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Regional Diversity of Juvenile Pink Salmon Diet in Autumn in the Bering, Okhotsk and Japan Seas

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Abstract: Regional variability in the diet of juvenile pink salmon was studied in the Bering, Okhotsk and Japan seas during the autumn of 2002–2004. During this time young pink salmon preyed mainly upon ichthyo- and mero-plankton in the eastern Bering Sea. In the Okhotsk, western Bering and northwestern Japan seas the most frequently occurring prey items in the juvenile pink salmon diet were planktonic crustaceans: hyperiids (*Themisto pacifica*, *T. libellula* and *Primno macropa*), euphausiids (*Thysanoessa longipes*), copepods (*Neocalanus plumchrus*) and pteropods (*Limacina helicina*). Other food organisms (irrespective of their high biomass in the pelagic plankton community) were of secondary importance or would only occur occasionally in fish stomachs. We suspect that food habits of juvenile pink salmon were associated with the accessibility of forage groups in the habitat strata of juvenile pink salmon. In the upper epipelagic layer (0–50 m), the biomass of zooplankton (particularly copepods and euphausiids) increased at night due to vertical migrations from deeper layers, while hyperiids and pteropods (small- and medium-size *L. helicina*) were present in dense aggregations in the surface layer during day and night hours. However, juvenile pink salmon consumed prey mainly during daylight hours. Thus, juvenile pink salmon preyed upon plankton groups and species that were more abundant in habitat strata of juvenile pink salmon during daylight hours.

Keywords: juvenile pink salmon, diet, stomach contents, prey composition, Japan Sea, Okhotsk Sea, Bering Sea

INTRODUCTION

Juvenile Pacific salmon are among the main consumers of forage resources in the upper epipelagic layers in the Bering, Okhotsk and Japan seas during autumn. This raises an interest in the study of food habits, forage demands and trophic relationships of juvenile Pacific salmon. An extensive database on the ecology and forage activity of Pacific salmon species has been collected during the last decades in TINRO-Centre expeditions into the Far Eastern seas. Simultaneous studies were conducted in the Okhotsk, Bering and northwestern Japan seas in autumn 2002–2004. Data collected in these studies made it possible to compare food habits of pink salmon from different regions of the Far Eastern seas under various forage base conditions.

MATERIALS AND METHODS

In this study, we present data on food habits of juvenile pink salmon and on the composition of plankton, collected in autumn 2002–2004 in the Japan, Okhotsk and Bering seas. Field data were collected on TINRO-Centre research vessels and also on the R/V *TINRO*, R/V *Sea Storm* and the R/V *Kaiyo maru*, under the international research program Bering-Aleutian Salmon International Survey (BASIS). A total of 411 plankton stations were sampled in the epipelagic zone (0–50 m), and a total of 5,125 juvenile pink salmon stomachs were examined (Table 1).

The trawling surveys of the upper epipelagic layer in the northwestern Japan, Okhotsk and western Bering seas were conducted using a standard midwater rope trawl (the length of the headrope is 80 m, and the perimeter of the trawl opening is 396 m). The trawl hydrodynamic plate (6 m^2, 0.6 x 10 m) had floats on the headrope. The trawl was 30 m long with quadrangular mesh in the body and wings and a small mesh codend.

Standard methods, developed earlier and widely used in TINRO-Centre studies (Volkov and Chuchukalo 1986), were used for collecting data and the analyses of fish stomach contents. We combined stomach contents from fish of one size (for pink, 10–20 and 20–30 cm) from each trawl sample, and identified prey items, total prey weight and weight of each prey component. After that we calculated mean values for the sample and for each region.

Plankton stations were sampled with a Juday Net (nylon, with a 0.168-mm mesh; mouth opening area 0.1 m^2) in the epipelagic layer (0–50 m and 0–200 m) during both day and night before trawling for nekton. Samples of plankton were

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subdivided into three size groups: small (animals < 1.2 mm in length), medium (animals 1.2–3.2 mm) and large (animals > 3.2 mm). After that, we analyzed species composition of a sample, and weight, size and developmental stages for each species. The biomass was determined using a volumeter. We also incorporated net catchability coefficients (CC) in calculations of abundance and biomass for each plankton

Table 1. The numbers of stations and stomachs analyzed, by area.

	Number of stations	Number of stomachs analyzed
Western Bering Sea	131	1,427
Eastern Bering Sea	114	692
Sea of Okhotsk	114	2,252
Northwestern Japan Sea	52	754
Total	411	5,125

Table 2. Catchability coefficients for different plankton size groups (from Volkov 1996a).

Plankton size groups	Catchability coefficients (CC)
Small (animals < 1.2 mm)	1.5
Medium (animals 1.2–3.2 mm)	2.0
Large (animals > 3.2 mm):	
euphausiids < 10 mm	2.0
euphausiids 10–20 mm	5.0
euphausiids < 20 mm	10.0
chaetognaths < 10 mm	2.0
chaetognaths 10–20 mm	5.0
chaetognaths 10–20 mm	10.0
hyperiids < 5 mm	1.5
hyperiids 5–10 mm	5.0
copepods < 5 mm	2.0
copepods > 5 mm	3.0

