Environ Biol Fish (2009) 86:451–456
DOI 10.1007/s10641-009-9547-7

Offshore Dolly Varden charr (*Salvelinus malma*) in the North Pacific

Kentaro Morita · Shoko H. Morita · Masa-aki Fukuwaka · Toru Nagasawa

Received: 16 February 2009 / Accepted: 13 October 2009 / Published online: 27 October 2009

Abstract Many studies have investigated the ecology of charrs in freshwater, however, little is known about charrs in the ocean. This study examined the distribution, seasonal abundance, and some biological features of Dolly Varden (*Salvelinus malma*) in the Pacific Ocean. An analysis of by-catch data of Japanese offshore salmon monitoring showed that Dolly Varden were distributed across a wide range in the offshore waters of the Pacific Ocean, including the Japan Sea, Bering Sea, and Okhotsk Sea. The catch per unit effort showed a sharp increase from May to August, followed by a sharp decrease in September. Offshore areas served as an important summer habitat for anadromous Dolly Varden.

Keywords Offshore · Anadromous Dolly Varden · Pacific salmon · Marine

Introduction

Ontogenetic habitat shifts between freshwater and marine environments are a common feature of salmonid fishes like charrs *Salvelinus* spp. Charrs use a wide range of habitats, including small streams to large rivers, lakes, and marine habitats (Dunham et al. 2008). Although many studies have investigated the ecology of charrs in freshwater, little is known about charrs in the ocean (Dunham et al. 2008), especially in offshore waters. It has been suggested that most charrs do not move far offshore and that their movement is generally along the coast (Armstrong and Morrow 1980; Johnson 1980; Power 1980). However, in the case of the Dolly Varden *S. malma*, there is some empirical evidence indicating that this species is able to use offshore waters (Larkins 1964; Mishima 1975; Volkov et al. 1996). Additionally, a tag-recapture study reported long-distance movement of Dolly Varden between Alaskan and Russian rivers (DeCicco 1992). It is still unknown to what extent Dolly Varden use offshore waters.

The purpose of this study was to examine the distribution, seasonal abundance, and biological features of Dolly Varden in offshore waters. Japanese research vessels have monitored the stock condition of Pacific salmon with extensive fishing efforts (Ishida and Ogura 1992; Azumaya and Ishida 2000). Although the research program was designed to capture Pacific salmon, the by-catch data allowed us to examine the ecology of Dolly Varden in offshore waters.

This paper is presented in 2006 International Charr Symposium, Reykjavik, Iceland (Noakes 2008).

K. Morita (✉) · S. H. Morita · M.-a. Fukuwaka · T. Nagasawa
Hokkaido National Fisheries Research Institute,
Fisheries Research Agency,
Kushiro 085-0802 Hokkaido, Japan
e-mail: moritak@affrc.go.jp

Materials and methods

Japanese research vessels have monitored the stock condition of Pacific salmon since 1952 using research gillnets, commercial gillnets, longlines and trawls in the Pacific Ocean (Ishida and Ogura 1992). The by-catch data from this offshore salmon monitoring were compiled for the periods 1960–1962 and 1972–2007. The data included fishing location, gear type, sea surface temperature, number of fish caught, fork length, body weight, and sex. Fishing locations are basically at least 22 km away from shore. The total number of fishing operations and the total number of Dolly Varden caught were 17,008 and 17,684, respectively. Fishing stations were scattered throughout the North Pacific Ocean (Fig. 1a).

Data obtained using research gillnets that consisted of ten mesh sizes ranging between 48 mm and 157 mm (Takagi 1975) were used to evaluate density and fork length distribution. The total number of fishing operations using the research gillnets was 10 073. The catch per unit effort (CPUE), or the number of fish caught per 30 tans (ca. 1.5 km) of research gillnets, were calculated as density index. The CPUEs were stratified by month and 2° latitude × 5° longitudinal grid areas, following Azumaya and Ishida (2000).

