BIOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF *PARALITHODES BREVIPES* IN COASTAL WATERS OF NEMURO

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Spiny king crab *Paralithodes brevipes* hatch as zoea at the water temperature of 5–8°C. After molting three times in 21 days at about 10°C, they develop into non-feeding glaucothoe stage and molt juvenile crabs in about 21 days. In the laboratory, zoea and glaucothoe are infected with Vibrio and Virus. Quarantine system must be established prior to seedling experiment. Zoea has reserved yolk, therefore, tolerates starvation for about 3 days. They are depending on nutritiously plankton in the wild. In the laboratory, we can rear early zoeae fed cultured diatom, *Thalassiosira nordenskioeldii*, and advanced zoeae with additional feeding *Artemia* nauplii. The morphological change of the mouthparts and digestive organs were observed. The oral appendages and the foregut are temporarily atrophied during the glaucothoe stage. Large lipid droplets are observed in the midgut gland cells of the early glaucothoe, but they disappear at the later stage due to consumption as energy source for the glaucothoe. *T. nordenskioeldii* is nutritious food that has lipid content of 12.5% of dried matter. The metamorphosed glaucothoe has well-developed pleopods and actively swim around looking for a habitat to settle. Being phototaxis, they swim to the surface and settle on the substrate during the day and take rest on the bottom at night. The grip strength of pleopods is weak at the early stage so that they are easily detached by stimulation, but within two weeks, they become immovable, and another two weeks later, they molt into the juvenile crab and hide out in the bottom. They select periphytons, which have a three-dimensional structure, rather than planer beds such as rocks. Young crabs were released in the sheltered seashore. After wintering, some of them remained there as the equivalent sized crabs reared in the laboratory. Young crabs reared in the laboratory grew to CL 30, 51, 71, 89 and 94 mm, at instar 14, 17, 19, 21 and 22 at 2+, 3+, 4+, 5+ and 6+ years, respectively. Most females brooded eggs beginning after 6+ year (CL 95 mm) in the wild, while 6+ year in the laboratory (also, CL 95 mm) carried eggs, and hatched zoea at 7+ year. The zoea had less red color, week photaxisis and poor swimming activity, which could be improved by feeding during larval, juvenile and adult stages. The ratio of egg brooding female and non-egg brooding female was much higher at 70:30% in 1992 compared to 24:76% in 2004 for the carapace width of 110–120 mm. From food remains in the stomach of king crabs, it is suggested that macroalgae, sea urchins and spiny king crabs compose critical components of the ecosystem in southern Kuril Islands including Nemuro waters. Further studies is necessary to clarify structure and function of the ecosystem.

Tabl. – 3, fig. – 4, ref. – 40.

INTRODUCTION

The family Lithodidae (Crustacea, Decapoda), commonly known as king crabs, includes 16 genera and 95 species in both hemispheres (**Dawson, 1989**). Among them, the most important fisheries resource is the genus of king crabs (*Paralithodes*) that is found in the cold North Pacific waters, which consists of the red king crab (*Paralithodes camtschaticus*), the blue king crab (*P. platypus*) and the spiny king crab (*P. brevipes*). While red king crabs occur widely from the Sea of Okhotsk to the Bering Sea, the distribution of spiny king crabs is limited to a part of the coastal area of Nemuro, Kuril Islands and Sakhalin, and blue king crabs are found only in isolated populations in the Bering Sea and Gulf of Alaska. The largest catch is shown by the red king crabs, with recent landings of about ten thousand tons per year. Stocks of the blue king crab and the spiny king crab are much lower, with the catch of the spiny king crab along the Nemuro Peninsula being no more than some dozens to hundreds tons per year.

Biological research on king crabs has been conducted mainly on the red king crab (**Nakanishi, 1987; Paul and Paul, 1980, 1997; Paul, et al., 1989; Sato, 1958; Shirley and Shirley, 1988; Shirley and Shirley, 1987; Stevens, 1990; Stevens and Kittaka, 1998**). There are few studies on the spiny king crab except on larval rearing (**Kurata, 1963**) and its growth (**Abe and Koike, 1982**). This report is presented based on past findings and recent ecological findings obtained by Nemuro Fisheries Research Institute.

1. ECOLOGY OF LARVAE

1.1. Development of larvae

The species of *Paralithodes* hatch as zoea at water temperature of 5–8°C develop into glaucothoe after molting four times in 28 days for *P. camtschaticus* and three times in 21 days for *P. brevipes* at about 10°C. The glaucothoe lasts approximately 21 days before molting to the first juvenile stage at about 10°C.

Through larval rearing, the morphological alterations of the mouthparts, foregut, midgut, midgut gland and hindgut that accompany the developmental stages were observed. The oral appendages and the foregut are temporarily atrophied since they do not feed during the glaucothoe stage (**Abrunhosa and Kittaka, 1997a, b**). Though large lipid droplets are observed in the midgut gland cells during the early glaucothoe, they disappear at the later stage and, instead, granular lipid droplets are observed on the outer edge of epithelial cells. In addition, the body lipid content of the *P. camtschaticus* zoea increases as they grow, reaching a maximum value at the late zoea/early glaucothoe, and then decreases until molting to the juvenile stage. These observations indicate that lipids are accumulated by feeding during the zoeal stage and are used as an energy source during the non-feeding glaucothoe stage.

