Fisheries Science 61(3), 415-422 (1995)

Feeding Habits of Pacific Cod Larvae and Juveniles in Mutsu Bay, Japan

Tetsuya Takatsu,*1 Toshikuni Nakatani,*1 Takashi Mutoh,*2 and Toyomi Takahashi*1

*1Faculty of Fisheries, Hokkaido University, Minato, Hakodate, Hokkaido 041, Japan
*2Hokkaido Kushiro Fisheries Experimental Station, Hama, Kushiro, Hokkaido 085, Japan

(Received August 18, 1994)

The diets and prey widths of Pacific cod (*Gadus macrocephalus*) larvae and juveniles were examined in Mutsu Bay. In early March, 11 yolk-sac larvae were caught in midwater of the bay mouth. Five of 11 larvae captured had not opened their mouths, and the remaining six had not fed. Post-larvae ≤7 mm in total length (TL) fed on copepod nauplii, particularly *Pseudocalanus* nauplii. Prey items of post-larvae >7 mm TL were chiefly crustacean eggs, and *Pseudocalanus* spp. copepodites and adults. From April to June, the main food organisms of cod juveniles were calanoid copepods, and changed from *Pseudocalanus* spp. to *Calanus pacificus*, *Acartia clausi*, and *Centropages abdominalis*. In addition, cod juveniles opportunistically fed on large-sized food organisms, namely, reptant megalopae, planktonic gastropods, and natant zoeae. In July, cod juveniles mainly fed on benthic prey items, such as gammarid amphipods and fish. It seems probable that these large-sized food organisms play an important role as alternative prey for cod juveniles when they change their main food from calanoid copepods to benthic prey items.

Key words: Pacific cod, larvae and juveniles, feeding habits, Mutsu Bay

The Pacific cod (*Gadus macrocephalus*) is distributed on or near the continental shelf in the northern North Pacific from the west coast of Korea to California.[1,2] Mutsu Bay is one of the spawning grounds of Pacific cod in Japan. From early December to mid February, adult cod migrate into the bay from the open sea,[3] mainly from the Pacific Ocean off Hokkaido,[4] and are harvested by bottom set nets and gill nets. From late December through January, the spawning of Pacific cod takes place in the mouth and inner parts of the bay.[3,5] The eggs of cod are 0.98–1.08 mm in diameter,[6] and are demersal and adhesive.[2,7,8] The larvae hatch ten days after fertilization at 6.3–7.0°C, and newly hatched larvae are approximately 4 mm in length.[6] Copepod eggs, nauplii, and copepodites were found in the stomachs of Pacific cod larvae,[9,10] and various species of crustaceans, such as copepods and amphipods, were found in the stomachs of juveniles.[7,11-13]

Food availability for fish larvae is believed to be one of the key factors controlling mortality and affecting the subsequent year-class strength. To assess food availability in the field, the species and size compositions of the larval prey must be determined. In this study, we examined changes in the food and feeding intensity of Pacific cod larvae and juveniles with increasing size in Mutsu Bay.

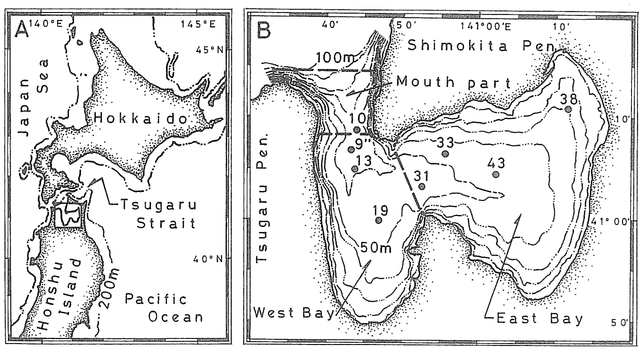

Fig. 1. Location of Mutsu Bay (A), contours of depth (m) and the location of net sampling stations for gut and stomach contents analysis of Pacific cod (B).

Materials and Methods

Field Samplings

Samplings were conducted on March 1–4, May 19–23, and July 22, 1989 and April 26 and June 13, 1990 in Mutsu Bay (Fig. 1). In March and April, larval and juvenile Pacific cod were collected with a beam trawl net[14,15] (2.0×2.5 m mouth, 20 mm mesh, and 0.33 mm cod-end mesh) in midwater. From May to July, cod juveniles were collected with a small otter trawl net[14,15] (4.4×5.9 m mouth, 90 mm mesh, and 12 mm cod-end mesh) along the bottom. Both trawl nets were towed for 10–15 min at a speed of approximately 1.5 m/sec. The depths of these nets were determined using a Net Monitor (Kaijo Corporation). Collections of samples were carried out by the R/V Ushio-maru (107.85 ton) in the daytime. On board, Pacific cod larvae and juveniles were immediately fixed in 5–10% buffered formalin in sea water, and after 24–36 hours, they were transferred into a 70% ethanol solution. The length shrinkage and weight loss of cod due to fixation and preservation were not taken into consideration in this study.