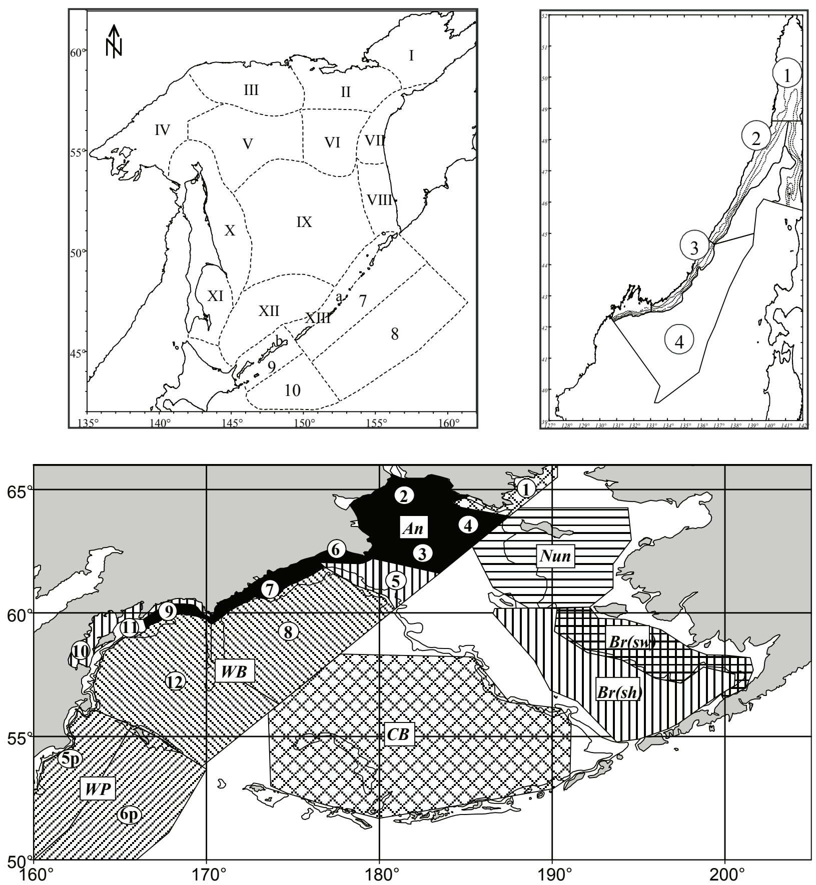

Fig. 1. Biostatistical regions of data averaging: in the Okhotsk Sea (upper left): I–VI = northern regions, VII–VIII = Western Kamchatka, IX = central Basin, X = eastern shelf of Sakhalin, XI = Terpenya Bay, XII = southern Basin, XIII a = northern and b = southern Kuril regions, 7–10 = Pacific regions; in the northwestern Japan Sea (upper right): 1 = Tartar Strait, 2 = northern Primorye, 3 = southern Primorye, 4 = deepwater area; in the Bering Sea (lower panel): 1 = Bering Strait, 2 = northwestern Anadyr Bay, 3 = southeastern Anadyr Bay, 4 = eastern Anadyr Bay, 5 = Navarin region, 6 = Koryak shelf, 7 = Koryak slope, 8 = western Aleutian Basin, 9 = Olutorskyi slope, 10 = shelf of Karaginskyi and Olutorskyi bays, 11 = Karaginskyi slope, 12 = Commander Basin, 5p = Kamchatka Trench, 6p = oceanic waters off Kamchatka and Commander Islands, An = Anadyr Bay, WB = western Bering Sea basins, WP = oceanic waters near Commander Islands, CB = central deep Bering Sea, Nun = Nunivak region, Br(sw) = shallow area of Bristol Bay (< 50 m), Br(sh) = shelf zone of Bristol Bay (> 50 m) (from Shuntov et al. 1986; Shuntov et al. 1988a, b; Volkov et al. 2004).

species (Table 2).

All numerical data were averaged by standard biostatistical regions, which had been established based on water circulation schemes and distribution patterns of water masses (Fig. 1) (Shuntov et al. 1986; Shuntov et al. 1988a, b). Areas of data averaging based on BASIS expeditions in the eastern Bering Sea followed Volkov et al. (2004).

RESULTS

Juvenile pink salmon prey on a variety of planktonic and nektonic organisms (Volkov 1996b; Gorbatenko 1996a; Dulepova 1998; Lazhentsev and Bokhan 2001; Efimkin 2003; Efimkin et al. 2004; Volkov et al. 2006). Amphipods (hyperiids) and euphausiids were the predominant zooplankton prey during the entire research period. Pteropod mollusks may also be of high value as prey items. Copepods and chaetognaths were much less important. The amount of nektonic prey, such as larvae and juvenile fish (walleye pollock, capelin, sand lances and other species) and juvenile squid and crab, varied significantly (depending on the season and region). Prey composition in the diet of pink salmon depended on the seasonal abundance and vertical distribution of prey organisms in a particular area. The composition of species and groups of plankton, which formed the forage base for juvenile pink salmon, varied among the Bering, Okhotsk and Japan seas.

Bering Sea

Research conducted in 2002–2004 revealed that the composition of the forage base for Pacific salmon was different in the western, central and eastern parts of the Bering Sea. Large-sized zooplankton dominated plankton communities in the upper epipelagic layer in the western and central Bering Sea. Small- and medium-sized zooplankton were more abundant in the upper epipelagic layer in the eastern Bering Sea (Fig. 2). The dominant groups in the eastern Bering Sea plankton communities in autumn were ichthyoplankton and meroplankton (Efimkin et al. 2004; Volkov et al. 2004, 2006).

The study of Pacific salmon food habits reveal that in September–October of 2003–2004, in the eastern Bering Sea (shallow and shelf zones of Bristol Bay and Nunivak region) juvenile pink salmon preyed mainly upon larvae and juveniles of walleye pollock and capelin, crab larvae and larvae of bottom fish (Fig. 3) (Efimkin et al. 2004; Volkov et al. 2006).

