded at 250 frames s^{-1} for a total duration of 0.032s, 3 photos were extracted every 0.016s to create schematic sketches demonstrating the change in appendage motions (Fig. 2). Fig. 2a shows the MP during the up-stroke with setae bending posteriorly and the A2 during the down-stroke with spread setae. The setae of the MP in Fig. 2b is almost straight, as it is about to change direction from an up-stroke to a down-stroke, while those of the A2 are bending posteriorly during the up-stroke. Both the MP and A2 are about to turn and change direction in Fig. 2c. As the A2 beats down, the MP is coming up and vice versa, creating a rotary pattern, which does not rotate in unison, giving a constant thrust.

A slight change in angle allowed the endopods and exopods motions of the MP position in the water column to be observed. The animal was tethered perpendicular to the horizon and the lens axis was mounted directly above. From sequential digital images recorded at 250 frames s^{-1} for a total duration of 0.044 s, 3 photos were extracted at intervals of 0.024 s and 0.020 s, demonstrating the change in appendage motions and accompanied by schematic sketches (Fig. 3). A relaxed appendage occurred when setae were evenly spaced with the tips pointing in the same direction, as illustrated by the A2 in Fig. 3a. The up-stroke is

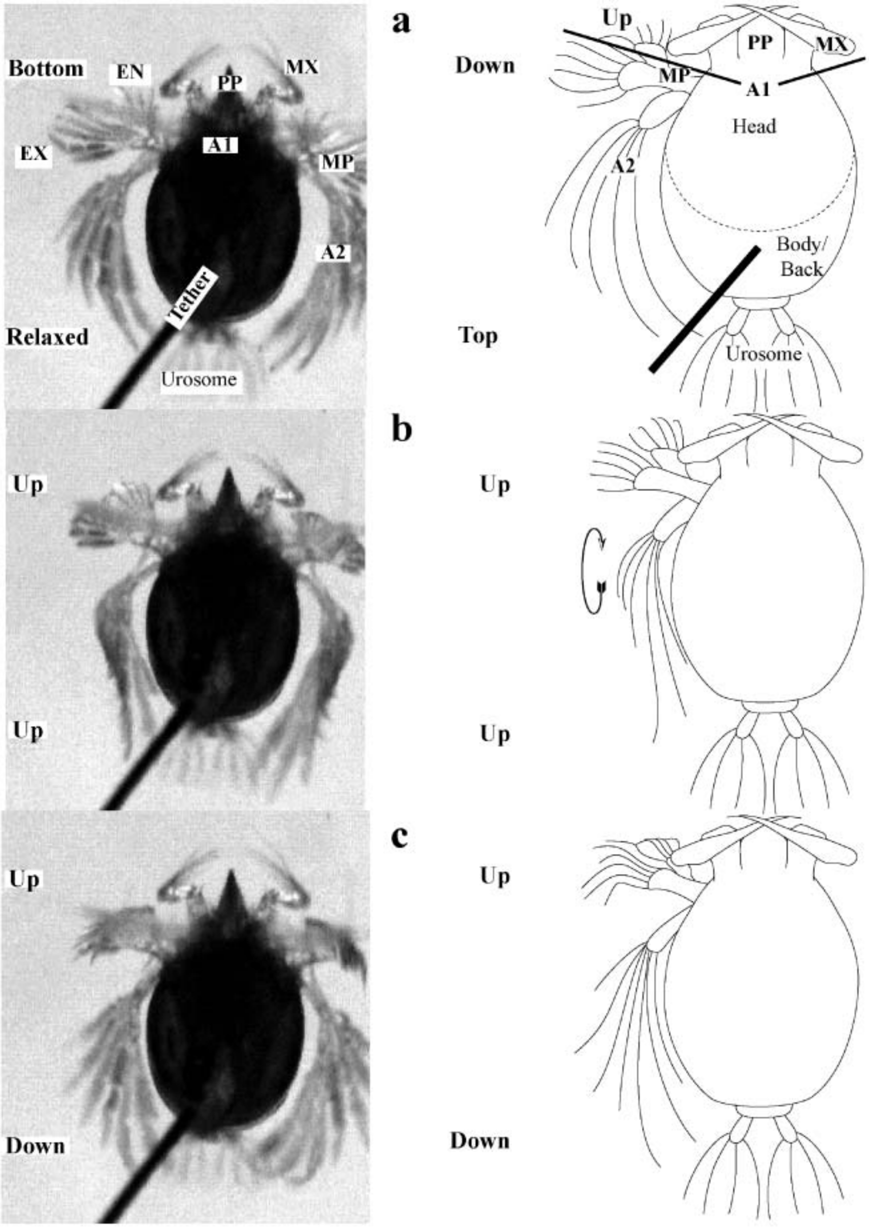

Fig. 3. Typical swimming photos and schematic sketches of a female *Subeucalanus crassus*, when unfed. The animal is vertically tethered with the lens axis located above the head. Circles with arrows represent the stroke direction of both the 2nd antenna (A2) and mandibular palp (MP) on each side of the animal in (b). See text for details.

where all the setae become pushed together; as the appendage is pulled through the water (refer to the A2 in Fig. 3b). The down-stroke is shown by the A2 in Fig. 3c, the setae are spread further apart and no longer point in the same direction as they are being pushed through the water.

The A2 and MP of the left side rotates as a mirror image of the right side (Fig. 3b: arrows). The MP endopods and exopods also exhibit a rotary motion. In Fig. 3a, the MP is almost at the bottom of its stroke as the

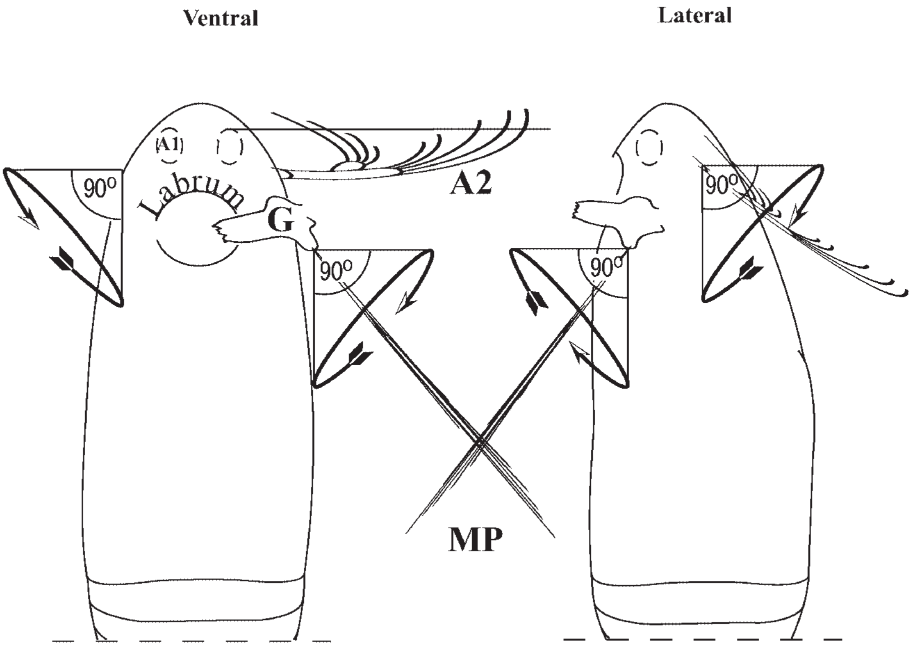

Fig. 4. Schematic ventral and lateral view of the left side of *Subeucalanus crassus* mandibular palp (MP) and 2nd antennae (A2) during typical swimming, unfed. The MP pivots around the gnathobase (G) joint within a 90° circular motion, as does the (A2), whose angle references is on the right side of the front view.

endopod is just turning and starting to come up to the anterior endopods of the stroke, while the exopod remains in the down-stroke. The same motion is also exhibited by the A2 and its associated endopods and exopods.

