Occurrence of the pelagic shrimp *Pasiphaea japonica* (Decapoda: Pasiphaeidae) in gut contents of demersal predators in a submarine canyon (Toyama Bay, Japan)

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Abstract.— The purpose of present study is to clarify the predation of *P. japonica* including larvae by investigating guts of predators caught as a by-catch in the *P. japonica* fishery. The by-catch, including fish, cephalopods and decapods, were caught once or twice a month between April and November 2008 in a submarine canyon adjacent to the mouth of the Jinzu River in Toyama Bay. Size of the potential predators was measured and the gut contents were identified to the lowest possible taxa. Ostracods, copepods, mysids, cumaceans, amphipods, euphausiids, and decapods were the most common prey in the gut contents of the predators. *Pasiphaea japonica*, including larvae before metamorphosis, were preyed upon by demersal fishes *Crystallichthys matsushimae*, *Lycodes nakamurae*, and *Bothrocara hollandi*. Occurrence of *P. japonica* in the guts of these predators may be due to the aggregation of larvae in the canyon head which is enclosed by the steeply sloping bottoms and the truncation of the vertical migration of *P. japonica* from the pelagic to the benthopelagic environment.

Key words: *Pasiphaeidae*, shrimp, larva, predation, net feeding, submarine canyon, Toyama Bay

■ Introduction

Pasiphaea japonica, a pelagic shrimp of the family Pasiphaeidae, are found in Suruga Bay, Sagami Bay, Enshu-Nada sea region, and Toyama Bay in Japan (Doi, 1990; Hayashi, 2007). The biology of this shrimp has been described in several reports. In Toyama Bay, reproduction of shrimps occurs throughout the year, having a high hatching intensity from October to May, and ovigerous females carry up to 281 eggs (Doi, 1975; Omori, 1976; Nanjo & Ohtomi, 2009). It is reported that the density of hatched larvae is higher in submarine canyons (Nanjo & Katayama, 2014).

The shrimps are recognized as a valuable species for fisheries of Toyama Prefecture, being commercially caught by fishing boats using trawl nets in the depths of 40–200 m in the submarine canyons (Doi, 1975). The annual

catch of *P. japonica* was about 600–700 t in 1997–2007, but a tendency of decreasing catch has been observed since 2008, indicating that the stock may be decreasing.

Generally, recruitment of marine species is affected by high mortality in the early life stages, and varies due to starvation, transport, or predation (Hjort, 1914; Cushing, 1978; Houde, 1987; Nakata, 1991). It is reported that larval stages of crustaceans also play a role in recruitment fluctuations to the stock (e.g. DeLancey *et al.*, 1994; Kodama *et al.*, 2003). Nanjo and Konishi (2009) described that larvae of *P. japonica* metamorphosed at 12 days after hatching with no food items under 13°C, indicating that larvae have a high starvation tolerance by consuming endogenous nutrition stored from the yolk. Larvae of *P. japonica* aggregate around submarine canyon heads without being transported offshore where food resources are

poorer (Nanjo & Katayama, 2014). Accordingly, it is thought that starvation and dispersal offshore are not direct causes of larval mortality. On the other hand, Minello *et al.* (1989) described that predation is a direct cause of larval mortality of crustaceans.

Predation of *P. japonica* was reported by Uchiyama (1999), indicating that the semi-pelagic fish *Theragra chalcogramma*, caught by bottom gill nets, mainly fed on *P. japonica*. In other studies, it has been reported that *Pasiphaea sivado* and *Pasiphaea multidentata*, which are allied species to *P. japonica*, are preyed upon by the fishes *Lampanyctus macdonaldi* (Myctophidae) in the east Greenland Sea, *Lampanyctus crocodilus* (Myctophidae) in the western Mediterranean Sea, *Lycodes frigidus* (Zoarcidae), and *Paraliparis bathybius* (Liparidae) in the eastern Norwegian Sea (Stefanescu & Cartes, 1992; Bjelland *et al.*, 2000; Klimpel *et al.*, 2006), squids *Illex coindetii* and *Todarodes sagittatus* (Ommastrephidae) in the northwestern Mediterranean Sea (Rosas-Luis *et al.*, 2014), and shrimps *Plesionika edwardsi*, *Plesionika martia*, and *Plesionika acanthonotus* (Pandalidae) in the western Mediterranean Sea (Cartes, 1993). There are, however, only a few reports on the occurrence of caridean larvae or juveniles in the gut contents of predators (e.g. Young & Davis, 1992; Beyst *et al.*, 1999).