1.2. Food of larvae

In situ zoeal food consists of various zooplankton and phytoplankton (**Paul, et al., 1989**). If the hatching of larvae coincides with diatom multiplication in spring, when the water temperature reaches 8–10°C, the survival rate of the larvae is increased and it is likely that the movement and settlement of juveniles are improved. Multiplication of diatoms such as *Thalassiosira nordenskioeldii* and *Phaeodactylum* sp. is desirable. *T. nordenskioeldii* is a particularly nutritious food because it has lipid content of 12.5% of dried matter, and an EPA and DHA content at 1.40 and 0.52% respectively, both being n-3 highly unsaturated fatty acids (**Kittaka and Kihara, 2000; Kittaka, et al., 2002a; Kittaka, et al., 2002b**).

1.3. Phototaxis of larvae

Hatching of *P. brevipes* from eggs occurs around April in the wild. The larvae hatch as prezoea and come to the surface within several minutes. They are planktonic from zoea I through zoea IV, and then metamorphose into the transitional glaucothoe stage, during which they swim actively. After the mid- glaucothoe stage, they settle on suitable substrate.

Swimming velocity was measured using an aquarium (90×20×30 cm deep) filled with seawater at about 10°C. A 100-watt electric light was set at one end. Animals were placed in the starting side and the swimming speed was measured. Average swimming velocity was 2.4, 2.3 and 2.6 cm/sec for zoea I, II and III, and it was 2.7 and 3.1 cm/sec for early and mid-stage glaucothoe, respectively (**Table 1**). Swimming velocity showed little variation during the zoea stages, but increased in the mid-glaucothoe stage with development of pleopods.

Table 1

The swimming time and speed for *P. brevipes* larvae of each developmental stage

	Development stage				
	Zoea I	Zoea II	Zoea III	(Early) Glaucothoe	(mid.) Glacothoe
Average (cm/sec)	2.4	2.3	2.6	2.7	3.1
Maximum (cm/sec)	3.5	3.4	3.4	3.5	3.9
Minimum (cm/sec)	1.3	1.3	1.8	2.0	2.3
Standard deviation (σ)	0.5	0.6	0.5	0.4	0.5

The significance of phototaxis for larval dispersion decreases with larval growth. Red king crab zoea larvae are positively phototactic, and migrate vertically during the daytime for feeding, in opposition to normal zooplankton; for this reason they are considered to be reverse diel migrators (**Shirley and Shirley, 1988, 1989**). Further experiments are required on the role of phototaxis and vertical migration to larval transport and dispersion of spiny king crab after hatching in the wild.

1.4. Settlement behavior and habitat selection

Glaucothoe of both spiny and red king crabs begin vertical movements to the bottom and testing of substrata soon after metamorphosis (**Stevens and Kittaka, 1998**; **Kittaka and Stevens, 2002**). The grip strength of pleopods is weak at the early stage of settlement so that they are easily detached by stimulation, but within two weeks or so, they become immovable, and another two weeks later, they molt into the first juvenile stage, and hide out in benthic substrata. As in-situ settling habitats, they select periphytons, which have a three-dimensional structure, rather than flatter surfaces such as rocks. Glaucothoe of red king crabs prefer to settle on structurally complex substrata such as the stalks of hydrozoans and bryozoans, which resemble glaucothoe in color and size, and protects them from natural predators (**Stevens, 2003**; **Stevens and Kittaka, 1998**; **Stevens and Swiney, 2005**).

Hydrozoans can be cultured in the laboratory on a diet of *Artemia* nauplius and/or cultured diatom *Chaetoceros gracilis*. The inner surface of culture containers was covered with hydrozoans for some time after being filled with sea water pumped from adjacent Nemuro Bay. The behavior of glaucothoe towards the attached hydorozoans is observable using such simple methods. We found a kind of periphyton *Sabellastsarte japonicus* (Marenzellar) grows wild in some intertidal

areas in Nemuro Bay. We cultured the species using the same food organisms applied to the hydrozoans. We need further observation for glaucothoe settling behavior in the laboratory as well as in the wild.