Both the A2 and MP are angled away from the body during typical swimming. Animals constantly adjust the stroke angle within a maximum appendage rotation of 90° as seen in Fig. 4. The setae lagged behind and trailed beyond the 90° maximum. When the copepod was tethered perpendicular to the horizon the angled stroke pattern of the A2 and MP appeared to give the animal lift as it pulled against the tether.

Hovering Mode

Hovering photos were taken when food was present and the animal was first positioned perpendicular to the horizon and then slanted 45° towards the right to allow the left side of the cephalic appendages to be observed. The copepod changed the A2 and MP stroke frequency to 60–70 Hz, and also changed the path of the appendage rotation. From sequential digital images recorded at 250 frames s^{-1} for a total duration of 0.044 s, 3 photos were extracted at intervals of 0.024 s and 0.020 s demonstrating the change in appendage motions (Fig. 5). The A2 (left panel) and a magnified view of the same A2 motion (right panel) are shown. The endopod of the A2 was rotating in the ventral direction on the ventral side of the A1, while the exopod is rotating dorsally on the dorsal side of the A1. Both follow horizontal elliptical paths which remain in the focal plane most of the time (Fig. 5a). Fig. 5a also shows the A2 endopod to be completing its up-stroke, with the exopod beginning its down-stroke. The down-stroke of the exopod can be seen in Fig. 5b, while the endopod is being pulled upward. Both the endopod and the exopod are reaching a turning point in Fig. 5c. The setae of the endopods aligned perpendicular to the horizon and the exopod has reached its lowest point, with the setae trailing behind. The magnified photos of the A2 exopod (Fig. 5c) show the left and right motions relative to the animals' body as well as the exopods turning to the side with the setae aligning parallel to the body for a directional change. Fig. 6 shows generalized

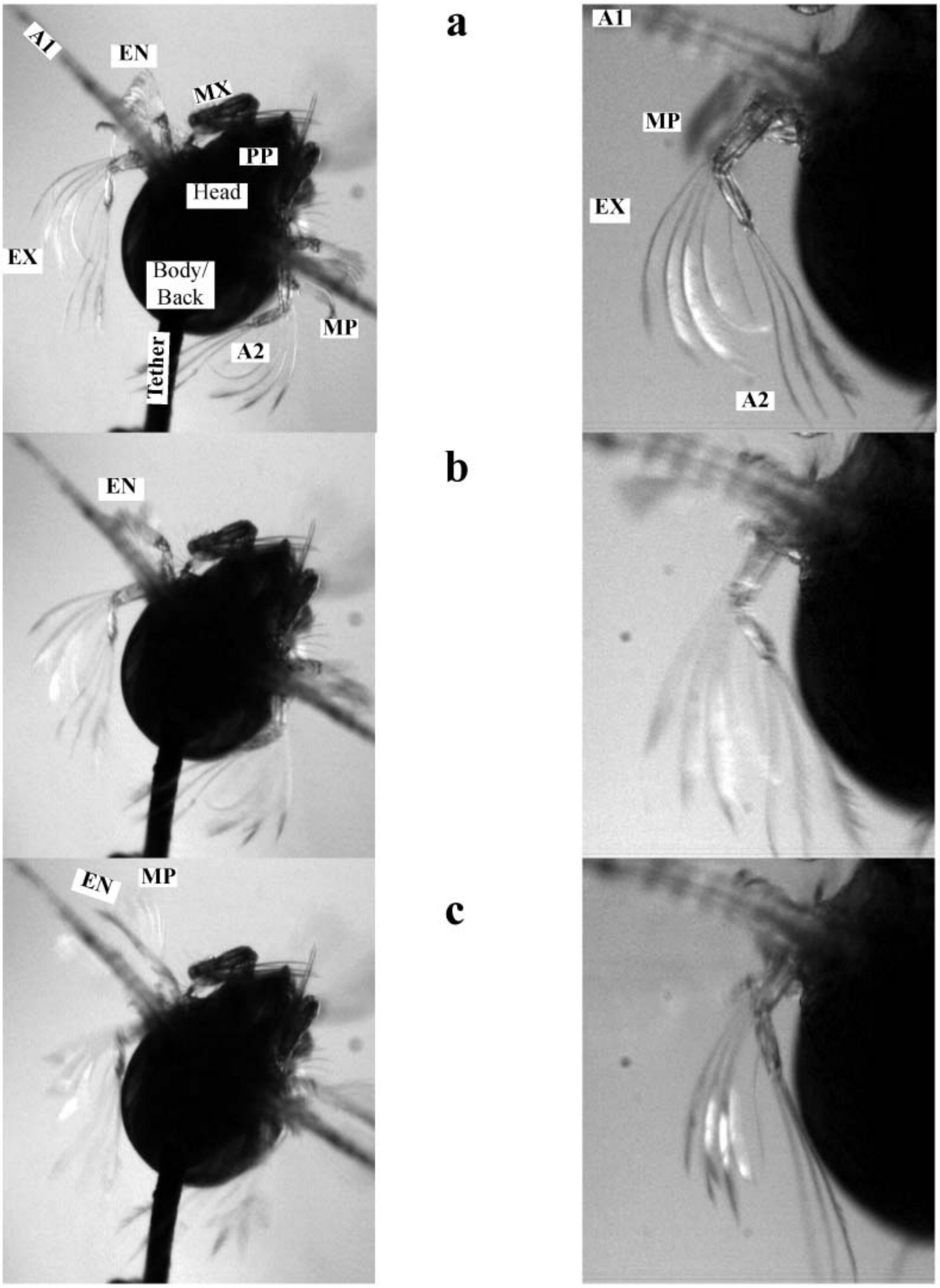

Fig. 5. Photos of the hovering behavior of the 2nd antennae (A2) and mandibular palp (MP) of a female *Subeucalanus crassus*, fed. The copepod is tethered vertically and tilted horizontally 45° angle to the right, with the lens axis located above the head. See text for details.

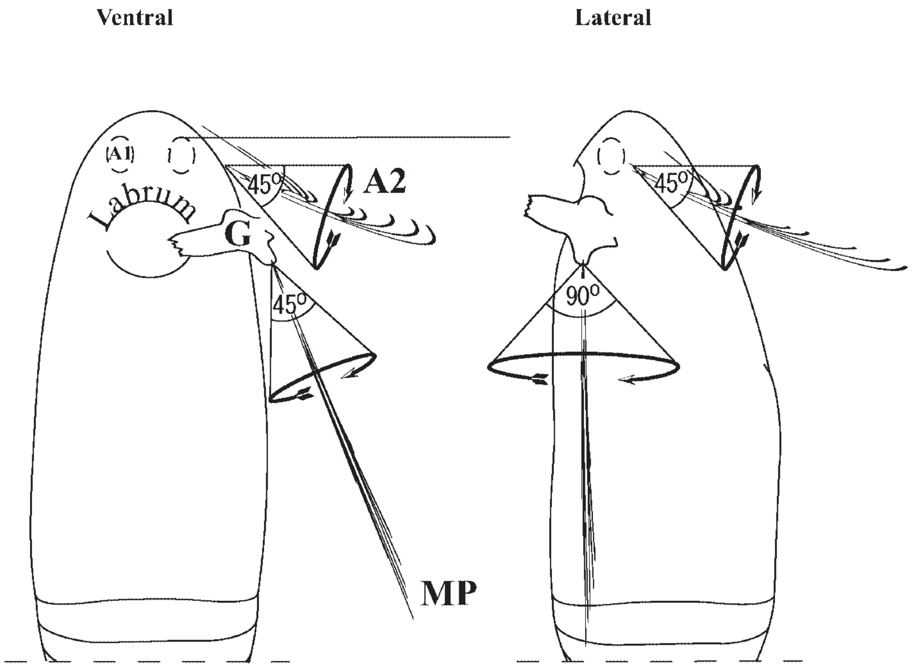

Fig. 6. Schematic ventral and lateral view of the left side of *Subeucalanus crassus* mandibular palp (MP) and 2nd antennae (A2) while hovering, fed. The MP pivots around the gnathobase (G) joint within a 45° elliptical motion and the A2 pivots around the joint at a 90° circular motion.

ventral and lateral sketches of this behavior mode, in which both the A2 and MP still contain a rotary action, but the MP stroke shifted posteriorly and gave the copepod a vertical thrust. The A2 endopod rotated horizontally in the dorsal direction with the exopod being raised anteriorly above the endopod. When tethered perpendicular to the horizon, the animal appeared to be balanced as it did not pull away from the tether and the urosome remained in the dorsal position.