Identification of Larval and Juvenile Gadids

Larvae and juveniles of Pacific cod and walleye pollock (*Theragra chalcogramma*) were found together in Mutsu Bay.[16] In the laboratory, larvae of two species ≤20 mm in standard length (SL) were distinguished by examining the pigmentation patterns.[17-19] In cod larvae >20 mm SL, small melanophore spots occurred in two rows along the ventral surface of the gut.[19] These two rows changed to a single row in cod >28.10 mm SL in Mutsu Bay (Fig. 2B–C). Walleye pollock larvae >20 mm SL had a few melanophores scattered on the ventral surface of the gut, and melanophores never formed in a row (Fig. 2F–I). Walleye pollock >32.60 mm SL lost these melanophores (Fig. 2J).

Pacific cod of 21.40 mm SL had a chin barbel 0.32 mm long, and 23.54 mm SL cod had a 0.35 mm chin barbel (Fig. 2A). Walleye pollock of 34.70 mm SL had a 0.15 mm chin barbel (Fig. 2J), but smaller pollock had no barbel (Fig. 2F–I).

The upper jaw of Pacific cod >47 mm SL slightly protruded beyond the lower jaw, while the upper jaw of walleye pollock never extended beyond the lower jaw from larval to adult stages.

From these facts, Pacific cod and walleye pollock 20–22 mm SL were distinguished using the pigmentation patterns on the ventral surface of the gut. For individuals >22 mm SL, the two gadid species were identified by the length of the chin barbel. For those >50 mm SL, both species were distinguished by the features of the jaw and the chin barbel length.

Division between Larvae and Juvenile Pacific Cod

Hashimoto and Abe[13] noted that Pacific cod >27 mm in total length (TL) underwent ossification. Uchida *et al.*[20] described that Pacific cod 17.5 mm TL belonged to the larval stage and those 26.0 mm TL were in the juvenile stage. In this study, larvae and juveniles of Pacific cod were distinguished by the number of pectoral fin rays, which developed slower than other fins. Pacific cod >60 mm TL had 20–22 pectoral fin rays ($N=10$, Mean $\pm$S.D.$=20.4\pm0.70$) and Pacific cod >25 mm TL (22 mm SL) had 20–21 pectoral fin rays. So, cod >25 mm TL (22 mm SL) were identified as juveniles.

Biological Measurements and Analysis of the Diet

Stomachs from Pacific cod larvae >11 mm TL were clearly distinguishable from their guts. Gut contents were