The purpose of present study is to clarify the predation of *P. japonica* including larvae by investigating the gut contents of fish, squid, and shrimp caught as by-catch in the *P. japonica* fishery, since it was reported in previous studies that these predators feed on shrimp species allied to *P. japonica*. This information could be helpful for analyzing of the stock of *P. japonica*.

Materials and Methods

The fishing season for *P. japonica* runs from April to November under the regulations for the fishery. Possible predators caught as by-

Fig. 1. Fishing grounds where the specimens were collected in the present study (shaded area).

catch during commercial fishing aimed at *P. japonica*, which runs throughout the morning, in the submarine canyon adjacent to the mouth of Jinzu River in Toyama Bay were examined once or twice a month in the fishing season of 2008 (Fig. 1). The specimens were kept cold (approximately 1–2°C) and taken to the laboratory. In the laboratory, the sizes of the specimens, i.e., total length (TL) and fork length in fishes, mantle length in cephalopods, or carapace length (CL) in decapods, were measured with a digital slide caliper (Mitutoyo Corp. Digimatic Caliper), and then the guts were eviscerated, and the contents were identified to the lowest possible taxa under a stereoscopic microscope (approximately 10–40 x magnification; Olympus SZH).

Data on the gut contents of specimens were

expressed as the percent frequency of occurrence ($F\%$):

$$F\%_i = m_i \cdot 100/M$$

where m_i is the number of specimens that fed on the prey taxon i , and M is the total number of specimens examined, excluding specimens without food in the gut. Carapace length from the tip of the rostral spine to the medial posterior margin of the carapace of *P. japonica* that occurred in the guts was also measured with a digital slide caliper or a micrometer under a stereoscopic microscope.

It is reported that feeding activities within the trawl nets by fishes (termed as "net feeding") could cause bias problems for dietary studies (Lancraft & Robison, 1980; Buckel *et al.*, 1998). Therefore, in the present study, *P. japonica* caught by fishing boats were also sampled on the same days when the by-catch species were collected to estimate the minimum size of *P. japonica* caught by trawl nets. In the laboratory, 200 individuals were chosen randomly and the CL was measured with a digital slide caliper, indicating that the minimum size of *P. japonica* captured in the fishing trawl nets was 6.8 mm CL.

Results

Specimens caught as the by-catch included 12 species of fishes, 3 cephalopods, and 3 decapods from April to November (Table 1). The number of specimens ranged between 1 and 24 individuals for each species. Frequency of the specimens without food in the guts ranged from 0 to 75.0 in fishes, 0 to 72.2 in cephalopods, and 37.5 to 66.7 in decapods, excluding *Tanakius kitaharai* and *Watasenia scintillans* with no food in the guts (Table 2). Crustaceans were fed on by most of the by-catch specimens, and fishes, mollusks, and polychaetes were also found in the guts of some specimens. Crustaceans found in the guts of the specimens were mainly ostracods, cope-

pods, mysids, cumaceans, amphipods, euphausiids, and decapods (Table 3). The number of *P. japonica*, including larvae before metamorphosis, in the guts of predators was 20 individuals, which were fed on by the fishes *C. matsushimae*, *A. lineatus*, *L. nakamurae*, *B. hollandi*, and *T. japonicus*, and the cephalopod *B. magister*. The gut contents of fishes were easy to identify *P. japonica* due to feeding on without chewing. On the other hand, *P. japonica* that occurred in the guts of *B. magister* were identified from the shapes of mandibles, eyes, and eggs, which were carried by females (Fig. 2). These species also fed on mysids, copepods, amphipods, and cumaceans, excluding *T. japonicus* and *B. magister* which fed only on *P. japonica*.

