# Present State of Asian Coho Salmon (*Oncorhynchus kisutch*) Stocks

**V.I. Radchenko** and **I.I. Glebov**
Pacific Scientific Research Fisheries Center (TINRO-center)
4, Shevchenko Alley, Vladivostok, 690600, Russia

Radchenko, V.I., and I.I. Glebov. 2000. Present state of Asian coho salmon (*Oncorhynchus kisutch*) stocks. N. Pac. Anadr. Fish Comm. Bull. No. 2: 145–154.

Keywords: Coho salmon, migration pattern, stock assessment

**Abstract:** Data from pelagic trawl surveys by TINRO-center from 1987 to 1996 in the Okhotsk Sea indicate that coho abundance is underestimated by coastal observations. The approximate Asian coho spawning biomass is 7,300–16,000 tons for the 1990s. Ways of improving Asian coho salmon resource management are discussed. Collection of precise fishery and escapement statistics must be expanded in areas previously considered as non-traditional for coho. More attention must be paid to protection of coho spawning grounds from illegal fishing. Spawning stock abundance estimates must be substantiated by marine survey results. If Asian coho reproduction can be successful throughout the area around the Russian Far East, an artificial rearing program is highly recommended, which would not likely be detrimental to wild populations.

## INTRODUCTION

Integrated studies of pelagic ecosystems have been conducted by the TINRO-center in far-eastern seas since 1984 until the present. This program has collected a significant database on common plankton and nekton species biology and ecology. The trophic structure of planktonic and nektonic communities has been examined, and some regulations and trends of community structure dynamics were found for recent years (Shuntov et al. 1997). The program on Pacific salmon sea life studies was conducted as a part of this integrated project in 1991–1995. Its next stage is from 1996–2001. Findings of this program added to and fundamentally changed some previous understandings on seasonal distribution, diet ration and feeding habits of Pacific salmon, and their role in pelagic ecosystems (Shuntov and Chigirinsky 1995). For all salmon species, seasonal and inter-annual abundance dynamics were estimated, the whole spectrum of prey organisms was assessed, and stock differentiation studies were executed by different methods.

Pink salmon (*Oncorhynchus gorbuscha*) migration patterns were analyzed and described for Asian stocks by Shuntov (1994). A significant part of the local pink salmon stocks was discovered to be overwintering in the Okhotsk Sea during January–March (Radchenko et al. 1991, 1997a). From an analysis of collected samples, the scleritogramm method was developed for differentiation of the Sakhalin and western Kamchatka regional stocks (Temnykh 1996; Temnykh et al. 1997). Natural mortality rates of pink salmon at sea during the 1990s were estimated for the Okhotsk Sea populations (Radchenko 1998). The possibility of large-scale re-distributions of anadromous pink salmon aggregations between spawning areas was shown (as an example in 1993) (Shuntov 1994; Shuntov et al. 1995). This supports Glubokovsky's (1995) hypothesis on pink salmon population organization by the fluctuating stock principle, which regards such re-distributions as an important mechanism of genetic information exchange between pink salmon populations.

Migration patterns have also been described for chum salmon (*O. keta*). In particular, size group segregation of chum salmon has been found for feeding aggregations in the Bering Sea (Shuntov 1989a, b; Sobolevsky et al. 1994). It was noted that chum feeding aggregations usually appeared in areas of downwelling (anticyclonic eddies, flow convergency zones, etc.) (Radchenko and Chigirinsky 1995). Other data support previous hypotheses that maturing chum spent some time in near-bottom layers in the shelf zone (Radchenko and Glebov 1998), where their diet composition significantly changed.

The ecology of sockeye salmon (*O. nerka*), which feed and migrate in the Bering Sea, was described by Radchenko (1994). Sockeye aggregations adhere to well-stratified waters during their feeding migration. The prevalence of inter-zonal zooplankton and micronecton species in the sockeye diet



All correspondence should be addressed to V.I. Radchenko.
e-mail: vlrad@tinro.sakhalin.ru

(Chuchukalo et al. 1994) indicated the sockeye salmon's probable preference for feeding in the thermocline zone. It was also found that immature sockeye use an insignificant part of the Okhotsk Sea area for their feeding migration (Radchenko et al. 1997b). Average natural mortality and growth rates at sea were estimated for sockeye salmon belonging to the eastern Kamchatka stocks (Radchenko 1994).

For chinook salmon (*O. tschawytscha*), vertical segregation by size has been found for feeding aggregations in the western Bering Sea (Radchenko and Glebov 1998). Chinook in their second marine year mostly spend their feeding migration in the upper pelagic layer where they feed upon zooplankton and gonatid squid juveniles. Older chinook dwell near the bottom layers where they feed on adult squids. Accordingly, overwintering on the north-western Bering Sea shelf is possible for older chinook.

Unfortunately, the studies cited above do not deal with coho salmon (*O. kisutch*). Coho salmon were only mentioned in the annual surveys with respect to their late return to the spawning grounds. Fragmented information was usually collected on coho, and much of this information was not published. Relatively recent summaries of data on coho described the pattern and conditions of their migration in the far-eastern seas (Glebov and Rassadnikov 1997). Further analyses presented in this study resulted in some new findings, in particular the possible underestimation of coho abundance in stocks migrating to feed and returning to spawn along the far-eastern seas' coast.

## MATERIALS AND METHODS

Data on coho salmon distribution and biology were collected in the far-eastern seas and adjacent Pacific waters during integrated ecosystem expeditions in 1986–1996. Coho salmon were not abundant in our trawl survey catches due to their relatively low abundance, and their late and short migrations to spawning areas in comparison with pink, chum, and sockeye salmon. However, the data collected suggest that coho are widely distributed through the far-eastern seas—more widely than was previously thought. This also raised questions about estimates of coho salmon abundance in coastal areas.

Trawl surveys were conducted by research vessels of TINRO-center Fleet Base (Vladivostok, Russia). Vessels were middle tonnage trawlers. Hauls were executed by pelagic rope trawls, measuring roughly 108/528 m (trawl length on the topping lift/trawl mouth perimeter). The length of the wings was 32.6 m and the rope mesh size in the wings was 11 m. The conical part of the trawl (75.4 m) was made with nets with mesh size from 1,200 to 60 mm. The trawl bag (length 30–40 m) had a mesh size of 30 mm and a small-mesh insert 15 m long and mesh size of 6–12 mm. The width of the trawl mouth was about 50–55 m and the height 45–50 m. Thus, in 1 hour an area of 0.49 $km^2$ was swept at a tow speed of 5.0 knots (swept volume 0.023 $km^3$). The trawl hauls (typically one-hour duration) were conducted using a pre-established scheme of stations around the clock. The trawl surveys were concentrated in a 0–50 m layer, and the tow speed was kept relatively constant at 5 knots. Wire lengths, roughly reflecting distance from trawl mouth to vessel were 350–400 m. The upper trawl panel was kept at the sea surface.

