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Relationship between soak time and number of enmeshed animals in experimentally lost gill nets

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ABSTRACT: In order to determine the effects of ghost fishing by lost gill nets, the relationship was examined between soak time and number of enmeshed animals in experimentally lost gill nets by using diving observations. Two experimental gill nets were set at 13 m depth in Tateyama Bay, Chiba Prefecture, Japan for approximately 200 days. One gill net was deployed in a small trough surrounded by artificial reefs, and the other was deployed on an adjacent open sandy bed. Twelve species of crustaceans, six species of gastropods, and five species of bony fish were enmeshed in the experimental gill nets. The number of enmeshed animals in the artificial reef gill net was substantially larger than that in the sandy bed gill net. The number of enmeshed animals in the experimental gill nets increased rapidly within one month after deployment, and then declined gradually showing fluctuations caused by the decrease in newly enmeshed animals, and the drop off from gill nets caused by the decomposition of dead animals. The decrease in the number of enmeshed animals was expressed by logarithmic equations, and based on these equations, the duration of capture function for the lost gill nets was calculated to be 284–561 days in the artificial reef gill net and 200 days in the sandy bed gill net. The duration of capture function for the lost gill nets for non-commercial by-catch species such as small crustaceans and gastropods was longer than for commercial species such as Japanese spiny lobster and bony fish.

KEY WORDS: **ghost fishing, gill net, Japanese spiny lobster, lost gear, soak time.**

INTRODUCTION

Gill nets are typical passive fishing gears set on fishing grounds to enmesh animals. Therefore, the catch and species composition can be influenced by the soak time of the gill nets. The relationship between the soak time and the catch of gill nets has been studied in field and tank experiments.[1–5] For example, Koike and Takeuchi[2] reported that the catch of gill nets for pondsmelt *Hypomesus nipponensis* increased according to the prolonged soak time. In these studies,[1–5] the soak time of the gill nets were set up for several hours to several days because gill nets deployed in the fishing ground are usually retrieved after several hours to several days. However, bottom gill nets are sometime snagged on obstacles such as sunken rocks or artificial reefs, and are left in the fishing ground over extended periods. These lost gill nets may continue to induce mortality of aquatic animals. This phenomenon is commonly referred to as ghost fishing.[6] The FAO Code of Conduct for Responsible Fisheries[7] assumes ghost fishing to be one of the most serious negative effects on the present capture fishery.[6] Ghost fishing mortality forms part of the unaccounted fishing mortality.[8] Therefore, it is necessary to evaluate the ghost fishing impact on aquatic animals for resource management in the coastal area. The ghost fishing impacts by lost gill nets have been estimated by diving observations[9–13] and comparative fishing experiments.[14–17] Diving observations are suitable for research in shallow water such as fishing grounds for the small-scale gill net fishery in coastal areas of Japan. However, there are few research reports[12,13] that have evaluated the effects of ghost fishing by lost gill nets in coastal areas of Japan. Accordingly, in the present case study, in order to determine the effects of ghost fishing by lost gill nets, the relationship between soak time

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and number of enmeshed animals in experimentally lost gill nets was examined by means of diving observations.

MATERIALS AND METHODS

Experimental site

The experimental site was located on sandy or rocky bed areas of 13 m depth approximately 500 m north of the Banda fishing port, Tateyama Bay, Chiba Prefecture, Japan (Fig. 1). In this site, 33 artificial reefs 1.5 m long on each side have been previously installed (1979–1980) in a random pattern,[18] and local fishers capture the Japanese spiny lobster *Panulirus japonicus* with bottom gill nets. Two experimental gill nets were set and allowed to remain over a long period to simulate ghost nets at this site. One gill net was deployed in a small trough surrounded by the artificial reefs, and the other gill net was deployed on an adjacent open sandy bed. In this paper, the former is termed the artificial reef gill net, and the latter is termed the sandy bed gill net.

Experimental gill nets

Local bottom gill nets for the Japanese spiny lobster were used in the experiments. The netting was made of multifilament polyamide (210 denier, 20 fibers, 2-strand, PA 210d/20F × 2). One fleet of local gill nets usually consists of several panels 40 m long. However, the experimental gill nets were 10 m long to simulate net loss. The average measured mesh size and standard deviation of 100 randomly sampled meshes were 75.3 ± 0.5 mm. The hanging ratio was 0.73, and the net height in still water was 0.94 m. Float lines of gill nets were marked at 1-m intervals with numbered plastic tape for measurement of net height. The experimental gill nets were set on the sea bed with 2-kg lead sinkers at each end. A surface marker buoy and buoy line were not used in the experiments.

