

Salmon Food Habits Studies in the Bering Sea, 1960 to Present

Nancy D. Davis¹, Masa-aki Fukuwaka², Janet L. Armstrong¹, and Katherine W. Myers¹

¹School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195-5020, USA

²Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
116 Katsura-koi, Kushiro 085-0802, Japan



Keywords: Salmon food habits, diet overlap, daily ration, bioenergetics

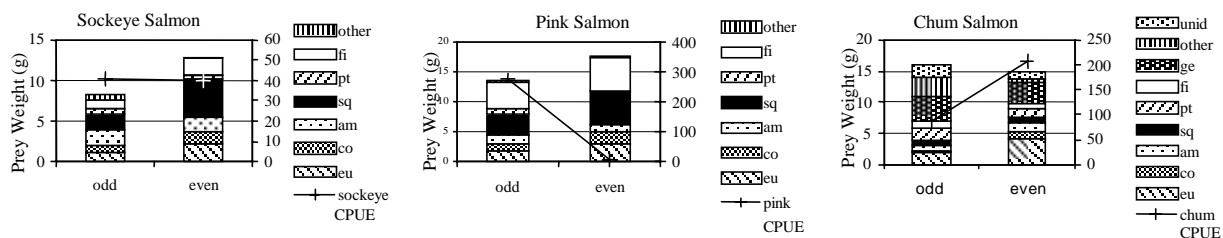
Salmon food habits studies are important to BASIS research because they help identify salmon density-dependent effects on growth and survival and can be used for food web models (NPAFC 2001). Since the 1960s these studies have been conducted in the western (e.g., Ito 1964; Andrievskaya 1966; Machidori 1968; Karpenko 1982a; Karpenko and Maksimenkov 1988; Chuchukalo et al. 1995; Klovach et al. 1996; Koval and Karpenko 1998; Bugaev and Shaporev 2002; Karpenko 2003; Smorodin et al. 2004), eastern (e.g., Nishiyama 1974; Straty 1974; Carlson et al. 1998; Murphy et al. 2003; Davis et al. 2004; Farley et al. 2004), and central (e.g., Kanno and Hamai 1972; Azuma 1992; Davis et al. 2000; Myers et al. 2004) Bering Sea. In this abstract, we review information on Bering Sea salmon food habits useful to BASIS researchers investigating salmon prey, diet overlap, ration, and bioenergetics.

Salmon distribution during their ocean migration has been linked to prey availability (Nishiyama 1974; Straty 1974; Carlson 1976; Karpenko 1979, 1983; Karpenko and Piskunova 1984; Sobolevskiy et al. 1994; Farley et al. 2004; Klovach and Gruzevich 2004). Review of 40 Bering Sea salmon food habits studies showed the major prey common to all species of salmon include euphausiids (*Thysanoessa*), hyperiid amphipods (*Themisto*), pteropods (*Limacina*), and juvenile squids (*Gonatopsis*, *Gonatus*, and *Berryteuthis*). Important fish prey include *Stenobranchius leucopsarus* and juvenile greenlings (*Pleurogrammus*) in basin habitats, and juvenile walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), and sand lance (*Ammodytes*) in shelf habitats. Future studies should focus on distribution and abundance of these major prey because this will improve our assessment of diet overlap and feeding competition.

In response to the biennial cycle of pink salmon abundance in the Bering Sea, density-dependent shifts in prey composition have been observed in the food habits of pink, chum, and sockeye salmon (Ito 1964; Andrievskaya 1966; Tadokoro et al. 1996; Karpenko et al. 1998; Davis 2003). During even-numbered years (low abundance of maturing pink salmon), total stomach content weight and proportions of euphausiids, copepods, fish, and squid increase in sockeye and pink salmon, and the proportion of euphausiids and other crustaceans increase in chum salmon stomach contents (Fig. 1).

Salmon diet overlaps (percent similarity index) were calculated for sockeye, chum, pink, and chinook salmon collected in the basin during the summer cruises (1991–2003) of the *Wakatake maru* (Fig. 2). Results showed a very high (> 75%) diet overlap between sockeye and pink salmon in odd- and even- numbered years. In odd-numbered years, however, diet overlaps between chum and sockeye, and chum and pink salmon were reduced. Comparing summer to fall overlaps using data collected onboard the *Northwest Explorer* in 2002 (Davis et al. 2004), indicated seasonal reduction in diet similarity between sockeye and chum salmon, and sockeye and chinook salmon (Fig. 2). In fall, overlap between sockeye and chum salmon in the Aleutian Islands was very high (> 75%), while overlap between chum and chinook salmon was moderate (28–30%) in the basin and the eastern shelf.

Fig. 1. Mean weight (g) of each prey category observed in the stomach contents of sockeye, pink, and chum salmon and mean CPUE (number of fish/50-m tan of research gillnet) observed during odd- and even-numbered years in the central Bering Sea in July, 1991–2000. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, unid = unidentified.



