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Interannual and Interregional Analysis of Chum Salmon Feeding Features in the Bering Sea and adjacent Pacific Waters of Eastern Kamchatka

by

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Abstract

Statistical comparison of prey composition for different size chum salmon in the Bering Sea and Pacific waters of Kamchatka was conducted using Kolmogorov-Smirnov's criterion and cluster analysis. It was established that within the limits of large waters areas statistical differences depending on regions were not observed in the diet composition of chum salmon. On the given stage of data processing prey spectrum in quality and quantity aspects is different for chum salmon fishes with body length more or less than 40 cm. These differences mainly concern such groups as amphipods, copepods, medusas and nekton as a whole. Medusa as a prey is a distinctive feature of chum salmon with body length of more than 51 cm. The presence of medusa and ctenophores in diet is likely to be an age morpho-ecological adaptation. Besides, using cluster analysis it was established, that for big chum salmon fishes diet composition for 1986, 1993, 1995 and 1990, 1992, 2000 and 2002 are overlapped. For small chum salmon fishes the highest diet composition overlap was observed in 1986 and 1990, and in 1992 and 2002. It was shown that chum salmon diet composition differ statistically in the Bering Sea and Pacific waters of Kamchatka. These differences are likely to be connected with the condition of food resource and great plasticity of the species diet.

Introduction

Intensive investigations of the Far-Eastern seas ecosystems conducted by TINRO-Center from the early 1980s and the study of main commercial fish species diet allow us to judge about trophic relations of these species. To improve our knowledge and to reveal the reasons of dominating species biomass formation, and finally for estimation of curring capacity of certain water areas of the Far-Eastern economic zone it is necessary to obtain data on trophic status of dominating nekton species. In this case trophic status of a species implies its role in trophic structure of its populations and in the degree of its effect on the prey populations (Konchina, 1993). In this respect chum salmon (O. keta) is the most interesting for investigation as one of the most numerous salmon species in the Far-Eastern sea.

Materials and Methods

Our work is based on data, obtained during 15 complex expeditions to the Eastern part of the Bering Sea and Pacific waters of Kamchatka and Kuril Islands in summer-autumn period (Fig. 1). These expeditions were conducted by the Laboratories of the Applied Biocenology and Hydrobiology of TINRO-Center within 1987-2002. Totally 3130 stomachs were collected and processed. The materials were processed in accordance with the Manual on investigation of fish feeding (1986). Samples (up to 25 stomachs of one size class) were selected from every catch by net, taking into account fish size. Stomachs were treated immediately after fish dissection without prior fixation. Stomach fullness was assessed on a scale of 1-5. After that total weight of stomachs of the entire sample, species composition of prey, importance of mass species, general and particular indices of fullness were estimated (Volkov et al., 1997).

For statistical comparison of species and groups abundance in fish diet between size groups or regions, the comparison methods of empirical and theoretical, or two empirical distributions can be applied. The famous Pearson's criterion $?^{2}$ is the most popular among them. But application of this criterion implies a number of limitations, which cannot be observed every time due to the lack of material or its features, when we, for example, have a similar frequency sum for compared distributions. That is why it is necessary to make normalizing transformations and union of classes. Kolmogorova-Smirnova's criterion ? is free of these limitations (Zaks, 1976).

Results and Discussion

In the course of long-term investigations it was established that the diet of almost all Pacific salmons is very flexible. It includes macroplankton, small fish and squids. Depending on specific conditions in this or that region they can easily switch over from one prey to the other one.

Chum salmon occupies its special place among Pacific salmons, as it has a very big stomach with underdeveloped muscular tissues, gullet with clear sphincter, which prevents regurgitation. At that, its ratio stomach volume/body length is approximately 3.5 times bigger than that of the other salmon species (Arai et al., 2000). Therefore this species should have some peculiar diet features, elaborated in the process of evolution, which distinguish it from other salmons.

