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Underwater brightness in nighttime and behaviors of Japanese spiny lobsters*

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Abstract: Diurnal variation of moving activity of Japanese spiny lobsters was investigated in small indoor tanks of the Fisheries Research Laboratory of the Mie University. We modeled the diurnal variation of light intensity with step-like brightness variation having 12 hour light period (daytime) and 12 hour dark period (nighttime). The lobster movement was detected by measuring tension of wire which hangs lobster cage.

Nocturnal habit of lobsters was reproduced; lobsters stay almost in rest in daytime if brightness is higher than 3.5×10^{-2} *lx*. The moving activity of the lobster in nighttime is strongly controlled by brightness. If nighttime brightness is lower than 2.3×10^{-5} *lx*, lobsters move very actively as just as in 0 *lx* brightness. The nighttime activity is suppressed when brightness is higher than 5.2×10^{-3} *lx*. Above this value, the activity tends to decrease slightly with brightness increase. The difference in activity level of lobsters is very conspicuous between in brightnesses higher than 2.3×10^{-5} *lx* and lower than 5.2×10^{-3} *lx*.

1. Introduction

Japanese spiny lobsets, *Panulirus japonicus*, have nocturnal habit, and are usually rest in cracks of rock in daytime. It has been reported by various investigators (e.g. YOZA, 1977) that the catch of spiny lobsters is low in the period of full moon. Decay rate of light with depth is generally high especially in coastal waters, and the underwater brightness at night would be very limited. It appears that Japanese spiny lobsters are aware of a little change of the brightness of moonlight level. The relationship between underwater brightness and fish activities (or fish catch) has been studied by many investigators; for examples, by KUBO and ISHIWATA (1964) for spiny lobster, and by MASHIKO (1979) and TABATA *et al.* (1991) for catfish.

Japanese spiny lobster is one of the most important species in Japanese fisheries. In this paper, we shall model the diurnal variation of the light intensity with step-like brightness variation having 12 hour light period and 12 hour dark period. Lobster cages are hanged by three wires, and movements of a lobster were detected by measuring the variation of tension of one of these wires. The tension was recorded continuously for several days, and diurnal variations of lobster activities were observed under various combinations of brightnesses in light and dark periods. In order to check the reliability of the experiment, movements of a lobster were also observed in an outdoor pool of much larger dimension which was covered with a blackout sheet, and the brightness in which was artificially controlled.

2. Experimental apparatus and procedure

2–1. Japanese spiny lobsters used

Japanese spiny lobsters used in our experiments had been caught near the Shima Peninsula of the Mie Prefecture. We selected lobsters having weight between 250g and 350g. We used three cages in parallel for each experiment, and put one lobster in each cage. Though three experiments were carried out in parralel, no data was obtained for many runs as some of lobsters were not active enough, some died or casted out their skin on halfway of experiments. In average, only one record of the lobster activity was

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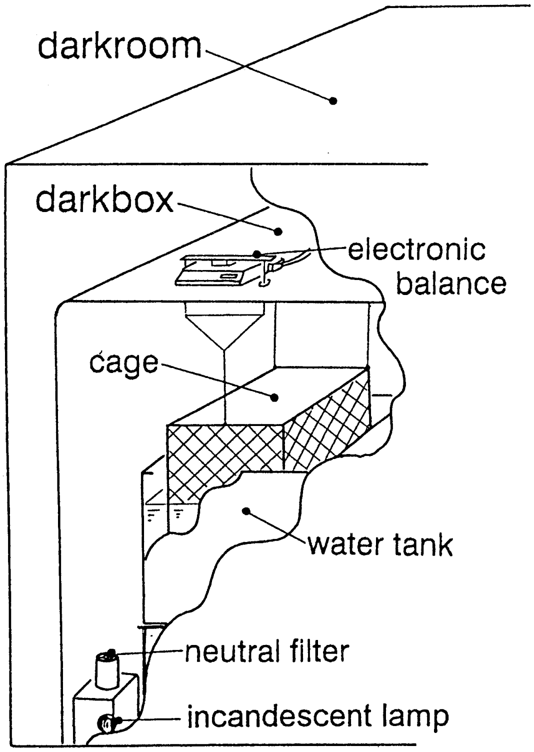

Fig. 1. Schematic sketch of the indoor experimental apparatus.

obtained for each experimental run. We usually replaced with a new lobster at beginning of each experimental run, except one case when the lobster was full of vigor for several consecutive experimental runs.

2–2. Dark box, water tanks and lobster cages.