In upper epipelagic layers of the western Bering Sea during autumn 2002–2004, copepods (mainly *Neocalanus plumchrus*, *Calanus glacialis*, *Metridia pacifica*, *Eucalanus bungii*, and *Oithona similis*) and chaetognaths were the predominant groups in the zooplankton community. Maximum copepod biomass ranged from 163.9–1280.3 mg/m^3 in coastal areas and 75.5–498.8 mg/m^3 in the deep-sea areas; the biomass of chaetognaths reached 101.9–420.2 mg/m^3 in coastal areas and 124.1–288.7 mg/m^3 in deep-sea areas. Pteropods and amphipods (mainly hyperiids) were more common in the Anadyr Bay and Navarin regions than in other areas (Fig. 4). Although copepods and chaetognaths dominated the zooplankton community, hyperiids, euphausiids and pteropods were the three most important food items in the juvenile pink salmon diet. For example, hyperiids (*Themisto pacifica* and *T. libellula*) and euphausiids (*Thysanoessa longipes*), whose abundance was relatively low, dominated in the juvenile pink salmon diet in the autumn of 2002 (Fig. 5). In the autumn of 2003, juvenile pink salmon preyed largely on pteropods (*Limacina helicina*), which accounted for up

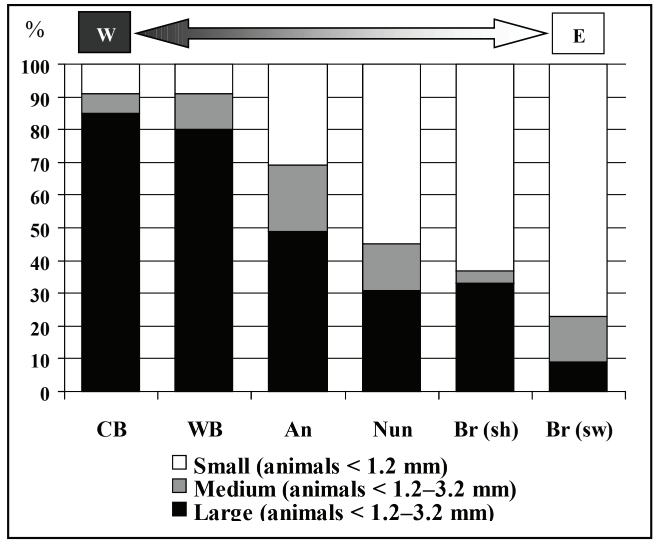

Fig. 2. Structure of plankton communities (%) in the epipelagic layer in the Bering Sea in autumn 2003–2004 (from Volkov et al. 2006 with modifications). Names of biostatistical regions according to Fig. 1.

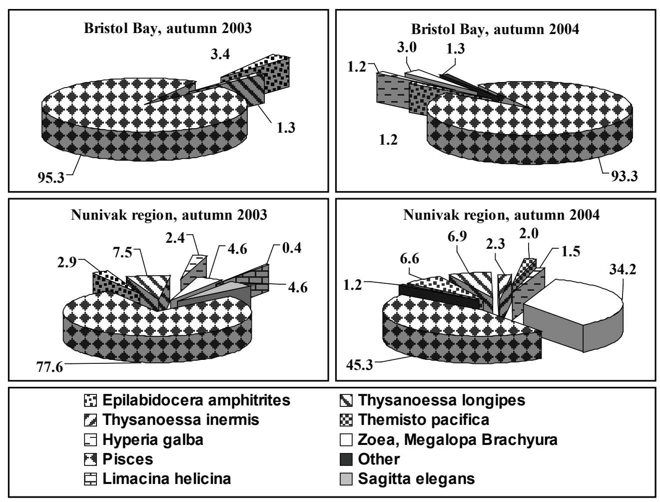

Fig. 3. Diet (%) of juvenile pink salmon in the upper epipelagic layer in the eastern Bering Sea in autumn 2003–2004 (from Efimkin et al. 2004; Volkov et al. 2006 with modifications).

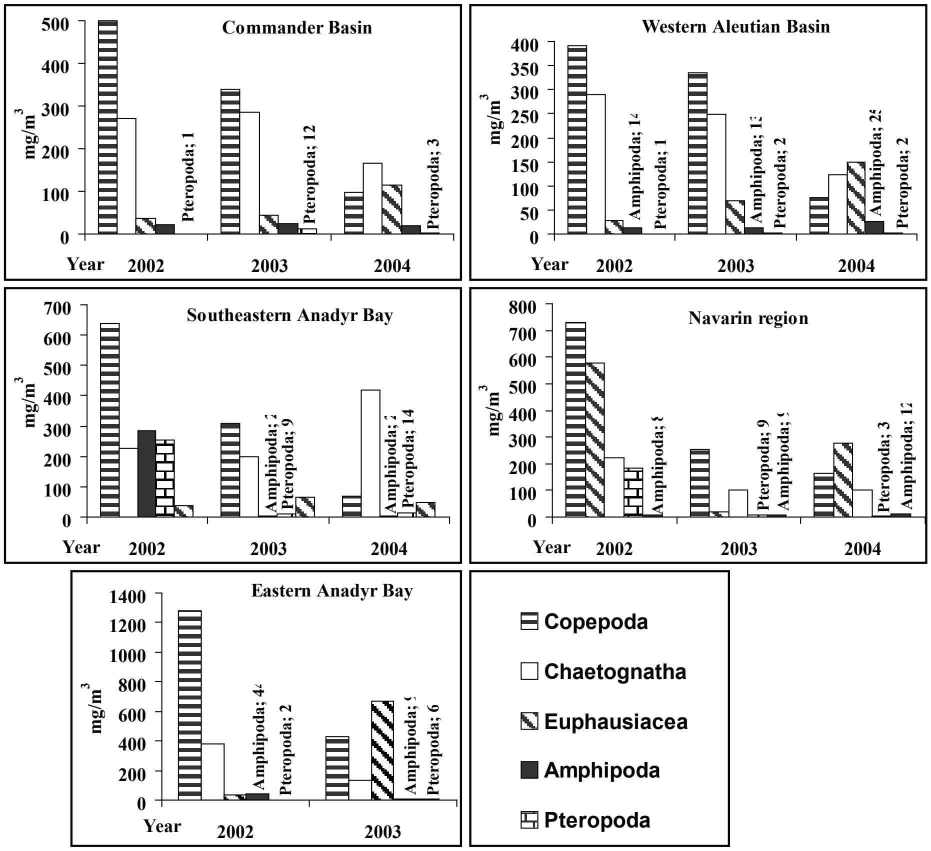

Fig. 4. Biomass (mg/m³) of some groups of zooplankton in the epipelagic layer in the western Bering Sea in autumn 2002–2004.