When comparing diet composition of similar size chum salmons from different regions, it was established that within the limits of large water areas diet compositions of certain size groups do not differ (? criterion is always less than in the table). The most notable is the fact that at the given level of data treatment diet spectrum in quality and quantity aspects substantially depends on fish size and differs for individuals with body length up to 40 cm and bigger ones with body length more than 41 cm, and it can be observed in all areas. On this basis we distinguished only two mentioned size groups, which will be further called "big" and "small" individuals. A detailed comparative analysis was made particularly for these size groups. Mean values of diet composition of separate groups for the entire period of investigation, beginning from 1986 to 2002, are given in Table 1. It should be noted that the greatest values (in %) of diet compounds for chum salmon size groups fall at amphipods, medusas and undigested remains. If for small chum salmon the bulk of the prey consists of euphausiids, amphipods and copepods, pteropods and tunicates, for the big ones it mainly includes fishes, squids, gelatinous plankton (mainly medusas), euphausiids, pteropods and tunicates, and to the less extent – amphipods and copepods.

More detailed comparative analysis of interannual diet spectrum can be conducted on the basis of Table 2 and Figures 2 and 3 (dendrograms of the Bering Sea). The Table gives mean values of diet composition in different years for big and small chum salmons, and the dendrograms show visually similarity of composition in Euclidean metric (squared Euclidean distance-sum of difference) for the studied groups in different years. It can be seen from Figure 2 that the most similar diet composition for big chum salmon were in 1993 and 1995; 1992 and 2002. 1986 joins the first group, and 1990 – the second group. The most distant are diet composition in 2000 and 1987. Qualitative analysis of the composition testifies that both in 1993 and 1995 big chum salmon preferred pteropods. And in 1992 and 2002 it consumed both euphausiids and amphipods. As to fishes, the most of them were consumed in 2002. But as using cluster analysis similarity is determined for all components, in this case we took into account undigested remains as well, which relative amount in the diet was rather substantial and which presence was reflected in the comparative analysis of composition.

The comparison of close clusters according to Kolmogorov-Smirnov's criterion for big chum salmons (Fig. 2) testifies that clusters 4 and 8, and 5 and 6 are the most similar, which corresponds to 1992 and 2002, and 1993 and 1995. In the first case calculated bilateral Kolmogorov-Smirnov's criterion was equal to 0.853, which corresponds to the probability rate of 0.47 and considerably exceeds the level of probability adopted in biology, which is equal to 0.05. In the second case these values were equal to 0.43 and 0.99 respectively. Thus, the differences between chum salmon diet composition in these years were not determined (i. e. they were not proved). There are no differences between more distant 4 and 7 clusters as well, i. e. between diet composition of 1992 and 2000 (?=0.43 and p=0.99). Therefore one can conclude that diet composition of big salmon form three groups, which corresponds to 1986, 1994, 1995; 1992, 1990, 2000 and 2002, and separately 1987. This year is particularly noted for a great number of tunicates in the diet of big chum salmon.

Diet composition of small chum salmon (Fig. 3) are the most similar in 1986 and 1990 (?=1.1; p=0.2, differences are not reliable), as well as in 1992 and 2002 (?=1.6; p=0.011, differences are reliable). In the rest of the years – 1987, 1995 and 2000 – diet composition occupy detached positions. However, ?-criterion does not show reliable differences between, for example, 1987 and

1995 (?=0.85; p=0.47), between 1987 and 2000 (?=1.1; p=0.2) and between 1995 and 2000 (?=0.8; p=0.56).

The conducted analysis of diet composition of chum salmon from the Bering Sea and adjacent Pacific waters allow us to conclude that chum salmon diet statistically differs in these two areas (Fig. 1). Main differences consist in a greater share of predatory zooplankton (amphipods and chaetognaths), fishes and squids in small chum salmon diet from the Bering Seas, and in a greater share of phyto- and euryphagous organisms (euphausiids and copepods) in that of the Pacific waters. Besides, in the Pacific waters the share of pteropods, which, according to their taxonomic composition, belong both to predatory (Clione limacine) and non-predatory (Limacina helicina) zooplankton, is greater. Such differences in diet composition compositions are quite understandable, as exactly in the Bering Sea in summer and especially in autumn predatory zooplankton becomes more important in populations in comparison with that of the Pacific waters of Kamchatka (Dulepova, 2002).