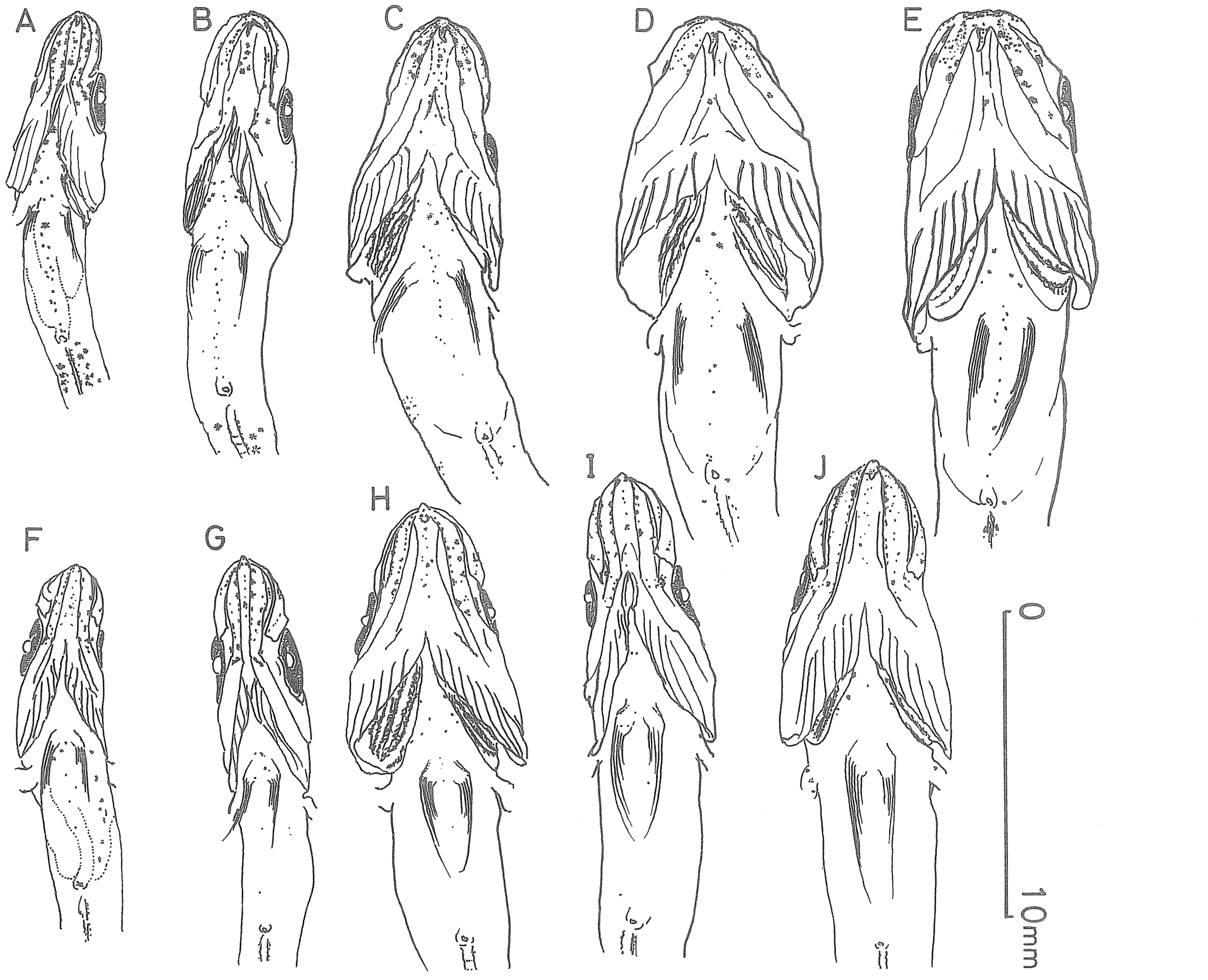

Fig. 2. Diagnostic sketches showing ventral views of Pacific cod (*Gadus macrocephalus*); A–E and walleye pollock (*Theragra chalcogramma*); F–J collected in Mutsu Bay.

A, 23.54 mm SL (26.97 mm TL); B, 28.10 mm SL (32.18 mm TL); C, 31.13 mm SL (34.73 mm TL); D, 32.26 mm SL (35.53 mm TL); E, 35.68 mm SL (39.71 mm TL); F, 23.34 mm SL (25.69 mm TL); G, 27.78 mm SL (30.50 mm TL); H, 31.50 mm SL (34.32 mm TL); I, 32.60 mm SL (36.36 mm TL); J, 34.70 mm SL (39.07 mm TL).

analyzed in larvae ≤11 mm TL, and stomach contents were examined in larvae >11 mm TL. In March 1989, cod larvae for dietary analysis were obtained at three sampling stations; Stn. 10 in Mouth part, Stn. 19 in West Bay, and Stn. 31 in East Bay (Fig. 1). These stations are close to the spawning grounds of Pacific cod.[3] In April, June, and July, stomach contents were observed at one station (Stn. 33, Stn. 43, and Stn. 9″, respectively) where the density of larvae and juveniles was high. In May, analyses of stomach contents were carried out at two stations (Stn. 13 and Stn. 38) to examine geographical differences in the diet.

Pacific cod larvae and juveniles were measured in TL and SL to the nearest 0.01 mm with an electric slide caliper, and then weighed to the nearest 1 mg. Guts and stomachs were removed, and the contents were identified to the lowest practical taxa and counted. Copepod nauplii were sorted to the genus with diagnostic characters of antennules and caudal armatures, and the body length in each stage.[21-30] In stages of nauplius IV-VI (N IV-N VI), *Metridia lucens* are distinguishable from *Pseudocalanus minutus* by the character that the two distal setae on the dorsal edge of antennule arise from the same notch.[25] However, it is difficult to distinguish between *Pseudocalanus* and *Metridia* in stages N I-N III because they have similar diagnostic characters and sizes.[31] For this reason, they were treated as *Pseudocalanus* and *Metridia* N I-N III. Maximum prey widths in gut and stomach contents were measured to the nearest 1.25 μm or 12.5 μm under a binocular photomicroscope or a binocular dissection microscope with micrometer, respectively. Egg and shell diameters were measured for crustacean eggs and gastropods, respectively. The contents sorted to the major taxa were weighed to the nearest 1 mg in the samples collected during April-July. Data on gut and stomach contents were expressed as percent frequency of occurrence (F%), percent by number (N%), and percent by weight (W%) of food items. To compare the feeding intensity between samples, stomach contents indices (*S.C.I.*) were calculated by the following formula:

$$S.C.I. = Stomach\ contents\ weight\ (\mathrm{g}) \times 10^2 / Body\ weight\ (\mathrm{g}).$$

Body weight of cod included the stomach contents weight.

Results

Diet of Pacific Cod Larvae in March

In early March, 11 yolk-sac larvae ranging from 3.20 mm to 5.30 mm TL (Mean ± S.D. = 4.41 ± 0.650 mm) were caught at 45 m depth at Stn. 10. Among them, five larvae did not open their mouths, and the other six larvae had already opened their mouths, but had no food in their guts.

The food organisms of post-larvae obtained at three stations in March 1989 are shown in Table 1. Post-larvae fed mainly on crustacean eggs (F% = 45.0, N% = 49.0), *Pseudocalanus* spp. copepodites and adults (F% = 63.3, N% = 20.5), and copepod nauplii (F% = 28.3, N% = 13.1). Both F% and N% of crustacean eggs differed among stations (G-test, F%; $P<0.05$ and N%; $P<0.001$). Those of *Pseudocalanus* spp. copepodites and adults did not differ