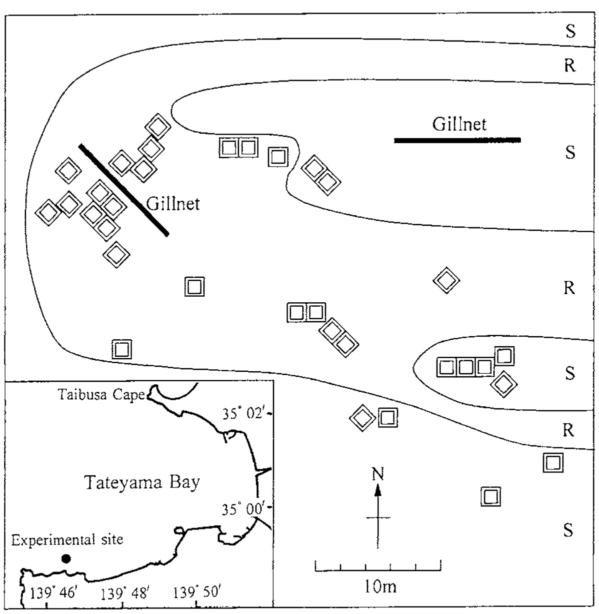

Fig. 1 Experimental site of 13 m depth in Tateyama Bay, Chiba Prefecture, Japan. Double squares, artificial reefs; S and R, sandy and rocky beds, respectively. Solid lines, boundary between sandy bed and rocky bed.

Underwater monitoring

The experimental gill nets were soaked in the sea for 191 days from 10 May–18 November 2003 (Exp-1), and for 198 days from 16 February–1 September 2004 (Exp-2). During each period, two scientific divers monitored the experimental gill nets at the following intervals: daily during the first week, weekly during the next 2 months, and every 2 weeks thereafter. Net height,[9] defined as the vertical distance between the sinker line and the float line, and species, size, number, and state (alive or dead) of enmeshed animals were recorded *in situ* by the divers. The net height and the size of animals were measured to the nearest lowest centimeter with a ruler. Some enmeshed animals were either tagged with plastic tags or marked with crayons for individual identification. Bottom water temperature in the experimental site ranged 18.5–24.2°C in Exp-1 and 12.9–24.5°C in Exp-2.

RESULTS AND DISCUSSION

Enmeshed animals

During the experimental periods, 12 species of crustaceans including Japanese spiny lobster as the main target species, six species of gastropods, five species of bony fish, and two other species were enmeshed in the experimental gill nets (Table 1). The number of enmeshed animals in the sandy bed gill net and the artificial reef gill net were 17 and 59 in Exp-1, and eight and 44 in Exp-2, respectively. The number of enmeshed animals in the artificial reef gill net was significantly larger than in the sandy bed gill net in each experiment (Student's *t*-test, $P < 0.05$). The reason for this difference is considered to be caused by the function of the artificial reef to aggregate animals, and the prolonged duration of capture function for the