Escape Mode

While tethered, this escape mode was very erratic and usually resulted in death or escape from the tether. During tether acclimation, the copepod would flick the urosome and the A1 although it was unclear if this mode was due to unusual disturbances or foraging attempts. Once the animal acclimated to the tether, the urosome jerking was rarely observed on 20 animals of 23 filmed. However, 3 of the animals constantly flicked the urosome and exhibited escape mode, resulting in quick exhaustion and death, as also observed by STRICKLER (1982) on *S. crassus*. Once adjusted to the tether, escape mode was only observed in response to external disturbances, such as large vibrations or jarring caused by adjusting nearby equipment. The A2 and MP held close and parallel to the body; the A1 was pulled into the center of the body and were held in place with the MX, while the pereiopod (PP) moved rapidly. The actual stroke beat of the PP involved in this mode could not be observed and no cephalic appendages were observed to contribute to the copepods thrust, as it is beyond the scope of our equipment.

Discussion

Three dimensional movements of the cephalic appendages have been historically difficult to study, but accepted as a means for propulsion through the viscous ocean environment (HUTCHINSON, 1967; JIANG *et al.*, 2002; STRICKLER, 1984). CANNON (1928) originally studied a copepod in a drop of water, as a restraint was needed to observe the fine movements of the animal. LOWNDES (1935) employed various techniques in an attempt to observe the 3-dimensional movements of the appendages, as well as inferences from larger visible unrelated crustacean analogs *Chirocephalus* (fairy shrimp). An overview of a single animal requires the assembling of several papers utilizing different study methods and techniques (Jiang *et al.*, 2002). Recent optical technology has not been used for the observations of 3-dimensional movements of cephalic appendages on a single species.

Precise high-speed recordings of *S. crassus* appendage motions showed 3-dimensional stroke angles during typical swimming and hovering. Typical swimming copepods were found to have an elliptical rotation of 90° for both the A2 and MP in Fig. 2, creating the downward force that propels the copepod through the water. During hovering, the right and left MP rotated much like a set of egg beaters (two beaters on electric hand mixers). The A2 rotated dorsally at 45° and the MP at a 45° posterior orientation resulting in a reduced posterior elliptical angle (Fig. 6). The mechanisms for the creation of differing behavior modes were attributed to the reorientation of the appendage rotational angles and changing of stroke frequencies.

Typical swimming behaviors were exhibited by our non-tethered and tethered animals. Only the A1, A2, MP, PP and the urosome movements were observed on non-tethered animals. When *C. wailesii* was introduced, the copepod would use the jerky swimming mode to ascend to the surface. When cells were encountered, the animal would hover, assumably taking time to ingest the item. The animal would also swim in a jerky line to the surface to capture closely spaced cells, as also noted by Strickler (1982), and the behavior was attributed to flicking of the urosome. Jerky swimming was a modified version of typical swimming, as the only difference was the use of the urosome for steering. Non-tethered animals used a combination of typical swimming, hovering and sinking behaviors to search for prey. Tethered *S. crassus* with small phytoplankton in the media behaved as though the animal were actively remaining in areas of food.

The A2 and MP were the main active propulsionary appendage for typical swimming, jerky swimming and hovering, and were used passively as parachutes during sinking. The combined rotary action of the A2 and MP appendages allowed for constant propulsion or negated each others' thrust, suspending the copepod when hovering. The A1 remained stretched out for all swimming modes except for escape. During escape behaviors, the A1 were pulled into the body by the MX and held as the PP and the urosome moved erratically. Other cephalic appendages such as the M1, M2 as well as the MX were not observed to be used for creating swimming currents.

Different swimming modes or combination of swimming modes were used to feed on prey of different sizes. *S. crassus* has relatively large A2 and MP. By changing the frequency, position and angle of rotation of these appendages the copepod is able to alter its orientation in the water. Copepods were able to ascend and descend to search for prey and hover in areas of small diatom prey. In the presence of large *C. wailesii* cells the copepod would swim directly towards the cells, in a jerky manner. A size-dependent change in foraging behavior was supported by the 3-dimensional movements of the cephalic appendages.

The basic behavior of *S. crassus* from Sagami Bay was observed to differ from previous studies. Strickler (1982, 1984) examined *S. crassus* from Great Barrier Reef, Australia and off Georgia, USA; the sampling locations were unreported, but confirmed by personal communication. The natural body orientation of *S. crassus* was observed to be vertical for those from Sagami Bay, Australian and off Georgia waters, although the achieved position was different. The *S. crassus* from Sagami Bay maintained its vertical orientation with no aid from the urosome. *S. crassus* from Australian and off Georgia waters vibrates the urosome to maintain its natural orientation (Strickler's personal communication). The typical swimming mode was created by the rotary action of the A2 and MP for the *S. crassus* from Sagami Bay. Non-tethered and tethered recordings of *S. crassus* from Sagami Bay, typical swimming, hovering and its natural orientation in the water showed the urosome to be positioned dorsally. On the contrary, the tethered or non-tethered, photos and sketches of *S. crassus* from Australian and the off Georgia waters, while swimming and in the natural position have the urosome pointing along the body axis (Fig. 1b in STRICKLER, 1982) or with a ventral orientation (Fig. 1b and Fig. 2 in STRICKLER, 1982). The urosome placement would change how the copepod moves through the water. STRICKLER (1982) observed backwards swimming in *S. crassus* from Australian and off Georgia waters. This could only physically be achieved if the urosome is positioned ventrally. Combined with movements of the M1 and M2, the copepod would gain a backward thrust.

Behavioral differences may have been caused by different experimental conditions, such as food, light, and container size, etc. However, it was most likely caused by species differences, as fundamental behaviors differed. Recently, DNA research by GOETZE (2003) has found genetic differences among Eucalanidae copepods. *S. crassus* from the South Korean Strait was found to be a cryptic species, diverging from the original *S. crassus* line in the North Atlantic and the South Western Pacific (GOETZE, 2003). Behavioral observations suggest that *S. crassus* from Sagami Bay is not the same as the *S. crassus* from Australian and off Georgia waters. The proximity between Japan and Korea may indicate that the *S. crassus* from both waters are more closely related if not the same species.

Acknowledgement

We would like to thank Dr. Naho HORIMOTO, Ms. Haruko EMOTO and the captain and crew of the TR/V Seiyo Maru for their continuous help for collecting copepods. Thanks go to Dr. Shuhei NISHIDA who aided us with our taxonomic problems. This project was partly funded by the Sasagawa Scientific Research Grant from the Japan Science Society. E.W. would like to thank the Honjo International Scholarship Foundation and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for providing scholarships. This study was also supported by MEXT KAKENHI (16580148).

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Received May 4, 2007
Accepted December 4, 2008

La mer 46 : 97–104, 2009
Société franco-japonaise d'océanographie, Tokyo

Evaluation of stock status of *Channa micropeltes* in Tonle Sap Lake, Cambodia, by means of CPUE analysis

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ABSTRACT: Data collection and interview survey were conducted to evaluate stock status of a snake head, *Channa micropeltes,* which is one of the major fisheries target species around Tonle Sap Lake, Cambodia. The catch data classified by species was collected for the first time in a project cooperated with the Mekong River Commission during 1995–1999 around Tonle Sap Lake. The four provinces continued collecting individual species catch data even after the project. The catch of *C. micropeltes* decreased during 1995–2008 in the four provinces. Additionally, individual species catch data sorted by fishing lot, exclusive fishing area, were recorded in Kampong Thom province. Catch per unit effort (CPUE) of *C. micropeltes* in the fishing lot No. 3, 4 and 5, which is situated in the margin of Tonle Sap Lake, was calculated. The CPUEs rapidly decreased during 1995–2001, and the values then remained low. These results suggest the stock has been depleted in Tonle Sap Lake. We also found that the recent catch had recovered since 2006 in another smaller lake in Kampong Thom province. This may be attributed to the effect of the decrease of the illegal fishing for the fingerling in closed season according to the prohibition of the aquaculture of *C. micropeltes* since 2004.