Trophic affiliation of taxonomic groups of chum salmon prey is very different. Analyzing average long-term status of the chum salmon diet, one can state with certainty that diet objects of chum salmon (prevailing in the diet) belong to the 2nd trophic level (euphasiids, copepods, partially pteropods, tunicates), to the 3rd trophic level (amphipods, chaetognaths, decapods, ctenophores, medusas, partially pteropods and fishes) and to the 4^{h} trophic level (fishes and squids). Since the structure of chum salmon gastrointestinal tract considerably differs from that of the other salmon species, its diet composition should differ as well. The only substantial and characteristic of only chum salmon feature is the presence of a considerable number of so-called gelatinous organisms in the species diet. In this case gelatinous organisms include coelenterats and ctenophores. This group of animals is not uniform by its trophic affiliation: if coelenterats consume mainly macroplankton, ctenophores consume both macroplankton and medusas with ctenophores themselves. Thus, gelatinous organisms as chum salmon prey belong simultaneously to two trophic levels: medusas - to the 3rd trophic level, and ctenophores - most likely to the 4th one.

The presence of gelatinous organisms, and medusas in particular, in the chum salmon diet was noted by many authors (Synkova, 1951; Volkov et al., 1997; Davis et al., 1998). Already in 1950s Aglantha digitale was noted by A.I.Synkova as one of the species forming chum salmon diet in the Sea of Okhotsk. Our data, obtained during long-term complex expeditions (1986-2002), allow us to analyze the importance of all gelatinous organisms in the diet of different chum salmon size groups from the Bering Sea and adjacent waters in summer and autumn periods.

Average concentration of coelenterats does not exceed 8% in the diet of big size and age groups of fishes from the Bering Sea in autumn. The case, when in 1987 in Olutorsko-Navarinsky area coelenterats made 45% of the diet of big fishes with the length over 51 cm, can be considered as an exclusive one.

In summer time the share of medusas and especially ctenophores in the chum salmon diet is much greater, and in some cases it may reach 40%. The situation like that was observed in 1995 in the deep-water areas of the Bering Sea with chum salmon of more than 50 cm length. But it is untimely to state that such a considerable contribution of ctenophores to the chum salmon diet is connected with insufficient forage reserve. In that period production of non-predatory and predatory zooplankton in that area was relatively high and reached 576 and 259 g/m^2 respectively (Dulepova, 2002). Besides, the given area is hydrodynamically active, and it is quite clear that the share of plankton, introduced in the result of such activity, is rather considerable.

Coelenterats can be often met not only in the diet of many epipelagic fish species but also in that of mesopelagic fishes, and particularly such as Leuroglossus schmidti (northern smoothtongue) and Bathylagus ochotensis (slender blacksmelt) (Gorbatenko, Ilyinsky, 1991). Coelenterats made up to 24% of the diet of northern smoothtongue, and up to 35% of the diet of slender blacksmelt. Therefore, it is more advantageous for these two species, which have at their disposal food resources of a vertical zone from 0 to 500 m and deeper, to consume quickly digested food than high-calorie one.

All above-said, together with high digestion rate, allows us to suppose that the diet of this group is more favorable from physiological point of view, especially because it allows to avoid competition with some other fish species and to extend its feeding niche. Though when this prey group is actively consumed and makes the bulk of chum salmon diet, this diet is most likely used only for metabolism. The similar fact has been already noted by Ishida et al. (1993) for chum salmon of the North-Western Pacific: consuming medusas, chum salmon either does not grow or loses its weight. Apparently that is why, according to our data, only big individuals, which reached definitive size (more than 50 cm), consume gelatinous organisms.