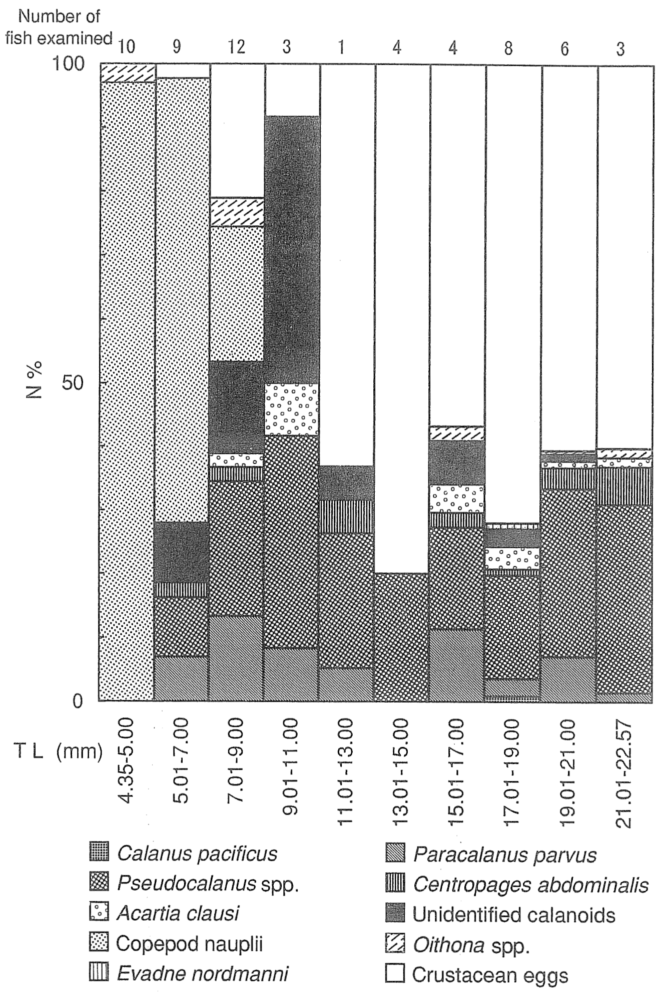

Fig. 3. Diet compositions (percent by number) in guts (≤11 mm TL) and stomachs (>11 mm TL) of Pacific cod post-larvae by size groups in Mutsu Bay on March 1-4, 1989.

among stations (G-test, F%; $P>0.05$ and N%; $P>0.05$). At Stn. 10, copepod nauplii were eaten by post-larvae in high rates (F% = 60, N% = 34.9). As shown in Fig. 3, copepod nauplii occupied 97.1% in N% for larval cod ≤5.00 mm TL. Copepod nauplii were not found in the guts of larvae >8.02 mm TL. N% of copepod nauplii decreased from 69.8% (5.01-7.00 mm TL) to 21.1% (7.01-9.00 mm TL), while N% of crustacean eggs and *Pseudocalanus* spp. copepodites and adults increased from 2.3% to 21.1% and from 9.3% to 21.1%, respectively. Cod >7.00 mm TL changed their main food to crustacean eggs and *Pseudocalanus* spp. copepodites and adults. Table 2 shows the composition of copepod nauplii eaten by cod larvae. *Pseudocalanus* N IV-N VI occurred frequently regardless of cod size, but no *Metridia* N IV-N VI were found in the guts. Although the various species of nauplii were eaten by larvae ≤5.00 mm TL, *Pseudocalanus* N IV-N VI and *Oithona* nauplii were mainly taken by larvae >5.00 mm TL. As shown in Fig. 4, the prey widths for cod larvae ≤5.00 mm TL ranged from 67.5 μm (*Oithona* N II and *Paracalanus* N III) to 129 μm (*Pseudocalanus* N IV). *Pseudocalanus* N IV-N VI (114-195 μm) were larger than other nauplii (67.5-116 μm) in the larval guts. The maximum width eaten by a cod larva of 5.30 mm TL, 7.07 mm

Table 1. Percent frequency of occurrence (F%) and percent by number (N%) of food items in Pacific cod post-larvae in March 1989

Food organism	Stn. 10		Stn. 19		Stn. 31		Total	
	F%	N%	F%	N%	F%	N%	F%	N%
Evadne nordmanni	0	0	0	0	5	0.4	1.7	0.2
Calanus pacificus	0	0	5	0.5	0	0	1.7	0.2
Paracalanus parvus	35	8.1	55	9.3	20	1.8	36.7	6.3
Pseudocalanus spp.	50	17.2	65	22.3	75	21.5	63.3	20.5
Centropages abdominalis	0	0	45	7.0	5	0.4	16.7	2.6
Acartia clausi	15	1.6	30	2.8	15	1.3	20.0	1.9
Unidentified calanoid copepods	30	5.9	45	6.5	30	2.7	35.0	5.0
Oithona spp.	5	0.5	35	3.3	0	0	13.3	1.3
Copepod nauplii	60	34.9	10	2.8	15	4.9	28.3	13.1
Crustacean eggs	25	31.7	40	45.6	70	66.8	45.0	49.0
Mean and S.D. number of food organisms	9.3±14.3		10.8±10.4		11.2±11.1		10.4±12.1	
Number of fish examined	20		20		20		60	
Number of empty guts and stomachs	3		1		1		5	
Mean TL (mm) of fish examined	6.94		11.97		15.46		11.46	
Range of TL (mm)	4.35–20.07		4.40–21.34		4.54–22.57		4.35–22.57	

Table 2. Composition of copepod nauplii in guts of Pacific cod post-larvae in March 1989

