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Russian Salmon Research under the NPAFC Science Plan 2006-2010: A Review and Future Issues

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Russian Salmon studies in 2006-2010 were conducted in accordance with the Far Eastern research program of Pacific salmon (Shuntov, 2008). These investigations have been integral part of the five-year science plan "Status and Trends in Production of Anadromous Stocks in Ocean Ecosystems” the main themes of which were three major research components:

(1) Juvenile Anadromous Stocks in Ocean Ecosystems;

(2) Anadromous Stocks in the Bering Sea Ecosystem (BASIS); and

(3) Anadromous Stocks in the Western Subarctic Gyre and Gulf of Alaska Ecosystems.

The purposes of this paper are to review the results of Russian salmon research related with the present Science Plan, and to propose future research for the appropriate conservation and utilization of Pacific salmon.

1. JUVENILE ANADROMOUS STOCKS IN THE OCEAN ECOSYSTEMS

The research of juvenile Pacific salmon’s marine life period was an integral part of Russian EEZ ecosystem research programs for period 2006–2010. During 2006–2010, studies on juvenile salmon’s marine life period, which were initiated in early 1980s, were continued and new information was obtained from 10 research trawl surveys of TINRO-Centre in the Okhotsk and Bering Seas and research trawl surveys in coastal area off Sakhalin Island (SakhNIRO) and Penincula Kamchatka (KamchatNIRO).

Major results of research of juvenile salmon’s marine life period can be summarized as follows:

1.1. Seasonal distribution and migration route/timing of juvenile salmon

The study of the early marine life period of juvenile salmon in the coastal waters off Kamchatka and Sakhalin was continued. The new data on biology, ecology and habitats conditions (hydrology, forage base) of juvenile salmon at the first stage of sea life in the coastal waters were received (Shubin et al. 2006; Koval 2008; Tepnin 2008; Kolomeytsev 2009; Maksimenkov and Maksimenkova2008; Maksimenkov et al. 2008). Migration features of juvenile salmon from coastal waters off Kamchatka and Sakhalin to deep waters were studied. It was shown that juvenile pink and chum salmon from Aniva Bay (south-eastern Sakhalin) stay for a long time (to 1.5-2.5 months) in a coastal zone after their appearing in sea waters. Juveniles' migration from a shore to the open waters of the bay takes place independently of the dates when specimens enter sea waters. This migration is brief and usually happens in the first half of July. As a rule, by the 20s of July, all juvenile pink and chum salmon leave the bay area. Then they concentrate along southeastern Sakhalin and stay there up to the end of July. Juvenile salmon of western Kamchatka' stocks tend to move northward during first stages of their coastal life (Koval, 2008). And then they migrate to the deep-water area of Okhotsk Sea.

Data on the distribution of juvenile salmon in the Far Eastern Seas acquired during the last years (2006-2009) and archival data from trawl surveys of TINRO-Center was used to trace seasonal dynamics of juvenile salmon quantitative distribution in the Russian exclusive economic zone (EEZ). Comparisons of species-specific distribution patterns clarified the existing schemes of migration routes (Shuntov and Temnykh 2008a; Shuntov et al. 2006; Shuntov et al 2010a). The different areas of Russian EEZ were ranked in relation to juvenile salmon abundance, species composition and duration of feeding period. TINRO-Centre archival trawl surveys databases of the last 25 years were utilized for this ranking. It is the deep-water part of the Okhotsk Sea that is the major feeding ground of juvenile salmon within the Russian EEZ. Despite the great role as a feeding ground of large-size Pacific salmon during summer-autumn period, western Bering Sea has a low foraging importance for juveniles (Temnykh and Kurenkova 2006; Shuntov and Temnykh 2008a). Only last years significance of western Bering Sea for juvenile salmon forage is increased, by reason of raising abundance of juvenile pink and chum salmon in this area.