Salmon biomass and numbers in the epipelagic layer were calculated by square method (Shuntov et al. 1988) such that

$$B(orN) = \frac{Sq}{sk} \qquad (1);$$

where B is fish biomass, N are numbers, S is survey area, q is average arithmetic catch over the whole survey area, s is the area swept in a one-hour haul, and k is a factor of trawl catchability. This factor (k) takes into account body size, form and mobility of fish, and their propensity to form schools. After long-term testing, the factor (k) has been estimated for different marine species, and for salmon was 0.3 (Shuntov et al. 1988, 1995).

Some data collected from Japanese commercial salmon fishery vessels were also used here to describe coho migration. These data were mostly collected in Pacific waters off the northern Kuril Islands and eastern Kamchatka in May–August of 1993–1998. Commercial salmon gill nets with mesh size 60–65 mm and a research net with mesh size 57.5 mm were deployed overnight usually for 12–14 hours. Net set length usually was 4 km, net height was 6 m.

## RESULTS

### Asian Coho Salmon Distribution and Migrations

Coho salmon are harvested along with other Pacific salmon species in coastal waters in the Russian Far East. They spawn in rivers around the southwestern Bering Sea, eastern and western Kamchatka, northern and western Okhotsk Sea, and the Sakhalin, Shantar and Hokkaido Islands. The main Asian populations of coho salmon spawn in the larger Kamchatka Peninsula rivers: the Kamchatka River (up to 70% of coho salmon harvested on the eastern Kamchatka coast) and Bolshaya River (up to 40% harvested on the western coast). The Okhota River coho population occurs chiefly on the continental Okhotsk Sea coast. Wild coho stocks of the Sakhalin and the Bering Sea coast are at low abundance currently, and are not harvested commercially. Coho also hardly ever occurred in the northern Korea and Japan rivers (Zolotukhin 2000).

Coho, chinook, masu (*O. masou*) and sockeye salmon spend one to three years in freshwater, but coho, like pink salmon, spend only 1+ years at sea (Sandercock 1991). Coho aged 1.1+ predominate among spawners in the Kamchatka rivers (Gribanov 1948; Zorbidi 1975, 1993). Coho of the same age also predominate on the continental Okhotsk Sea coast, but in several rivers coho aged 2.1+ are slightly more numerous (Rogatnykh 1985). All spawner age groups occur in the Sakhalin rivers, but they are for the most part (more than 80%) aged 2.1+ (Zhulkov 1978). Coho salmon migrating through the Pacific waters off the northern Kuril Islands and entering the Okhotsk Sea through the northern straits of the Kuril Archipelago were aged 1.1+ to 2.1+ (Table 1). Coho salmon aged 3.1+ also occurred.

Juvenile coho aged 1.0+ and 2.0+ migrate from the inshore zone to the outer shelf and offshore over an extended period. The migration begins in July in the eastern Okhotsk Sea. The earliest catch of coho smolt (fork length 16 cm) occurred 16 July 1991 above the 200 m depth contour off northwestern Kamchatka (Fig. 1a). Coho juveniles have been sampled in the Okhotsk Sea from July to December. In October–November most juvenile coho left the Okhotsk Sea through the middle and northern straits of the Kuril Archipelago (Fig. 1b). In late November, almost all juvenile coho migrated in the Pacific waters off middle Kuril Islands (Fig. 1c). In the western Bering Sea, juvenile coho occurred from the second half of September to November, and in Pacific waters off Kamchatka up to late October–November (Fig. 2).

Coho salmon overwinter within the subarctic frontal zone, which is 4° latitude wide on average. This frontal zone defines the southern limit of the subarctic circulation. The subarctic halocline, which provides the stratification between the mixed layer and the underlying ocean, emerges there near the sea surface. The associated temperature front is an important salmon boundary. Coho demonstrate the most southern distribution among salmon species during winter. Optimal water temperature was approximately 9–10°C for coho salmon feeding in winter (Glebov and Rassadnikov 1997).

**Table 1.** Average fork length (fl, cm) and body weight (kg) of different coho age groups in Pacific waters off the northern Kuril Islands (fishery region 3) and in the Okhotsk Sea near the western Kamchatka coast (fishery region 4), June 18–July 21, 1995.

| Region | Age groups | Fork length (cm) | | Weight (kg) | | Fish numbers | Sample* numbers |
|---|---|---|---|---|---|---|---|
| | | Range | Mean±δ | Range | Mean±δ | | |
| 3 | 1.1+ | 47–66 | 57.9±0.34 | 1.7–3.6 | 2.54±0.05 | 94 | 17 |
| | 2.1+ | 48–66 | 58.3±0.35 | 1.8–3.8 | 2.61±0.05 | 78 | 17 |
| | 3.1+ | 59–61 | 60.0 | 2.4–2.8 | 2.60 | 2 | 2 |
| 4 | 1.1+ | 54–59 | 56.9±0.55 | 2.25–2.8 | 2.55±0.06 | 11 | 2 |
| | 2.1+ | 54–64 | 58.4±0.75 | 2.0–3.45 | 2.72±0.11 | 14 | 2 |

*One sample includes fish collected from driftnet fishery.

**Fig. 1.** Seasonal juvenile coho catch distribution in the Okhotsk Sea and adjacent Pacific waters in: a) July–August, 1991–1996. (1 July; 2 early; 3 mid; 4 late August). Russian EEZ in the Pacific ocean and some place-names are indicated in the inset; b) September–October, 1991–1996 (1 mid September; 2 late September; 3 early October; 4 mid October; 5 late October); and c) November, 1986–1994 (1 early; 2 mid; 3 late). Crosses, fishing but no catch.