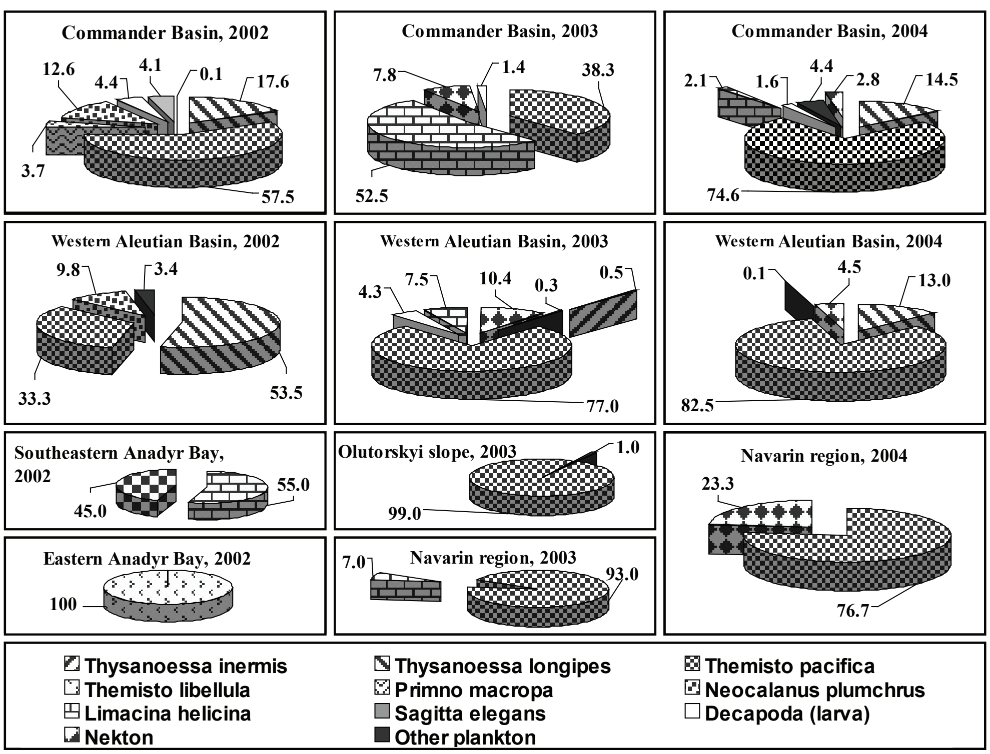

Fig. 5. Diet (%) of juvenile pink salmon in the upper epipelagic layer in the western Bering Sea in autumn 2002–2004.

to 53% of the fish diet in the Commander Basin. In this particular area, pteropods were more numerous than in the other regions of the sea, and accounted for 2% of the total zooplankton biomass. Biomass of pteropods in the Aleutian Basin was lower than in the Commander Basin; however, hyperiids were found in similar quantities in both areas (Fig. 4), and comprised major portions of the juvenile pink salmon diet in the Aleutian Basin (Fig. 5). In the autumn of 2004, the biomass of euphausiids was high and comprised from 8% to 49% of the zooplankton biomass depending on the area (Fig. 4). However, at that time they accounted for about 15% of the juvenile pink salmon diet, which was even less than in 2002. The hyperiid (*T. pacifica*) was the major prey of juvenile pink salmon in all of the research regions of the western Bering Sea in the autumn of 2004 (Fig. 5).

Okhotsk Sea

Euphausiids (mainly *T. longipes*, *T. inermis*, *T. raschii* and to a lesser extent *Euphausia pacifica*), copepods (mainly *N. plumchrus*, *M. pacifica*, *M. okhotensis*, *Pseudocalanus minutus*, and *O. similis*) and chaetognaths dominated the zooplankton community in most areas of the Okhotsk Sea. The maximum biomass of euphausiids (195.3–1077.0 mg/m^3) was located in the southern Okhotsk Sea, particularly in the coastal waters of eastern Sakhalin and Terpenya Bay. A high biomass of hyperiids (118.7–193.0 mg/m^3) was also found in these areas. The biomass of copepods and chaetognaths varied among the Okhotsk Sea areas, and their total biomass in the Okhotsk Sea was notably lower than in the Bering Sea (Fig. 6).

The diet of juvenile pink salmon was more diverse in the Okhotsk Sea than in the Bering Sea. Two hyperiids (*T. pacifica* and *Primno macropa*) and two euphausiids (*T. longipes* and *E. pacifica*) were the main prey items for juvenile pink salmon in the Okhotsk Sea in the autumn of 2002 (Fig. 7). However, juvenile pink salmon also consumed calanoid copepods, pteropods, and chaetognaths in notable quantities. A similar pattern of juvenile pink salmon food habits was observed in the autumn of 2003 (Fig. 7). It is worth noting that *P. macropa* comprised a large portion of the fish diet in 2002 and 2003 in spite of the fact that the biomass and occurrence of these hyperiids were low in the plankton community. The same was true for the pteropod mollusk *L. helicina*. The biomass of copepods (particularly *M. okhotensis* and *O. similis*) was high in the study area in 2004; however, juvenile pink