The experimental apparatus used is shown schematically in Fig. 1. The apparatus is set in a dark box in a dark room in the Fisheries Research Laboratory of the Mie University in Zaga Island in Ago Bay near the tip of the Shima Peninsula. The dark box is of 2.0m length, 1.0m width and 1.5m height, and its sides and ceiling are covered with blackout sheets. In order to diffuse and homogenize the downward reflected light, a black fine net is placed just below the ceiling in wavy form. Three water tanks of 0.62m length, 0.42m width, and 0.35m depth are set in the dark box. The inside walls of the box are painted black and its surface is frosted. In each tank, one lobster cage of 0.40m length, 0.30m width, and 0.30m depth is set. One lobster was kept in each cage. Each cage is hanged by three wires from the ceiling of the dark box, and the variation of strain of one of the wires was measured to detect the movement of the lobster. The water inside tank is continuously replaced by supplying sea water at the rate of 3 liter per min. The water is supplied from a subtank where the water is kept overflowing to keep the supplying rate constant. The water is drained through two pipes, one of which is placed near the water surface and the other is placed near the tank bottom. The level of the lower drain is well below the bottom of the lobster cage.

2–3. Control of brightness

Eight incandescent lamps are installed on the floor of the dark box so as that each water tank has two lamps on its both sides, respectively. The light is shed upward, is reflected on the ceiling, and then penetrates into the experimental tanks. The downward illuminance at the level of the water surface at the center of each tank was measured by a high sensibility illuminance meter (International Light INC SELL 100/Y/L30) or a digital illuminance meter (Minolta T 1M). Obtained illuminance is used in this paper as a measure of brightness.

The light is turned on and off with 12 hours interval by using timekeepers (TWM–901 and TWI–101 made by Toshiba are used in parallel). Usually, we put the light on at 6:00 and off at 18:00 everyday. Hereafter, we shall call the light period as daytime and the dark period as nighttime for convenience' sake.

The light intensity is changed by putting various semitransparent filters (HOYA OPTICAL GLASS with transmission rates of 13.0%, 1.0% and 0.3%) on front of the lamps. Six combinations of the daytime and nighttime brightnesses were adopted in this experiment, and are shown in Table 1, together with several experimental parameters such as water temperature and density, dates of experiments and so on.

When all of the lamps are off, no signal comes out from our illuminance meters. We denote such brightness as 0 *lx* here.

Table 1. Experimental conditions for each experimatal run. Run 1 through run 6 were conducted in the indoor tanks and run 7 was in the outdoor tank.

	Brightness(lx)		Water temp. (℃)	Water density (σt)	Dates		Period (days)
	daytime	nighttime					
①	3.5×10^{-2}	0	23.1-26.0	24.8-25.3	Jun. 21-Jun. 30	1990	9
②	3.3×10^{2}	0	17.8-19.2	22.9-25.2	Nov. 18-Nov. 27	1992	10
③	3.3×10^{2}	2.3×10^{-5}	16.6-17.7	24.0-25.6	Apr. 14-Apr. 21	1992	7
④	3.3×10^{2}	5.2×10^{-3}	17.8-18.2	23.1-25.6	Apr. 24-May. 10	1992	15
⑤	3.3×10^{2}	3.5×10^{-2}	18.2-21.3	22.1-24.8	May. 11-May. 28	1992	16
⑥	3.3×10^{2}	2.0	22.6-25.0	21.5-23.8	Jun. 25-Jul. 12	1992	14
⑦	4.6×10^{2}	0	***	***	Jun.	1991	1

***no data

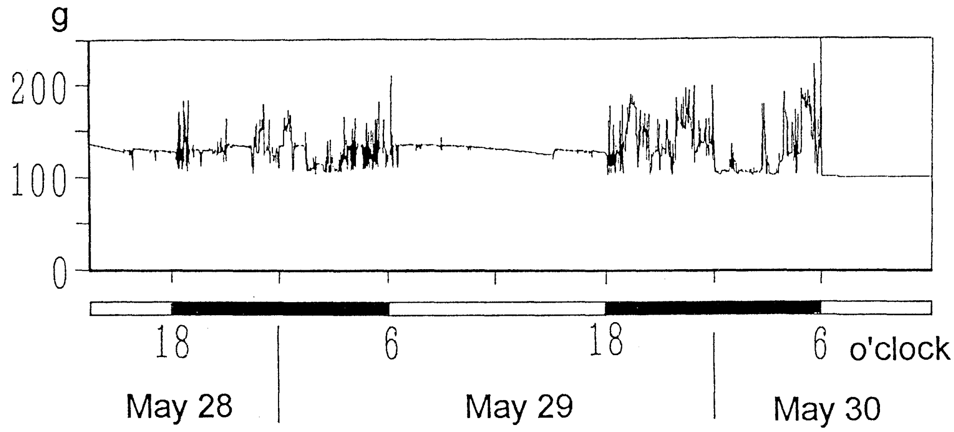

Fig. 2. An example of the recorded variation of the strain of a wire which hangs the lobster cage (the last two days of run 5). A clear diurnal variation of the lobster activity can be seen in the figure: the lobster is almost at reast in daytime and moves actively in nighttime. An extremely high strain value at 1.5 min. past 6 o'clock on May 29 indicates that the lobster jumped out from the tank. The constant strain value after this event shows the strain resulted from weight of the cage itself.