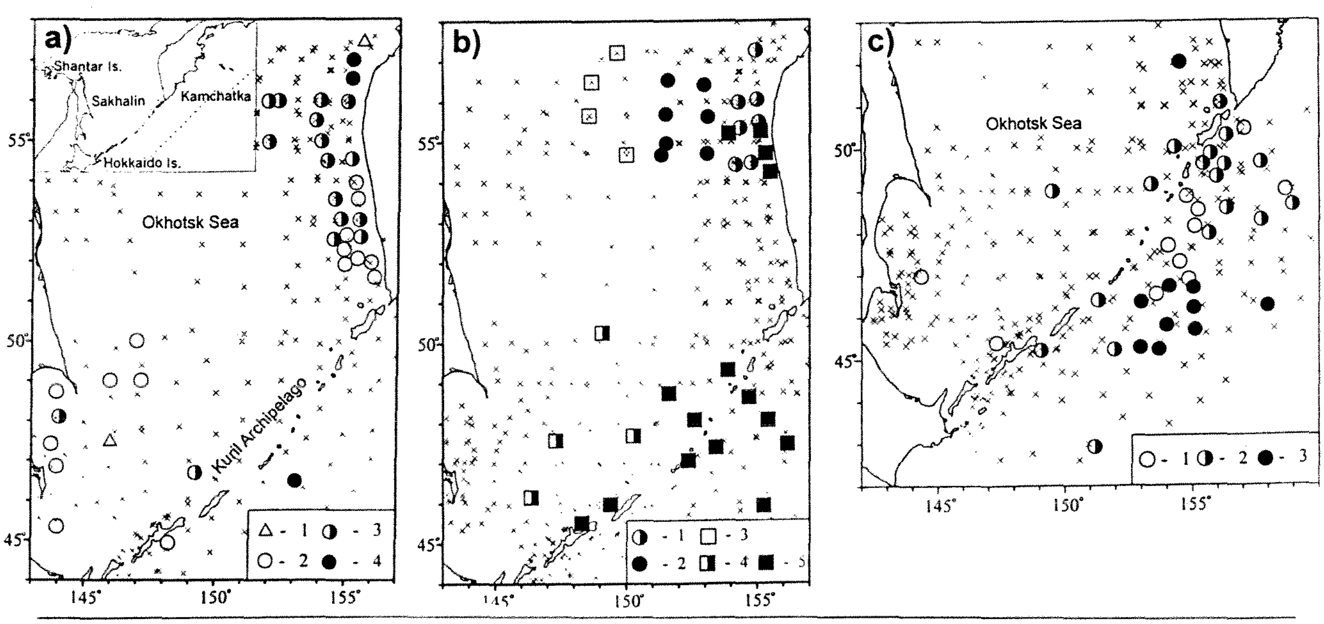
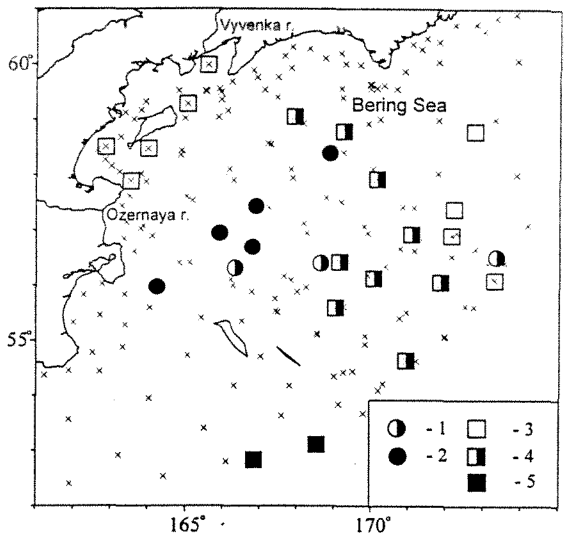


**Fig. 2.** Seasonal juvenile coho catch distribution in the southwestern Bering Sea September–October 1986–1994. (1 mid September; 2 late September; 3 early October; 4 mid October; 5 late October). Crosses, fishing but no catch.




Most chum, sockeye, and chinook salmon feeding in Russian waters were immature. Unlike these species, coho migrated later and over a brief period from the wintering localities to inshore areas near natal rivers through the Russian exclusive economic zone (EEZ). In the 1990s, the earliest seasonal coho catch was from salmon driftnet fishing in the area 50°10' N 160°55' E on 12 June 1998. Coho aged 1.1+ and 2.1+ occurred there, in Pacific waters off the northern Kuril Islands, and began to enter the Okhotsk Sea from the second week of June (Figs. 3, 4). In July, coho occurred northward up to 55° N along the western Kamchatka coast and up to 51° N near Sakhalin and in the central Okhotsk Sea. In August, coho migration continued through the middle and northern Kuril Archipelago straits. Two migration routes are available in the Okhotsk Sea, a northern and southern route (Fig. 5). The percentage of coho migrating through each pathway varied each year. Coho distribution density increased on the western Kamchatka shelf (trawl survey catches increased to 12 fish per one-hour haul) and reached 57° N in August. Most of the migration through the Kuril Archipelago straits finished by late August.

In the western Bering Sea, the earliest catch of coho salmon (54–64 cm) was 30 June 1993, by trawl. In July, coho salmon reached the Kamchatka coastal waters but still occurred in the offshore Bering Sea until the third week of October. In the Pacific waters off eastern Kamchatka, coho first appeared in abundance in early July. At this time, coho occurred near the Russian EEZ shore. Their migration also continued there until late October.

**Fig. 3.** Seasonal adult coho catch distribution in the Okhotsk Sea and adjacent Pacific waters in July, 1991–1996 (1 early; 2 mid; 3 late). Crosses, fishing but not catch.

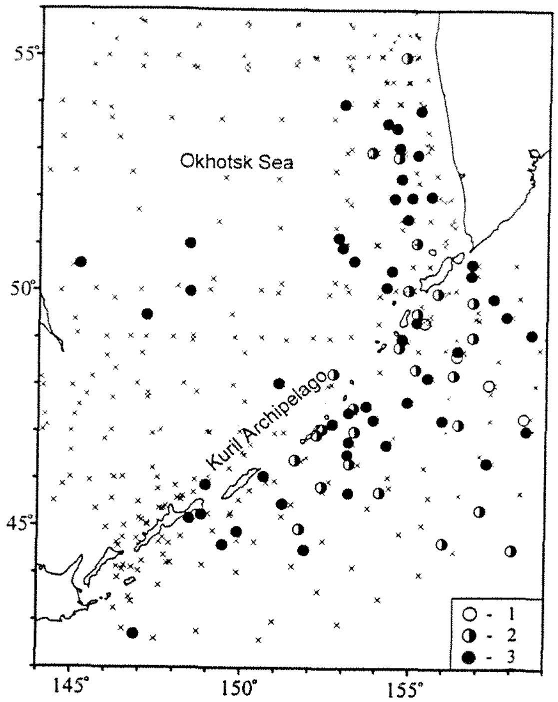



**Fig. 4.** Seasonal adult coho catch distribution in the Okhotsk Sea and adjacent Pacific waters in August, 1991–1996 (1 early; 2 mid; 3 late). Crosses, fishing but no catch.