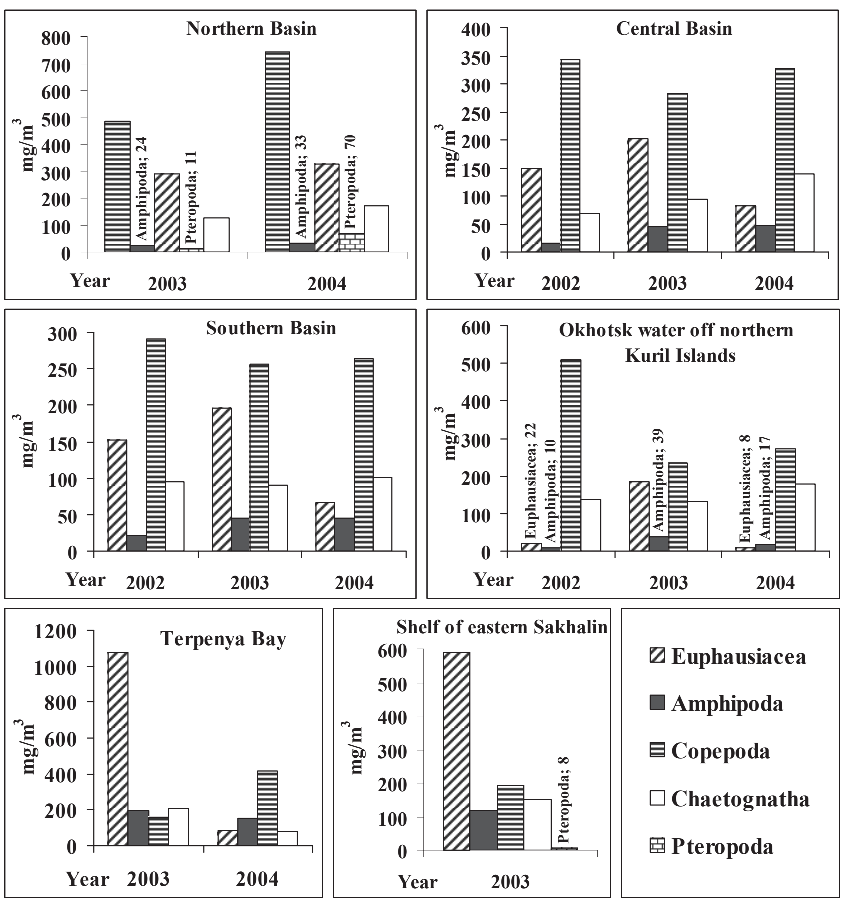

Fig. 6. Biomass (mg/m^3) of some zooplankton groups in the epipelagic layer in the Okhotsk Sea in autumn, 2002–2004.

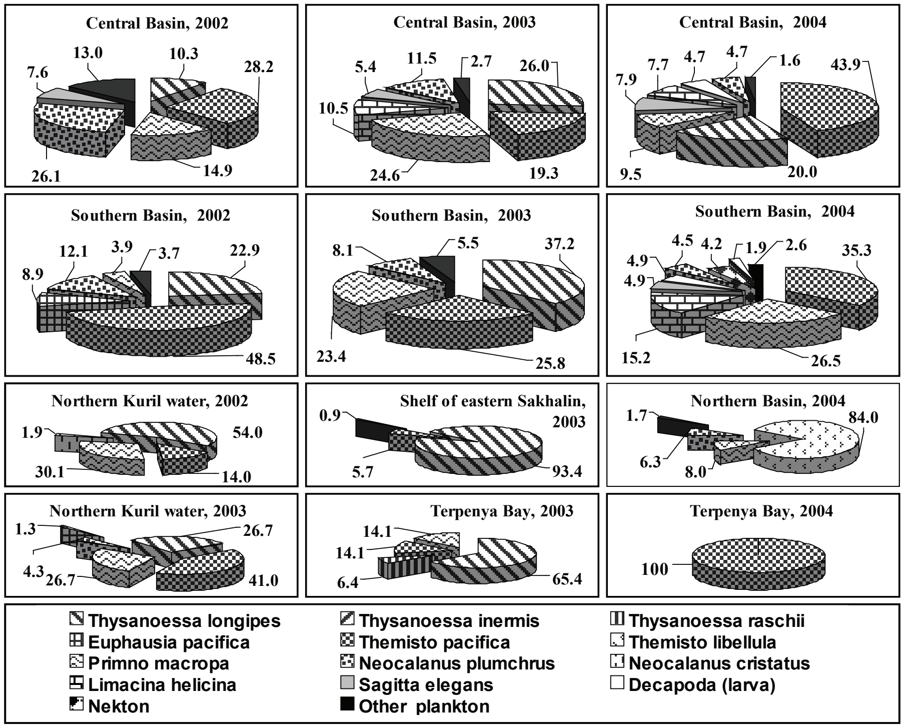

Fig. 7. Diet (%) of juvenile pink salmon in the upper epipelagic layer in the Okhotsk Sea in autumn 2002–2004.

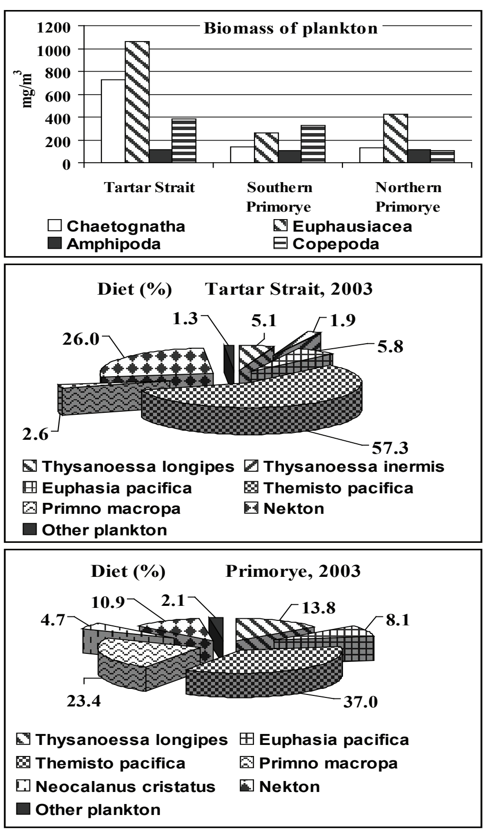

Fig. 8. The composition (mg/m^3) of plankton community and diet (%) of juvenile pink salmon in the epipelagic layer in the northwestern Japan Sea in autumn 2003.

salmon did not consume these animals.