Conclusion

The performed statistical analysis of the long-term data on diet composition of different size cum salmon from the Bering Sea testifies that reliable differences in the diet are observed only for fishes smaller or bigger that 40 cm. Big chum salmon consumes fishes, squids and gelatinous zooplankton more actively in comparison with small one. Consumption of the latter group of predatory zooplankton by big chum salmon is a characteristic feature of this species with body length more than 51 cm. Presence of medusas and ctenophores in the diet is more probably an age morpho-ecological adaptation. It is not impossible that in the period of sex products maturing on the final stages of pre-anadromous migrations spawning individuals organisms require additional easily digested diet components.

Statistically reliable differences in chum salmon diet were not found in the Bering Sea. But at the same time, diet composition of chum salmon from the Pacific waters of Kamchatka and the Bering Sea differs reliably, as chum salmon diet in the Bering Sea includes more amphipods, tunicates and fishes and less pteropods than that of the Pacific waters of Kamchatka.

Revelation of chum salmon diet regularities in the studied areas allowed us to attribute this salmon species to certain (although relative) trophic levels. Chum salmon from the Bering Sea can be attributed to the 4^{h} order consumers to the greater extent than that of the Pacific waters, and its affiliation with the 5^{th} trophic level makes 15% for small individuals and 23% for big ones. Chum salmon from the Pacific waters of Kamchatka belongs to the 4^{h} order consumers (6%, 9%) to the less degree, and to the 2^{nd} order consumers – phyto- and euryphagous organisms (more than 50%) - to the greater degree. Besides, in this area chum salmon begins to consume more 3^{rd} order consumers (predatory zooplankton), but not fish, with the increase of its size. Such change of priorities in the diet is quite explainable, as the Bering Sea is known for its highest level of biomass and production of pelagic fishes among all far-eastern seas (Shuntov, 2001, Dulepov, 2002). At the same time, Pacific waters slightly surpass Bering Sea waters in the number of predators in zooplankton communities (Dulepova, 2002).

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Table 1

Differences in feeding of chum salmon smaller and larger than 40 cm

Size	Taxonomic groups									
	Euphau-Siids	Amphi-pods	Cope-pods	Deca-pods	Ptero-pods	Tunicates	Cteno-phores	Medu-sae	Chaetog-nats	Nekton	Undigested part.
B	16.9	9.30	0.6	0.5	14.8	11.0	2.7	6.7	0.9	18.1	18.6
s	21.0	12.0	0.3	0.8	19.0	19.0	6.0	15.0	1.0	14.0	16.0
S	14.7	30.0	8.0	1.6	13.4	11.0	0.1	0	3.0	14.6	3.6
s	24.0	23.0	13.0	3.2	24.0	16.0	0.15	0	5.5	11.0	5.4

Notice: S- small chum salmon (< 40 cm) , B-big chum salmon (> 40 cm)

Table 2

Interannual dynamics of chum salmon feeding composition (%)in fall in the Bering Sea

Year	Size	Taxonomic groups										
		Euphau-siids	Amphipods	Copepods	Decapods	Pteropods	Tunicates	Ctenophores	Medusae	Chaetog-nats	Nekton	Undigested part.
1986	B	42,1	50.8	0	0	0	0	0	0	0.5	3.7	2.9
	S	65.4	0	0	0	3.0	0	0	0	0	14.8	16.8
1987	B	0	1.2	18.2	8.9	0.4	44.2	0.4	0	0	26.7	0
	S	0	0	0	0	0	55.0	0	45.0	0	0	0
1990	B	28.3	61.6	0.5	0	0	0	0	0	0.7	8.8	0
	S	25.1	35.8	1.0	0	14.1	1.7	0	0	0.6	14.3	7.4
1992	B	7.9	24.8	0.9	0.7	16.3	6.5	0	0	0	33.0	10.5
	S	6.2	10.9	1.5	0	9.5	6.2	0.6	0.1	1.7	10.6	52.7
1993	B	10.8	0.1	0.3	0	44.2	0.3	4.1	3.4	0.8	21.4	14.4
1995	B	8.8	8.8	0	0	65.1	2.3	0	0	0.6	14.3	0.1
	S	14.8	6.2	0.8	0.2	47.0	1.7	17.0	4.0	0.6	7.7	0
2000	B	8.9	15.9	34.0	1.5	0	20.7	0	0	15.1	4.0	0
	S	0.6	11.5	0.1	2.6	0.3	23.1	0	0.8	3.0	30.2	27.8
2002	B	7.9	43.6	2.4	1.0	12.9	3.3	0	0	4.0	12.7	12.2
	S	12.5	9.6	1.1	1.1	0.1	0	0	0	0.4	45.4	29.3