2-4. Detection of lobster movements

The lobster cages are hanged with three wires as shown in Fig. 1. One of the wires is connected to an electronic balance (AND EWA/B), and the output of the electronic balance is sent very three seconds to a personal computer (NEC 9801LV21) through RS232C cable.

Prior to the experiments, we observed movements of lobsters by eyes for several hours, and found that lobsters move usually by creeping on bottom of the cages, though they move occasionally by jumping. Interval of lobsters' stay and move, and changing frequency of the moving speed and direction, and moving trajectory were analyzed. We concluded that 15 sec would be the best for time interval to measure the moving activity of lobsters.

The strain is changed by about 13.7 gw when a lead weight of 150 gw (137 gw in water) is moved over 4cm distance in the longitudinal direction, and no strain change occurs when the weight is moved in the traverse direction. 2 gw strain change would correspond to 2.3cm move of 350g lobster (about 35 gw in water) or to 3.2cm move of 250 g lobster (about 25 gw in water) in the logitudinal direction. The sudden movement of lobsters, however, appears to cause a large strain change, probably when a lobster kicks the bottom hard and when a swing of cage occurs.

In Fig. 2, an example of the records of strain change is shown for the last two days of run 5 (Table 1). A diurnal variation of the lobster activity can be clearly seen in the figure: the lobster is almost at rest in daytime and moves actively in nighttime. At 1.5 min. past 6 o'clock on May 29 (just after the lamps were on), the strain value becomes extremely high (scaled out) and indicates that the lobster jumped out from the tank. The dead lobster was found on the floor of the dark box in the late morning (thereafter, we covered the surface of cage with net). The constant strain value after this event shows the strain resulted from weight of the cage itself. Small wiggles found in daytime may be caused from occasional chages of supply rate of sea water. This effect is, however, very small and is estimated to be of order of 0.1 gw in strain change. It should be noted that the strain changes occur both in the directions of strain increase and decrease by showing that the lobster goes and back in the cage. However, spike-like strain changes usually occur in the direction of strain increase. These would be caused mainly by jumps of the lobster. So, the strain change occurs not only due to the lobster movement in the longitudinal direction but also due to sudden movement of the lobster in any directions.

The strain data are basically obtained for every 3 sec, but the first and the last data in each segment of 15 sec length are missed as the digits of these parts are used to control the recording system. In order to make quantitative discussion, we defined a measure of lobster activities as follow. The averaged strain value was obtained for each experimental run, and then the deviations of the strain values from the averaged value were calculated. The deviations averaged for 9 sec (three successive data) for each 15 sec segment were obtained, and those larger than 2 gw is assumed to represent lobster movements. The occurrence frequency of these relatively large deviations for every 1 hour was calculated, and is used for a measure to represent lobster activity in this paper.

The threshold value, 2 gw, is selected empirically: if we count deviations larger than 1 gw, the occurrence frequency is enormously increased, presumably due to some occasional noise such as swings of cage. If we count deviations larger than 4 gw, the frequency is considerably decreased as we miss to detect small movements of the lobster.

2-5. Experimental procedure

In order to be habituated to the new circumstance in the tank, the lobster was kept under a control condition with daytime brightness of 3.3×10^2 *lx* and nighttime brightness of 0 *lx* for the first 2–4 days, except for run 1. This condition is the same as that in the experimental run 2 (see Table 1). We observed the variation of the lobster activity under various conditions for the periods ranging from 6 to 16 days (see Table 1). For one experimental run (run 5) in which the same lobster was used in the previous run (run 4), we added another two days experiment under the control condition, in order to check that the lobster activity was almost the same at beginning and end of the experiment.

We fed several living mussels, *Mytilus edulis*, to each lobster for each day. The weight of each mussel is about 5 gw. Feeding was made in daytime, but the feeding times were randomly selected by using a table of random numbers. However, the feeding time appears not to affect our experimental results as lobsters eat mussels usually in nighttime.