1.2. Juvenile salmon in nekton communities of the Far Eastern Seas

During 2006–2009 TINRO-Centre continued to monitor upper epipelagic nekton communities' status, as well as interannual and seasonal dynamics of Pacific salmon in nekton communities (Shuntov and Temnykh 2008a,b,c; Temnykh and Kurenkova 2006; Glebov et al. 2006; Glebov et al. 2008a). In 2006-2009, biomass of juvenile Pacific salmon in the epipelagic layer of Russian EEZ remains at the high level. In the southern Okhotsk Sea, biomass of juvenile Pacific salmon varied from 217 to 444 th. ton. But their share in the total nekton biomass decreased to 12-47 % compared to previous years because of high mesopelagic fish biomass. Despite of development of hydrological processes according to the cool year type was evident in the Bering Sea in 2006-2009 (increasing of ice covering area, prevalence of cold types of atmospheric circulations), abundance of juvenile salmon increased significantly in this region (Glebov et al., 2008a). In 2008, abundance of juvenile salmon in the western Bering Sea was even more than in the Okhotsk Sea (Shuntov and Temnykh 2009; Temnykh 2009). In this year juvenile salmon consist about 20 % of the total salmon biomass. In 2002-2005, their share in total salmon biomass was significantly lower (4-10 %) (Shuntov and Temnykh 2008a). Increase of juvenile abundance is supposed to relate to favorable reproduction conditions and low mortality during early stages of sea life.

1.3. Plankton communities and forage base of nekton.

Long-term data (1980-2009) of complex ecosystem studies of TINRO-Center on the composition and dynamic of plankton communities of Far Eastern Sea and adjacent Pacific waters were summarized (Volkov et al. 2007a; Shuntov and Temnykh 2008a; Volkov 2008a,b; Shuntov et al. 2010b).

The main part of zooplankton biomass (77-87 %) in the most regions of North Pacific Ocean is comprised of macroplankton. Plankton forage base is more favorable for salmon in Asian waters compared with the North America waters, in reason of high biomass of euphausiids, hiperiids, pteropods and appendicularia (Volkov 2008a,b; Shuntov et al. 2010b).

The rank of productivity of Pacific salmon forage regions is: Okhotsk Sea > Bering Sea > North-western Pacific Ocean > Japan Sea (Shuntov and Temnykh 2008a; Shuntov et al. 2010b).

The highest plankton biomass occurred in spring and summer. Average macroplankton biomass in deep-water region was at 966-1202 mg/m^3 in the Okhotsk Sea, 792-1055 mg/m^3 in the western Bering Sea, 451-529 mg/m^3 in the Japan Sea, 314-743 mg/m^3 in the North-western Pacific Ocean. In winter, zooplankton biomass do not decrease sharply. Average macroplankton biomass in this season was at 578, 314, 282 and 258 mg/m^3 correspondingly for above-listed areas (Volkov 2008a; Shuntov et al. 2010b).

Total zooplankton biomass in the epipelagic layer of the Bering and Okhotsk Seas and North-West Pacific Ocean was at 720 million tons in 1980th, 600 million tons in 1991-1995 and 590 million tons in 1996-2006. In 1980-2000th, plankton biomass tends to decrease only in the Okhotsk Sea.

The important food item of Pacific salmon is small-size nekton. By the data of trawl surveys of TINRO-Center, micronekton biomass is comparable to hiperiid biomass (Shuntov and Temnykh 2006). In the western Bering Sea, average micronekton biomass varied from 140 to 180 mg/m^3 (Zavolokin et al. 2007a; Zavolokin 2009).

1.4. Growth and survival of juvenile salmon.

Pink and chum yearlings are more abundant in the southern Okhotsk Sea. Synchronous changes in their abundances are observed during fall feeding period in the southern part of the Okhotsk sea (Temnykh 2009; Shuntov and Temnykh 2008a; Shuntov et al. 2010d). In addition to synchronous changes in their abundances, positive correlation between the sizes of pink and chum yearlings is noted for the same period. Average sizes of chum and pink salmon yearlings were larger in even years while their total number was about the same for the even and odd years. On the whole, statistically significant correlations between macroplankton biomass and yearlings abundance or size were not observed (Temnykh 2009; Shuntov and Temnykh 2008a; Shuntov et al. 2010d). These data may testify the absence of strong influence of forage base to abundance and growth of salmon yearlings in the Okhotsk Sea.