Figure 3 shows the frequency of CLs of *P. japonica* caught by commercial fishing boats on the same days when specimens were sampled, and the relationship between TLs of the by-catch specimens and CLs of *P. japonica* that occurred in the guts of the specimens. The CLs of the measured *P. japonica* occurred in the by-catch specimen guts ranged from 1.7 to 17.2 mm. The size of the partially digested larvae was assumed to be 1.6 mm CL, based on the size described by Nanjo and Konishi (2009), since these larvae were judged larval stage 1 or 2 from the morphological characters. The average size of *P. japonica* caught by fishing boats was 18.3 mm CL $\pm$ 2.5(SD), which was larger than the size of *P. japonica* that occurred in the guts of predators. The TL range of the by-catch specimens that fed on *P. japonica*, with CLs less than the minimum size of shrimp caught by the commercial trawl nets, was between 79.0 and 171.0 mm for *L. nakamurae*, 227.0 mm for *B. hollandi*, and 64.4 mm for *C. matsushimae*, from May to September. On the other hand, *P. japonica* with CLs more than the minimum commercial size of shrimp were fed on by *L. nakamurae*, with sizes of 110.8 and 204.0 mm, and by *T. japonicus*, with sizes between 371.0 and 406.0 mm, from June

Table 1. Number of potential predator specimens caught as a bycatch in commercial trawl nets for *Pasiphaea japonica*

Species	9 Apr.	8 May	June			July			Aug.			Sep.			Oct.			7 Nov.	Total
			6	24		24	10	24	7	22	11	25	7	28					
FISHES																			
<i>Maurolicus japonicus</i> (Sternoptychidae)	—	2	—	—	3	—	—	3	5	5	—	5	5	—	1	24			
<i>Bregmaceros nectabanus</i> (Bregmacerotidae)	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	3			
<i>Crystallichthys matsushimae</i> (Liparidae)	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	2			
<i>Doederleinia berycoides</i> (Acropomatidae)	—	—	—	—	—	—	—	2	—	—	—	—	2	—	—	4			
<i>Apogon lineatus</i> (Apogonidae)	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	2			
<i>Upeneus japonicus</i> (Mullidae)	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	4			
<i>Lycodes nakamurae</i> (Zoarcidae)	1	2	2	—	4	9	3	—	—	—	1	—	—	—	—	22			
<i>Bothrocara hollandi</i> (Zoarcidae)	1	—	3	—	—	—	2	—	—	—	—	1	—	—	—	7			
<i>Lumpenus sagitta</i> (Stichaeidae)	—	—	—	—	—	—	2	2	—	—	—	—	—	—	—	4			
<i>Arctoscopus japonicus</i> (Trichodontidae)	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2			
<i>Trichiurus japonicus</i> (Trichiuridae)	—	—	3	—	—	—	—	—	—	—	1	4	1	2	11				
<i>Tanakius kitaharai</i> (Pleuronectidae)	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1			
CEPHALOPODS																			
<i>Enoplateuthis chunii</i> (Enoplateuthidae)	2	—	—	—	—	—	4	4	3	3	5	—	—	—	—	18			
<i>Watasenia scintillans</i> (Enoplateuthidae)	2	1	—	—	—	—	—	—	—	—	—	—	—	1	—	4			
<i>Beryteuthis magister</i> (Gonatidae)	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	4			
DECAPODS																			
<i>Trachysalambria curvirostris</i> (Penaeidae)	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	8			
<i>Pandalus eous</i> (Pandalidae)	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	3			
<i>Neocrangon communis</i> (Crangonidae)	—	—	—	—	1	—	—	—	—	—	5	—	—	—	—	6			