2. GROWTH

2.1. Age-length relation

From the analysis of individuals caught in the wild, the relationship among age, instar, and carapace length (CL) of *P. brevipes* has been estimated as follows: (1) 1+ year old (i. e., one year after hatching) grows to 11th instar with CL 31 mm, (2) 2+ year old reaches the 14–15th instar with CL 48–56 mm, and (3) 6+ year old reaches a size of CL 94 mm for the female and CL 96 mm for the male (**Abe and Koike, 1982**). But under laboratory cultivation at water temperatures between –1°C and 15°C (with peak at 17–15°C in summer), they grew beginning at 0+ year old first instar crab with CL 1.8 mm as follows: (1) 1+ year old reached the 10th instar with CL 12 mm, (2) 2+ year old reached the 14th instar with CL 30 mm, (3) 3+ year old reached the 17th instar with CL 52 mm, (4) 4+ year old reached the19th instar with CL 71 mm, (5) 5+ year old reached the 21st instar with CL 89 mm and (6) 6+ year old reached the 22nd instar with CL 95 mm, indicating annual molting frequency with decreasing tendency at 9, 4, 3, 2, 2, 1 and 1 for 0–6 year old, respectively (**Kittaka and Onoda, 2002**).

However, examining the relation between average CL and average CW for each instar obtained by **Abe and Koike (1982)** in the wild and by **Kittaka and Onoda (2002)** in the laboratory, the results of the latter showed a difference after exceeding 80 mm CL as shown in **Figure 1.** Furthermore, after reaching 30 mm CL, relative growth of CL became too large, compared with the results of the formers obtained from wild samples. Therefore, the growth of reared individuals larger CL than about 30 mm is considered to be different from wild individuals (**Torisawa, 2005**).

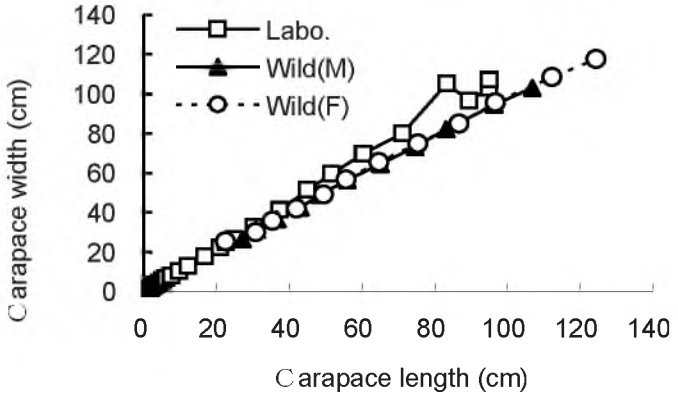

Fig. 1. *Relation between carapace length and carapace width of Paralithodes brevipes*

During the Hanasaki Crab Research Program, the age-length relationship was studied intensively. **Torisawa (2005)** examined the first year growth of young crabs in intermediate rearing on artificial seabeds, and supported the results of **Sasaki and Yoshida (1999)** and **Kittaka and Onoda (2002)**. **Torisawa et al. (1999)** showed that the young crab of instar-1 grew from spring to autumn, reaching an average size of 10 mm CL in November of the second year and average size was still 10 mm even in April of the

third year. This intermediate rearing was made without artificial feeding, and reared individuals were thought to have been feeding on the organisms attached to the rearing net. Probably because of the effect of this situation, the growth, especially after the second year, became worse than the results of **Kittaka and Onoda (2002)**. However, by April of the second year, the reared individual attained growth close to the results of **Sasaki and Yoshida (1999)** or **Kittaka and Onoda (2002)**. Synthesizing the above results, **Torisawa (2005)** proposed a new age-length relationship as shown in **Table 2.**

Table 2

Summary of re-examination on age-length relation of *P. brevipes*

Age	Instar	CL (mm)		CW (mm)		Reference
		Male	Female	Male	Female	
0	1	1.8		1.8		Kittaka and Onoda (2002)
0	2	2.2		2.1		
0	3	2.8		2.8		
0	4	3.5		3.7		
0	5	4.3		4.6		
0	6	5.3		5.7		
0	7	6.1		6.9		
0	8	7.5		8.3		
0 → 1	9	11.8				Sasaki and Yoshida (1999)
0 → 1	10	11.8				
0 → 1	11	14.3				
0 → 1	12	17.2				
0 → 1	13	20.8				
0 → 1	14	23.2				
0 → 2	15	26.8				
1 → 2	11 → 16	31.0	31.3	35.4	35.7	Abe and Koike (1982)
1 → 2	12 → 17	36.6	36.6	42.0	42.0	
1 → 2	13 → 18	43.0	42.6	49.5	49.0	
2 → 3	14 → 19	48.3	49.0	55.7	56.6	
2 → 3	15 → 20	55.9	56.5	64.7	65.4	
2 → 3	16 → 21	65.0	64.5	75.4	74.8	
4 → 5	17 → 22	74.6	73.2	86.7	86.0	
5 → 6	18 → 23	83.1	82.2	96.7	95.6	
6 → 7	19 → 24	96.4	94.5	112.3	108.5	
7 → 8	20 → 25	106.8	103.0	124.5	117.5	
8 → 9	21 → 26	115.8	110.9	135.1	125.8	
9 → 10	22 → 27	124.9	118.8	145.8	134.2	
10 → 11	23 → 28	132.8	124.5	155.1	140.2	
11 → 12	24 → 29	138.5		161.8		
12 → 13	25 → 30	145.8		170.4		