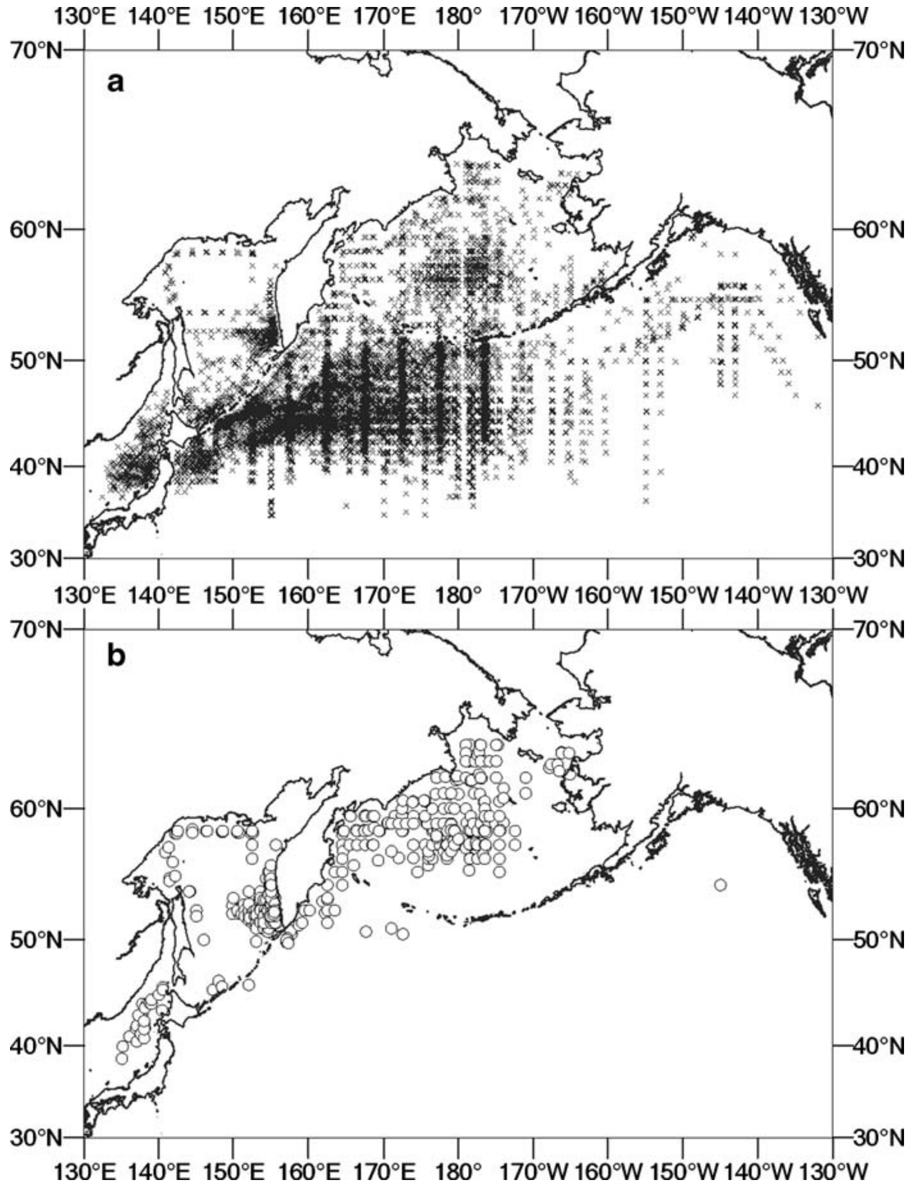


Fig. 1 **a** Distribution of fishing stations by all fishing gear types (gillnets, longlines, trawls) compiled in this study and **b** the fishing stations where Dolly Varden were caught