Notice: S- small chum salmon (< 40 cm) , B-big chum salmon (> 40 cm)

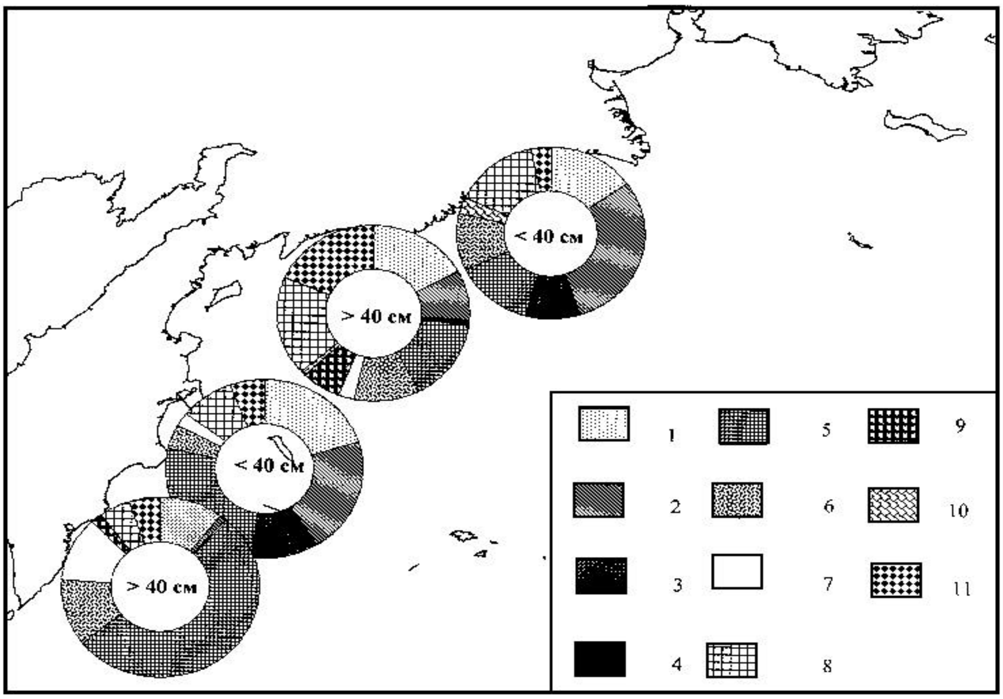

Fig. 1. Diet composition of two size groups of chum salmon from the Bering Sea and Pacific waters of Kamchatka. Table of symbols: 1 – euphausiids, 2 – amphipods, 3 – copepods, 4 – decapods, 5 – pteropods, 6 – tunicates, 7 – nekton, 8 – undigested food, 9 – chaetognaths, 10 – medusas, 11 – ctenophores