Other studies have shown that red king crabs reach a size of CL 8–12 mm at age 1, and 36–45 mm at age 2 (**Kurata, 1961**; **Stevens, 1990**; **Stevens and Munk, 1990**; **Weber, 1967**), and a size of 9 mm at age 1, 23 mm at age 2, and 47 mm at age 3 at Unalaska and Kodiak Islands, Alaska (**Loher, Armstrong and Stevens, 2001**). Also, our spiny king crabs showed a slower growth in early juvenile stage as red king crabs. Therefore, it appears that **Abe and Koike (1982)** may have mistakenly identified age 2+ crabs as age 1+ crabs; this would account for many of the differences observed by us. Thus, laboratory rearing is seemed to be most effective approach to find precise growth pattern in young stage until 6+ crabs. However, after matured stage older than 6+ crabs, age-length relationship could be obtainable from wild samples which have been applied to present resource management.

One possible disadvantage in laboratory rearing is poor water temperature control. Prior to the experiment, we set the maximum water temperature at 15°C in summer, but temperature increased above 17°C early October in the laboratory at Onnemoto, Nemuro. For laboratory rearing of age 0+ and 1+ year juvenile crabs, we initially used 5–10 cm long PVC pipe that had one end covered with fine mesh as rearing containers. For crabs of 2+ years of age, we made assembly of compartments (each about 25×25×25 cm deep) of a wooden frame and plastic net (commercial name: Netron). Crabs were reared individually in the pipe or compartment and fed pelletized food (made for penaeid shrimp) or a piece of mussel with shell every the other days. Mussels are considered one of best food for growing king crabs, and we fed with pelletized food for initial 2 years and mussels exclusively after 3 years. We may feed pelletized food exclusively, but as it falling through the net, it causes deterioration of water quality.

Water quality might be improved by using cages made from titan netting for rearing (**Nimura, pers. comm.**). Bacterial films were formed on the surface of both wood and net materials. They rapidly covered the surfaces of rearing containers following elevation of water temperature, and necessitated repeated cleaning of the compartments, which required removing and replacing the crabs quite often. In order to avoid confusion between crabs, it is important to mark the experimental crabs individually. We reared young *P. camtshaticus* in the same laboratory as *P. brevipes* with much lower mortality than the latter. The former were reared in plastic netting compartments, in tanks of 0.8 m deep, whereas *P. brevipes* were raised in wooden frame compartments in tanks of only 0.4 m deep. To keep deeper for the rearing tank and daily removal of food remains is a key for successful growing. We do not recommend using wooden materials for rearing experiments because mortality increased after 3 years. We could not discriminate easily between normal and diseased individuals. Rearing of *P. camtshaticus* was done in the same room as *P. brevipes*. Less mortality was observed for *P. camtshaticus* indicating that the latter could be a better species for aquaculture.

2.2. Molting procedures

Zhou et al. (1998) observed that *P. camtshaticus* ceased feeding up to 3 weeks prior to molting and did not resume feeding until more than a week afterwards. **Matsuura and Takeshita (1976)** observed abdominal swelling at least one day before molting. **Later, Stevens (2002)** also observed abdominal swelling, and recorded the behavioral events of molting using video for 2 females and 4 males (average CL: 90mm) in January, 2002. He classified the molting events as follows: (1) Crab extracts dactyl from old shell, (2) Abdominal portion of exoskeleton detaches from body, (3) Crab tilts anterior carapace while sitting or standing, (4) Crab shoves body forward abruptly, (5) Back of carapace splits at epimeral line, (6) Crab has backed out and two large spines in the center of carapace are revealed and (7) Tip of rostrum has been removed from the old shell. Excluding one individual which had a longer time for molting at 2 h 21 min 36 sec, the average time for molting was 20 min 17 sec in 5 individuals of *P. camtshaticus*.

We also observed abdominal swelling for *P. brevipes* one day before molting as shown in **Figure 2.** This swelling has not been observed for most crustaceans including natantia and reptantia, lobster and crabs. Before molting, the new outer shell is created inside of the carapace and this new shell does not harden until the completion of molting, thus for a while after molting, the body of the crustacean

softens. This swelling is caused by increased water absorption and results in splitting of the old carapace at the posterior margin. Common to many crustaceans, the horizontal split of carapace opens up in the posterior part of the prosoma, and from this split, the body of the crab slips out to the rear, while holding her abdominal part and prosoma part doubled over.

Fig. 2. *Top Left: Swelled abdominal part of P. brevipes before molting; Top Right: Crab just before molting; Bottom Left: Crab just after molting and Bottom Right: Shape of abdominal part of the same crab as Left*

3. REPRODUCTION

Most female *P. brevipes* bear eggs in situ when their CL reaches 90–100 mm (**Abe and Koike, 1982**). While rearing under ambient water temperature conditions, females of 6+ year old (estimated to be 22nd instar s with CL 93–105 mm) mated immediately after molting with hard-shelled males of the same instar. Three females spawned on the day of mating, and carried fertilized eggs for about 10 months next year until hatched as the first zoea (**Kittaka and Onoda, 2002**). After hatching in the laboratory these individuals were fed exclusively on mussels *Mytilus edulis galloprovincialis*. The latters are exotic, non-indigenous species introduced to Japan attached on the bottom of ships, and are listed as a harmful exotic species in Japan. We planned to utilize this species for food in king crab cultivation.