Table 1 Numbers of animals enmeshed in gill nets

Species	Size† (cm)	Exp-1 SB	Exp-1 AR	Exp-2 SB	Exp-2 AR
Japanese spiny lobster *Panulirus japonicus*	2–8 CL	0	9	0	15
Other crustaceans		8	35	7	18
Hermit crabs *Pagurus* spp.	4–13 SL	7	8	4	4
Reef crab *Atergatis floridus*	3–5 CW	1	4	0	7
Rock crab *Charybdis japonica*	3–7 CW	0	7	1	3
Decorator crab *Schizophrys aspera*	3–5 CW	0	7	0	1
Lumpy crab *Paraxanthias elegans*	2–4 CW	0	4	0	0
Hairy crab *Pilumnus vespertilio*	3–4 CW	0	2	0	2
Arrowhead crab *Huenia heraldica*	1–2 CW	0	0	2	0
Locust lobster *Scyllarides squamosus*	7 CL	0	1	0	0
Violet-eyed swimming crab *Carupa tenuipes*	4 CW	0	1	0	0
Spider crab *Micippa philyra*	2 CW	0	1	0	0
Swimming crab *Thalamita sima*	2 CW	0	0	0	1
Gastropods		4	11	1	5
Neapolitan triton *Cymatium echo*	5–11 SL	4	6	1	3
Horned turban *Turbo cornutus*	6–10 SL	0	3	0	0
Saul's triton *Charonia sauliae*	15 SL	0	1	0	0
Stained miter *Mitra inquinata*	4 SL	0	1	0	0
Giant abalone *Nordotis gigantea*	13 SL	0	0	0	1
Cap shell *Thais bronni*	3 SL	0	0	0	1
Bony fish		1	2	0	5
Flag fish *Goniistius zonatus*	19–23 BL	0	1	0	2
Rock fish *Sebastiscus marmoratus*	23–24 BL	0	0	0	2
Flat head *Platycephalus indicus*	37 BL	1	0	0	0
Box fish *Ostracion immaculatus*	12 BL	0	1	0	0
File fish *Stephanolepis cirrhifer*	13 BL	0	0	0	1
Others		4	2	0	1
Sand dollar *Clypeaster japonicus*	8–11 TD	4	2	0	0
Sea cucumber *Stichopus japonicus*	16 BL	0	0	0	1
Total		17	59	8	44

†BL, body length; CL, carapace length; CW, carapace width; SL, shell length; TD, test diameter.
SB, sandy bed gill net; AR, artificial reef gill net.

artificial reef gill nets, as mentioned later. As for previous reports,[11–13] the present results also suggest that the effect on resources by lost gill nets depends on the environmental and topographic conditions of the immediate area of the sea bed where the net is lost.

Net height

Relationships between the soak time and the average net height of the experimental gill nets are shown in Figure 2. Here, the average net height is defined as the average value of the net height at the 11 measuring points on the experimental gill nets. Just after deployment, the average net height of the artificial reef gill net was larger than that of the sandy bed gill net because the artificial reefs reduced the effects of the water current. The average net height of each gill net declined rapidly within the first few days after deployment because of enmeshed animals and drifting sea weeds. In both experiments, sandy bed gill nets were washed away during typhoons and were snagged on a nearby artificial reef in the middle of the experimental periods. After that, the sandy bed gill net rolled up into a small clump. In contrast, the artificial reef gill net remained in its original position and the average net height remained at approximately 10 cm during both experimental periods. As mentioned above, the number of enmeshed animals in the artificial reef gill net was larger than in the sandy bed gill net. These results clearly show that the capture function of the artificial gill net was longer than that of the sandy bed gill net.

Soak time and enmeshed number

Relationships between the soak time and the number of enmeshed animals in the experimental