Results and discussion

Anadromous Dolly Varden were distributed throughout a wide range in the Pacific Ocean, including the Japan Sea, Bering Sea, Okhotsk Sea, and the Gulf of Alaska (Fig. 1b). In particular, many Dolly Varden were caught in the Bering and Okhotsk Seas. Their distribution in the Bering Sea was biased toward northern areas, which is consistent with a previous report (Larkins 1964). The southern limit of their offshore distribution was in the Japan Sea (38° 46′ N, 135° 02′ E), which is south of the southern limit of fluvial Dolly Varden populations located in Hokkaido Island, Japan (ca. 42°30′N, Nakano et al. 1996). Anadromous Dolly Varden rarely occur in rivers of Hokkaido, Japan (Morita et al. 2005).

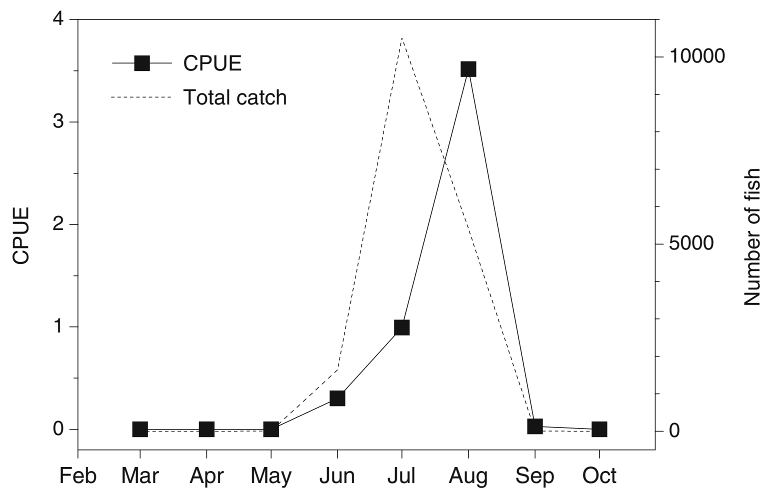
The total number and CPUE of offshore Dolly Varden showed a sharp rise from May to August, followed by a sharp decrease in September (Fig. 2). CPUE was comparatively high in the northwestern part of the Bering Sea and western Kamchatka, and the mode of the high CPUE group moved from offshore to coastal areas between July and August (Fig. 3). However, fishing stations were scarce between September and May, so it is unknown whether Dolly Varden occurred in offshore waters during these months. Additionally, Dolly Varden catches from the Japan Sea (ca. 40°N, 135°E) were reported between March and June (Machidori 1986).

Fechhelm et al. (1997) found that coastal CPUE of Dolly Varden in northern Alaska was typically bimodal, with the highest catches occurring early and late in the summer, and a notable mid-summer decrease. They suggested that this pattern is due to the early-summer outmigration of Dolly Varden from fresh waters (high early-summer catch), followed by dispersal along the coast or out to sea (mid-summer decrease in CPUE), and a late-summer return migration to fresh waters (high late-summer catch). Our results are consistent with this hypothesis, as we found that offshore CPUE of Dolly Varden was unimodal, with the highest catches occurring mid-summer.

The CPUE of Dolly Varden in July in the central Bering Sea (175°E–175°W, 55°N–59°N), where fishing stations were densely distributed between years, did not show significant decadal trends during the period 1972–2007 [linear regression of ln(CPUE + 1) on year, $r=-0.153$, $p=0.37$]. However, large annual variations in Dolly Varden catches in offshore areas would limit an accurate assessment of the population status. Commercial Dolly Varden catches in a Khabarovsk region of Russia were reported to decrease during the same periods (Zolotukhin et al. 2002).