Table 2. Frequency of prey items that occurred in the guts of specimens

Species	N	No food in guts	Fishes	Mollusks	Crustaceans	Polychaetes	Others	Unknown
FISHES								
<i>Maurolicus japonicus</i>	24	58.3	10.0	—	60.0	—	—	30.0
<i>Bregmaceros nectabanus</i>	3	33.3	—	—	100.0	—	—	—
<i>Crystallichthys matsushimae</i>	2	—	—	—	100.0	—	50.0	—
<i>Doederleinia berycoides</i>	4	—	—	—	100.0	25.0	—	—
<i>Apogon lineatus</i>	2	—	—	—	100.0	—	—	—
<i>Upeneus japonicus</i>	4	75.0	—	—	—	—	100.0	—
<i>Lycodes nakamurae</i>	22	—	4.5	9.1	95.5	18.2	27.3	18.2
<i>Bothrocara hollandi</i>	7	—	—	—	100.0	—	—	—
<i>Lumpenus sagitta</i>	4	—	50.0	75.0	100.0	75.0	25.0	—
<i>Arctoscopus japonicus</i>	2	—	—	—	100.0	—	—	—
<i>Trichiurus japonicus</i>	11	—	45.5	—	54.5	—	9.1	9.1
<i>Tanakius kitaharai</i>	1	100.0	—	—	—	—	—	—
CEPHALOPODS								
<i>Enoploteuthis chunii</i>	18	72.2	—	—	40.0	—	60.0	—
<i>Watasenia scintillans</i>	4	100.0	—	—	—	—	—	—
<i>Berryteuthis magister</i>	4	—	—	—	100.0	—	25.0	—
DECAPODS								
<i>Trachysalambria curvirostris</i>	8	37.5	—	—	100.0	—	—	—
<i>Pandalus eous</i>	3	66.7	100.0	—	100.0	—	—	—
<i>Neocrangon communis</i>	6	50.0	—	—	—	—	33.3	66.7

to July.

Discussion

Among the by-catch specimens, *P. japonica* were found in the guts of *C. matsushimae*, *A. lineatus*, *L. nakamurae*, *B. hollandi*, *T. japonicus* and *B. magister*. Although these species fed on *P. japonica* of various sizes, some shrimps might have been fed on during net feeding. Assuming that the minimum CL of the shrimp caught by trawl nets is the threshold of the shrimp exposed to net feeding, it was possible that the occurrence of 2 shrimps in the guts of *L. nakamurae* and 3 shrimps in *T. japonicus* were due to net feeding.

Larvae of *P. japonica* were identified in the guts of *L. nakamurae* on some sampling days. *Lycodes nakamurae* belongs the family Zoarcidae, which is known as one of demersal fishes caught by trawl nets (Møller & Jørgensen, 2000; Okiyama, 2004; Balanov & Solomatov, 2008). In the present study, *L. nakamurae* fed

also on mysids and cumaceans, which are typically benthic crustaceans, since it is reported that mysids living near the sea bottom are dominant in the fishing grounds of *P. japonica* (Nanjo, 2007) and cumaceans are mainly benthic (Gamo, 1997). On the other hand, larvae of *P. japonica* that occurred in the guts of demersal fishes are mainly pelagic, occurring in depths of 100–150 m, with no difference in the range of vertical distribution between daytime and nighttime (Nanjo & Katayama, 2014). Mauchline and Gordon (1991) suggested a truncation of the vertical distribution or impingement of the horizontal movement of pelagic species enabled predation of pelagic organisms by benthopelagic predators. It is thought that both of the larval truncation and impingement hardly occur due to a narrow range of the vertical distribution and horizontal movement in larval stages. Larvae of *P. japonica*, however, may reach the benthic boundary layer, since the larval distribution aggregates in the canyon head enclosed by the steeply slop-