The number of hatched zoeae was 15,200 per berried female. Their survival rate until the first juvenile stage was at 24.0%, comparable to those imported spiny king crabs from Russia, whose hatched zoeae were 18,200 with survival rate of 16.2%. These results indicate feasibility of aquaculture for spiny king crab in the future.

3.1. Maturation and Mating

In order to use larvae hatched out from good eggs in seed production for *P. brevipes*, 100 individuals of brooding female crab were sampled in summer under

special permission issued from Hokkaido and reared in our laboratory until hatching out in the next spring. However, due to limited water exchange in the laboratory, an outbreak of pathogenic bacteria became a serious problem. Furthermore, similar numbers of brooding females were not available each year, and some of females were used for mating trials just after hatching and molting in the tanks. There is concern about a decrease in both available numbers of brooding females and their egg production in the wild. Maturity for females was examined in 2004 and compared with results from 1992–1994. The size of males needed for successful mating was also studied in the tanks.

Field surveys on distribution and density of spiny king crab were conducted off Hanasaki and Ochi-ishi area in the Pacific coast of Nemuro, during the period of 1991–1993 (herein-after 1991 past) and 2002–2004 (herein-after 2002 recent). Numbers of berried and non-berried crabs were compared within 10 mm intervals, and their ratio was calculated. Fertilized eggs were carried by females larger than 80 mm CW, and numbers of eggs increased dramatically above 100 mm CW. The number of fertilized eggs carried was much higher in 1991 compared to 2002 (**Fig. 3**).

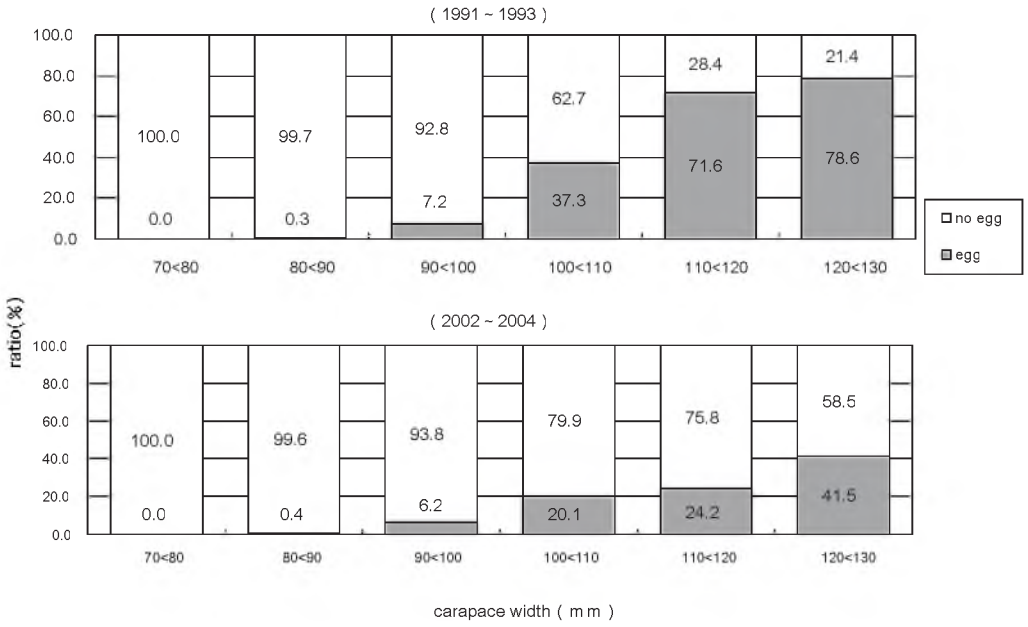

Fig. 3. *Ratio of appearance for egg-brooding (with shading) and non-egg-brooding (without shading) female P. brevipes*

The ratios of egg-brooding to non-brooding females in the intervals of 70–100 mm CW are almost similar between the periods of 1991 past and 2002 recent, but for the interval of 100–120 mm CW, ratios were about 3:1 (brooding: non-brooding) in 1991 past, but <1:1 in 2002 recent.

3.2. Number of brooding egg by carapace width rank

For female crabs sampled during the field survey in the Hanasaki and Ochi-Ishi area during June 10–20, 2004, the egg numbers were counted for 5% of total egg wet weight, and the total egg numbers were obtained by extrapolating partial numbers to total egg weight.

The results of regression analyses of brooding egg number (Y) on the sample CW (X) are as follows:

FY1992:	Y=1343.8.9X−109228	(r^2=0.8263)
FY1993:	Y=1333.2X−107565	(r^2=0.6217)
FY2004:	Y=1121.8X−88419	(r^2=0.7054)

Comparing these regression formulas, slopes are similar and numbers of brooding eggs are in proportion to CW, although variance increases with CW (**Fig. 4**). However, comparing recent and past data, a decreasing trend can be seen in the number of brooding eggs per individual.