Western Bering Sea is less favorable for yearlings forage. Plankton productivity is low in this area compared to southern Okhotsk Sea. This may affect the distribution and size of juvenile salmon in the years of high salmon abundance (Shuntov et al 2006; Temnykh and Kurenkova 2006). So, decrease of juvenile pink salmon size in 2008 may be influenced by density-dependent factors (Temnykh 2009; Shuntov et al. 2010d). But these factors did not lead to decrease of this brood abundance. Pink salmon runs in the western Bering Sea was the highest in summer 2009.

Comparison of pink salmon abundance at each stage of sea life (downstream migrations, anadromous and catadromous migrations, runs to the spawning areas) showed the decreasing of pink salmon mortality in 2000th (Radchenko 2007). The highest survival during sea life occurred for pink salmon generation of 2007. It was 35 % for stocks of western Bering Sea and 40 % for stocks of Okhotsk Sea during period from autumn to summer (Shuntov and Temnykh 2009; Temnykh 2009).

1.5. Pacific salmon feeding behavior.

Data on seasonal changes of feeding intensity of juvenile salmon were summarized (Chuchukalo 2006; Shuntov and Temnykh 2008a). It was shown that decrease of food consumption of Pacific salmon was caused not only by relatively low forage base, but mainly by endogenic physiological factors (Shuntov and Temnykh 2008a).

During migration to offshore waters of the Okhotsk and Bering seas stomach fullness of salmon decrease and food composition changes (Karpenko et al. 2007). Dominant species in the food of pink, chum and sockeye salmon becomes of hyperiids and euphausiids; in the food of chinook and coho salmon - juvenile squids and crab larvae. In the offshore waters of seas the maximum stomach fullness is observed in the daytime and in the evening (Volkov and Kosenok 2005). Changes of juvenile salmons forage base on the daily stations determine the correlation between diurnal dynamics of feeding and vertical migrations of basic salmon forage organisms (forming the sound-dispersing layers) (Karpenko and Koval 2007).

Studies on feeding selectivity showed that juvenile pink, chum and sockeye salmon selectively feed on hiperiid amphipods (mainly *Themisto pacifica*), decapods, pteropods *Limacina helicina* and euphausiids *Thysanoessa longipes*. Juvenile chinook and coho salmon prey mainly small-size nekton – fish and squid larvae and juvenile (Volkov et al. 2007b; Shuntov et al. 2010c). Feeding selectivity of juvenile salmon relates not only to composition and size of forage base, but also to abundance and availability of prey (Naydenko et al. 2008). High and stable feeding selectivity of juvenile salmon testifies their sufficient food supply (Zavolokin et al. 2007b; Shuntov and Temnykh 2008a).

Average size and size range of salmon prey increase with salmon growth (Zavolokin 2008). Wide size range of prey allows salmon to increase their forage base.

Maximum values of total calorie content, level of total metabolism, increment expenditures, and maximum daily rations of juvenile salmon during August-October were observed in September. Among all the species pink and coho are the most active ones (Erokhin and Shershneva 2007). Sockeye is the least active species (Koval 2007). Chum is closer to the first group. In September the average level of expenditures on fish growth for pink, coho and chum is 4.0, 3.9 and 3.5% of total organism energy, respectively, that is much higher than for sockeye (2.1%). Total metabolism intensity regularly reduces with drop of water temperature in October. Intensity of energy expenditures on growth is nearly equal for all the species by this period (1.6-1.9% of total energy balance).

1.6. Ecology and biology of juvenile salmon in marine period of life.

The results of long-term researches on marine ecology of juvenile salmon are generalized (Shuntov and Temnykh 2008a). The basic materials for this generalization are database of numerous complex TINRO-Center ‘s expeditions in the Far Eastern Seas and adjacent waters of North Pacific in 1980-2000-th. Comparisons of species-specific distribution patterns clarified the existing schemes of juvenile salmon migration routes. New ideas on ecology of Pacific salmon juveniles during early marine period were developed. It was shown that the peculiarities of Pacific salmon migrations are viewed from evolutionary adaptive strategy. The analysis of composition of nektonic communities and abundance of juvenile salmon in these communities in different regions reveals that most juvenile salmon are distributed over deep-water areas, influenced oceanic water masses by or water masses with similar physical-chemical properties. This observation may suggest that major adaptations of salmon to marine habitat were associated with their expansion into the upper epipelagic zone over the Subarctic Pacific deep-sea areas, rich in forage resources such as the macroplankton and small nekton. This evolutionary adaptation could have arisen form the relationships with other marine nektonic species through the avoidance of the food competition and influence of predators, which were more extensive in the highly populated shelf regions than in the offshore areas.