Table 3. Frequency of crustaceans that occurred in the guts of specimens

Species	N	Ostracods	Copepods	Mysids	Cumaceans	Amphipods	Euphausiids	<i>Pasiphaea japonica</i>		Other shrimps	Unknown
								Larvae	Juveniles + Adults		
FISHES											
<i>Maurolicus japonicus</i>	6	—	33.3	—	—	16.7	—	—	—	—	66.7
<i>Bregmaceros nectabanus</i>	2	—	—	—	—	—	—	—	—	—	100.0
<i>Crystallichthys matsushimae</i>	2	—	50.0	100.0	—	100.0	—	—	50.0	—	—
<i>Doederleinia berycoides</i>	4	50.0	50.0	—	—	25.0	—	—	—	—	100.0
<i>Apogon lineatus</i>	2	50.0	—	50.0	—	—	—	—	50.0	—	—
<i>Lycodes nakamurae</i>	21	—	57.1	14.3	9.5	52.4	—	19.0	23.8	9.5	38.1
<i>Bothrocara hollandi</i>	7	—	42.9	57.1	—	71.4	—	—	14.3	14.3	14.3
<i>Lumpenus sagitta</i>	4	—	100.0	—	25.0	50.0	—	—	—	—	—
<i>Arctoscopus japonicus</i>	2	—	—	—	—	100.0	100.0	—	—	—	—
<i>Trichiurus japonicus</i>	6	—	—	—	—	—	—	—	50.0	—	50.0
CEPHALOPODS											
<i>Enoploteuthis chunii</i>	2	—	—	—	—	—	50.0	—	—	—	50.0
<i>Berryteuthis magister</i>	4	—	—	—	—	—	—	—	100.0	—	—
DECAPODS											
<i>Trachysalambria curvirostris</i>	5	—	—	—	—	—	—	—	—	—	100.0
<i>Pandalus eous</i>	1	—	—	100.0	—	—	—	—	—	—	100.0

ing bottoms (Nanjo & Katayama, 2014). It is also reported that zooplankton are transported towards the coast by currents within submarine canyons (e.g. Allen *et al.*, 2001).

The sizes of some *P. japonica*, excluding larval stages, that occurred in the guts of *C. mat-*

Fig. 2. A photograph showing a mandible and eggs of *Pasiphaea japonica* that occurred in the guts of *Berryteuthis magister*.

sushimae, *L. nakamurae*, and *B. hollandi* are similar to the sizes reported by Nanjo & Katayama (2014), which these shrimps migrate down to the depth of about 200 m in the daytime (weighted mean depths of 171.3–227.3 m). *Crystallichthys matsushimae* and *B. hollandi* are also demersal fishes like *L. nakamurae* (Okiyama, 2004). Accordingly, it is thought that the occurrence of *P. japonica* after larval stages in the guts of these fishes is caused by the truncation of vertical migration as described by Mauchline & Gordon (1991), since the depth range of the fishing grounds, where these demersal fishes were caught by commercial fishing boats, is similar or shallower than the lower limit of vertical distribution (Doi, 1975).

The present study firstly examined predators feeding larvae of *P. japonica*. Although only a small number of larvae were observed in the guts of fishes, occurrence during sampling days

Fig. 3. Frequency of carapace length of *Pasiphaea japonica* caught by fishing boats in the present study (left upper) and relationship between total length of predator fishes and carapace lengths of *P. japonica* that occurred in the guts of specimens, excluding specimens that fed on *P. japonica* that were partially digested and therefore having an unknown CL. Solid circles show *Lycodes nakamurae* that fed on *P. japonica* larvae. Dotted line is the minimum size (6.8 mm) of carapace length of *P. japonica* caught by fishing nets in the present study.

is a significant result, indicating that demersal fishes should be also investigated to explain the fluctuations in stocks of *P. japonica* as a potential predator.

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