	4.35–5.00 mm (TL)		5.01–7.00 mm (TL)		7.01–8.02 mm (TL)		Total	
	Number of Inds.	N%	Number of Inds.	N%	Number of Inds.	N%	Number of Inds.	N%
Paracalanus nauplii	5	15.2%	4	13.3%	1	5.3%	10	12.2%
Pseudocalanus N IV–N VI	4	12.1%	9	30.0%	3	15.8%	16	19.5%
Pseudocalanus and *Matridia* N I–N III	3	9.1%	3	10.0%	0	0%	6	7.3%
Centropages nauplii	3	9.1%	3	10.0%	0	0%	6	7.3%
Acartia nauplii	2	6.1%	0	0%	0	0%	2	2.4%
Oithona nauplii	2	6.1%	7	23.3%	4	21.1%	13	15.9%
Unidentified nauplii	14	42.4%	4	13.3%	11	57.9%	29	35.4%
Total	33	100.0%	30	100.0%	19	100.0%	82	100.0%
Number of fish examined	10		9		7		26	
Number of empty guts	2		1		0		3	
Number of guts containing copepod nauplii	7		6		4		17	

TL, and 17.53 mm TL was 245 μm (*Centropages abdominalis* copepodite), 313 μm (*Pseudocalanus* sp. adult), and 503 μm (*Calanus pacificus* copepodite), respectively. Crustacean eggs were smaller prey items and ranged from 73.8 μm to 135 μm.

Diet of Pacific Cod Larvae and Juveniles from April to June

Pacific cod larvae and juveniles from April to June fed chiefly on calanoid copepods, and the principal prey species differed from month to month (Table 3). *Pseudocalanus* spp. showed the highest N% in April (F%=100, N%=42.3), and then decreased in May and June. *Acartia clausi* was eaten in the highest N% (F%=100, N%=31.2) in identified food items at Stn. 38 in May. At Stn. 13 in May, *Centropages abdominalis* and reptant megalopae occupied higher N% (F%=95, N%=45.5) and W% (F%=60, N%=1.6, W%=36.5), respectively. In June, Pacific cod juveniles fed mainly on *Centropages abdominalis* (F%=100, N%=72.5).

Figure 5 shows the relation between cod size and prey width from April to June. In April, cod 28.72 mm TL fed on adult *Calanus pacificus* of 763 μm width. *Calanus pacificus* copepodites and adult were large-sized prey items (344–888 μm width) in comparison with other calanoid species (196–450 μm width). In May, the maximum width of calanoid species was 441 μm. Planktonic gastropods (294–699 μm) and reptant megalopae (885–1,580 μm) were large-sized prey items. In June, no prey item larger than 1,000 μm was found in juvenile stomachs. Natant zoeae (441–919 μm) and *Calanus pacificus* copepodites and adult (441–613 μm) were larger than other prey items in June.

Diet of Pacific Cod Juveniles in July

In July, Pacific cod juveniles fed on benthic gammarids (F%=80, N%=33.2, W%=23.3), chiefly *Synchelidium* sp. and *Anonyx ampulloides*, and fish (F%=25, N%=5.8, W%=64.7) such as walleye pollock juveniles and pleuronectiforms (Table 3). Benthic gammarids were eaten by cod juveniles regardless of cod size. Five cod juveniles ≥135.26 mm TL ate 5 walleye pollock juveniles, 3 pleuronectiformes, and 5 unidentified fish. In contrast, 15 cod juveniles <135.26 mm TL ate no fish. Walleye pollock juveniles occupied the major part of fish in weight. As

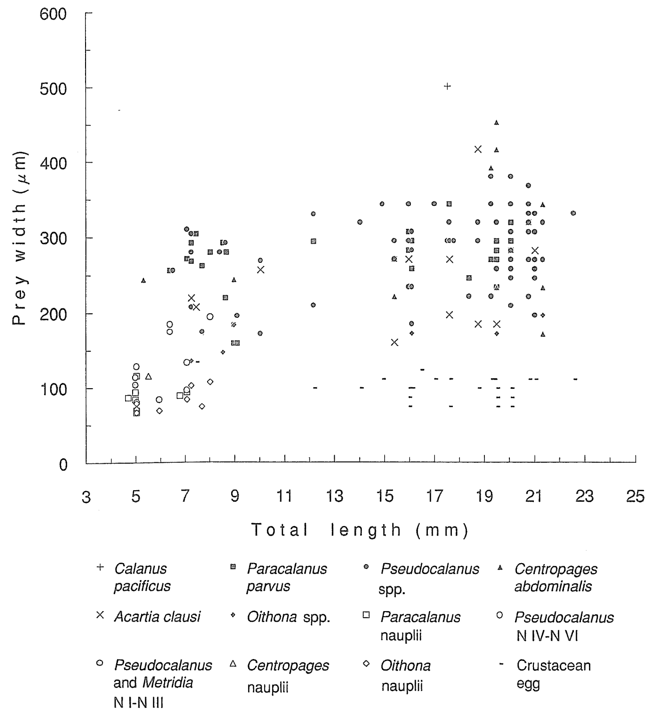

Fig. 4. Prey width distribution of Pacific cod post-larvae in Mutsu Bay on March 1-4, 1989.