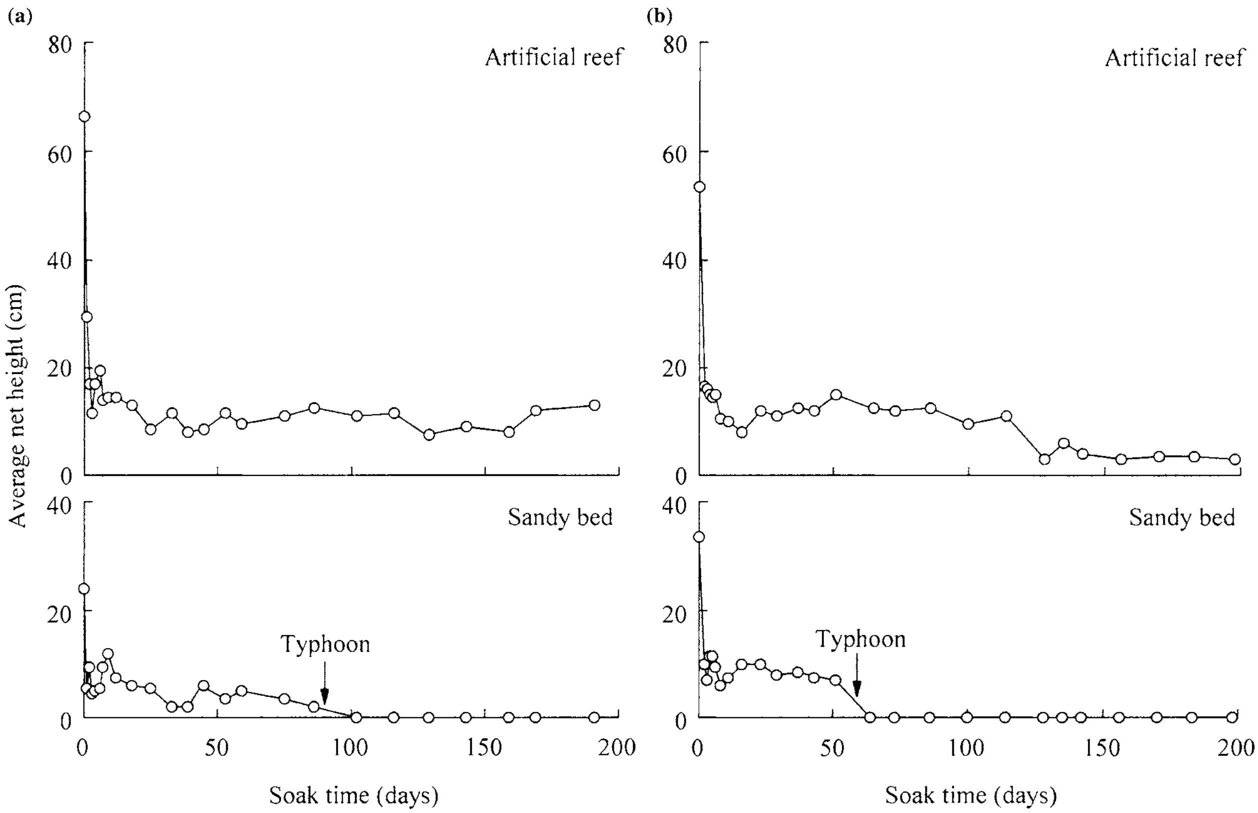

Fig. 2 Relationships between the soak time and the average net height of the experimental gill nets. (a) Exp-1, (b) Exp-2.

gill nets are shown in Figure 3. The number of enmeshed animals in each gill net increased rapidly within one month after deployment, and then declined gradually showing fluctuations because of the decrease in newly enmeshed animals and the drop off from gill nets caused by the decomposition of dead animals. In the artificial reef gill net, maximums of 20 and 21 animals were enmeshed at four and 11 days after deployment in Exp-1 and Exp-2, respectively. In the sandy bed gill net, maximums of seven and four animals were enmeshed at 25 and 16 days after deployment in Exp-1 and Exp-2, respectively. On the last day of each experiment, a small number of animals remained in the experimental gill nets. The decrease in the number of enmeshed animals after the peak is reached is important to estimate the duration of the capture function for lost gill nets. The relationships between the soak time T and the number of enmeshed animals n in the experimental gill net after the number of enmeshed animals reached the peak are expressed by equations 1–4:

Artificial reef gill net in Exp-1:

$$n = -4.05 \times \ln T + 25.63\ (r = 0.95, P < 0.05) \quad (1)$$

Sandy bed gill net in Exp-1:

$$n = -2.76 \times \ln T + 14.64\ (r = 0.91, P < 0.05) \quad (2)$$

Artificial reef gill net in Exp-2:

$$n = -5.19 \times \ln T + 29.34\ (r = 0.87, P < 0.05) \quad (3)$$

Sandy bed gill net in Exp-2:

$$n = -0.70 \times \ln T + 3.54\ (r = 0.54, P > 0.05) \quad (4)$$

Except on the sandy bed gill net in Exp-2, significant correlations were observed between the soak time and the number of enmeshed animals (Spearman's correlation coefficient test, $P < 0.05$). Accordingly, from these equations, the soak time that the number of enmeshed animals became 0, which is the duration of the capture function for the lost gill nets, was calculated to be 561 and