One of the important aspects of juvenile salmon adaptation to oceanic life was the development of the scattered distribution type. Non-schooling active swimmers such as salmon are able to forage successfully even when prey organisms are not distributed in dense congregations. That is why salmon, unlike most schooling fish, are not necessarily associated with local productive regions and high gradient zones. Multiple data on the distribution of salmon in the Far Eastern seas suggest that juveniles are distributed relatively evenly over vast areas, and they usually move in a wide “front”. These features reduce the negative influence of the density factor on the forage conditions, food availability and growth.

Data from juvenile pink salmon autumn surveys were utilized to improve annual forecasts of mature escapement into Kamchatka and Sakhalin Rivers (Erokhin 2006, 2007; Shuntov et al. 2007a, 2008; Shuntov and Temnykh 2006, 2010). This was possible through two steps: estimation of overall abundance of juvenile salmon in offshore waters of Okhotsk and Bering Seas and discrimination of major groups of stocks from mixture marine juvenile salmon aggregations based upon scale pattern analysis.

2. ANADROMOUS STOCKS IN THE BERING SEA ECOSYSTEM (BASIS)

Russian BASIS-I and BASIS-II research programs are continuation of the TINRO-Center’s and KamchatNIRO’s research programs of 1980^{th} and 90^{th} in the western Bering Sea. The main components of the Russian BASIS Program are: the status and role of Pacific salmon in the nekton community of the Bering Sea; the influence of abiotic and biotic factors on spatial distribution and production of Pacific salmon stocks; Pacific salmon trophic interactions in nekton communities; Pacific salmon differentiation and population structure; carrying capacity of the Bering Sea for Pacific salmon and causes of its dynamics.

The surveys by RV TINRO were carried out in the fall of 2006-2009 (4 surveys) and in the summer of 2007 and 2009 in the western Bering Sea (Russian EEZ) and adjacent Pacific waters off eastern Kamchatka. Each of the trawl tow was accompanied by plankton, trophic and oceanographic observations.

2.1. Seasonal distribution and migration route/timing of juvenile salmon

Long-time data of distribution, migration and dynamic of maturing and immature Pacific salmon were summarized based on the large-scale surveys in the Bering, Okhotsk, Japan Seas and adjacent waters. Generalize schemes of quantitative distribution of Pacific salmon were represented (Shuntov et. al 2010a). The highest concentrations of immature salmon occurred in the western Bering Sea. Like the southern Okhotsk Sea for juvenile salmon, Bering Sea is the main forage area for adult Pacific salmon.

Archival data of gill-net cruises of research vessels of KamchatNIRO, TINRO-Center, SachNIRO, MagadanNIRO and VNIRO were analyzed (Bugaev 2010). Principle scheme of monthly redistribution of maturing Pacific salmon during the period of their intense prespawning migrations (May-August) in the EEZ of Russia were obtained.

2.2. Modern status of salmon in upper epipelagic nekton communities of the western Bering sea.

In 2006-2009, the abundance of many Russian stocks of Pacific salmon increased. By the data of TINRO-Center surveys, very high runs of anadromous pink salmon occurred in the Bering Sea in summer 2009. Pink salmon biomass was estimated at 400 th. t. It is 4 times higher compared to previous years (Glebov et al. 2009a,b; Shuntov and Temnykh 2009)..

Marine surveys results are confirmed by data of total coastal catch of Pacific salmon in the Russian Far East. In 2006-2009, total catch varied from 253 to 542 th. t with an average of about 167 th. t for the last 40 years (Rassadnikov 2009). Pink and chum salmon dominated the catches, and both species tended to increase in abundance. Positive relation of pink salmon catch and ocean heat content was shown (Radchenko et al. 2007; Radchenko 2008).