2-6. Supplemental experiment in an outdoor pool

The measure of the lobster activity defined above is arbitrary and somewhat ambiguous, as it may miss to count the movement of lobster in the traverse direction and may pick up erroneous signals caused by occasional swings of cage.

We conducted another supplementary experiment (run 7: see Table 1 for its experimental parameters) in an outdoor pool of 5.0m length, 2.0m width and 1.5m depth in the Fisheries Research Laboratory of the Mie University. The pool was covered with a blackout sheet, the brightness in which was artificially controlled just as similar to the indoor tank experiments. The light and dark periods were set from 6:00 to 18:00 and from 18:00 to 6:00, respectively. The daytime brightness is 4.6×10^2 *lx*, and a little higher than the control run above mensioned (see Table 1). The nighttime brightness can be regarded as 0 *lx* within our experimental accuracy.

A small red luminous diode was attached on the back of a lobster. The horizontal and vertical sizes of this cylindrical marker including a

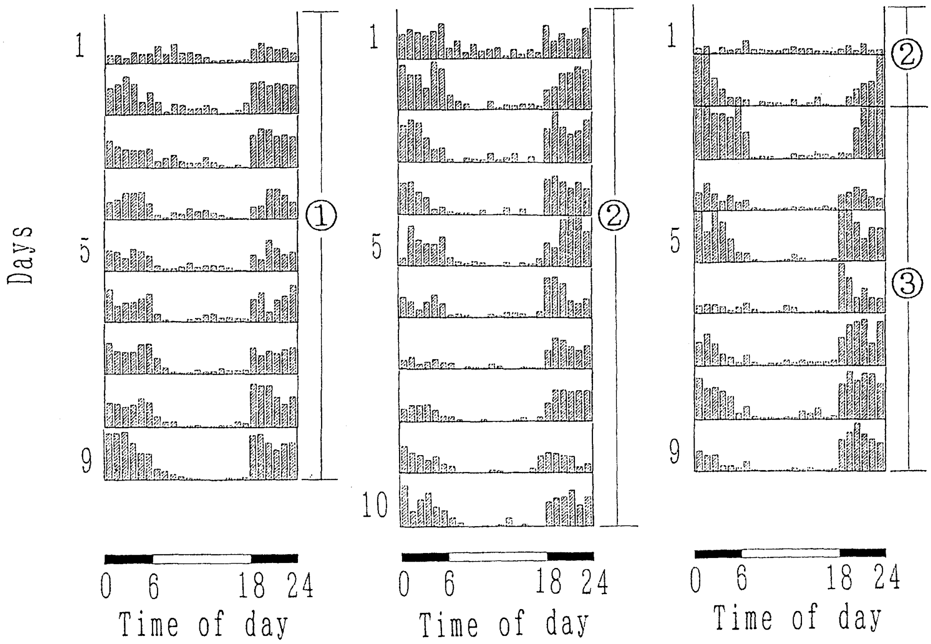

Fig. 3. Daily variation of the diurnal activity change of lobsters: the left column for run 1, the central column for run 2, and the right column for run 3. Run numbers are indicated by numbers in circles and are shown left side of each figure. The number 2 in the right figure indicates the habituation period under the control condition (as the same as run 2). The frequency of mean lobster activity (see text for its definition) per hour is shown. The day number from the beginning of each run is shown left side of each figure. The black and white horizontal bars beneath each figure indicates the dark period (nighttime) and the light period (daytime), respectively. The numbers attached below the bars indicate the time.

lithium battery are 35mm in length and 4mm in diameter, respectively, and its weight in water is 0.5 gw. The surface of the diode is painted by water-insoluble black ink, and its light intensity is decreased as just the position of the lobster can be traced by eyes.

One spiny lobster with the marker was released in the pool. The observation was conducted for one day after several hous habituation period, and the position of the lobster was determined every 15 sec. From this data, we calculated the moving distances for every 1 hour intervals.

Both the indoor and outdoor experiments were conducted in spring and autumn seasons as shown in Table 1. The water temperature and water density lie in the ranges from 16 to 23℃ and from 21.5 to 25.6 sigma-t, respectively (Table 1). The activity of the lobster would be influenced by changes of water temperature and density (salinity). However, the changes within these ranges appear not so significant in our experiments with limited accuracy.

3. Results

3-1. Diurnal variation pattern of lobster activity and its dependence on daytime brightness

The nighttime brightness is 0 *lx* both in runs 1 and 2, but the daytime brightness is 3.5×10^{-2} *lx* in run 1 and 3.3×10^{2} *lx* in run 2, respectively (see Talbe 1). The daily diurnal variations of the lobster activity for run 1 and for run 2 are shown in the left column and in the center column of Fig. 3, respectively.