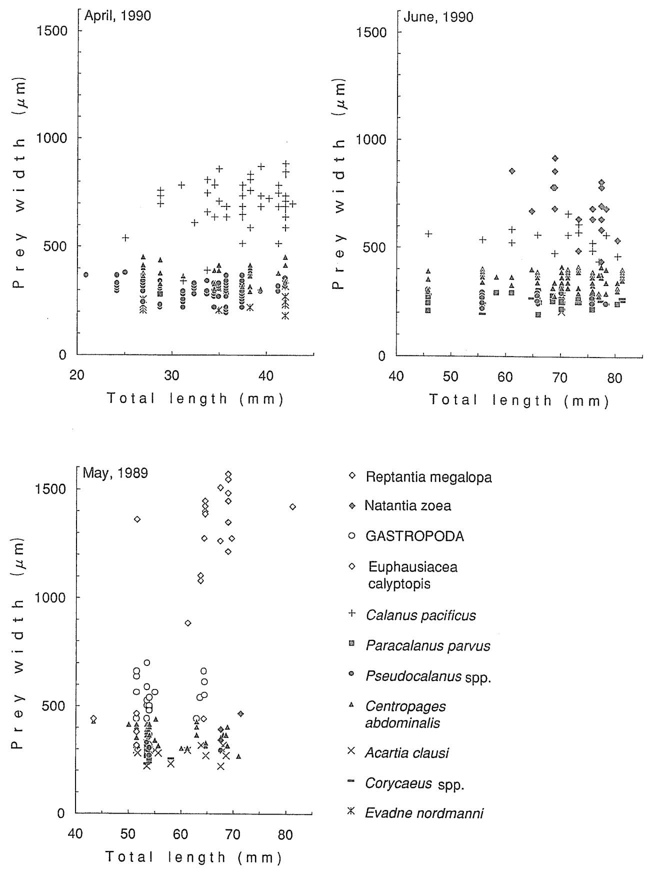

Fig. 5. Prey width distribution of Pacific cod larvae (≤25 mm TL) and juveniles (>25 mm TL) in Mutsu Bay on May 19-23, 1989, April 26, 1990, and June 13, 1990.

shown in Fig. 6, the maximum size of cod feeding on calanoid copepods was 97.53 mm TL. Pacific cod measuring 107.62 mm TL fed on *Anonyx ampulloides* of 3.08 mm width. An individual *Crangon affinis* of 4.52 mm width was eaten by a 135.26 mm TL cod, and a walleye pollock of 7.26 mm width was eaten by a 169.50 mm TL cod. Widths of *Synchelidium* sp. and *Anonyx ampulloides* in the cod stomachs ranged from 0.39 mm to 1.17 mm and from 1.32 mm to 3.68 mm, respectively.

Feeding Intensity of Pacific Cod Larvae and Juveniles

Feeding intensities among samples were compared by the mean values (±S.D.) of *S.C.I.* (Table 3). High values were found in the samples at Stn. 33 in April (2.9±1.34) and at Stn. 13 in May (3.2±1.18), but the samples at Stn. 38 in May and at Stn. 9″ in July showed low values (1.0±0.53 and 0.6±0.72, respectively).

Discussion

It is well known that many species of marine fish begin to feed as yolk-sac larvae. Last[32] showed that 28% of stomachs from Atlantic cod (*Gadus morhua*) between 3.0-3.9 mm in length, mainly in the yolk-sac stage, contained food. In this study, no food occurred in the yolk-sac larvae of Pacific cod. Yoseda *et al.*[10] noted that six post-larval Pacific cod (3.79-4.77 mm TL) had fed mainly on copepod nauplii near the coast of Noto-shima in the Japan Sea. In this study, post-larvae ≤7 mm TL fed chiefly on copepod nauplii (Fig. 3). *Pseudocalanus* N IV-N VI were large-sized prey (Fig. 4) and the most frequently occurring copepod nauplii (Table 2). In contrast, no *Metridia* N IV-N VI were found in larval guts. Larvae >7 mm TL

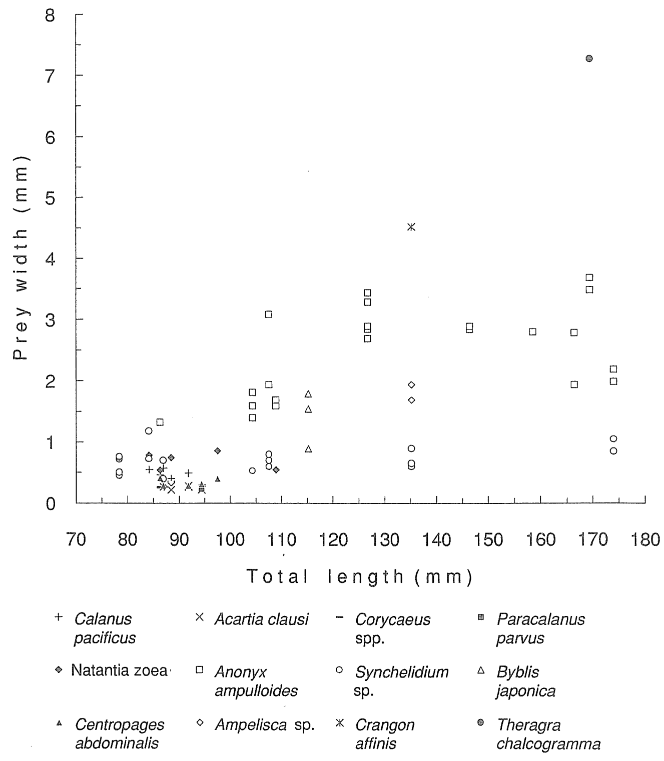

Fig. 6. Prey width distribution of Pacific cod juveniles in Mutsu Bay on July 22, 1989.