Keywords: *Tonle Sap Lake; fishery statistics; CPUE; Channa micropeltes*

1. Introduction

It is widely recognized that scientific stock assessment is an indispensable tool for conservation and effective use of aquatic resources. However, stock assessment is often abandoned in developing countries because of budgetary restrictions and weakness in fishery statistic systems (COATES, 2002). The low quality and quantity of the fishery statistics have been also pointed out as a problem for stock assessment in developing countries (SIMPSON, 1982). Demonstrating the practical usage of their existing fishery statistics for stock assessment could provide incentive for collecting and compiling fishery statistics and more effective utilization of fishery statistics.

In Cambodia, more than 75% of per capita animal protein intake is supplied from fisheries products (AHMED *et al.,* 1998), and approximately 85% of the total fish catch comes from inland fisheries (DEPARTMENT OF FISHERIES IN CAMBODIAN GOVERNMENT, 2007). Tonle Sap Lake, which is located in the central part of Cambodia, is the largest inland water body in Southeast Asia (Fig. 1). Around 60% of the inland fisheries products are provided from neighboring provinces around the lake (AHMED *et al.,* 1998). HORI *et al.* (2006) suggested that small-scale fishing is quite important as income sources in communities around the lake. On the other hand, deterioration of fisheries resources, especially fish stocks of large species with high price, in the lake was suggested recently (VAN ZALINGE *et al.,* 2001; HORTLE *et al.,* 2004). *Channa micropeltes* was major target

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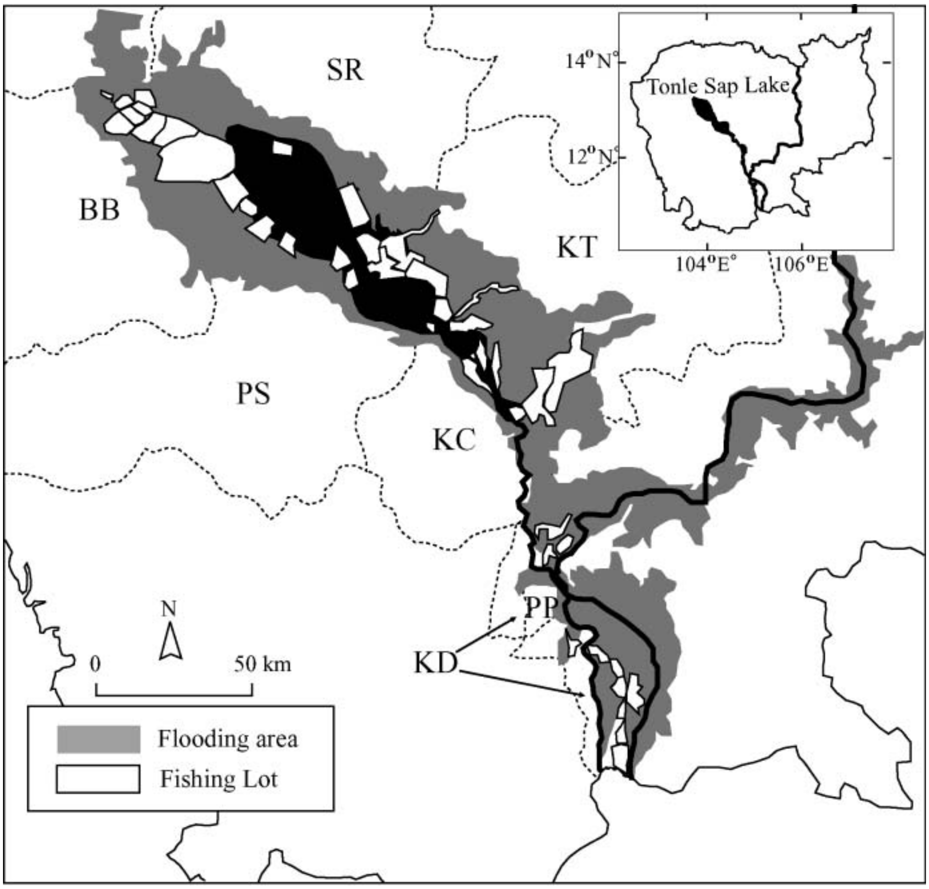

Fig.1. Map of Tonle Sap Lake with flooding areas and the 7 provinces where the catch assessment project was conducted (BB: Battambang, SR: Siem Reap, PS: Pursat, KT: Kampong Thom, KC: Kampong Chhnang, PP: Phnom Penh, KD:Kandal). Bold and dotted lines indicate rivers and boundary of provinces, respectively.

species in the inland fisheries and also one of the most highly valued commercial species (Van Zalinge and Thuok, 1999; Rainboth, 1996). The fish inhabits standing or slowly flowing waters and feeds mostly on fishes and crustaceans (Rainboth, 1996). Decrease in catch of *C. micropeltes* was reported in the northern part of Tonle Sap Lake (Troeung, 2001). The Department of Fisheries in Cambodian Government (DOF), considering this situation, has prohibited aquaculture of the species in order to prevent illegal fishing of the fingering of the fish since 2005. However, the stock analyses of individual species, including *C. micropeltes,* have not been implemented because of several weakness and unreliability of fishery data; therefore, the effect of fisheries management of the prohibition of aquaculture of the species could not be assessed.

The data in the total fish catch in Cambodian inland fisheries is available in statistical information such as reports by the DOF or "FAO Fish STAT." However, records of individual species catches and fishing efforts are not obtainable from these publications. Additionally, the relationship between the main fishing methods and the main target fishes are not clear. These weaknesses make it difficult to calculate the catch per unit effort (CPUE), the common indicator of fish stock fluctuation. The Cambodian government and international organizations deeply recognize the importance of freshwater resources in Tonle Sap Lake. DOF and the Mekong River Commission

(MRC) conducted a catch assessment of commercial fishing in the seven provinces adjacent to Tonle Sap Lake (Fig. 1). The project was carried out from 1995 to 1999 in order to grasp the accurate status of the quantity and value of the catch (e.g. Deap *et al.,* 1998). In the project, catch data classified by species was collected for the first time in inland fishery and that resulted in the improvements of the routine data collection (Sam *et al.,* 2003).

Cambodian inland fishery in Tonle Sap Lake are categorized into large-, middle- and small-scale fishing, according to types of fishing gear and the difference in fishing ground defined by fishery law (Department of fisheries in Cambodian government, 1990). The large-scale fishing is a type of fishing based on the fishing law in Cambodia, which is implemented in the fishing season (1st October-31st May) in specified licensed fishing areas called "fishing lot." The lot owners obtain the exclusive fishing right in fishing lots through the payment of lot license fee to the government. Three large fishing gears were operated in the fishing lot, namely bamboo fence system, barrage, and seine net operated with motor-powered boats or many fishers (Deap *et al.,* 2003). Lot owners have obligation to report their catch amounts to provincial fisheries office. The provincial fisheries officers sometimes confirm the accuracy of their report by checking the transportation quantities. The middle-scale fishing can be operated in the open access fishing area in fishing season. Only the registered and regulated fishing gears such as gillnet (>10 m length), seine net, round net and arrow-shape trap can be used in the middle-scale fishing. The small-scale fishing is defined as subsistence fishing wherein gill net (<10 m length), spear, hook with line and small trap are used in open access areas and rice fields. Fishers of the middle- and small-scale fishing have no obligation to report their catches, and the provincial fisheries officers conduct interviews at community or village level to estimate their catch amounts. In this study, the large-scale fishing could be analyzed because sufficient data in quality and quantity of the fishery statistics were available.

It is to our information that the collection of individual species catch data continued in several provinces even after the project had terminated. Field surveys were made to find out and acquire the records that would provide reliable data sets of fishing effort and individual catch record around Tonle Sap Lake. The aim of this study is to examine the stock of a snake head, *C. micropeltes,* around Tonle Sap Lake using an obtainable dataset.