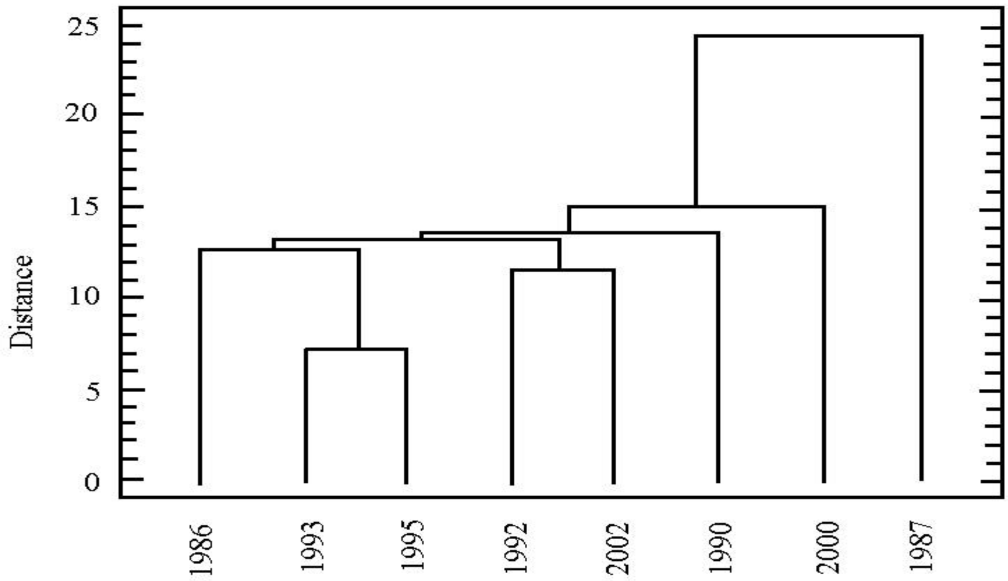

Fig. 2. Dendrogram of diet overlap of big chum salmon (>40 cm) in the Bering Sea

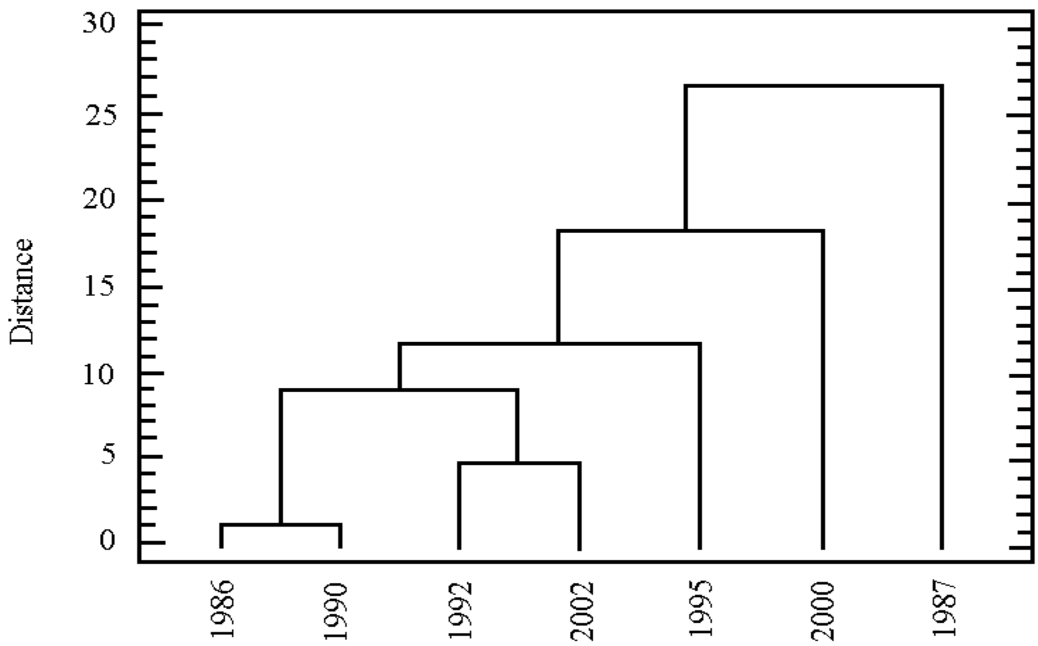

Fig. 3. Dendrogram of diet overlap of small chum salmon (<40 cm) in the Bering Sea