As seen in these figures, the pattern of the diurnal activity variation of the lobster is considerably disturbed for the first few days just after the lobster was put in the new circumstance. (Note that no habituation period is set for run 1.) Some systematic changes in daily variation pattern can be recognized for further periods, but it is not so significant. The diurnal varia-

Table 2. The mean lobster activities for daytime and nighttime and their standard deviation. The occurrence freqency of the lobster move per hour is shown for run 1 through run 6, and the moving distance per hour for run 7. The brightness conditions in Table 1 for each experimental run is reproduced for convenience' sake.

	Brightness(lx)		Activity(freqency/h)	
	daytime	nighttime	daytime	nighttime
①	3.5×10^{-2}	0	13.8±4.5	72.2±21.7
②	3.3×10^{2}	0	9.9±6.5	74.4±21.1
③	3.3×10^{2}	2.3×10^{-5}	9.3±2.8	76.1±26.5
④	3.3×10^{2}	5.2×10^{-3}	2.1±1.1	19.0± 6.3
⑤	3.3×10^{2}	3.5×10^{-2}	2.6±1.6	17.3± 6.2
⑥	3.3×10^{2}	2.0	2.1±1.0	7.5± 2.6
			Activity(meter/h)	
⑦	4.6×10^{2}	0	12.3±36.7	200.5±75.6

tion pattern in run 1 is very similar to that in run 2. There is clear tendency that the moving activity of the lobster responds to the diurnal brightness variation: very low activity in daytime and high activity in nighttime. The activity suddenly increases just after the nighttime starts, but some activity remains for the first few hours of the daytime.

The experimental condition of run 2 would be the most similar to the natural condition (the control run). The lobster behavior is almost the same when the daytime brightness is decreased to 3.5×10^{-2} lx (run 1). The variation pattern for runs 1 and 2 may be considered as a basic activity variation pattern of Japanese spiny lobsters.

The diurnal activity variations averaged for whole experimental periods were calculated for run 1 and run 2, and are shown in Table 2 and Fig. 4 (the top and middle figures), respectively, together with their standard deviations. The daytime brightness in run 1 is considerably weaker than that in run 2 (daytime brightness in run 1 is the same as nighttime brightness in run 5). Though the activity of spiny lobster in daytime in run 1 is slightly higher than that in run 2, such a difference might be caused by a difference in character among individual lobsters. We cannot find no significant change in nighttime activity between runs 1 and 2. Lobsters appear not to be influenced significantly by the daytime brightness, at least if it is higher than 3.5×10^{-2} lx.

By keeping the daytime brightness as in run 2 (the control run), the brightness in nighttime is increased a little and is set as 2.3×10^{-5} lx in run 3. The daily diurnal activity variations are shown in the right column in Fig. 3, and the mean daytime and nighttime activities and their standard deviations are given in Table 2. The diurnal activity variation in run 3 is almost identical to those in run 2. Lobsters appear to recognize the brightness 2.3×10^{-5} lx as like as 0 lx.

The diurnal variation of the moving distance of the lobster for every 1 hour observed in the outdoor pool (the supplementary experiment) is shown in the bottom figure of Fig. 4. The mean moving distances per hour in daytime and in nighttime and their standard variations are shown in Table 2. The lobster traveled over 2,406m during the nighttime of 12 hours or moved in speed of about 2km/day. TAKAGI (1972) observed movements of tagged Japanese spiny lobsters in the sea south of the Boso Peninsula and reported that moving speed of lobsters reaches about 1.8km/day (29km for 16 days). HERRNKIND (1980) observed movements of New Zealand spiny lobster, *Jasus edwardsii*, in the sea 25–45m deep, and estimated their moving speed is from 5 to 7km/day. Our result coincides with these results in order of magnitude.

This moving distance would be another measure of the lobster activity. As seen in Fig. 4, the diurnal variation pattern of the moving distance is very similar to those of the lobster activity in run 1 and run 2. This indicates that the measure adopted in this paper is meaningful enough to represent lobster activity.

3–2. Effects of nighttime brightness on lobster activity.

As discussed in the previous sub–section, the nighttime activity is much higher than the daytime activity. In this subsection, we shall check how the change of nighttime brightness affects on lobster activity, by keeping the daytime brightness as just the same as that of the control run (3.3×10^{2} lx). We increased the nighttime brightness from 2.3×10^{-5} lx in run 3 through 2.0 lx in run 6 (see Table 1 or 2).