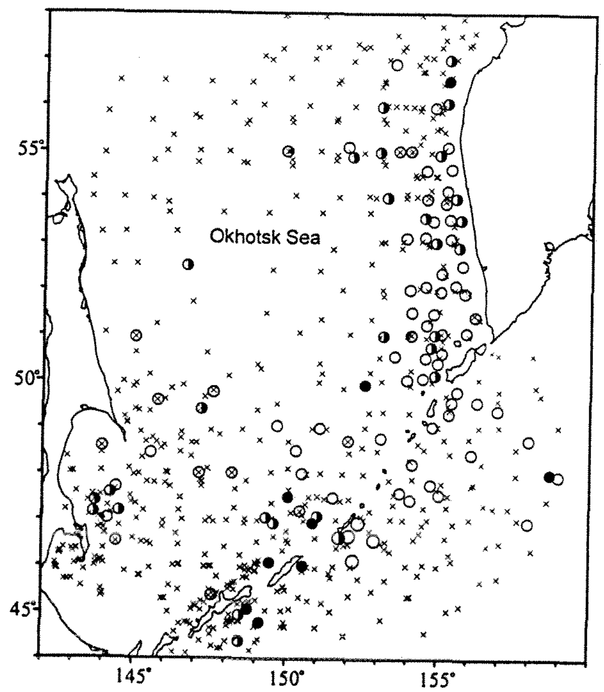


**Fig. 5.** Adult coho catch distribution in the Okhotsk Sea and adjacent Pacific waters a) 1992 and 1994, b) 1993 and 1995. Kamchatkan rivers: 1 Icha; 2 Krutogorova; 3 Kikhchik; 4 Bolshaya; 5 Nalycheva; 6 Zhupanova; 7 Kamchatka. Crosses, fishing but no catch.

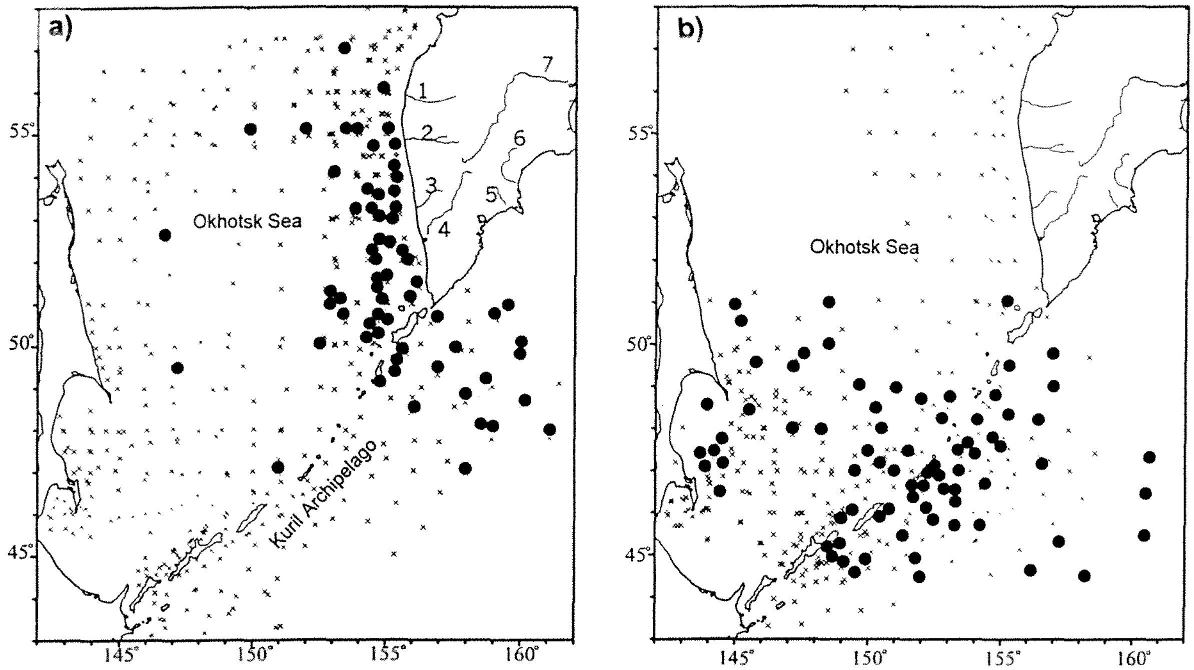
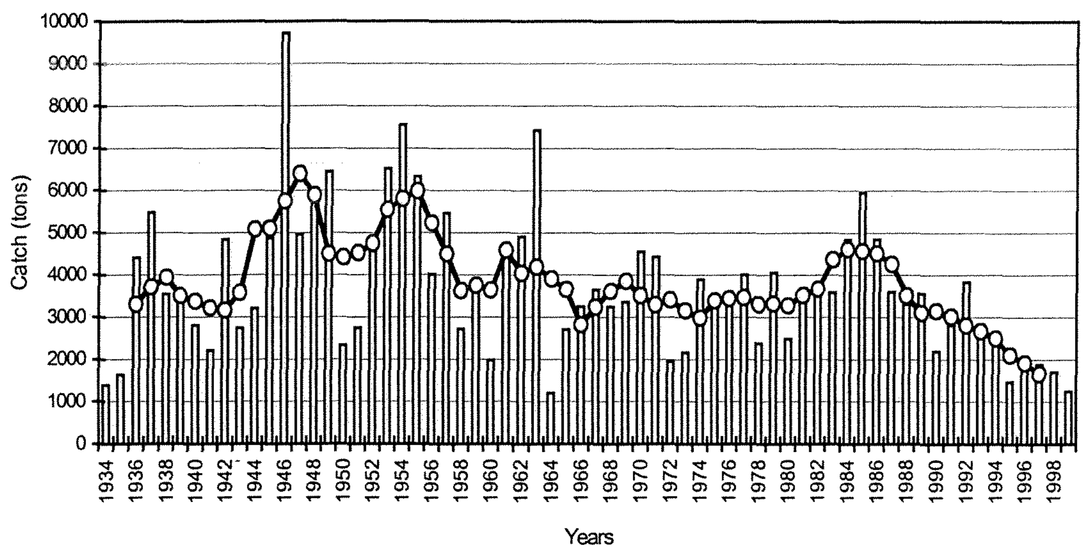



**Fig. 6.** Coho salmon catch in the Russian Far East (Eastern and western Kamchatka and the Okhotsk Sea continental coast), 1934–1999. Solid line indicates 5-years moving average.