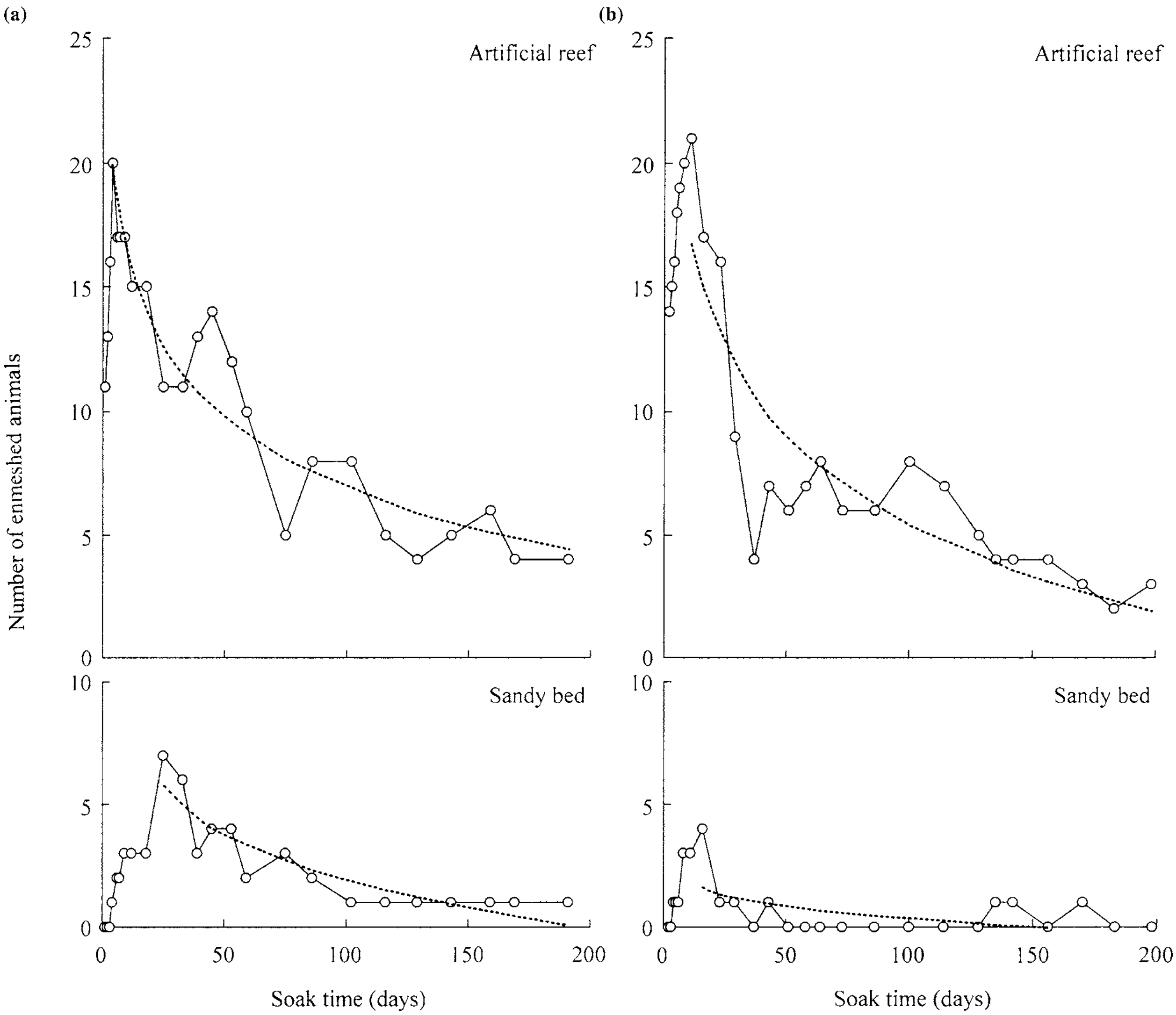

Fig. 3 Relationships between the soak time and the number of enmeshed animals in the experimental gill nets. (a) Exp-1, (b) Exp-2. Solid lines (○), experimental data; dotted lines, decrease in numbers of enmeshed animals expressed by equations 1–4.

200 days in the artificial reef gill net and the sandy bed gill net in Exp-1, respectively, and 284 days in the artificial reef gill net in Exp-2.