As discussed already, lobsters appear to rec-

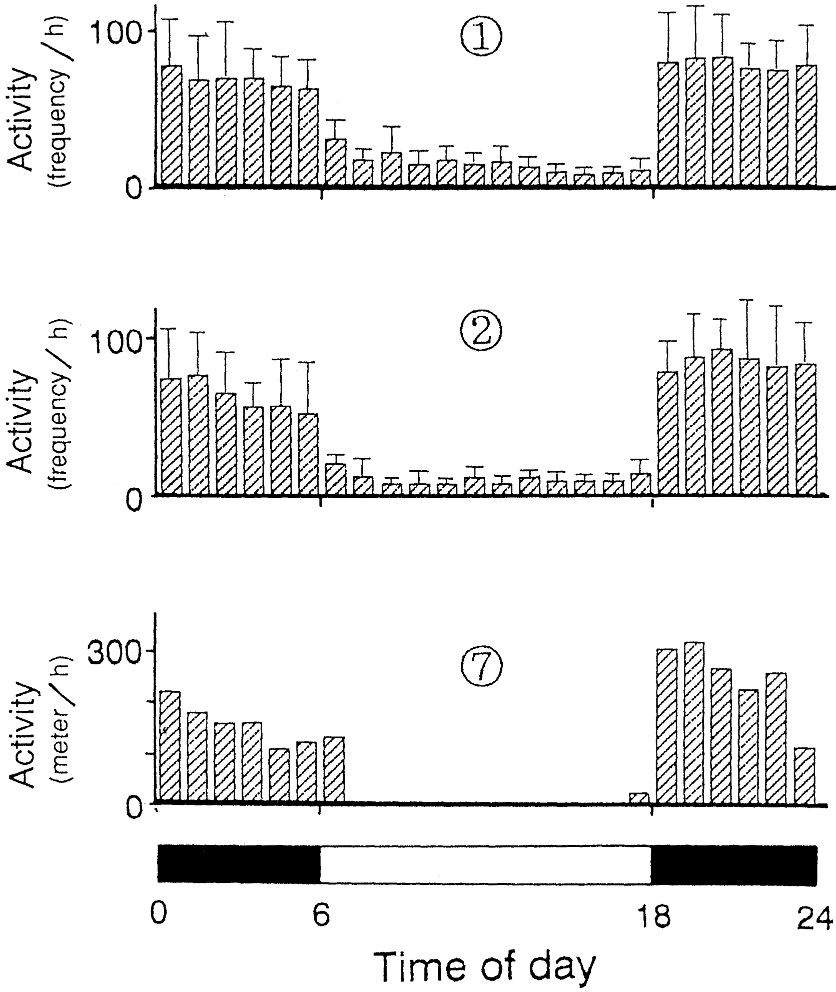

Fig. 4. Averaged diurnal variations of the lobster activity for run 1 (the top figure) and for run 2 (the middle figure). The activities per hour are shown by vertical columns, and their standard deviation by vertical bars. The result of the supplementary experiment (run 7) in a pool is shown in the bottom figure. The vertical column in this figure indicates the moving distance per 1 hour in m.

ognize that the brightness 2.3×10^{-5} *lx* is as just dark as 0 *lx*. However, when the nighttime brightness is increased to 5.2×10^{-3} *lx* (run 4), the nighttime activity is considerably suppressed as seen in the left column of Fig. 5. The daily diurnal variations for run 5 (the nighttime brightness is 3.5×10^{-2} *lx*) are shown in the center column in Fig. 5. The difference between run 4 and run 5 is not significant. Run 4 and run 5 are conducted successively by using the same lobster, and the lobster is kept in the condition of the control run for two days at beginning and end of the experiment, respectively. The activity of the lobster appears to be almost the same before and after this experiment.

The activity is generally higher in the first half than in the second half of nighttime both for run 4 and run 5. ARECHIGA and ATKINSON (1975) and PHILLIPS *et al.* (1980) reported that activity peak occurs just after sunset for other lobsters (*Nepherops norvegicus*, *Panulirus argus* and *Jasus lalandii*). This may correspond to our results. However, KUBO and ISHIWATA (1964) reported that catch of Japanese spiny lobster