## Coho Salmon Fishery and Stock Assessments

During the last 20 years, coastal catches of coho salmon varied from 1,476 metric tonnes (t) in 1995 to 5,993 t in 1985, with an average annual catch of 3,224 t (Fig. 6). In the second half of the 1940s–1950s, the coho salmon harvest exceeded 4,000 t, as a rule. Then, in the 1960s to early 1980s, it varied usually between 3,000 and 4,000 t. In the 1980s, Russian coho catch grew to nearly 6,000 t in 1985, and then began to decrease gradually. In the second half of the 1990s, coho coastal catch exceeded 2,000 t in 1997 only. In addition, the foreign fleet caught 580 to 710 t of Asian coho at sea. However, the driftnet fishery alone could not explain the decrease in coastal coho catch. The coho catch at sea totalled only 35 and 234 t in the first years of the decrease in coastal catch, 1994 and 1995 (Table 2).

**Table 2.** Foreign fishery fleet Pacific salmon catches in the Russian Exclusive Economic Zone, 1993–1998.

| Year | Pink | Chum | Sockeye | Coho | Chinook | Masu | Total |
|---|---|---|---|---|---|---|---|
| 1993 | 4948 | 8597 | 7705 | 187 | 419 | 0 | 21856 |
| 1994 | 797 | 14264 | 3670 | 35 | 187 | 0 | 18953 |
| 1995 | 3008 | 18796 | 6146 | 234 | 126 | 8 | 28318 |
| 1996 | 900 | 14710 | 5644 | 628 | 159 | 1 | 22042 |
| 1997 | 1857 | 13488 | 9150 | 579 | 462 | 1 | 25537 |
| 1998 | 918 | 12013 | 2645 | 709 | 329 | 3 | 16617 |

In 1979–1984, the average number of coho spawners was estimated by the KamchatNIRO scientists at 0.26–0.43 million fish in the main part of the spawning area on the western coast of the Kamchatka Peninsula, southward from Icha River (Nepomnyaschi 1985; Yanovskaya et al. 1989). Zorbidi (1993) estimated the coho spawning stock to be 0.3 to 1.25 million fish over the whole western Kamchatka coast between 1986 and 1993. Coho spawning biomass was estimated as 1,000–4,000 t, combined catch and escapement, with a mean individual weight of 3.19 kg. On the continental Okhotsk Sea coast, coho spawning numbers were estimated to be 0.16–0.43 million fish, or 650–1,760 t in 1980–1985 (Rogatnykh 1985). A high abundance of coho salmon occurred in the continental Okhotsk Sea coast in 1992 and 1993 (at the same time as the high pink salmon catch). In 1992, the coho salmon harvest reached 446 t in that area. In 1993, coho abundance was estimated at 580,000 fish (about 2,400 t), from which 774 t were caught. Therefore, according to coastal survey data, anadromous coho abundance totaled 1,500–5,400 t in the 1990s, and in 1992–1993 up to 6,400 t in the northern Okhotsk Sea (for this rough estimate, sums of minimum and maximum values were used).

If these coho abundance estimates (1,500–6,400 t) were correct, the Russian annual catch (569–1,987) in the Okhotsk Sea between 1990 and 1998 was notably less than allowable. In the 1950s–1960s, coastal catch averaged 27% in total anadromous coho abundance on the western Kamchatka. According to Zorbidi (1975), anadromous coho abundance was 0.62–5.0 million fish (average 2.1 million), or 2,140–17,250 t (average 7,250 t) there. Of course, coho abundance was undoubtedly higher in the 1950s–1960s, than in the 1990s. Average coho harvest was three times higher in that period on the western Kamchatka: 1,980 versus 640 t. If the same exploitation rate (27%) of coho salmon resources occurred for the 1990s, it would have implied an average abundance of coho stock on the western Kamchatka of about 2,400 t (640 t fish). This is less than the average estimated value for 1990–1998.

The eastern Kamchatka coho stock abundance was roughly assessed at 0.6–3.1 million fish (average 1.7 million), or 1,620–9,610 t (average 5,270 t) in 1950s–1960s (Zorbidi 1975). In 1984, about 0.54 million coho spawners were estimated in the Kamchatka River system, which includes the main coho spawning grounds on the east side of the peninsula (Nepomnyaschi 1985). This stock contributed 51% of the total coho spawner numbers estimated in the eastern Kamchatka region (except the Bering Sea coast). However, the Kamchatka River portion annually contributed up to 70% in coho salmon catch there. In 1993, this portion increased to 83.5% (Zorbidi 1993). This suggests that coho stocks from other rivers may be underexploited by the commercial fishery. Nevertheless, according to official statistics, the portion of coho catch from the total stock is incredibly high; in 1984, it reached 3,830 t, that was estimated to be 70.1% of catch plus escapement numbers (5,460 t) on the eastern Kamchatka.

Coho stocks on the Bering Sea coast are insignificant compared to those in the eastern Kamchatka. Coho catches in the Bering Sea are usually small during trawl surveys. In July of 1992, coho salmon biomass was estimated at about 12 t, and in July 1993, 26 t. According to official statistics of foreign driftnet fisheries, annual coho salmon catch does not exceed 1 t in the southwestern Bering Sea.