Decrease of immature salmon abundance in the western Bering Sea occurred after 2006. In fall 2007-2009, biomass of immature chum, sockeye and chinook salmon was estimated at 105-280, 47-94 and 4-6 th. t, correspondingly. In 2002, 2003 and 2006, it was 2-4 times higher: 246-343, 91-178 and 12-25 th. t, correspondingly (Temnykh et al. 2007; Glebov et al. 2008a, 2009a,b). Decreasing of Pacific salmon abundance in the western Bering Sea may be due to a changes in the productivity of some stocks (mainly, American salmon stocks) or (and) restrict migration to the western part of the sea. Spatial distribution of Pacific salmon in the western Bering Sea was similar to the previous years (Glebov et al. 2006, 2008a, 2009a,b; Zavolokina, Zavolokin 2007; Shuntov et al. 2010a). Pink salmon tends to distribute more widely to the north during anadromous migration in 2000th compared with 1990th (Temnykh and Kurenkova 2007).

2.2. Stock identification

Stock identification studies of Pacific salmon in the mixed aggregations in the western Bering Sea were continued (Bugaev et al. 2008, 2009a,b,c; Bugaev and Myers 2009a,b; Bugaev et al. 2009a,b; Shaporev et al. 2007). Russian stocks provide 64 % of chum salmon in the fall 2004 and 69 % in the fall 2006. The share of Japanese stocks was 27 % in the fall 2004 and 28 % in the fall 2006. The portion of American stocks was the least in both years: 9 % in 2004 and 4 % in 2006. Bristol Bay complex of sockeye salmon stocks dominated (55 %) the sockeye salmon in the western Bering Sea in fall 2006. The most abundant among the Asian stocks were the fishes from the rivers Kamchatka (15 %) and Ozernaya (14 %) (Bugaev et al. 2009b).

2.3. Salmon growth and carrying capacity of the North Pacific

Average body weight of all Pacific salmon species in different regions has a large variability during last decades. So, average body weight of chum salmon decreased in the most reproduction regions excluding Primorye (Karpenko et al. 2009; Zavolokin et al. 2009; Shuntov et al. 2010d). Analysis of long-term dynamic of Asian pink salmon size showed that the most stocks tended to increase in body length and weight from 1980th to 2000th (Temnykh 2009; Karpenko et al. 2009; Shuntov et al. 2010d). There were only some cases of pink salmon body size decrease, related most probably density-dependence fish interactions (Shuntov et al. 2010d). Particularly, size reduction occurred for super-abundant generation of pink salmon of East Kamchatka region in 2008. In some publications (Karpenko et al. 2006, Koval 2007, 2009) the argument on density-dependence salmon growth is based on the analysis of diet changes without the involvement of quantitative data on food resources.

Studies of annual changes in body size and growth of Anadyr chum salmon in 1962-2007 showed that fork length, weight, and growth during the second, third and fourth years of chum salmon significantly decreased from 1960s to 1990s (Zavolokin et al. 2008; Zavolokin et al. 2009). There was a significant negative correlation between annual total catches of Pacific salmon and size of Anadyr chum salmon. But increasing of Anadyr chum salmon body length and weight from 1990s to 2000s (during high total Pacific salmon abundance) testifies that salmon growth depend on several factors, and fish a abundance does not limit strongly the salmon productivity.

Change of biological characteristics and mortality of salmons for the period of their high abundance are discussed from positions of the North Pacific carrying capacity (Shuntov and Temnykh 2008 a,c, Shuntov et al. 2010 a-d). Interannual changing in food supply may affect to some biological features (e.g. body size or growth rate), but it does not lead to significant increase of Pacific salmon mortality. According point of view these authors, in some previous and last publications, the biomass and production of zooplankton are underestimated.

The food reserve is high in the Bering , Okhotsk Seas and North Pacific Ocean. . This opinion is based on long-term data of marine research expeditions. The scale of salmon aquaculture and the amount of food consumed by salmon species in general are much lower than the capacity of pelagic ecosystems and even separate trophic levels and their components. Though salmon species consume large amount of food, especially during periods of high abundance, their role in trophic chains is far from being highly important. Even two- or three-fold variations in Pacific salmon abundance will hardly lead to significant changes in the structure of nekton communities. A number of observations support the idea that salmon stocks are below the North Pacific carrying capacity, and that salmon do not overpopulate epipelagic ecosystems. Therefore, amount of salmon industrial factories in the Russian Far East may be considerably increased. (Shuntov and Temnykh 2008a, Shuntov et al. 2010a-d).