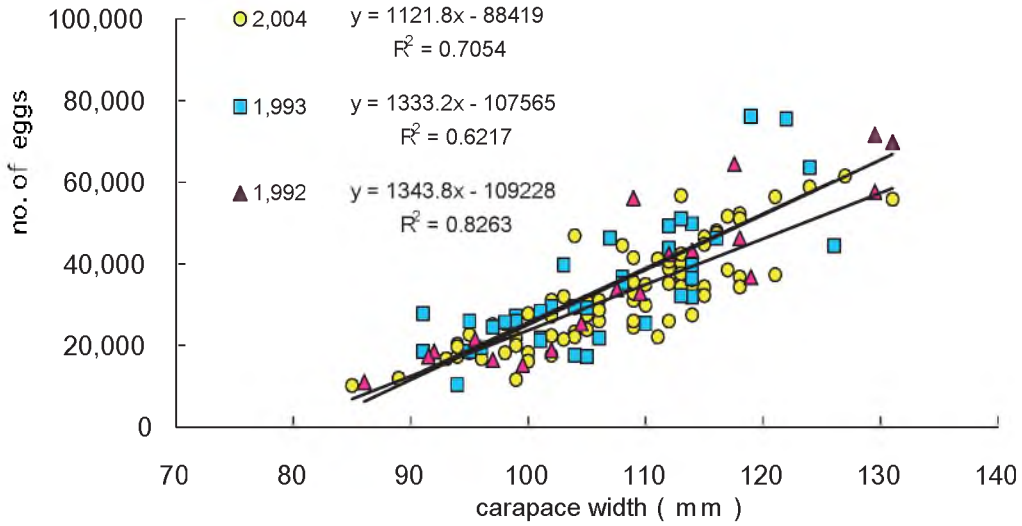

Fig. 4. *Relation between carapace width and number of egg brooded by female*

3.3. Mating and spawning of *P. brevipes*

Eight male spiny king crabs (CL: 61.6–100.9 mm) caught off Habomai in July 25, 2005 were collected and reared under conditions similar to those for brooding females. The male crabs were housed one individual in a compartment of a quarter of 2 m^3 square-shaped tank, separated by partitions, and were given females within 0–7 days after molting in sequence for mating and spawning. When spawning did not occur after 2 days, the male was exchanged with a new one. For confirmation of spawning, females were taken out and brooding was checked.

A total of 46 individual females mated with 8 males. The ratio of male to female was about 1:5. Males of 91.6–92.0 mm CL mated with up to 2 females, those of 95.1–98.0 mm CL mated with 5–6 females, and males of 100.0–100.9 mm CL mated with 6–12 females, indicating a tendency for larger males to mate more frequently. There was no clear difference in the number of brooding eggs between mates of males that mated more often, though no more than 8 female mates of a single male produced normal clutches (**Table 3**). In addition, we observed that some females cast-off many eggs within about 1 month after spawning, so fertility of males should be examined in the future.