2. Materials and Methods

Data collections and interview surveys were conducted in February-April, 2005 and July-August, 2008 in the DOF and seven provincial fisheries offices (PFO) around Tonle Sap Lake, namely, Battambang, Siem Reab, Pursat, Kampong Thom, Kampong Chhnang, Kandal and Phnom Penh where the DOF and MRC Capture Fisheries Project was performed (Fig. 1). Information on the fishery statistics system and the existing fishery statistics in the large-scale fishing were also collected. In addition, the fishing operation information, such as fishing method, fishing ground and gear size, was collected through interviews of fisheries officers and fishermen.

From the collected data, individual species catch records in provincial and fishing lot level were selected and sorted out. The fluctuation of catch of *C. micropeltes* in the provinces was observed. Additionally, the catch data classified by fishing lots, where large quantity of *C. micropeltes* was harvested, were sorted out. The relation between fishing method and main target species was examined using the collected data and information; the fishing gears that mainly used for the fishing of *C. micropeltes* was identified. Difference of catch ratio of *C. micropeltes* between the fishing lots was statistically examined by analysis of variance with the Turkey-Kramer honest significant differences test using JMP version 7 (SAS Institute, Cary, NC, USA). The CPUE of *C. micropeltes* in the fishing lot was calculated by dividing the catch quantities with the fishing effort of the main fishing gear.

As the fishing season spans from October to May of the following year, annual catch data of fishery statistics were calculated through totaling the monthly data for the period. In this paper, fishing year n was expressed as the year of the end of the fishing season.

3. Results

The results of field survey on data collection of individual species catch data in large-scale fishing are summarized in Table 1. In four provinces, Battambang, Siem Reab, Kampong Thom and Kampong Chhnang, data collection of individual species catch continued even after the DOF and MRC project. The catch quantities of *C. micropeltes* in the four provinces in 1995 ranged between 800 and 1200 ton. The quantities, however, decreased year by year until 2004 (Fig. 2), and since 2005, the catch volume remained low around 200 and 300 ton.

As shown in Table 1, it was possible to obtain the catch record of *C. micropeltes* in each lot in Kampong Thom province from 1995 to 2007 except for 1998. The catch record of lots in Battambang, Siem Reap and Kampong Chhnang provinces, but the duration of the record is short and old. There were 7 fishing lots in Kampong Thom (Fig. 3). The average ratios of catch quantities of *C. micropeltes* of each lot during 1995–2007 are shown in (Fig. 4); in Kampong Thom, *C. micropeltes* was mainly caught in fishing lot No. 3, 4, 5 and 6.

The geographic condition and the fishing gears used differed among fishing lots as shown in Table 2. The fishing lots No. 3, 4 and 5 are located in the lake, while lot No. 6 is located at the mouth of a river. Bamboo fence

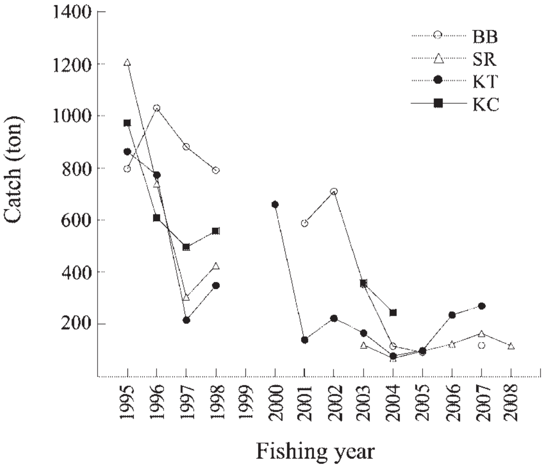

Fig. 2. Time series of catch in the four provinces, Battambang, Siem Reap, Kampong Thom and Kampong Chhnang during 1995–2008.

Table 1. Collected catch data sorted by species of large-scale fishing in the 7 provinces

Province	Period	Data contents	Data source
Battambang	1995–1997	Annual catch sorted by fishing lot	DEAP *et al.,* 1998
	1998	Annual catch sorted by fishing lot	THOR *et al.,* 1999
	2000, 2002, 2006–2007	Annual catch in fishing lot No.2	Stored at POF
	2001–2007	Total Annual catch	Stored at POF
Siem Reap	1995–1997	Annual catch sorted by fishing lot	DEAP *et al.,* 1998
	1998	Total Annual catch	THOR *et al.,* 1999
	2003–2008	Total Annual catch	Stored at POF
Pursat	1995–1997	Annual catch sorted by fishing lot	DEAP *et al.,* 1998
	1998	Total Annual catch	THOR *et al.,* 1999
Kampong Thom	1995–1997	Annual catch sorted by fishing lot	DEAP *et al.,* 1998
	1998	Annual catch sorted by fishing lot	THOR *et al.,* 1999
	2000	Annual catch sorted by fishing lot	Stored at POF
	2001–2007	Annual catch sorted by fishing lot	Stored at POF
Kampong Chhnang	1995–1997	Total Annual catch	DEAP *et al.,* 1998
	1998	Total Annual catch	THOR *et al.,* 1999
	2003	Annual catch sorted by fishing lot	Stored at POF
	2004	Total Annual catch	Stored at POF
	2005–2007	Total Annual catch of middle- and large-scale fishing.	Stored at POF
Kandal and Phnom Penh*	1995–1997	Annual catch sorted by month	DEAP *et al.,* 1998
	1998	Total Annual catch	THOR *et al.,* 1999

*The catch data of Phnom Penh and Kandal were summed up into one unit in the catch assessment project by DOF and MRC (DEAP *et al.,* 1998).

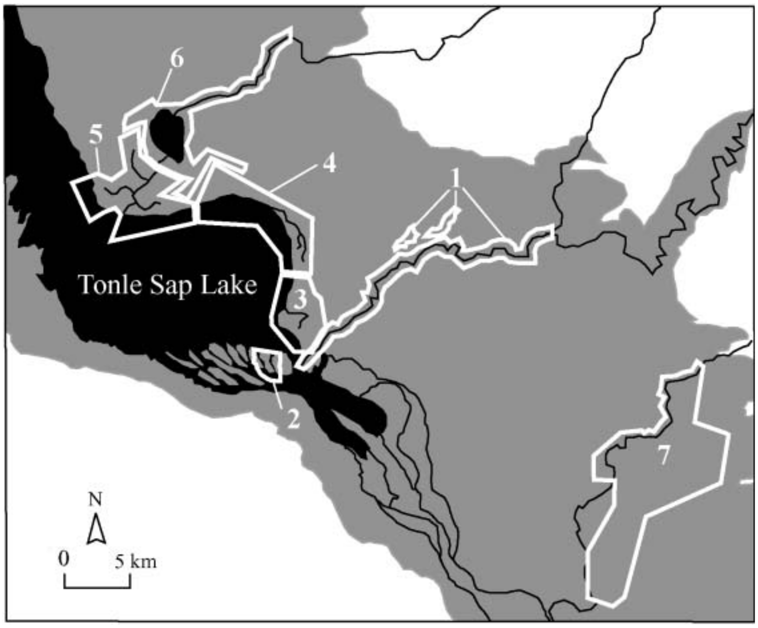

Fig. 3. Map of 7 fishing lots in Kampong Thom province. Black area indicates lake area and gray area indicates flooding areas in rainy season. Solid lines and white lines show rivers and boundaries of the fishing lots, respectively. Numeric character indicates fishing lot number.