In the autumn of 2003, juvenile pink salmon preyed upon the highly abundant euphausiids and copepods in the northern Okhotsk Sea (Fig. 6). In the autumn of 2004, juvenile pink salmon preyed mainly upon the hyperiid *T. libellula* (Fig. 7).

Northwestern Japan Sea

Copepods (mainly *Calanus glacialis*, *M. pacifica*, *M. okhotensis*, *N. cristatus*, and *N. plumchrus*), chaetognaths, and euphausiids (*T. longipes*, *T. inermis*, and *E. pacifica*) comprised the bulk of the plankton community in the northwestern Japan Sea in the autumn of 2003 (Fig. 8). Hyperiids (*T. pacifica*) were more abundant, and pteropods (*L. helicina*) were less abundant in the plankton community in this area than in the Bering and Okhotsk seas. However, the share of *T. pacifica* in the juvenile pink salmon diet was lower in the Japan Sea than in the Bering Sea, because juvenile pink also preyed upon another hyperiid species (*P. macropa*) as well as upon euphausiids and juvenile fish, which were highly abundant in the upper epipelagic layer in the northwestern Japan Sea (Fig. 8).

DISCUSSION

In all regions except for the eastern Bering Sea, the most common prey items in the juvenile pink salmon diet were planktonic crustaceans: hyperiids (*T. pacifica*, *T. libellula*

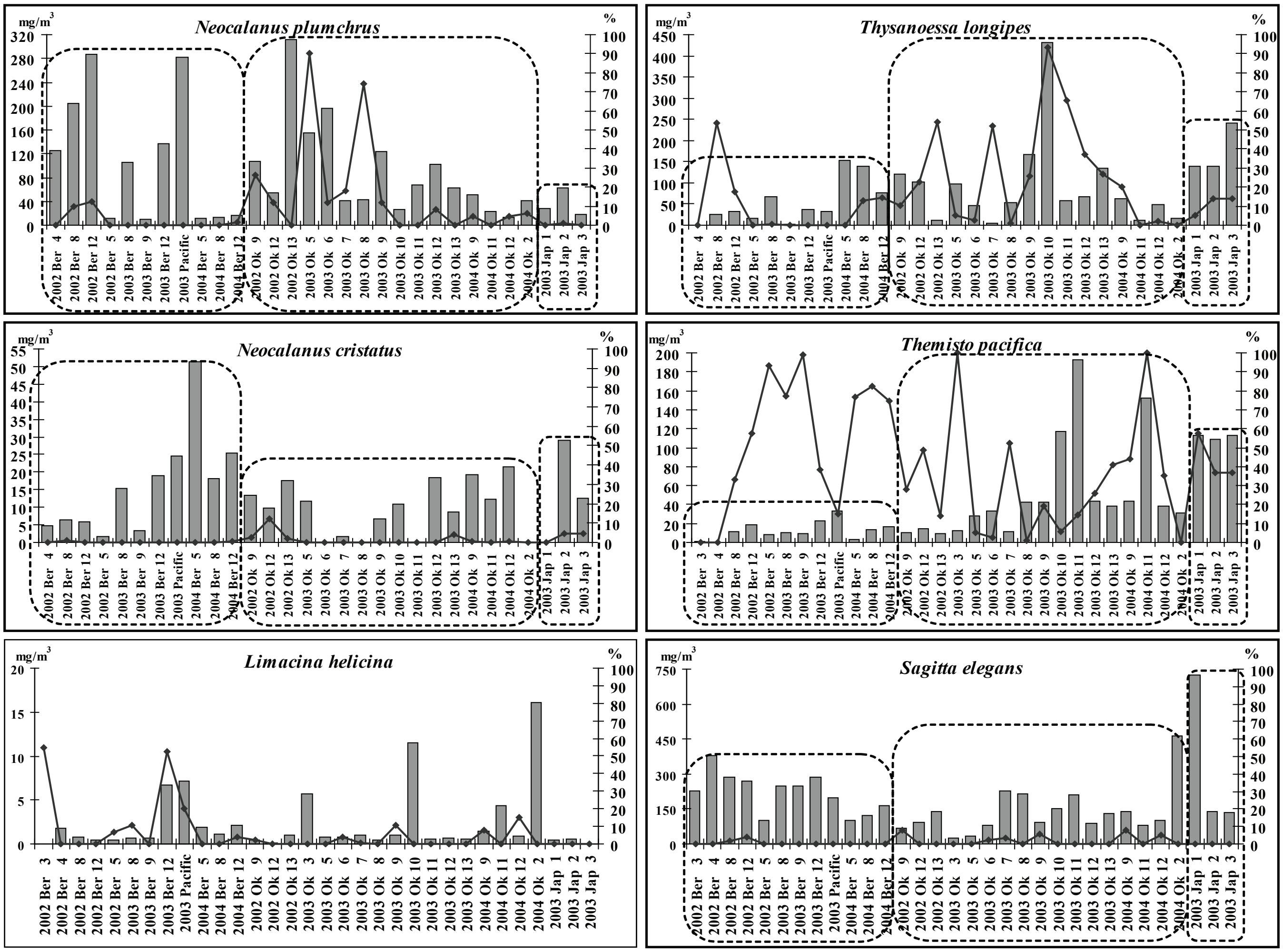

Fig 9. Biomass (mg/m^3) of some species of zooplankton and their share in the juvenile pink salmon diet (%) in different areas of Far East seas in autumn 2002–2004. 2002, 2003, 2004 = years; Ber = Bering Sea, Ok = Okhotsk Sea, Jap = Japan Sea, Pacific = Pacific regions; 1–13 = number of biostatistical regions according to Fig. 1.

and *P. macropa*), euphausiids (*T. longipes*), copepods (*N. plumchrus*) and gelatinous mollusks (pteropods *L. helicina*). In some research regions the higher the biomass of euphausiids (*T. longipes*), copepods (*N. plumchrus*) and pteropods (*L. helicina*) in the pelagic plankton community, the higher was their proportion in the juvenile pink salmon diet.