Regarding the duration of capture function for the lost gill nets, Kaiser *et al.*[9] reported that lost gill nets could continue to catch commercial crustaceans such as the spider crab *Maja squinado* for at least nine months after net loss. Erzini *et al.*[10] reported that the effective fishing lifetime of lost gill nets for finfish is a maximum of 15–20 weeks. These results are similar to the present study, although the duration of capture function for the lost gill nets estimated in the present study is longer than that of the previous studies,[9,10] which is presumably dependent on the experimental conditions. This difference in capture function is considered to be caused by the extended entangling of non-commercial species such as small crustaceans and gastropods.

Difference in species

Relationships between the soak time and the number of enmeshed animals in each taxonomic group in the artificial reef gill net are shown in Figure 4. The number of enmeshed Japanese spiny lobsters increased rapidly within the first 1–2 weeks after deployment and then decreased rapidly. The entangling in gill nets of Japanese

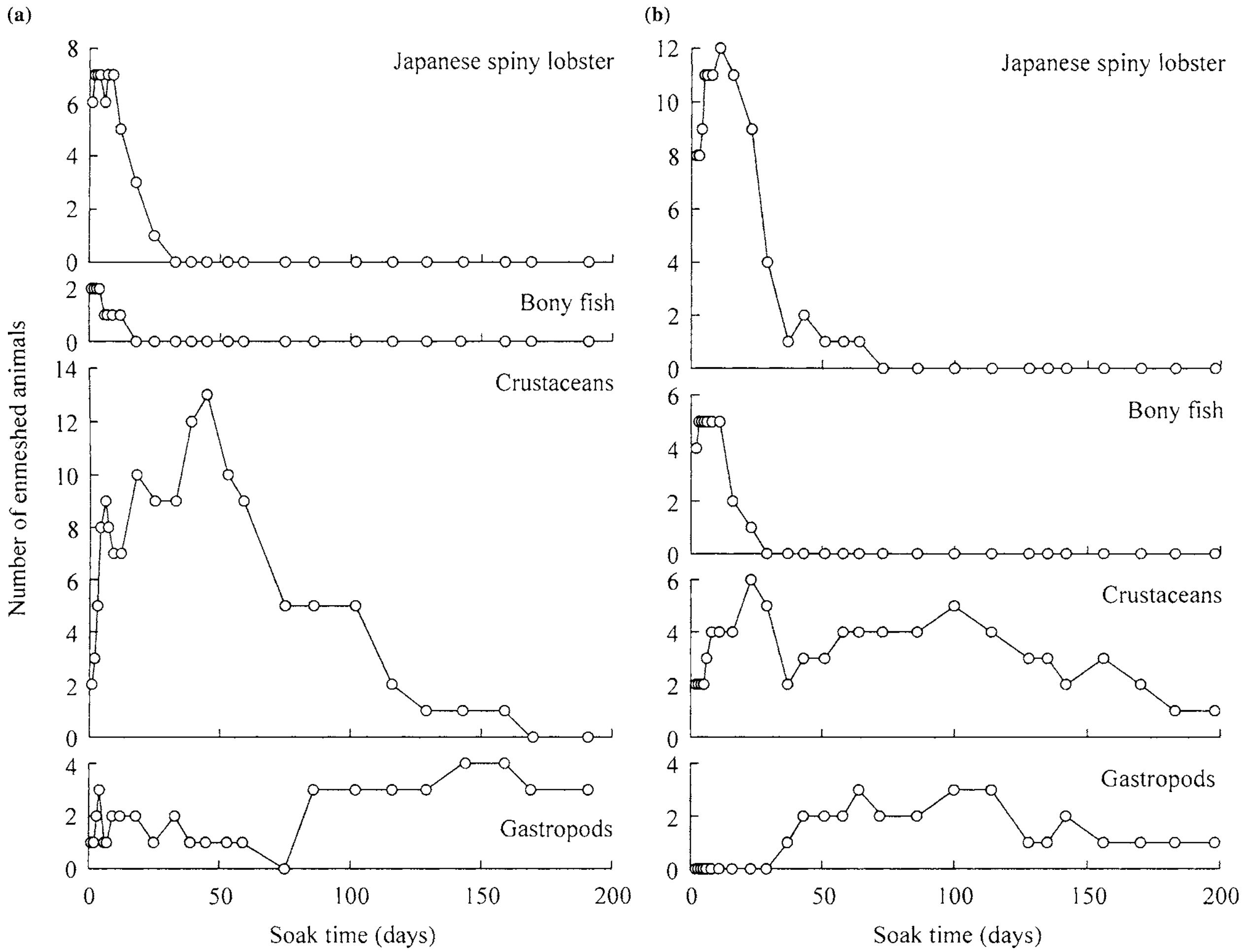

Fig. 4 Relationship between the soak time and the number of enmeshed animals in each taxonomic group in the artificial reef gill nets. (a) Exp-1, (b) Exp-2.