Bering Sea food habits studies have shown that prey composition shifts with salmon body size (Dell 1963; Andrievskaya 1968; Davis 2003; Dulepova and Dulepov 2003; Temnykh et al. 2003). In the basin, smaller sockeye and chum salmon contain a higher proportion of hyperiid amphipods than larger salmon (Fig. 3; Davis 2003). The proportion of squid in sockeye salmon increased with salmon body size, and the proportion of gelatinous zooplankton increased in chum salmon larger than 2500 g. Maturing chum salmon may consume more gelatinous zooplankton because it is easily digestible and widens their feeding niche (Dulepova and Dulepov 2003).

Fig. 2. Percent diet overlap of sockeye, chum, pink, and chinook salmon collected in the Bering Sea Basin, Aleutian Islands, and eastern Bering Sea shelf. Panel A = diet overlap in the basin for all years, summer 1991-2003; Panel B = even-numbered years, basin, summer 1992-2002; Panel C = odd-numbered years, basin, summer 1991-2003; Panel D = fall, 2002, basin; Panel E = fall, 2002, Aleutian Islands; Panel F = fall, 2002, eastern Bering Sea shelf.

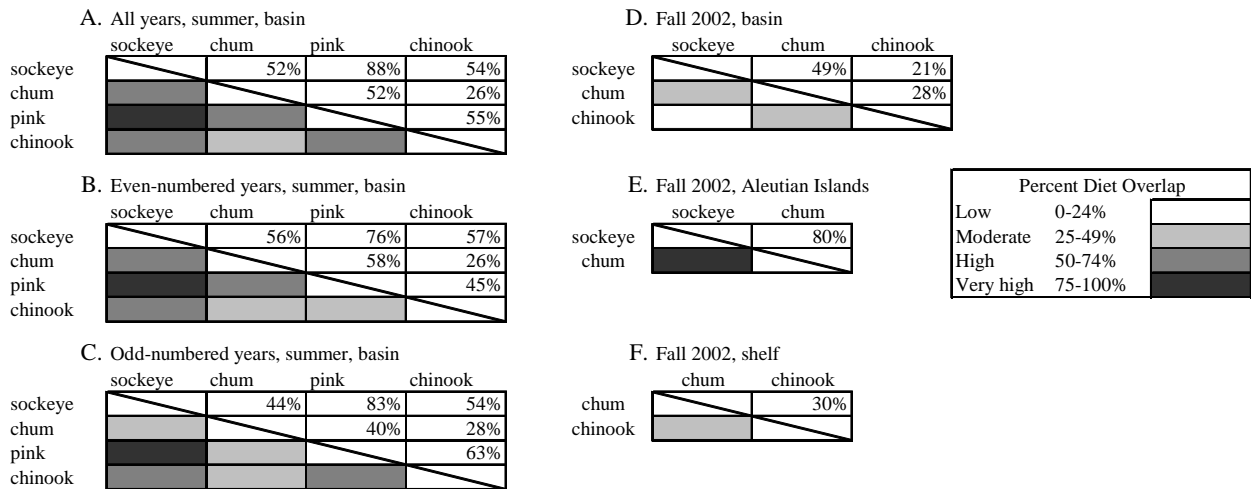
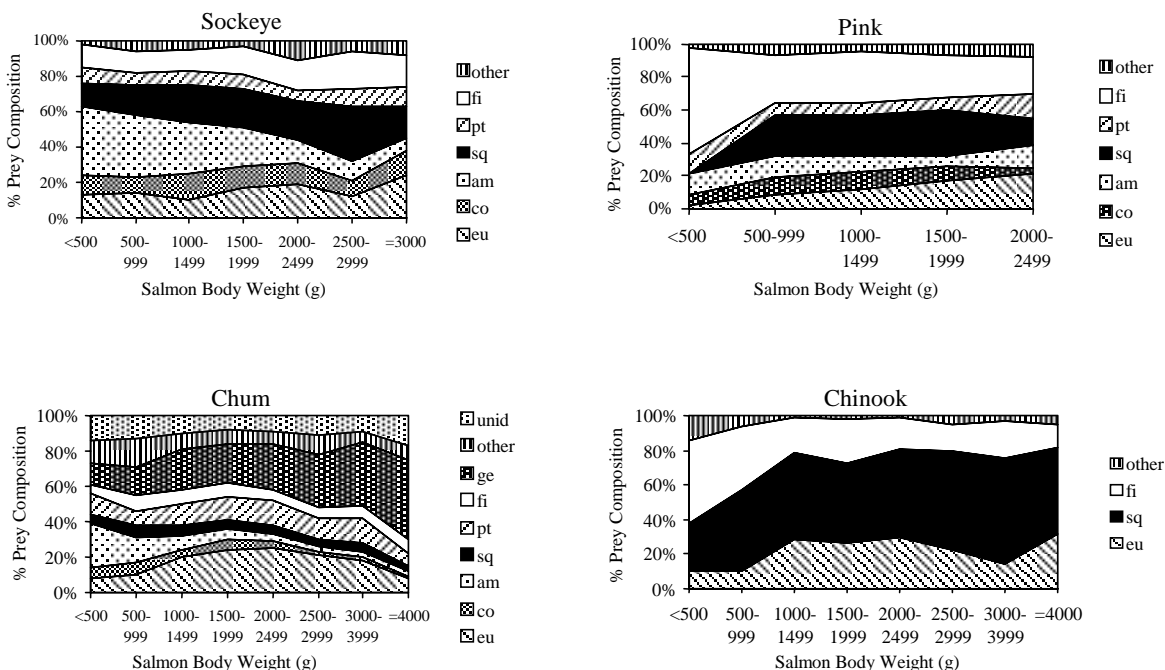