The fork lengths of offshore Dolly Varden varied considerably and ranged from 164 mm to 761 mm (Fig. 4). There were several modal groups, and the lowest modal group (<270 mm) likely represents fish smolted in that year, while the upper modal groups probably represent veteran migrants of post-smolt ages >1 year. This suggests that Dolly Varden used offshore waters after smolting. Upper modal groups appeared offshore first, and the lowest modal group appeared after August. This pattern is consistent with the stage-dependent timing of the seaward migration

Fig. 2 Seasonal changes in total number of catch and catch per unit effort (CPUE) for Dolly Varden in offshore areas of the North Pacific obtained by research gillnets



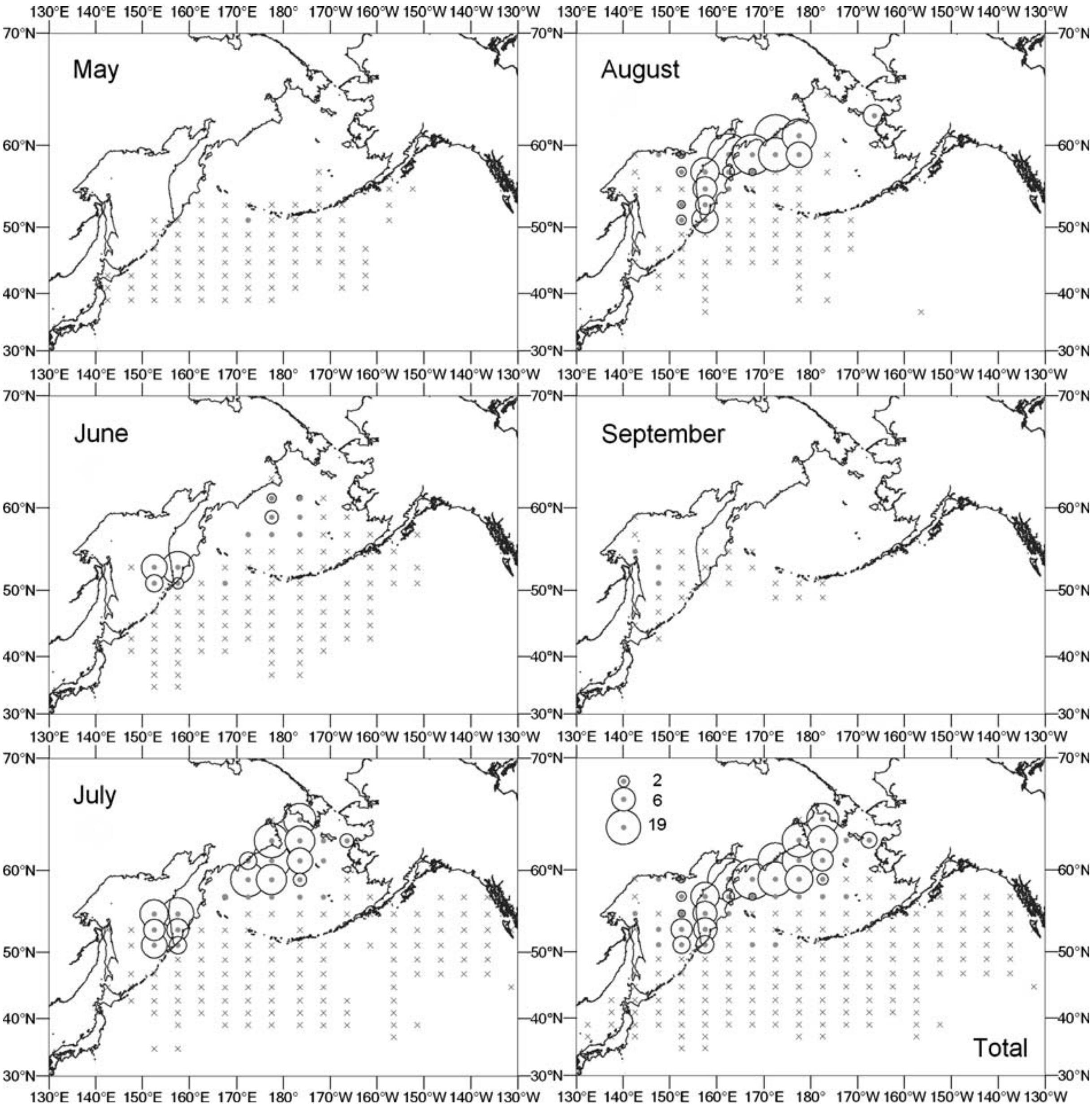


Fig. 3 Seasonal changes in area specific (2°×5° grid) CPUE for Dolly Varden in offshore areas of the North Pacific obtained by research gillnets. *Crosses* indicate grids where fishing by research gillnets were conducted but no Dolly Varden were caught