However, hyperiids (*T. pacifica*) frequently occurred in the juvenile pink salmon stomachs irrespective of their biomass in the pelagic plankton community (Fig. 9). Copepods (*N. cristatus*, *M. pacifica*, *O. similis*, and *P. minutus*) and chaetognaths (*Sagitta elegans*) rarely occurred in juvenile pink salmon stomachs irrespective of their high biomass in the plankton.

We suspect that the food habits of juvenile pink salmon are associated with the accessibility of their forage groups in their habitat strata. Accessibility of zooplankton prey for juvenile pink salmon may be governed by different factors, in particular, by zooplankton vertical distribution patterns and diel migrations. Vertical sections of plankton distribution in the Bering Sea in September of 2003 and August of 2004, suggested that in the upper epipelagic layer (0–50 m), the biomass of zooplankton (particularly copepods and euphausiids) increased at night due to vertical migrations from deeper layers (Fig. 10). Similar results of vertical plankton distribution in the Far Eastern seas (including the Okhotsk and Japan seas) were obtained earlier (Vinogradov 1954; Gorbatenko 1996b). Euphausiids mainly aggregated at depths of 200–500 m during the day and migrated to depths of 150–200 m at night. But in those areas where biomass of euphausiids was very high (especially in the southern Okhotsk Sea), they occurred in the upper epipelagic zone (0–50 m) during the day and could serve as prey for juvenile pink salmon. Hyperiids (mainly *T. pacifica*) were present in dense aggregations during both day and night in the subsurface layer (0–10 m). The most dense aggregations of pteropods *L. helicina* (particularly small- and medium-size groups) were also distributed in the upper epipelagic layer, 0–50 m (Chuchukalo and Napazakov 1998; Volkov 2003).

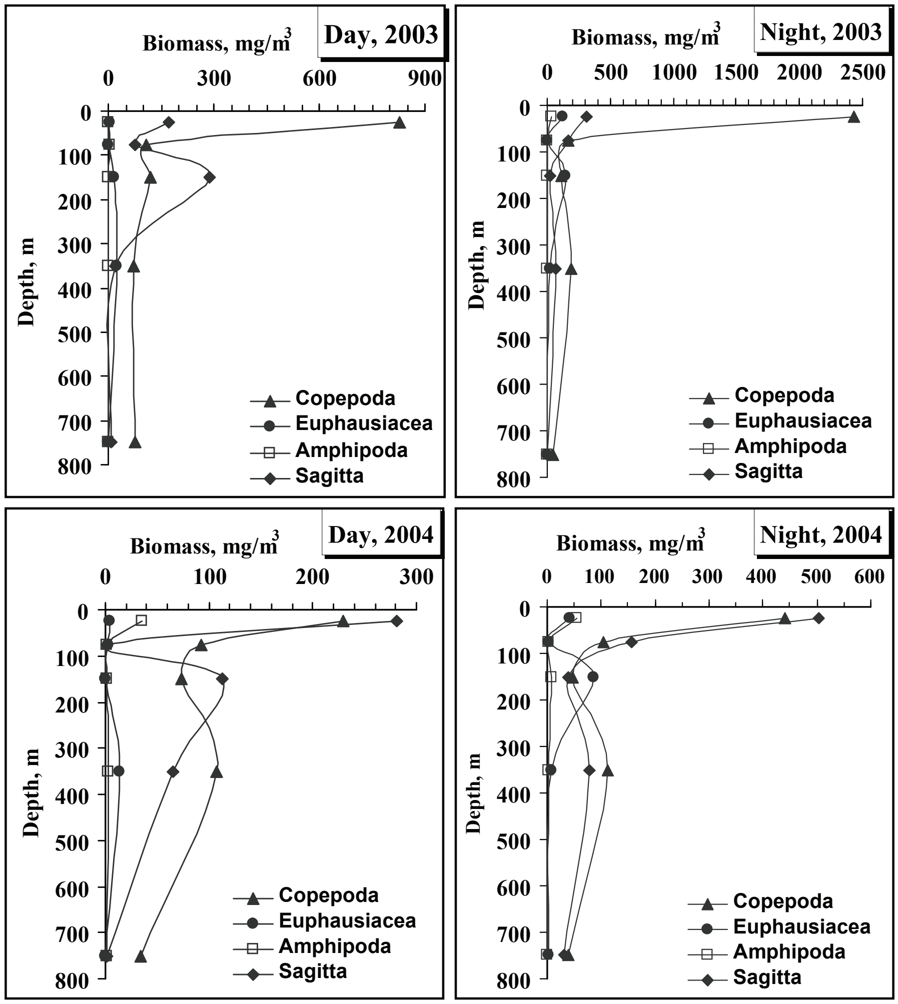

Fig. 10. Vertical sections of zooplankton at a daily station in the western Bering Sea from 8 to 9 September 2003 and from 23 to 24 August 2004 (A. Slabinsky, TINRO-Centre, Vladivostok, Russia, personal communication).