Table 3

Results of mating and spawning test

Male ID	Female	C.L.	Mating	Molting Date	Mating Test	Spawning	Fecundity		Remarks
C.L. (mm)	ID	(mm)	Order	(M/D)	(M/D)	(M/D)	Spawning	May	
♂1	♀10	92.8	1	3/20	3/23	3/24	Few	Few	
100.9	♀14	95.4	2	3/25	3/25	3/26	Normal	Few	
	♀18	92.4	3	3/27	3/27	3/28	Normal	Normal	
	♀22	92.2	4	3/31	3/31	4/1	Normal	Normal	
	♀25	101.7	5	4/1	4/1	4/2	Few	Few	
	♀28	91.4	6	4/3	4/3	4/4	Normal	Very Few	
	♀21	91.3	7	3/31	4/4	4/5	Normal	Normal	
	♀27	90.1	8	4/2	4/9	4/10	Normal	Very Few	
	♀30	86.8	9	4/10	4/10	4/11	Normal	Few	
	♀31	89.7	10	4/12	4/12	4/13	Normal	Few	
	♀32	86.2	11	4/13	4/13	4/14	Few	Very Few	
	♀33	95.7	12	4/19	4/19	4/20	Drop Eggs	-	
♂2	♀11	95.3	1	3/22	3/23	3/24	Normal	Normal	
97.0	♀15	95.0	2	3/25	3/25	3/26	Normal	Normal	
	♀19	94.7	3	3/28	3/28	3/30	Normal	Few	
	♀23	84.9	4	3/31	3/31	4/1	Normal	Normal	
	♀21	91.3	5	3/31	4/2	Not Spown	-	-	
♂3	♀12	92.5	1	3/24	3/24	3/25	Normal	Few	
95.1	♀16	85.7	2	3/26	3/26	3/27	Normal	Normal	
	♀20	94.7	3	3/30	3/30	3/31	Normal	Normal	
	♀24	93.5	4	3/31	3/31	4/1	Normal	Very Few	
	♀26	84.8	5	4/2	4/2	4/3	Normal	Few	
	♀29	88.4	6	4/3	4/3	4/4	Normal	Few	
	♀27	90.1	7	4/2	4/6	Not Spown	-	-	
♂4	♀13	95.8	1	3/25	3/25	3/26	Few	Very Few	
92.0	♀17	91.8	2	3/27	3/27	3/28	Normal	Normal	
	♀21	91.3	3	3/31	3/31	Not Spown	-	-	
♂5	♀34	92.6	1	4/20	4/20	4/21	Normal	Normal	
100.6	♀38	92.8	2	4/25	4/25	4/26	Normal	Normal	
	♀42	96.3	3	4/26	4/26	4/27	Normal	Few	
	♀46	92.0	4	4/28	4/28	4/29	Normal	Very Few	
	♀48	85.3	5	4/30	4/30	5/1	Normal	Few	
	♀51	90.6	6	5/3	5/3	5/4	Normal	-	killed by cannibalism after spawning
♂6	♀35	91.7	1	4/20	4/20	4/21	Normal	Normal	
100.0	♀39	90.4	2	4/25	4/25	4/26	Normal	Normal	
	♀43	88.7	3	4/26	4/26	4/27	Normal	Normal	
	♀47	92.1	4	4/28	4/28	4/29	Normal	Few	
	♀49	85.7	5	5/1	5/1	5/2	Normal	Few	
	♀52	92.0	6	5/4	5/4	5/5	Normal	Few	
	♀54	95.7	7	5/5	5/5	5/7	Normal	Normal	
	♀56	98.2	8	5/9	5/9	5/10	Normal	Normal	
	♀57	91.4	9	5/9	5/10	Not Spown	-	-	
♂7	♀36	96.0	1	4/22	4/22	4/23	Normal	Few	
98.0	♀40	89.9	2	4/26	4/26	4/27	Normal	Very Few	
	♀44	95.6	3	4/26	4/27	4/28	Normal	Few	
	♀45	89.1	4	4/27	4/29	4/30	Few	Very Few	
	♀50	93.0	5	5/2	5/2	5/3	Few	Few	
	♀53	101.1	6	5/4	5/4	5/5	Normal	Normal	
	♀55	88.9	7	5/7	5/7	Not Spown	-	-	killed by cannibalism after spawning
♂8	♀37	98.4	1	4/24	4/24	4/25	Normal	Few	
91.6	♀41	97.8	2	4/26	4/26	4/27	Normal	Normal	
	♀45	89.1	3	4/27	4/27	Not Spown	-	-	

4. MIGRATION

Juvenile *P. brevipes* that have settled on the near shore bottom migrate to deeper water as they grow. Individuals of 0–2 year old (CL<50 mm) inhabit the sub-littoral zone, and those greater than 6 years old (CL>80 mm) are caught offshore (**Abe and Koike, 1982**). This change of vertical distribution occurs in accordance with the feeding behavior of the younger instars and at the onset of reproductive activities in the matured phase, and is related to seasonal water temperature changes. Though horizontal migration is an important aspect of the king crab's life history, and helps understand the origins of the stock, there have not yet been enough data obtained from studies of tagged and released crabs.

5. ECOLOGICAL CHARACTERISTICS OF *P. BREVIPES*

While *P. camtschaticus* inhabit the silt-sand seabed widely, *P. brevipes* are specifically adapted to inhabit hard-bottom reef areas. The fact that the zoeal stage of *P. brevipes* is shorter than that of *P. camtschaticus* by one instar may be a means to facilitate settlement in a suitable habitat after metamorphosis. Moreover, though *P. brevipes* can secure food and escape from predators by hiding under rocks, they are adapted to live alone in a space separated by rocks and lose the benefits of group living, such as podding at the mature phase. Still, *P. camtschaticus* are susceptible to fishing pressure due to their aggregative habit and have disappeared from the Hokkaido coast while *P. brevipes* are still present, though their numbers are small. The ecology of *P. brevipes* suggests its suitability for aquaculture, which will reflect the effects of the release of seedlings. However, improvement of the coastal environments is a necessary requirement, as is evident when the present situation is compared with the past, when resources were abundant.

Macroalgae, sea urchins and large crustaceans are critical components of the coastal ecosystem that contribute not only to marine food production but also biodiversity and conservation of the marine environment. Sea urchins graze randomly around on the surface of rocky reefs consuming attached organic matter (**Kittaka et al., 1983; Hayakawa and Kittaka, 1984a; Kittaka, 1984b**). There are numerous examples of near shore ecosystems stabilized by sea urchins (e. g. **Estes et al., 1998**).