found in other iteroparous salmonids. That is, veteran migrants descend to the sea earlier than smolts (Jonsson et al. 1990). The sex ratio of the lowest modal group (<270 mm) was not biased, whereas that of the upper modal groups was biased toward females, particularly during early summer. However, most large individuals (>550 mm) were male.

Sea surface temperatures at sites where Dolly Varden were captured by research gillnets ranged from 2°C to 14°C, and the frequency of occurrence was highest between 4°C and 12°C (Fig. 5). The average sea surface temperature ± s.d. at the capture sites was 7.7±2.6°C. Thermal habitats of Dolly Varden were similar to the sympatric Pacific salmon *Oncorhynchus* spp. (Machidori and Ogura 1986; Azumaya et al. 2007).

In conclusion, anadromous Dolly Varden used offshore waters during the summer. Offshore areas

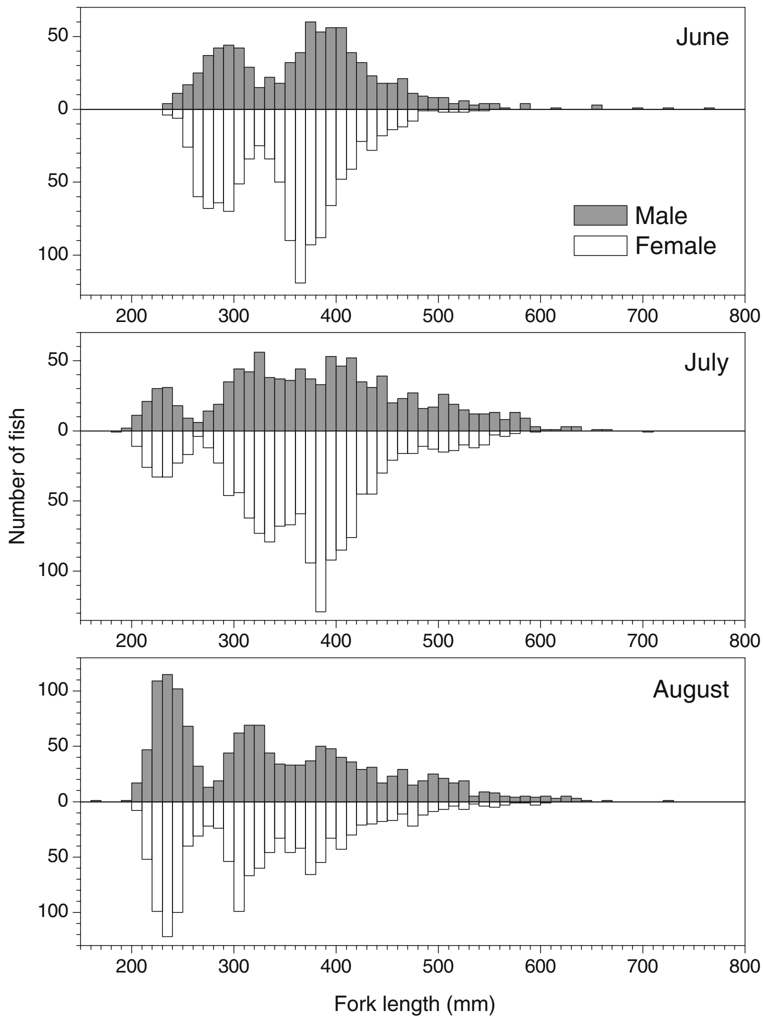


Fig. 4 Fork length distributions of Dolly Varden in offshore areas of the North Pacific during the summer obtained by research gillnets