spiny lobster stopped approximately 25 and 64 days after deployment in Exp-1 and Exp-2, respectively. Similarly, bony fish also were enmeshed within only 2–3 weeks after deployment. In contrast, gastropods and other crustaceans except Japanese spiny lobster were enmeshed in the artificial reef gill net over a longer period. The numbers of other crustaceans increased and decreased more gently than the Japanese spiny lobster and bony fish. Further, the number of gastropods increased in the middle or later stages rather than in the first stage of the experiment. Even on the final day, the artificial reef gill net continued to catch three gastropods in Exp-1, and one gastropod and one crustacean in Exp-2. From these results, it is clear that the duration of the capture function for the lost gill nets depends on the enmeshed species. Especially in this case study, the duration of the capture function for the lost gill nets for non-commercial by-catch species such as small crustaceans and gastropods was longer than that for commercial species such as Japanese spiny lobster and bony fish. In the present study, the underwater monitoring frequency decreased over time, as mentioned above. Accordingly, in the middle or later stages of the experimental period, there may have been oversight of mortality of non-commercial crustaceans and gastropods. Therefore, as frequent monitoring as possible is required to prevent underestimation of ghost fishing impacts by lost gill nets.

Death rate

Table 2 shows the death rate of the enmeshed animals in the experimental gill nets. Here, the death rate was defined as the percent ratio of the number of animals identified as dead to the

Table 2 Death rates of animals enmeshed in the experimental gill nets

Species	Number of enmeshed animals	Mortality	Death rate (%)
Japanese spiny lobster	24	18	75
Other crustaceans	68	22	32
Hermit crabs	23	5	22
Reef crab	12	6	50
Rock crab	11	2	18
Decorator crab	8	6	75
Lumpy crab	4	1	25
Hairy crab	4	0	0
Arrowhead crab	2	0	0
Locust lobster	1	0	0
Violet-eyed swimming crab	1	1	100
Spider crab	1	1	100
Swimming crab	1	0	0
Gastropods	21	0	0
Neapolitan triton	14	0	0
Horned turban	3	0	0
Saul's triton	1	0	0
Stained miter	1	0	0
Giant abalone	1	0	0
Cap shell	1	0	0
Bony fish	8	8	100
Flag fish	3	3	100
Rock fish	2	2	100
Flathead	1	1	100
Box fish	1	1	100
File fish	1	1	100
Others	7	0	0
Sand dollar	6	0	0
Sea cucumber	1	0	0
Total	128	48	38

number of enmeshed animals observed in the experimental gill nets. Eighteen dead bodies of 24 enmeshed Japanese spiny lobsters were identified in the experimental gill nets; therefore, the death rate was calculated to be 75%. The death rate of other crustaceans had a large variance in some species because of the low sample data, and the death rates of hermit crabs *Pagurus* spp. and rock crab *Charybdis japonica* were comparatively low. Dead bodies of gastropods were not identified in the experimental gill nets; therefore, the death rate was calculated to be zero. In contrast, all the bony fish decomposed and dead bodies of bony fish were identified in the experimental gill nets; therefore, the death rate was calculated to be 100%. These results suggest the possibility of escape from lost gill nets by gastropods and some crustaceans. Previous reports suggested that Japanese spiny lobster may be able to escape from gill nets.[19] Further, local fishers suppose from their experience that rock crab can escape by tearing the gill net (Kikuchi M, pers. comm., 2003). There is no report regarding the death rate of animals enmeshed in lost gill nets; therefore, the ghost fishing mortality has been estimated on the assumption of the entire kill of the enmeshed animals. However, results of present study suggest that the number of enmeshed animals is not always equal to the mortality. For a better understanding of the death rate of animals enmeshed in lost gill nets, laboratory experiments need to be conducted to clarify the escape behavior from gill nets of gastropods and crustaceans.

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