Trawl surveys of Pacific salmon at sea allow the estimation of oceanic stock abundance, in addition to coastal abundance estimates (Radchenko 1998). In mid July of 1991 and 1992, estimated coho biomass was relatively small at 160 and 1,600 t in the Okhotsk Sea. Later in 1992 (from July 28 to August 7), noticeable coho aggregations occurred eastward from the northern Kuril straits. During the R/V *Professor Levanidov* cruise, coho biomass in these aggregations was estimated at 12,200 t (5.28 million fish). Apparently, the pelagic survey in 1992 coincided with the coho migration that year. Later, from August 1–12, 1992, about 6,230 t, or 1.95 million t of coho were estimated in the area near western Kamchatka during another survey using the R/V *Professor Kaganovsky*. The two surveys overlapped by one week. Thus, it is possible that the same coho stock was only partly assessed on both surveys. Also, some of the coho caught eastward from the northern Kuril straits may have been fish belonging to the eastern Kamchatka stock migrating through this area to their own natal rivers. However, biomass of the eastern Kamchatka stocks did not likely exceed their average level (5,270 t). The total catch of the eastern Kamchatka coho appeared not to be higher in 1992 than the average for the previous five years (2,200 versus 2,266 t). It may be much less, since the eastern Kamchatka coho are fished in the coastal zone and begin entering rivers in July, far north of the R/V *Professor Levanidov's* survey area.

The possibility that part of the coho aggregations were assessed twice in adjacent areas in 1992 was examined assuming maturing coho migrate 50 miles/day. In this case, a double assessment appeared to be possible for approximately 2,300 t, if all the coho migrated to western Kamchatka. Of course, such unidirectional migration is unlikely. In late July–August 1993, coho biomass was estimated at 1,520 t in the central and western Okhotsk Sea, and in 1995 at 1,110 t. Despite this unreliable estimate, in 1992 the total biomass of coho migrating in the Okhotsk Sea could not have been less than 10,900 t (sum of both survey estimates minus a possible overestimate due to overlapping and potential eastern Kamchatka coho biomass: 12,200 + 6,230 – 2,300 – 5,270 = 10,900 t). Based on research recommendations, the quota for the coho salmon commercial fishery was increased from 500 to 1,500 t on the western Kamchatka. Coho harvest reached 1,226 t there, and 1,947 t for the whole Okhotsk Sea coast in 1992.

High coho abundance was also estimated in western Kamchatka waters in August 1996. During the pelagic trawl survey from August 5–21, 1996, coho biomass was estimated at 8,000 t. The coho portion of the total salmon biomass reached 7.1% there even though pink and chum salmon were migrating through that area (Radchenko et al. 1998). Note that adult coho could occur in the Okhotsk Sea until December (Rogatnykh 1985), although trawl catches were limited to July through August.

## DISCUSSION

Seasonal variability in coho abundance has been analyzed in the Okhotsk Sea. In early July 1991, coho biomass was estimated at 160 t in the survey area near western Kamchatka. At the end of July 1992, coho biomass was an order of magnitude higher at 1,600 t. In early August, it increased sharply and briefly in 1992 and 1996. After August, the biomass decreased again due to coho migrations into local rivers and northwards. In 1996, coho salmon coastal catch (645 t) was almost equal to the average catch for western Kamchatka in the 1990s: 640 t. The estimated level of coho salmon biomass at 8,000 t also seems close to the average, assuming average catch level. The estimated variance in biomass calculated for the survey data provided a range for the estimate of 6,300–9,700 t. These estimates were 1.5–4 times higher than values given by coastal observations, i.e. coho catch+escapement for the western Kamchatka in the 1990s (1,500–6,400 t) appeared to be too low in comparison with marine survey data.

The harvest rate for coho salmon was between 57.5–73.6% (average 63%) on the eastern Kamchatka coast in 1993–1997. For example, coho salmon spawning biomass totaled 1,601 t on the eastern Kamchatka, including a harvest at 1,085 t (0.45 million fish) and an escapement of 520 t (0.21 million fish) in 1997. As indicated above, this harvest rate appears too high and likely is incorrect. If a harvest rate of 63% was true for coho in the 1950s–1960s, coho spawning stock abundance on the eastern Kamchatka would be 1,110–4,510 t, or 0.36–1.45 million fish. Therefore, the average eastern Kamchatka coho stock abundance was 3,210 t, or 1.04 million fish in those years. This is notably less than the 5,270 t, or 1.7 million fish, of Zorbidi's (1975) estimates. The harvest rate of 38.9% obtained from anadromous coho biomass (Zorbidi 1975) seems more reliable. In the second half of the 1990s, the Kamchatka River coho stock declined, as reflected by a significant reduction in coho harvest. The average annual coho catch amounted to 1,356,200 t on the eastern Kamchatka in 1990–1998, or 60.1% of the salmon harvest in 1950–1969 (2,052,200 t). If the same percentage catch was assumed for the total anadromous run in the 1990s, coho spawning stock would be estimated at 1,070–6,350 t, (average 3,710 t) in eastern Kamchatka. There is no reason to presume that the coho harvest rate by the commercial fishery in the Soviet controlled economy was less than in the 1990s.

The main causes of the underestimation of coho abundance included an illegal fishery in river tributaries, in particular on the spawning grounds (S. Sinyakov, KamchatNIRO, Naberezhnaya 18, Petropavlovsk-Kamchatsky 683602, Russia, personal communication). In addition, small coho stocks were likely underestimated in rivers distant from densely populated regions. It should be noted that the coho run extends through the whole autumn, but beach and river seine fisheries are usually completed in September, seldom as late as October. A part of the coho stock, the so-called fall run, enters the rivers under ice (Gribanov 1948) and can not be utilized by the commercial fishery. The estimated biomass of fall run coho was 430–560 t (0.14–0.18 million fish) in the eastern Kamchatka in 1984 (Nepomnyaschi 1985). This late run was poorly covered by coastal observations in recent years.

In our opinion, coho salmon stocks are underexploited by the commercial fishery on the eastern Kamchatka, except for populations in the Kamchatka River and four other rivers: the Ozernaya River (not the well known river in western Kamchatka flowing from Kurilskoye Lake), and Vyvenka, Zhupanova, and Nalycheva rivers. These well exploited rivers and their fishing grounds are in the immediate vicinity of processing facilities and populated areas. However, the quota for the commercial coho fishery may be increased for active fishery grounds too, as was shown for the western Kamchatka region in 1992. In any case, strict protection of coho salmon spawning grounds from illegal fisheries must be ensured.

Juvenile coho population estimates from in-river monitoring support our suggestion on the total abundance of this species. In the Okhotsk Sea, coho juveniles occurred from August to November (Figs. 1, 2). The autumn trawl surveys rarely coincided with the migration time of juvenile coho, and its partial estimation was conducted only in the eastern Okhotsk Sea. In September–October 1994, juvenile coho numbers were estimated at 6.6 million fish (1,910 t) above the western Kamchatka shelf and in adjacent areas.