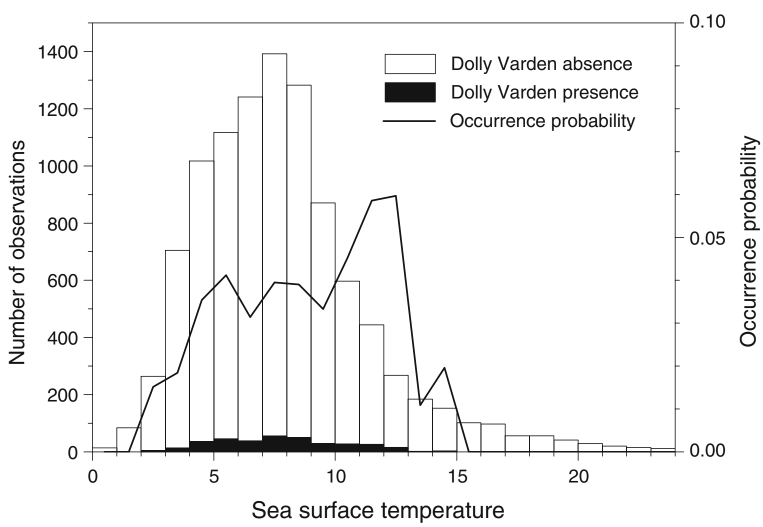


Fig. 5 Sea surface temperature distribution at fishing stations where Dolly Varden were caught (presence) or not caught (absence) in offshore areas of the North Pacific obtained by research gillnets and the occurrence probability [presence/(presence + absence)] in relation to sea surface temperature

are therefore considered an important summer habitat for anadromous Dolly Varden. Common use of offshore waters may be unique among *Salvelinus* spp. The white-spotted charr *S. leucomaenis*, which occur sympatrically with Dolly Varden in rivers of the far east of Asia, were rarely caught during the Japanese offshore salmon monitoring (Machidori 1986). Many white-spotted charr were caught in coastal areas instead (Takami et al. 1996), indicating that white-spotted charr do not move far offshore and that their movement is generally along the coast. In addition, migratory behaviour of Dolly Varden would vary among stocks. It has been suggested that most southern form followed the coastline in their migration whereas northern form may undertake oceanic migrations of considerable magnitude (Armstrong and Morrow 1980). Analysis of by-catch data from the Japanese offshore salmon monitoring would provide valuable insight into the ecology of commercially unimportant fishes in offshore waters.

Acknowledgements This research was supported by the Promotion Program for International Resources Surveys of the Fisheries Agency of Japan and a Grant-in-Aid for Young Scientists B (no.19780155) from Japan Society for the Promotion of Science.

References

Armstrong RH, Morrow JE (1980) The dolly varden charr, *Salvelinus malma*. In: Balon EK (ed) Charrs, salmonid fishes of the genus *Salvelinus* (pp 99–140). Dr W Junk bv Publishers, The Hague

Azumaya T, Ishida Y (2000) Density interactions between pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and their possible effects on distribution and growth in the North Pacific Ocean and Bering Sea. N Pac Anadr Fish Comm Bull 2:165–174

Azumaya T, Nagasawa T, Temnykh OS, Khen GV (2007) Regional and seasonal differences in temperature and salinity limitations of Pacific salmon (*Oncorhynchus* spp.). N Pac Anadr Fish Comm Bull 4:179–187

DeCicco AL (1992) Long-distance movements of anadromous Dolly Varden between Alaska and the U.S.S.R. Arctic 45:120–123