2.4. Mortality

Based on the annual fall and summer surveys of TINRO-Center and data of salmon runs (coastal catch + escapement), pink salmon mortality during sea life was estimated. In 1989-2006, mortality of pink salmon of Okhotsk Sea region during ocean life varied mostly from 60 to 80 % (Radchenko 2007; Temnykh and Kurenkova 2007). In 2008-2009, despite of very high Asian pink salmon abundance, mortality in the ocean was somewhat below the average. It was about 63 % for Bering Sea stocks and about 55-60 % for Okhotsk Sea stocks (Shuntov and Temnykh 2009).

Factor affecting salmon mortality during sea life (predators, parasites, deseases) were studied. Potential trophic interactions between Pacific salmon and their predators (Alepisaurus ferox, Anotopterus nikparini, Lamna ditropis, Lampetra tridentata, Somniosus pacificus, Squalus acantias) during marine life period were analyzed (Sviridov et al. 2007). Differences in predator abundance were noted among large-scale (Bering, Okhotsk, Japan seas and adjacent waters of North Pacific) and small-scale units (shelf, continental slope, and deep-water basins; epipelagic and mesopelagic layers). It was shown that the rate of occurrence of Pacific salmon injuries was species-, age—and region specific. Special distribution of injuried salmon was not good indicator of special allocation of predators.

Statistics on the sea lice invasion in Pacific Salmon in the Bering Sea and Pacific Ocean waters adjacent Kamchatka in summer-fall on the data from drift net catches in 2004–2005 are demonstrated (Bugaev 2009). Invasions of the most abundant species of Pacific Salmon (pink, chum and sockeye salmons) correlated to their abundance in the Asian part of distribution. Pink salmon had 43–63%, chum salmon 21–32% and sockeye salmon 3–10% of infected individuals.

Descriptive model of the infectious hematopoietic necrosis virus distribution in a sockeye salmon population was developed (Rudakova et al. 2007; Rudakova 2008). This model allowed to reveal three critical moments of infectious process, important for understanding of virus distribution and its influence on population. Estimation of health and pathomorphological changes of juvenile salmon was performed (Gavruseva 2007)

Study of influence of parasitic infection on salmon mortality in the ocean during winter and spring seasons was begun (Shvetsova et al. 2009).

2.5. Forage base and feeding habits of Pacific salmon

In the western Bering Sea, zooplankton composition and abundance were relatively stable in 2006-2009. Zooplankton biomass in the epipelagic layer (0-200 m) of deep-water regions varied from 550 to 650 mg/m^3, and macroplankton biomass was at about 500-600 mg/m^3. Copepods and chaetognaths dominated the macroplankton biomass (Volkov et al. 2007a; Shuntov et al. 2010b).

In the eastern Bering Sea, plankton structure varied strongly. In 2003-2005, zooplankton biomass was relatively low (< 500 mg/m^3). It was dominated by small and medium fraction of zooplankton. Biomass of large fraction (macroplankton) was low (Volkov et al. 2007a). In 2006-2009, biomass of large fraction of zooplankton (copepods, chaetognaths, euphausiids, amphipods) and total zooplankton biomass increased significantly. So, zooplankton structure and abundance of eastern Bering Sea became similar to the western part of sea (Volkov et al. 2009a,b). Last years (2008 and 2009), biomass of hiperiid *Themisto libellula* increased greatly in the eastern Bering Sea. This plankton species inhabit north regions, and increase of it biomass may be related to the change in water circulation in the Bering Sea (Volkov et al. 2009a)

In the western Bering Sea, Pacific salmon feeding did not changed significantly. In 2006-2009, most of diet (in average 30-60 %) of chum, sockeye and pink salmon comprised amphipods and euphausiids. Large-size salmon prey also micronekton (up to 30-40 %). Coho and chinook salmon feeding dominated fish and squids (80-90 %) (Naydenko 2007; Volkov et al. 2007b). In the eastern Bering Sea, changes in forage base influence to salmon feeding. In 2006-2009, the share of micronekton in their diet decreased and the share of macroplankton (euphausiids, amphipods, decapods larvae) increased (Kuznetsova et al 2007, 2008; Volkov et al. 2009b; Zavolokin et al. 2009b).