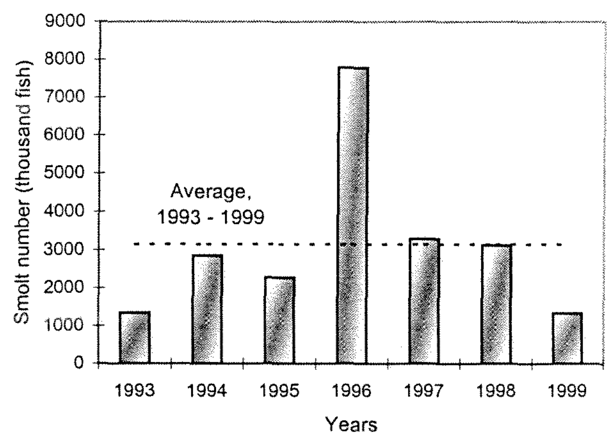
In 1996, the number of coho salmon smolts was estimated at 3.7 million fish from four rivers of the southwestern Kamchatka coast (two tributaries of the Bolshaya River, Bystraya and Klyutchevaya, and also Krutogorova and Kikhchik rivers). In 1997, coho outmigrant numbers were even higher (up to 5.1 million fish) from three monitored rivers, the Bystraya, Krutogorova, and Kikhchik. The total area of coho spawning grounds was assessed at 5–6 $km^2$. The Bystraya and Klyutchevaya rivers contribute only 0.47–0.52 $km^2$ (Ostroumov 1975, 1989). All spawning grounds were not utilized by coho in years of low stock abundance. Meanwhile, using data on coho spawning occurrence in the northwestern Kamchatka rivers, total juvenile coho abundance can be assessed to be at least 2.5 times higher than for monitored rivers (9.3–12.8 versus 3.7–5.1 million fish). If natural mortality rates for coho outmigrants are assumed to be 2% daily (Mathews and Buckley 1976; Karpenko 1998), the abundance of western Kamchatka juvenile coho stocks is 4.97–6.84 million fish 40 days after leaving freshwater.

According to the information above, abundance of the continental adult coho stocks in the northern Okhotsk Sea was assessed at 650–1,750 t from a total of 1,500–5,400 t in the whole Okhotsk Sea area, i.e. approximately 1.3–2 times less than the western Kamchatka stock abundance. If the ratio of juvenile to adult coho numbers is the same for these two regions, then approximately 2.49–5.26 million outmigrants must enter the Okhotsk Sea from the northern coast rivers. In this case, the total coho outmigrant abundance from wild stocks would be 7.46–12.1 million fish (1,110–1,810 t) in the Okhotsk Sea in summer. By October, the stock could decrease to 6.48–10.57 million fish. This estimation was consistent with the results from the autumn survey in 1994.

According to our estimate of coho spawning stock abundance in the Okhotsk Sea (1.97–3.04 million fish), coho salmon returns can be estimated at 28.8–30.4% of smolt output on average. This survival rate appears underestimated for salmon spending one year at sea. For example, pink salmon survival in the Okhotsk Sea was estimated at 25.2–61.6%, average 50% in the 1990s (Shuntov 1994; Radchenko 1998). This is consistent with our views on Asian coho salmon stock underestimation.

Besides wild stocks, 2.2–7.8 million coho smolts were annually released from the Sakhalin and northern Okhotsk Sea hatcheries in 1994–1998 (Fig. 7). Relatively low coho abundance at sea (in comparison with other salmon species) and its flexibility in food choice (wide spectrum of juvenile fish (Glebov

**Fig. 7.** Coho smolts released from Russian hatcheries, 1993–1998.




1998)) suggest a promising outlook for further development of hatchery production, of course, on a large scale, which would not be detrimental to wild populations. Juvenile coho are common in Sakhalin rivers (Gritsenko 1973), but this does not ensure high returns and catches. However, the progressive technology of hatcheries (release of fed juveniles, etc.) could change this situation and maintain coho abundance in the region at a significantly higher level.

## CONCLUSIONS

Asian coho stocks are underestimated. This has hindered the rational exploitation of this resource, and lead to an under-representation of its role in freshwater and marine ecosystems.

The pelagic survey employed for estimation of Pacific salmon abundance can provide data to clarify coastal observation results. These data should now be included in the monitoring system for salmon populations.

Further development of Asian coho hatcheries could increase coho abundance, harvest and importance in Russian Pacific salmon catches in the near future.

## ACKNOWLEDGEMENTS

This research was partially funded through the Russian Foundation of Fundamental Researches (RFFI) 99-04-48849. Two anonymous referees made helpful comments on the manuscript.

## REFERENCES

Chuchukalo, V.I., A.F. Volkov, A.Ya. Efimkin, and N.A. Kuznetsova. 1994. Feeding and daily diets of sockeye salmon (*Oncorhynchus nerka*) in summer. Izv. TINRO. 116: 122–127. (In Russian)

Glebov, I.I. 1998. Chinook and coho salmon feeding habits in the Far Eastern seas in the course of yearly migration cycle. (NPAFC Doc. 378) 57 p. Pacific Res. Fish. Centre (TINRO-Centre), Vladivostok, Russia.

Glebov, I.I., and O.A. Rassadnikov. 1997. Some features of coho salmon *Oncorhynchus kisutch* distribution in the north-western Pacific ocean in winter and spring seasons. Vopr. Ichthiologii 37: 558–562. (In Russian)

Glubokovsky, M.K. 1995. Evolutionary biology of salmonid fishes. Moscow, Nauka. (In Russian)

Gribanov, V.I. 1948. Coho salmon (*Oncorhynchus kisutch*, Walb) - biological description. Izv. TINRO 28: 45–101. (In Russian)

Gritsenko, O.F. 1973. Masu and coho salmon biology in the northern Sakhalin. Moscow, VNIRO. (In Russian)

Karpenko, V.I. 1998. Early marine life period of Pacific salmon. Moscow, VNIRO. (In Russian)

Mathews, S.B., and R. Buckley. 1976. Marine mortality of Puget Sound coho salmon (*Oncorhynchus kisutch*). J. Fish. Res. Board Can. 33: 1677–1684.