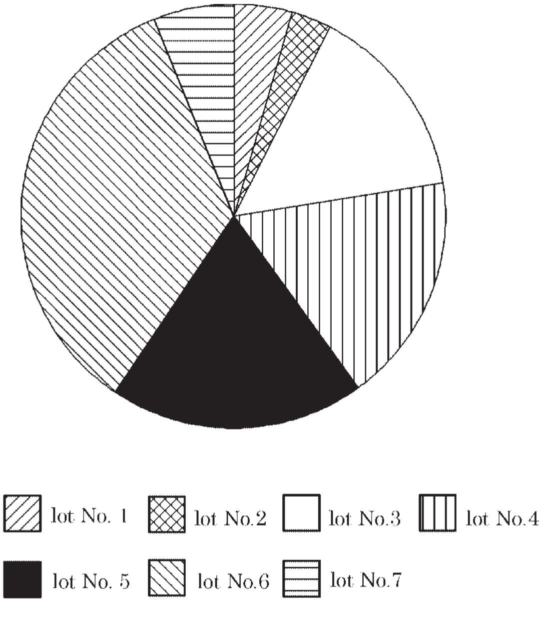

Fig. 4. Average catch ratio of *C. micropeltes* in seven fishing lots in Kampong Thom province during 1995–2007.

Table 2. The fishing area and fishing gear in each fishing lot in Kampong Thom province

Fishing lot No.	Fishing area	Fishing gear
1	River	barrage, seine net
2	River	barrage, seine net
3	Lake	bamboo fence system
4	Lake	bamboo fence system, seine net
5	Lake	bamboo fence system, seine net
6	River, Lake	barrage, bamboo fence system, seine net
7	River	barrage, seine net

system is a structure to enclose fishes in flooding area, and the long bamboo fence is set up along the fringe of the lake. Fishers catch the fish in late dry season, when the water depth and the flooding area decrease. Fishing lots No. 3, 4, 5 and 6 had a bamboo fence system. Seine nets were used in fishing lots No. 4.and 5 at the end of fishing season. In lot No. 6, a bamboo fence system, seine nets and a barrage (a setting net in the river) were used.

In order to examine the relationship between catch of the bamboo fence system and the length of the bamboo fence, the total catch amount of *C. micropeltes* in lot No. 3, 4 and 5 and the share of each lot in the total during 2001–2007 were calculated. The catch ratios of fishing lot No. 4 and 5 were statistically higher than that of fishing lot No. 3 (Turkey-Kramer test, $P<0.01$) (Table 3).

The place of the bamboo fence system was basically fixed in each lot, and there were little changes in the length of the bamboo fence. However, there seemed to have a little change in the length of the lot No. 3 in 2001. The fluctuations of the CPUEs in fishing lots No. 3, 4 and 5 are calculated by dividing the catch by the length of the bamboo fence (Fig. 5). The fluctuation patterns of the CPUEs were exactly similar among those fishing lots. The values of CPUE were between 6 to 9 in 1995 and 1996 in the lots, but in 1997 it was reduced to a value between one-fourth and half. The CPUE relatively increased much in 2000, but it decreased again in 2001, and since 2002 it maintained between 0.5 and 2.

It is impossible to calculate CPUE in lot No. 6, because *C. micropeltes* in the lot were caught by both bamboo fence system and barrage, and hence, the quantity of the catch by bamboo fence system in lot No. 6 could not be separated. Fig. 6 shows the fluctuation of the catch quantity of *C. micropeltes* in lot No. 6. The fluctuation of the catch in lot No. 6 was similar to the CPUEs of lots No. 3, 4 and 5 during 1995–2005 although the fluctuation was obviously different from CPUEs in lots No. 3, 4 and 5 in 2006 and 2007.

Table 3. Length of the bamboo fence and catch ration during 2001–2007 in fishing lot No. 3, 4 and 5 in Kampong Thom province

Fishing lot No.	Length of the bamboo fence (km)	Catch ratio (%)	n
3	20.7	22.1±5.0	7
4	24.6	37.1±7.7	7
5	25.6	40.8±6.5	7

4. Discussion

Data collection of catch was continued in the four provinces around Tonle Sap Lake, Battambang, Siem Reap, Kampong Thom and Kampong Chhnang. The catch fluctuation of *C. micropeltes* during 1995–2007 had negative trends in the all provinces (Fig. 2). This indicated a possibility that the fish stock was largely depleted around Tonle Sap Lake.

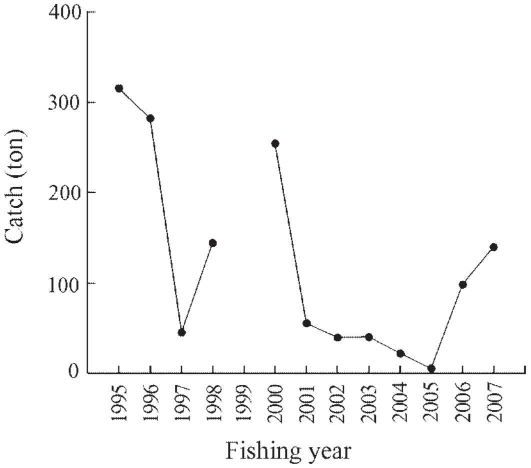

Fig. 6. Time series of catch in fishing lot No. 6 in Kampong Thom province during 1995–2007.

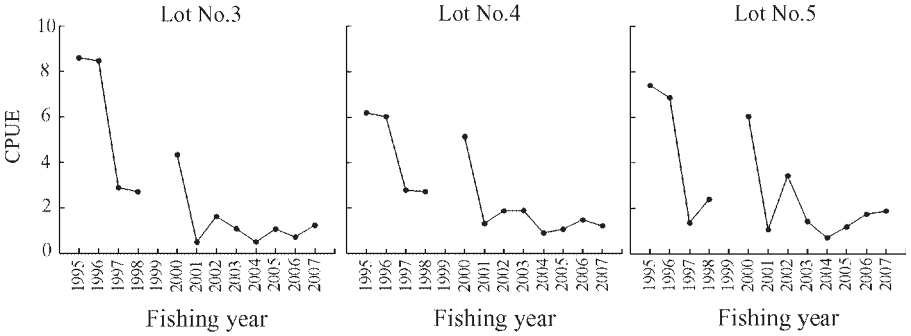

Fig.5. Time series of CPUE in fishing lot No. 3, 4 and 5 in Kampong Thom province during 1995–2007.

Catch records of each fishing lot after 1999 were obtained only from Kampong Thom. Kampong Thom was selected as target areas because the catch data of *C. micropeltes* in each fishing lot were available, and an estimate of the main fishing gear used to catch the fish was possible. There were 7 fishing lots in Kampong Thom as shown in Fig. 3, and *C. micropeltes* was the main species harvested in the lake and the river mouth fishing area (Fig. 4). Among the 7 fishing lots, No. 3, 4 and 5 were located in lake fishing area wherein bamboo fence system and seine net were operated. In the bamboo fence system, the fences were set along the boundary of a fishing lot in the lake side and prevented the fish from going out of flooded area to the lake. The fish was captured by several traps installed inside and along the boundary of the fishing lot. Seine net was used at the end of the fishing season in bamboo fence system to catch the fishes that remained in fishing lots No. 4 and 5. The water depth in fishing lot No. 3 was shallow and fishers do not need seine net for the harvest at the end of fishing season. Hence, the catch by seine net in the lake fishing lot should be considered and included as a catch by bamboo fence system. If the catch by seine net in fishing lots in the lake is presumed and accepted as a part of the catch by the bamboo fence system, overall the fish harvested in fishing lot No. 3, 4 and 5 are considered to be caught by the bamboo fence system. This means the main fishing gear that captures *C. micropeltes* in fishing lot No. 3, 4 and 5 can be identified, and CPUE analysis using proper unit of the fishing effort is possible. It was anticipated that the length of the fence could be used as the unit of the fishing effort; therefore, to examine this hypothesis, the shares of the catch among these three fishing lots in each year was calculated. The catch ratios of fishing lot No. 4 and 5 with the longer fence were higher than that of fishing lot No. 3 with the shorter fence (Table 3). The results suggest that the catch quantities of *C. micropeltes* in the lots depend on the length of the fence, and therefore the length could be used as fishing effort.

In the CPUE analysis, the fluctuations were basically synchronized with small differences in magnitude of the value among fishing lot No. 3, 4 and 5 (Fig. 5). From this, it could be said that the *C. micropeltes* in the fishing lots constitutes a population and that the stock of this population was drastically decreased between 1995 and 2001.