Trophic structure of the epipelagic layer of the Bering sea and adjacent Pacific waters was studied. The contribution of Pacific salmon to the consumption of forage resources in all investigated areas is not significant and changes from only 0.2 to 2.4% of total zooplankton biomass. It follows that the recent increase in Pacific salmon abundance is unlikely to cause serious shifts in the trophic structure of the upper pelagic zone of the Far Eastern Seas (Naydenko 2009; Shuntov et al. 2010d).

3. ANADROMOUS STOCKS IN THE WESTERN SUBARCTIC GYRE AND GULF OF ALASKA ECOSYSTEMS

According to Russian salmon research program on 2006-2010, studies in the Western Subarctic Gyre region were planed. The main purpose of these studies was to research the role of Pacific salmon in ecosystems of Subarctic Gyre region. The important applied result of surveys in this region was the estimation of Pacific salmon abundance (first of all, pink salmon) during some stages of their life cycle (catadromous migrations, wintering, beginning of anadromous migrations) and forecast their runs to different spawning regions. In 2006-2010, 2 surveys in winter and 4 surveys in summer were conducted in central and western parts of North Pacific Ocean.

The new data about quantitative distribution of Pacific salmon were received. In particular, significant salmon concentrations were occurred in the western part of Subarctic Gyre region. This area is considered to be less favorable for salmon wintering because of high gradients of surface temperature. The conclusion about eurythermal distribution of Pacific salmon (Shuntov Temnykh 2008) was confirmed. High salmon abundance occurred in areas with low surface temperature (1-3^{o}C). This temperature is considered to be unfavorable for salmon.

Data on the vertical distribution of salmon were obtained as a result of trawling in different water layers (30-90 m). In winter, salmon have habited in deeper layers of water as compared with summer period (Starovoytov et al. 2010a,b). It may be due to increasing of thickness of the upper quasihomogeneous water layer in the winter period (up to 160-180 m).

Share of salmon in total nekton biomass was 61% and 58% respectively in the central and western parts of Subarctic Gyre (Starovoytov et. al., 2009). But the share of salmon in nektonic communities was small - about 18% and 38% from total nekton biomass respectively in the central and western parts of investigated area. Squids (Watasenia scintillans and Gonatopsis borealis) were more abundant in the central part of Subarctic Gyre. Gonatopsis borealis and Mictophidae - in the western part.

In the central part of North Pacific Ocean, the salmon abundance was lower than in the western part. Most likely, in February-March, when the survey was conducted in the central part of the subarctic front zone, most of salmon have not yet migrated from adjacent waters of Aleutian Islands. For the same reason, the pink salmon abundance in this area (76 mln. sp.), in which the western Bering Sea' pink populations are more abundant during this period, was significantly lower compared to abundance of this stock in western Bering Sea in autumn 2008 (1300 mln. sp.).

The pink salmon abundance of Okhotsk Sea' stocks in the western part of North Pacific Ocean was only 30% lower than in the southern Okhotsk Sea in autumn. Perhaps, low mortality of pink salmon of this generation in winter relates to favorable habitat conditions. In particular, the low number of pelagic fish predators was noted in the central and western parts of Subarctic Gyre in winter. It suggests low marine mortality of salmon due to fish predation.

The zooplankton biomass in epipelagical layer (0-200 m) was 310 mg/m^3 in the central part and 630 mg/m^3 in the western part of North Pacific Ocean. The forage resources were sufficient for salmon feeding in winter-spring period. High index of salmon' stomach filling and selective feeding on euphausiids, hyperiids, and pteropods may indicate a sufficient abundance of forage in areas of winter habitat (Naydenko et. al. 2010).