Nepomnyaschi, K.Yu. 1985. Distribution and abundance of coho spawners in spawning water reservoirs of the Kamchatka Peninsula. TINRO Sci. Rep. (Manuscript), Vladivostok, No. 19682. (In Russian)

Ostroumov, A.G. 1975. Aerovisual methods of Pacific salmon abundance estimation, classification and spawning significance of water reservoirs of the Kamchatka Peninsula and Koryak Plateau. TINRO Sci. Rep. (Manuscript), Vladivostok, No. 14804. (In Russian)

Ostroumov, A.G. 1989. Pacific salmon spawning grounds of the southwestern Kamchatka rivers (from the Bolshaya River to Kekhta River). TINRO Sci. Rep. (Manuscript), Vladivostok, No. 20801. (In Russian)

Radchenko, V.I. 1994. Sockeye *Oncorhynchus nerka* in the Bering Sea. Izv. TINRO 116: 42–59. (In Russian)

Radchenko V.I. 1998. Inter-annual dynamics of pink salmon abundance in the Sea of Okhotsk populations in the 1990s. N. Pac. Anadr. Fish Comm. Tech. Rep. No. 1, pp. 11–13.

Radchenko, V.I., and A.I. Chigirinsky. 1995. Pacific salmon in the Bering sea. (NPAFC Doc. 122) 80 p. Pacific Res. Inst. Fish. and Oceanogr. (TINRO), Vladivostok, Russia.

Radchenko, V.I., and I.I. Glebov. 1998. Some data on Pacific salmon vertical distribution in the Bering Sea collected during bottom trawl surveys. Vopr. Ichthiologii 38: 627–632.

Radchenko, V.I., A.F. Volkov, and A.L. Figurkin. 1991. On pink salmon wintering in the Okhotsk Sea. Biologiya morya 17: 88–90. (In Russian)

Radchenko, V.I., K.M. Gorbatenko, A.V. Startsev, B.G. Tutubalin, and A.A. Balanov. 1997a. Environmental conditions in region of pink salmon wintering in the Okhotsk Sea. *In:* Far-eastern seas ecosystem studies. *Edited by* V.V. Sapozhnikov. Moscow, VNIRO. pp. 323–328. (In Russian)

Radchenko, V.I., I.V. Melnikov, A.F. Volkov, A. Yu. Semenchenko, I.I. Glebov, and A.A. Mikheev. 1997b. Environmental conditions, plankton and nekton composition in epipelagic layer of southern Okhotsk Sea and adjacent Pacific waters in summer. Biologiya morya 23: 15–25. (In Russian)

Radchenko, V.I., V.I. Chuchukalo, I.V. Volvenko, A.M. Slabinski, and A.N. Starovoitov. 1998. Plankton and nekton of upper epipelagic layer near the western Kamchatka in light of hypothesis on intermediate state of communities. Uspekhi Sovremennoi Biologii 118: 551–563. (In Russian)

Rogatnykh, A.Yu. 1985. Biological and commercial characteristics of coho salmon *Oncorhynchus kisutch* (Walb.) on the Okhotsk Sea continental coast. TINRO Sci. Rep. (Manuscript), Vladivostok, No. 20047. (In Russian)

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In* Pacific Salmon Life Histories. *Edited by* C. Groot and L. Margolis. UBC Press, Vancouver. pp. 395–445.

Shuntov, V.P. 1989a. Pacific salmon distribution and migrations in the Okhotsk Sea and Pacific waters off the Kuril Islands. Vopr. Ichthiologii 29: 162–169. (In Russian)

Shuntov, V.P. 1989b. Pacific salmon distribution and migrations in the Bering Sea and Pacific waters off the eastern Kamchatka. Vopr.

Ichthiologii 29: 843–851. (In Russian)

Shuntov, V.P. 1994. New data on Asian pink salmon marine life period. Izv. TINRO 116: 3–41. (In Russian)

Shuntov, V.P., and A.I. Chigirinski. 1995. Results of the TINRO-center Pacific salmon studies. *In* TINRO - 70. *Edited by* V.P. Shuntov and V.N. Akulin. Vladivostok. TINRO. pp. 55– 63. (In Russian)

Shuntov, V.P., A.F. Volkov, and A.Ya. Efimkin. 1988. Composition and present state of fish communities in the western Bering Sea pelagic layer. Biologiya morya 14: 56–65. (In Russian)

Shuntov, V.P., V.V. Lapko, A.A. Balanov, and A.V. Startsev. 1995. Interannual changes in Pacific salmon anadromous migrations in the Sakhalin-Kuriles waters. Biologiya morya 21: 116–124. (In Russian)

Shuntov, V.P., V.I. Radchenko, E.P. Dulepova, and O.S. Temnykh. 1997. Biological resources of Russian far-eastern economic zone: pelagic and bottom communities structure, present state, and long-term dynamics trend. Izv. TINRO 122: 3–15. (In Russian)

Sobolevski, E.I., V.I. Radchenko, and A.V. Startsev. 1994. Distribution and feeding of chum salmon *Oncorhynchus keta* in the western Bering Sea in fall. Vopr. Ichthiologii 34: 419–424. (In Russian)

Temnykh, O.S. 1996. Ecology and spatial differentiation of Asian pink salmon during the anadromous migrations. Izv. TINRO 119: 55–71. (In Russian)

Temnykh, O.S., M.E. Malinina, and A.V. Podlesnykh. 1997. Differentiation of anadromous pink salmon migrating aggregations of even-year broods in the Okhotsk Sea in 1990s. Izv. TINRO 122: 131–152. (In Russian)

Yanovskaya, N.V., N.N. Sergeyeva, E.A. Bogdan, A.V. Kudryavtseva, I.K. Kalashnikova, and E.A. Romanova. 1989. Pacific salmon catches, 1900–1986. Moscow, VNIRO. (In Russian)

Zhulkov, A.I. 1978. Biological features of coho salmon on Sakhalin Island. *In* Salmonid fish biology. *Edited by* S.M. Konovalov. Vladivostok, TINRO. pp. 40– 42. (In Russian)

Zolotukhin, S.F. 2000. The coho salmon *Oncorhynchus kisutch* of the Sea of Japan. Vopr. Ichthiologii 40: 112–115. (In Russian)

Zorbidi, Zh.K. 1975. Biological parameters and abundance of the Kamchatkan coho salmon. Tr. VNIRO 106: 34–42. (In Russian)

Zorbidi, Zh.K. 1993. Coho salmon stocks state in 1993 and analysis of prespawning aggregations at sea. TINRO Sci. Rep. (Manuscript), Vladivostok, No. 21795. (In Russian)