We screened out the CPUE analysis in fishing lot No. 6 because we could not estimate strength of fishing effort in the lot. Generally, place of the bamboo fence system and barrage was restricted by land form, and changes in the numbers of the gears are supposed to be little. When we presume there was no change in fishing effort in lot No. 6, the fluctuation pattern in the catch amount is similar to the pattern in CPUE. The catch fluctuation of the lot during 1995–2001 was very similar to the CPUE in fishing lot No. 3, 4 and 5. However, the catch largely increased during 2006–2007 (Fig. 6). This increase would be derived from the prohibition of capture of the seedling for aquaculture of the *C. micropeltes* since 2004. The illegal fishing activity for the fingering was punished in several provinces (DEPARTMENT OF FISHERIES IN CAMBODIAN GOVERNMENT, 2006). It could be explained that fishing lot No. 6 was located in a separated lake and river and thus the controlling the illegal fishing would be easier than the lots inside Tonle Sap Lake. On the contrary, the fisheries management for decreasing fishing pressure in closed season would be more difficult in Tonle Sap Lake. The delay in the recovery of the stock may be derived from the incomplete regulation of capture of the fingering.

This study revealed that stock assessment by CPUE analysis for *C. micropeltes* in Tonle Sap Lake is possible using catch record data of bamboo fence system. Moreover, by the CPUE analysis, the stock depletion of the fish in Tonle Sap Lake from 1995 to 2008 is confirmed. This study also suggested that the recent catch recovery in an adjunct small lake may be due to the prohibition of capture of fingerlings for aquaculture since 2004.

It is concluded that the bamboo fence system is a highly quantitative fishing method when length of the fence is used as fishing efforts, and that CPUE analysis for major target fish of bamboo fence system will provide accurate information of stock status and proper evaluation of stock management.

Acknowledgements

We are grateful to the staff of DOF and IFReDI who participated in the field survey for data collection. We appreciate I. McTaggart, S. Herman and Dr. Allapichay for English proofreading of the manuscript of this paper. We also appreciate N. Yagi for the check of logic forming of this paper. This study was supported in part by the research project "Water management system of the Mekong River" under Core Research for Evolutional Science and Technology by Japan Science and Technology Agency, and also the 21st Century COE Program "Biodiversity and Ecosystem Restoration Research Project" from the Ministry of Education, Culture, Sports, Science, and Technology.

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Received: October 23, 2008
Accepted: December 7, 2008

La mer 46 : 105-106, 2009
Société franco-japonaise d'océanographie, Tokyo

資　料

第46巻第3号掲載欧文論文の和文要旨

I.S.スヘンダル1)，柳　哲雄2)，ムアワナ3)：インドネシア・南スマトラ・ハラン湾における淡水平均滞留時間の季節変動と水質への影響

ハラン湾の水質特性とそれを決める要因を明らかにするために，2004年に観測された水温・塩分・DIN・DIP・TOM・DO・植物プランクトンデ—タを解析して，湾内における淡水平均滞留時間の季節変動を調べた．その結果，海水交換の指標としての淡水平均滞留時間の季節変動がハラン湾の水質に大きな影響を及ぼしていることがわかった．雨季—乾季，乾季—雨季の遷移期における長い淡水平均滞留時間は湾内の海水中にDIN・TOMを蓄積して，赤潮を起こし，DOを低下させる．この結果は，遷移期には赤潮発生・DO低下を防ぐために，湾内における給餌などの養殖活動を最低限のレベルに下げる必要があることを勧告している．

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Cara Miller1) and Nardi Cribb2)：オーストラリア水域における鯨類の生息環境に関する解説

オーストラリア水域における鯨類研究では，生息環境に関する理解が優先課題であるとこれまで認識されてきた．全球的見地からは，鯨類の生息環境の定義は，比較的広汎に，複数の変数及び要素を含むべきであると当時に，種，および地域に応じたものであるべきだと示唆されている．また，変数と要素は，適切な過程，現象，形態およびある変数が機能する時空間規模に適合するスケールで測定される必要があるということも認められてきた．オーストラリアにおける鯨類の生息環境に関する従来の研究では，対象が主に小型で沿岸性の種に絞られ，地理的にも範囲が限定され，環境要素も水深，海面水温，回遊経路といった限られたものしか取り扱っていなかった．個々の種毎の生息環境に関連した情報が得られているのは，オーストラリアの鯨類のうち4分の1以下の種しかない．オーストラリア水域における鯨類生息環境に関する総合的な調査が，有効な生息環境保護ならびに生存脅威緩和をめざし，また，鯨類保全への取り組みにおける適切で時宜を得た道具として，広汎で定量的な手法で着手されるべきである．

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Erin Wittke・石丸　隆・田中祐志：カラヌス目カイアシ類*Subeucalanus crassus*（Giesbrecht，1888）の遊泳にともなう頭部付属肢の挙動

相模湾産*Subeucalanus crassus*の運動の，ビデオ装置による観察を，第2触角（A2）と上顎触鬚（MP）の3次元的な動きを中心に行った．高速ビデオによる観察では，A2とMPのみが典型的な遊泳，ジグザグの遊泳およびホバリングにおいて用いられていることが明らかとなった．典型的な遊泳では，それらは70-80Hzで回転することによって推進力を生じ，それらの最大回転角度は90度であった．ホバリングでは，それぞれ60-70Hzと45度であった．相模湾産の*S. crassus*の行動は従来のオーストラリアや米国沿岸の同種に関するものとは異なっていた．すなわち，沈降時には第1触角のみならずA2，MPも水平に広げられていた．また，後体部が，体の後方に位置するのは，ジグザグ遊泳の際に後方に振られるときのみであり，相模湾産の*S. crassus*では，後体部が背面に位置しているため，後方への遊泳を行うことは不可能であると考えられる．また，第1，第2下顎および顎脚は遊泳肢と同様に，姿勢維持や遊泳，沈降のために用いられることは無かった．

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榎本憲泰1)・石川智士2)・堀　美菜1)・Lieng Saroeung3)・Hort Sitha3)・Srum Lim Song3)・Thuok Nao3)，・黒倉寿1)：カンボジア王国トンレサープ湖周辺における*Channa micropeltes*のCPUEを用いた資源動向の分析

カンボジア王国トンレサープ湖の主要経済魚種の一種である*Channa micropeltes*の資源動向を明らかにするために，トンレサープ湖周辺州において漁業統計データの収集及び漁業実態の聞取り調査を行った．1995年から1999年に

かけてメコン河委員会の協力によりトンレサープ湖周辺 7 州で初めて魚種別の漁獲量データが収集された．そのうち4州では2001年以降魚種別漁獲量データの収集が継続されており，*C. micropeltes*の漁獲量はそれら 4 州において1995年から2008年にかけて減少していた．また，コンポントム州では占有漁業区フィッシングロット別の漁獲量データが存在しており，トンレサープ湖に面するフィッシングロット 3，4，5 番において単位努力量当たり漁獲量（CPUE）の計算を行った．それらのCPUEは1995年から2001 年にかけて急激に減少しその後低水準で推移しており，トンレサープ湖の*C. micropeltes*の資源の減少が示された．また，コンポントム州の別のより小さい湖において2006年から漁獲量の回復が見られた．これは2004年から行われている*C. micropeltes*の養殖の禁止が禁漁期に行われる同魚種の種苗の違法漁業を減少させ，同湖の資源の回復に寄与した可能性があることを示唆していた．

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連絡先著者住所：〒164-8639　東京都文京区弥生1-1-1　東京大学大学院農学生命科学研究科　榎本　憲泰　TEL：03-5841-8115　FAX：03-5841-5189　E-mail：kzhr.enomoto@gmail.com）

La mer 46 : 107-108, 2009
Société franco-japonaise d'océanographie, Tokyo

学会記事

1. 2008年６月28日（土）日仏会館会議室において，平成20年度学術研究発表会が開かれ発表題目と発表者は次のとおり．

平成20年度日仏海洋学会学術研究発表会
期日：平成20年６月28日
場所：日仏会館501会議室（東京都渋谷区恵比寿3-9-25
Tel. 03-5421-7641）