Table 3. Percent frequency of occurrence (F%), percent by number (N%), and percent by weight (W%) of food items in stomachs of Pacific cod larvae and juveniles

Food organism	April, 1990			May, 1989						June, 1990			July, 1989		
	Stn. 33			Stn. 13			Stn. 38			Stn. 43			Stn. 9″		
	F%	N%	W%	F%	N%	W%	F%	N%	W%	F%	N%	W%	F%	N%	W%
GASTROPODA	0	0	0	65	1.5	1.5	10	0.1	<0.1	0	0	0	0	0	0
BIVALVIA	0	0	0	25	0.1	<0.1	15	0.1	<0.1	0	0	0	15	3.1	<0.1
POLYCHAETA	0	0	0	15	<0.1	<0.1	25	0.2	0.3	25	0.1	<0.1	5	0.4	2.4
CRUSTACEA															
Cladocera (Total)	60	14.1	2.2	35	0.2	<0.1	25	0.2	<0.1	50	0.2	<0.1	0	0	0
Podon leuckarti	45	2.4	<0.1	35	0.2	<0.1	25	0.2	<0.1	50	0.2	<0.1	0	0	0
Evadne nordmanni	55	11.7	2.2	10	0.1	<0.1	0	0	0	0	0	0	0	0	0
Copepoda															
Calanoida (Total)	100	73.0	97.0	100	95.3	61.4	100	98.5	91.1	100	97.6	97.4	45	40.4	0.2
Calanus pacificus	85	8.4		45	0.2		0	0		75	0.5		25	7.6	
Paracalanus parvus	50	0.8		95	4.1		55	1.1		100	4.4		15	2.2	
Pseudocalanus spp.	100	42.3		95	23.9		80	3.6		100	9.2		0	0	
Scolecithricella minor	0	0		0	0		0	0		5	<0.1		0	0	
Centropages abdominalis	85	13.0		95	45.5		100	16.5		100	72.5		25	6.7	
Pseudodiaptomus marinus	0	0		15	<0.1		0	0		0	0		0	0	
Acartia clausi	0	0		70	1.9		100	31.2		30	0.2		35	13.5	
Unidentified Calanoida	95	8.4		100	19.8		100	46.1		100	10.8		40	10.3	
Cyclopoida															
Oithona spp.	0	0	0	0	0	0	0	0	0	10	<0.1	<0.1	5	1.3	<0.1
Poecilostomatoida (Total)	0	0	0	35	0.1	<0.1	10	0.1	<0.1	95	1.2	<0.1	10	1.3	<0.1
Oncaea spp.	0	0	0	15	0.1	<0.1	5	<0.1	<0.1	0	0	0	0	0	0
Corycaeus spp.	0	0	0	25	0.1	<0.1	5	<0.1	<0.1	95	1.2	<0.1	10	1.3	<0.1
Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	0	5	0.4	<0.1
Cumacea	0	0	0	0	0	0	5	0.1	0.7	0	0	0	30	6.3	0.2
Amphipoda															
Gammaridea (Total)	0	0	0	25	0.1	0.3	10	0.2	4.3	0	0	0	80	33.2	23.3
Anonyx ampulloides	0	0		0	0		0	0		0	0	55	11.7		
Synchelidium sp.	0	0		0	0		0	0		0	0		20	13.9	
Other Gammaridea	0	0		25	0.1		10	0.2		0	0		45	7.6	
Hyperiidea	0	0	0	5	<0.1	<0.1	0	0	0	0	0	0	0	0	0
Caprellidea	0	0	0	0	0	0	10	0.1	1.3	5	<0.1	<0.1	0	0	0
Euphausiacea calyptopis	15	0.1	0.7	50	0.3	<0.1	0	0	0	0	0	0	0	0	0
Decapoda															
Natantia adult and juvenile	0	0	0	5	<0.1	0.1	0	0	0	0	0	0	10	1.3	3.8
Natantia zoea	5	0.1	<0.1	5	<0.1	0.1	40	0.5	2.0	75	0.8	2.6	45	6.3	0.1
Reptantia megalopa	0	0	0	60	1.6	36.5	10	0.1	0.3	0	0	0	0	0	0
Reptantia zoea	0	0	0	10	<0.1	<0.1	0	0	0	5	<0.1	<0.1	0	0	0
Crustacean egg	35	12.7	<0.1	15	0.6	<0.1	5	<0.1	<0.1	0	0	0	0	0	0
Sagittoidea	0	0	0	0	0	0	5	<0.1	<0.1	5	<0.1	<0.1	0	0	0
PISCES adult and juvenile (Total)	0	0	0	0	0	0	0	0	0	0	0	0	25	5.8	64.7
Theragra chalcogramma juvenile	0	0	0	0	0	0	0	0	0	0	0	0	15	2.2	64.3
Pleuronectiformes	0	0	0	0	0	0	0	0	0	0	0	0	5	1.3	0.4
Unidentified PISCES	0	0	0	0	0	0	0	0	0	0	0	0	10	2.2	<0.1
PISCES egg	0	0	0	0	0	0	0	0	0	5	<0.1	<0.1	0	0	0
Unidentified food			0			0			0			0			5.2
Mean and S.D. number of food organisms	101.0±70.9			383.6±227.2			161.6±78.7			383.6±117.8			11.2±11.5		
Mean and S.D. weight of food organisms (mg)	6.9±28.3			39.7±16.0			15.4±62.7			30.8±9.7			120±282.3		
Mean and S.D. of *S.C.I.*	2.9±1.34			3.2±1.18			1.0±0.53			1.6±0.64			0.6±0.72		
Number of fish examined	20			20			20			20			20		
Number of empty stomachs	0			0			0			0			0		
Mean TL (mm) of fish examined	33.79			59.98			63.58			69.30			111.9		
Range of TL (mm)	20.94–42.72			43.40–81.11			51.73–73.62			45.81–81.28			78.43–174.0		