Dunham J, Baxter C, Fausch K, Fredenberg W, Kitano S, Koizumi I, Morita K, Nakamura T, Rieman B, Savvaitova K, Stanford J, Taylor E, Yamamoto S (2008) Evolution, ecology, and conservation of Dolly Varden, white-spotted char, and bull trout. Fisheries 33:537–550

Fechhelm RG, Bryan JD, Griffiths WB, Martin LR (1997) Summer growth patterns of northern Dolly Varden (*Salvelinus malma*) smolts from Prudhoe Bay region of Alaska. Can J Fish Aquat Sci 54:1103–1110

Ishida Y, Ogura M (1992) Review of high-seas salmon research by National Research Institute of Far Seas Fisheres. In: Ishida Y, Nagasawa K, Welch DW, Myers KW (eds) Proceedings of the International Workshop on Future Salmon Research in the North Pacific Ocean. National Research Institute of Far Seas Fisheries, Shimizu, pp 23–30

Johnson L (1980) The arctic charr, *Salvelinus alpinus*. In: Balon EK (ed) Charrs, salmonid fishes of the genus *Salvelinus*. Dr W Junk bv Publishers, The Hague, pp 15–98

Jonsson N, Jonsson B, Hansen LP (1990) Partial segregation in the timing of migration of Atlantic salmon of different ages. Anim Behav 40:313–321

Larkins HA (1964) Some epipelagic fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska. Trans Am Fish Soc 93:286–290

Machidori S (1986) Distribution of fishes caught incidentally in the salmon gillnet in the Subarctic Region of the North Pacific Ocean II Fishes of Clupeiformes, Salmoniformes and Myctophiformes. Salmon Report Series 31:24–37 in Japanese

Machidori S, Ogura M (1986) Relation between salmon distribution and water temperature in the waters south of 50 degree north and the west of longitude 180 degree in the North Pacific Ocean. Salmon Report Series 31:66–82 (in Japanese)

Mishima S (1975) A biological study of the anadromous Dolly Varden Salvelinus malma (Walbaum) distributed in the west coast off the Kamchatka in summer season, 1972–1974. Bull Fac Fish Hokkaido Univ 26:154–168 (in Japanese with English abstract)

Morita K, Arai T, Kishi D, Tsuboi J (2005) Small anadromous *Salvelinus malma* at the southern limits of its distribution. J Fish Biol 66:1187–1192

Nakano S, Kitano F, Maekawa K (1996) Potential fragmentation and loss of thermal habitats for charrs in the Japanese archipelago due to climatic warming. Freshw Biol 36:711–722

Noakes DLG (2008) 2006 International Charr Symposium, Reykjavik, Iceland. Environ Biol Fishes 83:1–5

Power G (1980) The brook charr, *Salvelinus fontinalis*. In: Balon EK (ed) Charrs, salmonid fishes of the genus *Salvelinus*. Dr W Junk bv Publishers, The Hague, pp 141–203

Takagi K (1975) A non-selective salmon gillnet for research operations. Inter N Pac Fish Comm Bull 32:13–41

Takami T, Murakami Y, Mori M (1996) Growth and feeding habits of anadromous white-spotted charr (*Salvelinus leucomaenis*) in southwestern Hokkaido, Japan. Sci Rep Hokkaido Fish Hatchery 50:37–44

Volkov AF, Chuchukalo VI, Radchenko VI, AYa E, Kuznetsova NA (1996) Summer feeding habits of the Dolly Varden in the Bering Sea. Oceanology 35:827–832

Zolotukhin SF, Augerot X, Shishayev AV, Yakimenko LI, Kvasheva YV, Skopetz MB, Proskurin AA, Voidilov VB (2002) Sakhalin taimen in the Koppi River Basin: population status and perspectives on sustainable use. TINRO Wild Salmon Center Joint Report, Khabarovsk