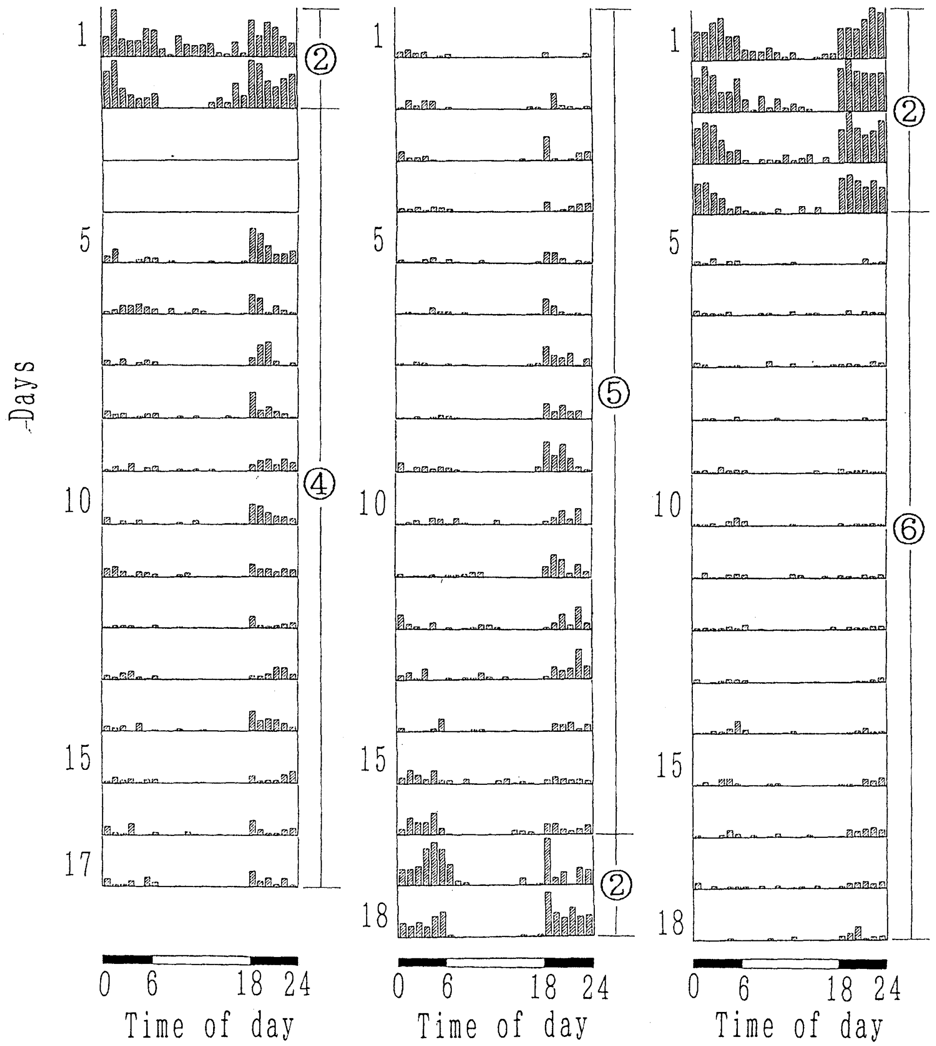

Fig. 5. The same as in Fig. 3 except for run 4 (the left column), for run 5 (the central column) and for run 6 (the right column), respectively. The habituation periods are shown with number 2 in circle. The same lobster was used for run 4 and run 5, and the habituation periods were set prior to run 4 and after run 5.

occurs not only just after sunset but also just before sunrise. For a prawn, *Penuaeus japonicus*, high activity is observed just after sunset and at midnight (NAKAMURA, 1987). The further elaborated investigation would be needed for such detailed activity variation of lobsters in nighttime.

When nighttime brightness is increased up to 2.0 *lx* (run 6), nighttime activity is much decreased as shown in the right column of Fig. 5. The mean daytime and nighttime activities and their standard variations are summarized in Talbe 2 and in Fig. 6. The difference between run 4 (or 5) and run 6 is much smaller than that between run 3 and run 4. This suggests that a threshould brightness value of lobster activity exists between 2.3×10^{-5} *lx* and 5.2×10^{-3} *lx*. Such a threshold brightness is often discussed for many kinds of fishes: for example, MASHIKO (1979) and TABATA *et al.* (1991) reported a threshold brightness for activities of catfish, *Pseudobagrus aurantiacus*, and showed that its