In summer (June – early July) 2006-2009, 4 surveys in the upper epipelagic layer of Pacific waters off Kuril Islands were conducted. The results of the quantitative distribution of salmon catches, as well as information on biological characteristics of fish (body size, maturity, sex ratio) were used for operational forecasting of pink salmon runs to the major areas of reproduction on the Kamchatka Peninsula and Sakhalin region (Shuntov et al. 2007a, 2008; Shuntov and Temnykh 2006, 2010; Radchenko et al 2009).

Composition and biomass of nekton and plankton communities were studied. Pacific salmon biomass comprised about 30 % of the total nekton biomass (Baytalyuk et al. 2007; Glebov et al. 2008b, Temnykh 2008). Mesopelagic fish and squids dominated the abundance and biomass of nekton community in Pacific waters off Kuril Islands, excepting 2009.

Long-term data on seasonal and interannual dynamics of plankton in Far Eastern seas, including areas of North-western Pacific Ocean, were summarized. In general, the plankton relative biomass in this region stay on lower level compared to Okhotsk and Bering Seas (Shuntov 2001). However, in 2000th biomass of plankton (as well as macroplankton – the main salmon prey) increased in this region as in winter and in summer (Shuntov et al 2010b).

Despite of the seasonal decline of plankton concentrations from summer to winter period, plankton biomass in winter and spring in North-western Pacific Ocean still remains high (in average more than 300 mg/m^3) (Volkov 2008a,b; Shuntov et al 2010b). Our estimates of zooplankton biomass are in order of magnitude higher than those of Japanese researchers (Nagasawa 1999). Biomass of small-size nekton (supplement component of salmon forage base) in this area are several times higher than in the deep-water regions of Okhotsk and Bering seas (Shuntov and Temnykh 2007; Shuntov et al. 2010b).

These data, as well as the results of study of fish feeding interactions (Naydenko 2008; Shuntov et al. 2010c), indicate favorable feeding conditions for Pacific salmon during their anadromous migrations. At a historically high abundance of Okhotsk Sea' stocks foraging in this area in spring-summer period, there was no strong effect of density factor on the production parameters of pink salmon (Temnykh 2009; Shuntov et al 2010d).

Future Salmon Research

Russian studies of salmon in 2010-2014 will be conducted in accordance with the 5-year multi-disciplinary Pacific Salmon Research Program of Scientific Technical Association "TINRO" (Shuntov 2010). Some questions identified in the NPAFC Science Plan have been resolved in cooperation with scientists of Japan , Korea, Canada and the United States .

1. Salmon in the North Pacific ecosystems

Large-scale ecosystem monitoring during marine and oceanic life of salmon is the base for the North Pacific currying capacity investigations. Except salmon, these observations also enable to gather valuable information about distribution and abundance of the entire upper epipelagic nekton (pelagic fish and squid, early ontogenetic stages of bottom fish) and plankton. These studies keep track of annual dynamics and structural rearrangements in pelagic communities, where salmon are only one of numerous components. When these studies are conducted together with large-scale trophologic investigations, reliable information is collected about feeding relationships of salmon in fish communities and on how predators influence salmon abundance.

To clarify status of salmon in the North Pacific ecosystem, we focus the following research items :

a) season and long-term dynamics of content and structure of pelagic nekton communities in different regions of the North Pacific in which salmon are one of the component,

b) season and long-term dynamics of content and structure of plankton communities,

c) salmon in trophic structure of pelagic nekton communities;

d) carrying capacity of the epipelagic layer of North Pacific for Pacific salmon, the causes of temporal changes in salmon carrying capacity.

Studies in this direction make it possible to understand how changes in pelagic community's structure affect on migration, mortality, growth, production of salmon during marine period of life.

(This issue partly overlaps with the some items of the program FUTURE (PICES))

2. BASIS-II

The Bering sea is very important feeding area for the most American and Asian salmon stocks. Continuation of investigation in frame of program BASIS-II (NPAFC Doc. 1164) make it possible to continue the time series of biological and oceanographic data to focus on how climate change and cycles affect the Bering Sea ecosystem.

Realization of these issues is possible only if **the large-scale ecosystem monitoring of Okhotsk, Bering seas and adjacent Pacific water** will be continued.

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