changed their main food from copepod nauplii to *Pseudocalanus* spp. copepodites and adults (Fig. 3). In March, the density of *Pseudocalanus* spp. increased at the bay mouth, and in April, *Pseudocalanus* spp. were widely distributed in Mutsu Bay.[16] Over a size range from nauplii to adults, *Pseudocalanus* spp. were important food for Pacific cod larvae.

Because crustacean eggs were mainly eaten by cod >11 mm TL and co-occurred with adult *Pseudocalanus* and *Oithona* spp. in the larval stomachs (Fig. 3), most of crustacean eggs would be taken with adult copepods. Judging from the fact that crustacean eggs are small (Fig. 4)

Table 4. Mean weight of major food organisms in stomachs of larval and juvenile Pacific cod in May and July 1989 and April and June 1990

Food organism	Total weight (mg)	Total number of individuals	Mean weight (μg)
Evadne nordmanni	3	236	12.7
Calanoida	1,439	19,714	73.0
GASTROPODA	11	118	93.2
Decapoda Natantia zoea	26	92	283
Decapoda Reptantia megalopa	262	122	2,150
Gammaridea	568	87	6,530
PISCES adult and juvenile	1,535	13	118,000

and are potentially indigestible,[33-35] it is inferred that the role of crustacean eggs is subsidiary as a food source for Pacific cod larvae.

Uchida[7] noted that Pacific cod larvae and juveniles fed mainly on copepods, juveniles >30 mm TL fed on amphipods and fish larvae, and juveniles 70–90 mm TL swallowed small crabs, small shrimp, small squid, polychaetes, and small fish in adjacent waters of Korea. Takeuchi[12] showed that Pacific cod juveniles 29.3–74.0 mm SL obtained near the coast of Hokkaido, Japan, fed on copepods, especially *Paracalanus* and *Pseudocalanus* spp., as their main food. Takeuchi also noted that the subsidiary food organisms of cod juveniles were larval crustacean decapods, gammarid amphipods, larval gastropods, and oikopleurids. Hashimoto and Abe[13] reported that cod juveniles 27–81 mm TL fed on calanoid copepods, mainly *Pseudocalanus* and *Calanus* spp., as their main food source and planktonic amphipods as a subsidiary food. As in Table 3, the main food organisms for cod larvae and juveniles were calanoid copepods in Mutsu Bay from April to June. There were geographic differences in the kind of subsidiary food, but the main food of Pacific cod juveniles <70 mm TL was consistently calanoid copepods. Cod juveniles were distributed on the bottom in Mutsu Bay after late May (unpublished data). Benthic foods such as gammarids and fish were scarcely found in cod juveniles until July. This indicates that cod juveniles cannot change their food immediately after migrating to the sea bottom.

An individual gastropod, natant zoea, and reptant megalopa are approximately equivalent in weight to 1.3, 3.9, and 29 calanoid copepods, respectively (Table 4). So, these large-sized food organisms play an important role as alternative prey for cod juveniles as they change their main food organisms from calanoid copepods to gammarid amphipods and fish.

Because the feeding intensity of Pacific cod declined in July (Mean *S.C.I.* = 0.6, Table 3), it appears the abundance of food in July is not enough for Pacific cod juveniles. Ishiwata[36] showed that the satiation ratio (satiation amount in stomach/body weight) declined with increasing body weight. To assess the food availability, it is necessary to clarify the change in capacity of the stomach fullness and the density of prey items in Mutsu Bay.

Acknowledgments The authors thank Professor Emeritus Tatsuaki Maeda who made valuable suggestions. Thanks are due to the crew of R/V Ushio Maru of Hokkaido University Faculty of Fisheries, and Messrs. Takashi Fujioka and Takanori Miyamoto for their cooperation on board in collecting the samples.

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