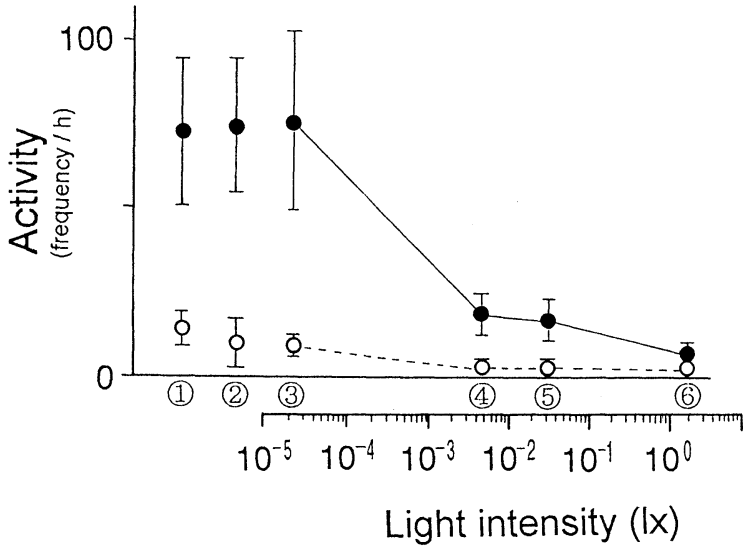

Fig. 6. Dependence of the lobster activity on change of the nighttime brightness. The daytime brightness is the same as in the control run (run 2). The nighttime brightness is taken in the abscissa, and the mean lobster activities for daytime and nighttime are shown with dark circles and white circles, respectively. The results for run 1 and run 2 (nighttime brightnesses are 0 *lx*) are also shown in the left-hand side of the figure. Run numbers are indicated with numbers in circles. The result might be influenced by individual lobster character, but the figure suggests that a threshold brightness value for the lobster activity exists between 2.3×10^{-5} and 5.2×10^{-3} *lx*.

value lies in the range from 10^{-2} to 10^{-3} *lx*.

The lobster catch by bottom-set gillnets, which are installed in depths ranging from 5 to 10 min the sea near the Boso Peninsula is influences by moonlight intensity (YOZA *et al.* 1977). The water off the Shima Peninsula, where is one of the good fisheries ground of Japanese spiny lobster and where the lobsters used in our experiment were caught, is considerably clean and corresponds to the coastal type of grade 1 according to JERLOV (1976) (MAEGAWA, personal communication). Acording to FUSHIMI (1978), the spiny lobsters are caught in the seas shallower than 50m. Lobster gillnets are usually set at the bottom shallower than about 15m depth off the Shima Peninsula. If we assume the brightness of full moon at sea surface is 0.24 *lx*, the brightness at 16.5m becomes to be 5.2×10^{-3} *lx*. It would be reasonable from our results that lobster catch is influenced by moonlight brightness.

4. Concluding remarks.

Diurnal variation of the activity of Japanese spiny lobsters was investigated in the small indoor thanks and in the outdoor pool of the Fisheries Research Laboratory of the Mie University. The nocturnal habit of the lobstaer is reproduced in our experiments, and lobsters stay almost in rest in daytime if the brightness is higher than 3.5×10^{-2} *lx*. the moving activity of the lobster in nighttime is shown to be strongly controlled by underwater brightness. If the nighttime brightness is lower than 2.3×10^{-5} *lx*, the lobster moves very actively as just as in 0 *lx* brightness. The nighttime activity is considerably suppressed when the brightness is higher than 5.2×10^{-3} *lx*. Above this value the activity tends to decrease with brightness increase. The difference in activity level is very conspicuous between in brightnesses higher than 2.3×10^{-5} *lx* and lower than 5.2×10^{-3} *lx*. There would be a threshold value of brightness which separates high and low activity regime.

Recently, we found that some of lobsters can be kept in the tank for long time, say more than one year. If we use such lobsters, we may get much more quantitative results and may determine the accurate value of the threshold and other quantities which characterize the lobster behavior.

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夜間の水中照度とイセエビの活動度

小池　隆・森川由隆・前川行幸

要旨：イセエビの日周行動を，屋内水槽で調べた．実験は三重大学附属水産実験所で行った．明るさの日変化は，12時間の明期（昼間）と12時間の暗期（夜間）がステップ状（短形）に変動するように設定した．イセエビの行動は飼育カゴを吊したひもの張力を測定することによって検出した．また，目印をつけたイセエビの行動を屋外の大型水槽で目視観察して補助実験とした．

イセエビは夜行性を示し，昼間明るさが 3.5×10^{-2} lx 以上あるとほとんど休止状態であった．夜間の明るさが 2.3×10^{-5} lx 以下の場合，イセエビは 0 lx（真暗）の場合と同様活発に行動した．イセエビの行動は，夜間の明るさがある限度を越すと非常に抑制された．夜間の明るさが，2.3×10^{-5} lx より低い場合と 5.2×10^{-3} lx より高い場合とでは活動度に顕著な差が認められ，活動度でみた明るさの閾値がこの間に存在することが推定される．夜間の明るさが 5.2×10^{-3} lx 以上では，明るさの増加とともに活動度が若干低下する傾向が見られた．