In the Northwest Atlantic Ocean, lobsters *Homarus americanus* consume sea urchins *Strongylocentrotus droebachiensis*, which depend mainly on dense growth of knotted-wrack *Ascophyllum nodosum*. We were surprised to see foraging by large numbers of sea urchins in Passamaqouddy Bay, NB, Canada. In the Northeast Atlantic Ocean, nearshore benthic communities are dominated by European lobster *H. gammarus*, European spiny lobster *Palinurus elephas*, sea urchin *Paracentrotus lividus*, and algae, *Fucus* spp., *A nodosum* and various laminarians in Kilkieran Bay near Galway. However, populations of these organisms are less dense than their ecological equivalents in the Northeast Atlantic Ocean (**Kittaka, 1984**).

Recently, feeding habits for spiny king crabs were investigated for young crabs in the littoral zone at Isomoshiri Inlet off Nemuro Peninsula (**Sasaki and Kuwahara, 1999**). They examined stomach contents of CL 8–31 mm crabs, and found that algae, *Laminaria longissima* and *Carallina pilulifera*, were the most dominant species in their stomach. On the other hand, **Klitin (2003)** exsamined stomach contents of commercial sized king crabs, *P. brevipes*, *P. camtschaticus* and *Lithodes aequispinus*, using trawl in southern Kuril Islands (2008). Maximum catch of these 3 species was

attained at 4, 15 and 5 kg per 0.5 h drag at water depth about 20–70, 60–200 and 180–290 m, and water temperature 10–14, 3–12 and 2–4°C, respectively. He found that sea urchins were the dominat prey for the king crabs. They consume every kind of food organisms in their habitats regardless rocky or sandy mud areas.

P. brevipes showed unique feeding habit in the laboratory. They were attracted to prey aggressively on live northern Pacific seastar *Asterias amurensis*. The species is listed up one of the most harmful animals in the coast of Hokkaido because they prey useful bivalves such as little-neck clams and scallops. Seastars contain small amount toxin Saponin, therefore, they could not be preyed from predators. *P. camtschaticus*, also, showed predacious behavior on seastar, but it is less active compared to *P. brevipes*. In the process of evolution, *P. brevipes* have acquired such feeding habit. The fact that *P. brevipes* consume kelp (**Sasaki and Kuwahara, 1999**) and seastars may suggest origin for their excellent taste.

Oceanographic conditions of Nemuro and the Southern Kuril Islands are strongly influenced by the southward flowing cold Oyashio current. It differs from the North Atlantic Ocean which is heavily influenced by the Gulf Stream. Marine animals at the top of the food chain include king crabs for the former and lobsters for the latter. Their growth is supported by food production among the benthos and attached organisms at lower trophic levels. Suitable water temperatures for larval growth are 8°C for king crabs and 16°C for lobsters. We have to study structure and function of the ecosystem in Nemuro and Southern Kulil Islands in details to manage and utilize resources of king crabs in the future.

The biology and ecology of *P. brevipes* suggest its suitability for aquaculture, which will reflect of the release of seedlings. However, the improvement of the coastal environments is a necessary promise when the present situation is compared with the past, when resources were abundant. Technically, we have to overcome disease problem in seed production.

6. NOTES ON CULTIVATION AND REARING OF KING CRAB LARVAE

In Nemuro, seedlings of both *P. camtschaticus* and *P. brevipes* were carried out in an old facility in 1994. In 1995, we produced 100,000 juvenile Crab-1 (Instar 1 crabs just after molted from glaucothoe) of *P. camtschaticus* and 50,000 juvenile Crab-1 of *P. brevipes* using each 4 m^3 tank, and released several tens of thousands of both juvenile crabs (Instar about 9) off Ochi-ishi area at the end of the year. In 1996, a new facility was completed. In 1997, we hatched about 100,000 zoeae of *P. camtschaticus* and reared to juvenile Crab-1 using for providing lipid analysis freeze dried samples.

Cultivation studies after 1997 were delayed because we had a disease outbreak due to *Vibrio* and Virus. **Watanabe et al. (1998, 1999)** reported heavy mortality among cultured glaucothoe of *P. brevipes* due to the white-turbid midgut gland necrosis which is common in cultured larvae of marine crustaceans in aquaculture facilities in the Seto Inland Sea. The pathogen was probably introduced to Nemuro with 20,000 *P. brevipes* glaucothoe brought from the Akkeshi Seedling Center to examine the age and instar relation beginning in April, 1997. Mortality was 99.9% during initial one month (case 1). At the same timing, pandemic mortality occurred within one day for 30,000 *P. brevipes* zoea at Z-I or Z-II. Mortality was 99% in one day, therefore,

we were unable to provide dry freezed samples for lipids analysis of *P. brevipes* (case 2). We did not discriminate cause of mortality between case 1 and case 2 due to Vibrio, Virus or both.

These mortalities were considered to be caused by pathogen which spread among shrimp farms in the Seto Inland Sea since 1971. The pathogen may have been introduced with glaucothoe of spiny king crabs for experimental use, and with visitors attached to their hands, clothes and boots from the contaminated areas. Therefore, it is critical to provide a quarantine system in the seedling centers including our own laboratory.

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