プログラム

午前（10：00－11：00）　座長　堀本奈穂

1．環境サンプルからの微生物同定に関する簡易手法の検討…奥村　裕・黒川忠英・坂見知子・斉藤憲治（(独)水研セ・東北水研）・鈴木敏之（(独)水研セ・中央水研）・神山孝史（(独)水研セ・瀬戸内水研）

2．Occurrence of Pseudo-nitzschia species in San Pedro Bay, Philippines…○Leni G. Yap-Dejeto (Univ. Philippines), T. Omura and Y. Fukuyo (Univ. Tokyo)

3．断続照射光の波長の違いがハプト藻Isochrysis galbanaの増殖と脂肪酸組成へ与える効果
…○矢後貴英・吉岡美和・荒川久幸・吉江由美子・森永　勤（海洋大）

（11：00－12：20）　座長　長島秀樹

4．Adelie Depressionにおける乱流混合と二重拡散対流の定量評価…○平野大輔・北出裕二郎（海洋大）

5．東京湾の海況変動特性に関する研究…○岩沢知毅・北出裕二郎・根本雅生・川村有二　（海洋大）

6．東京湾湾口部における半日周期内部潮汐の強化について……………………………○北出裕二郎（海洋大）

7．相模湾における半日周期内部潮汐の散乱…○川村有二・北出裕二郎・根本雅生・松山優治（海洋大）

午後（14：00－15：00）　座長　北出裕二郎

8．Argoフロートデータを用いた南大洋における密度比の分布の研究
………○根本萌由・根本雅生・吉田次郎（海洋大）

9．太平洋における混合過程に果たす二重拡散対流の役割…………………○嶋田啓資・吉田次郎（海洋大）

10. 発電所のCO_2削減量を想定したCO_2海洋隔離による濃度予測…○中村倫明・和田　明（日大総合科学）・長谷川一幸（(財)海生研）

2. 2008年６月28日（土）日仏会館において評議員会後，第49回（平成20年度）総会が開かれた．議題は次のとおり．

1．平成19年度事業報告

a）庶務関係

会員異動状況

	H19年4月	入会	退会	逝去	資格変更	20年3月
名誉会員	2	－	－	－	－	2
正会員	261	10	▲9	－	2	264
学生会員	10	1	▲4	－	▲2	5
賛助会員	7	0	▲1	－	－	6

b）活動状況

評議員会　１回（19/6/9　日仏会館）
幹事会　３回（19/4/10,19/11/5,20/3/27 日仏会館）
総　会　１回（19/6/9　日仏会館）
学術研究発会　１回（19/6/9 日仏会館）
学会誌発行　44巻3-4号, 45巻１号，２号

c）学会賞の選考について，学会賞選考委員長から報告．

d）編集関係

学会誌「La mer」44巻3-4号, 45巻１号，２号　発刊

2．平成19度収支決算報告が行われ，監査から監査報告がなされた．

収入の部

費目	決算額	備考
前年度繰越金	788,938	
正会員会費	889,300	111名（クレジットカード払い外国会員含む）
特別会員	72,000	12名
学生会員会費	16,000	４名（4000×４名）
賛助会員会費	120,000	（６社，12口）
学会誌売上金	128,610	
広告料	40,000	
別刷り印刷費	238,900	
掲載料，印刷費	760,000	
雑収入	22,079	（研究発表会，学術著作権使用料他）
DVD作製助成金	300,000	笹川日仏財団より
寄付金	0	
収入合計	3,375,827	

支出の部

費目	決算額	備考
学会誌印刷費	1,561,580	44（3-4）合併号，45（１），45（２）各350部
送料•通信費	120,583	
事　務　費	703,516	人件費，事務用品，封筒他
交　通　費	16,260	
会　議　費	6,825	
学会賞経費	292,059	メダル，賞状他
雑　　　費	13,925	郵便•銀行振込手数料他
次年度繰越	661,079	DVD製作費含む
支出合計	3,375,827	

原案のとおり，承認された.

3. 平成20年度事業（案）審議
   - a）総会（１回），学術研究発表会（１回），評議員会（１回）の開催
   - b）La mer 発刊（45巻３号，４号，46巻１号，２号）
   - c）バックナンバーのDVD化事業
   - d）日仏海洋学シンポジウム（Marseille+Paris 2008）の準備状況
   - e）日仏交流150周年総合シンポジウムへの参加
     八木宏樹副会長「海洋学及び水産学分野における日仏間協調の歴史と今後」
     講演　９月28日11時　日仏会館

4. 平成20年予算案が審議された.

収入の部

費目	20年度予算	備考
正会員会費	1,160,000	145名×8000円
特 別 会 員	72,000	12名×6000円
学生会員会費	20,000	５名×4000円
賛助会員会費	120,000	（６社，12口）
学会誌売上金	60,000	
広　告　料	50,000	
別刷り印刷費	240,000	
掲載料，印刷費	800,000	16編×50000円
雑　収　入	100,000	（要旨集売上，学術著作権使用料他）
19年度繰越	661,079	DVD製作費含む
収入合計	3,283,079	

支出の部

費目	20年度予算	備考
学会誌印刷費	2,120,000	出版，DVD製作費含む
送料•通信費	100,000	
事　務　費	700,000	人件費，事務用品，封筒他
交　通　費	20,000	
会　議　費	5,000	
学会賞経費	50,000	メダル，賞状他
雑　　　費	25,000	郵便•銀行振込手数料他
予　備　費	263,079	
支出合計	3,283,079	

原案通り承認された.

5. 2008-2009年度役員，評議員および賞委員が報告，承認された.

会　長：今脇資郎
副会長：八木宏樹　森永　勤
幹　事：（庶務）河野　博　荒川久幸，（会計）神田穣太　山崎秀勝，（編集）田中祐志 北出裕二郎，（研究）石丸　隆　和泉　充，（渉外）小松輝久　小池康之
監　事：長島秀樹　小池　隆
編集委員長：吉田次郎
評議員：荒川久幸　有元貴文　石丸　隆　磯田　豊　今脇資郎　神田穣太　北出　裕二郎　小池勲夫　河野　博　小松輝久　斉藤誠一　関根義彦　千手智晴　田中祐志　寺崎　誠　中田英昭　長島秀樹　森永　勤　門谷　茂　柳　哲雄　八木宏樹　山口征矢　山崎秀勝　吉田次郎　以上24名
賞委員：石丸　隆　磯田　豊　神田穣太　北出　裕二郎　小松輝久　田中祐志　◎長島秀樹　森永　勤　吉田次郎（◎委員長）

6. 佐伯和昭会員，須藤英雄会員，野村正会員，松生洽会員，村野正昭会員，森田良美会員が名誉会員に推薦され，承認された.

賛助会員

ＪＦＥアレック株式会社	神戸市西区井吹台東町７－２－３
株式会社 イーエムエス	神戸市中央区東川崎町１－３－３ 神戸ハーバーランドセンタービル　13F
有限会社 英和出版印刷社	北区中里２－14－８シャンボール駒込101
財団法人 海洋生物環境研究所	千代田区神田神保町３－29　帝国書院ビル５Ｆ
ケー・エンジニアリング株式会社	台東区浅草橋５－14－10
いであ株式会社	世田谷区駒沢３－15－１
テラ株式会社	文京区湯島４－１－13－402

日仏海洋学会入会申込書

（正会員・学生会員）

	年度より入会	年　　月　　日申込
氏　　名 ローマ字		年　　月　　日　生

住　所　〒

勤務先　機関名

電　話　　　　　　　　E-mail:

自　宅　住　所　〒

電　話　　　　　　　　E-mail:

紹介会員氏名

送付金額　　　　　　円	送金方法
会誌の送り先（希望する方に○をつける）	勤務先　　　　自　宅

（以下は学会事務局用）

受付	名簿 原簿	会費 原簿	あて名 カード	学会 記事

入会申込書送付先：〒150-0013 東京都渋谷区恵比寿 3-9-25
（財）日仏会館内
日仏海洋学会

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