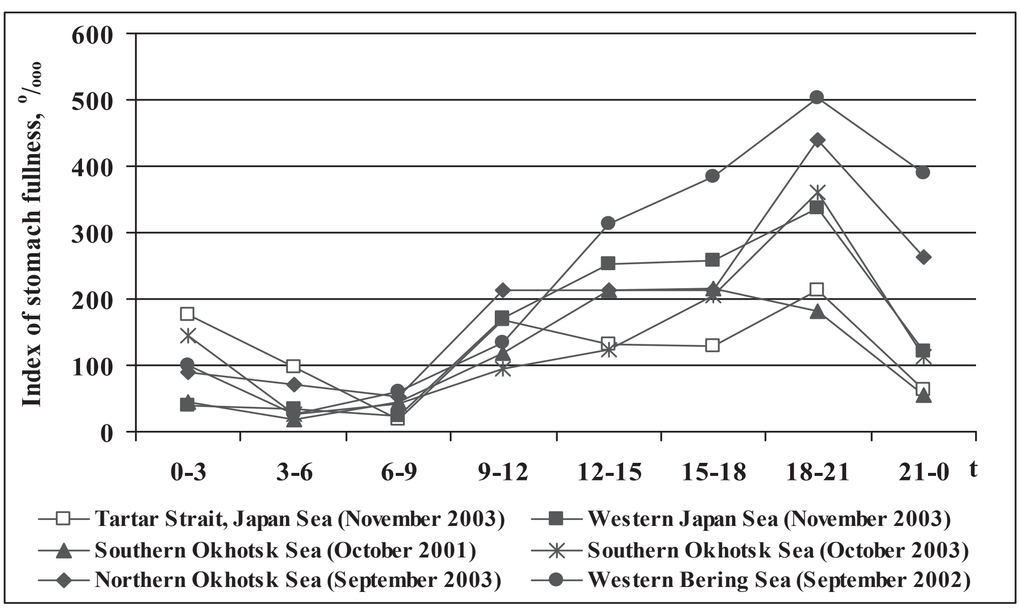

Fig. 11. Daily rhythm of juvenile pink salmon feeding in the Far Eastern seas in autumn.

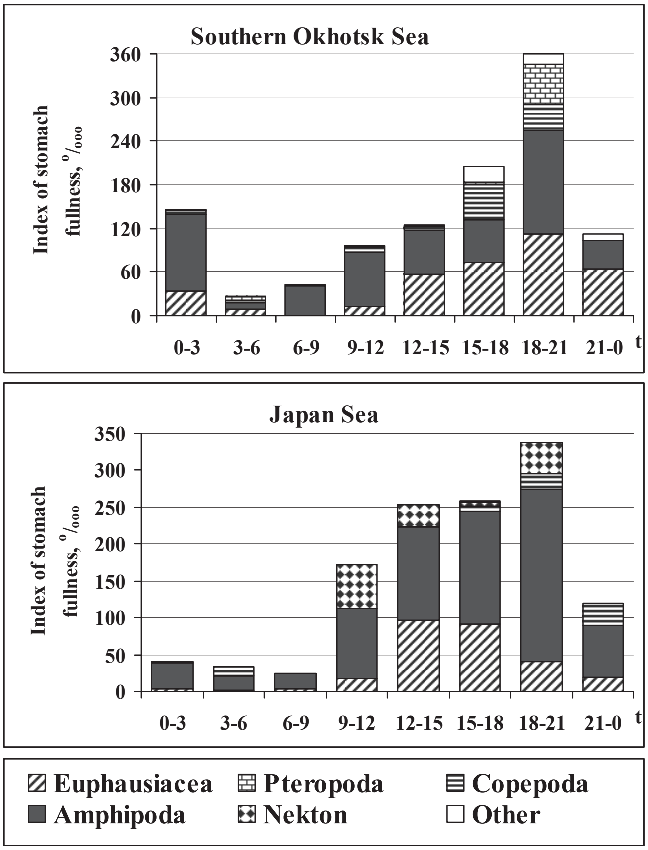

Fig. 12. Consumption of some zooplankton groups by juvenile pink salmon during day and night in the southern Okhotsk and northwestern Japan seas in autumn 2003.

High copepod abundance in the epipelagic zone was also observed at night, because most copepods tend to migrate to deeper waters during daylight hours. In August of 2004 in the western Bering Sea, the biomass of copepods averaged 440.4 mg/m^3 at night and 229.9 mg/m^3 during the day. Copepods (*N. plumchrus*: C IV and V stages of development) dominated among copepods during the day (138 mg/m^3) and at night (165 mg/m^3). Deep-water copepods (*N. cristatus*) did not occur in the upper epipelagic zone during the day, while at night their biomass increased up to 141.8 mg/m^3. Copepods (*M. pacifica*: C IV and V stages of development and adult specimens) aggregated during the day at depths of 0–500 m, and at night part of the population concentrates at depths 10–50 m (Shebanova 1996). In September of 2003 in the western Bering Sea, the biomass of copepods (*M. pacifica*) increased up to 128.5 mg/m^3 at 0–50 m; in 2004 copepods (*M. pacifica*) did not occur in the upper epipelagic zone during the day, and increased up to 23.2 mg/m^3 in the upper epipelagic layer at night. Surface copepods (*O. similis*) occurred in the upper epipelagic layer during the day (70.4 mg/m^3) and at night (62.8 mg/m^3), while the biomass of the copepod genus *Pseudocalanus* increased in the upper epipelagic layer at night in 2004. The biomass of chaetognaths in the upper epipelagic layer also increased considerably at night. In summary, species of zooplankton (and stages of development) vary considerably in their vertical distribution and diel vertical migrations. Accordingly, the consumption of different species of zooplankton by juvenile pink salmon (or their share in the diet) changed during the day.

It is a well-known fact that juvenile pink salmon consume prey mainly during the day, between 10:00 a.m. and 10:00 p.m. (Gorbatenko 1996a; Lazhentsev and Bokhan 2001; Efimkin 2003). During autumn (for example, in the western Bering Sea in September, 2002, in the northern and southern Okhotsk Sea in September–October 2001 and 2003, and in the northwestern Japan Sea in November, 2003) the weakest forage activity of juvenile pink salmon was observed at night, while forage activity peaked between 3:00 p.m. and 9:00–10:00 p.m. (Fig. 11).

Juvenile pink salmon preyed primarily on zooplankton groups and species that were more abundant in the juvenile pink salmon habitat strata during daylight hours (Fig. 12). As a result, hyperiids (*T. pacifica*, *T. libellula* and *P. macropa*), euphausiids (*T. longipes*), copepods (*N. plumchrus*) and in some areas pteropods (*L. helicina*) were primary food items for juvenile pink salmon. Larvae, juvenile fish, and decapod larvae were primary food items for juvenile pink salmon in the upper epipelagic zone in the eastern Bering Sea, where these forage groups dominated the plankton community.

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