Fig. 3. Percent composition (by weight) of major prey categories collected from sockeye, chum, pink, and chinook salmon stomach contents for size groups of fish caught in the central Bering Sea basin in July, 1991-2000. Size class < 500 g represents the smallest size group for ocean age-1 fish. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, and unid = unidentified.



Daily ration estimates should be age- or size-specific, rather than generalized to life history stage because consumption rates shift as the fish grows (Davis et al. 1998). Such estimates will lend more realism to Bering Sea trophic models. Until recently, most consumption estimates for salmon were for fish described only by maturity stage. In addition, reporting ration as a percentage of body weight and energy per gram body weight would improve assessment of salmon diet quality.

Using bomb calorimetry, caloric value of some salmon prey organisms have been determined (Davis 2003). Gelatinous zooplankton (salps, ctenophores) had the lowest caloric value (< 100 cal/g wet weight, ww). Pteropods, hyperiid amphipods, smaller euphausiids, and juvenile squid (< 2 cm mantle length) had values ranging from 500–1000 cal/g ww. Caloric values of juvenile fishes, small Atka mackerel (*Pleurogrammus monopterygius*), larger euphausiids, and medium-sized squids (approximately 4 cm ML) ranged from approximately 1000 to 1500 cal/g ww, and 1500 to 2000 cal/g ww was measured from larger squid (8–9 cm ML). High values (> 2000 cal/g ww) were found in deep sea smelt (*Leuroglossus schmidti*) and *S. leucopsarus*.

Bering Sea salmon daily rations have been estimated from gut fullness and bioenergetics models (Nishiyama 1974; Karpenko 1982b; Karpenko and Nikolaeva 1989; Shuntov et al. 1993; Chuchukalo et al. 1995; Radchenko and Chigirinsky 1995; Volkov et al. 1995; Sobolevskiy and Senchenko 1996; Davis et al. 1998; Glebov 1998; Walker et al. 2000; Temnykh et al. 2003; Radchenko and Mathisen 2004). Gut fullness can be corrected for digestion rate, which is affected by prey composition, prey size, meal size, and water temperature (Windell 1978; Ney 1990). However, this method requires frequent sampling (approximately every 3 hrs) and assumes stomach contents measure food consumed. Because gut evacuation and feeding occur simultaneously, stomach contents at the end of the feeding period can underestimate the amount consumed (Elliott and Persson 1978). The bioenergetics approach uses a balanced energy budget. The Winberg bioenergetics model assumes waste and food processing costs are fixed proportions of consumption, and active metabolism is a multiple of standard metabolism (Ney 1990). The Wisconsin bioenergetics model estimates consumption as a proportion of maximum consumption of a fish at any weight or temperature and could provide relative consumption or growth estimates under differing conditions of temperature and prey availability (Ney 1990). Future bioenergetics models can simulate growth potential based on temperature predictions from Bering Sea climate models and improve our assessment of potential effects of climate change on salmon food habits and growth.

REFERENCES

- Andrievskaya, L.D. 1966. Food relationships of the Pacific salmon in the sea. *Vopr. Ichthyologii* 6:1(38): 84–90. (Translated from Russian by Prelim. Transl. Bureau of Comm. Fish., Seattle, 1966.)
- Andrievskaya, L.D. 1968. Feeding of Pacific salmon fry in the sea. (Translated from Russian by Fish. Res. Board Can. Transl. Series 1423.)
- Azuma, T. 1992. Diel feeding habits of sockeye and chum salmon in the Bering Sea during the summer. *Nippon Suisan Gakkaishi* 58: 2019–2025.
- Bugaev, A.V., and R.A. Shaporev. 2002. Results of marine research on the RMS “Moskamalfa” in 2001. (NPAFC Doc. 607). 20p. KamchatNIRO, Kamchatka Fishery and Oceanography Inst., Fisheries State Commit. of Russia, Petropavlovsk-Kamchatsky, Naberezhnaya Street 18, Russia.
- Carlson, H.R. 1976. Foods of juvenile sockeye salmon, *Oncorhynchus nerka*, in the inshore coastal waters of Bristol Bay, Alaska, 1966–67. *Fish. Bull.* 74: 458–462.
- Carlson, H.R., E.V. Farley, K.W. Myers, E.C. Martinson, J.E. Pohl, and N.M. Weemes. 1998. Survey of salmon in the southeastern Bering Sea, Gulf of Alaska, and northeastern Pacific Ocean April-May, 1998. (NPAFC Doc. 344). 33p. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 11305 Glacier Highway, Juneau, AK 99801-8626 USA.
- Chuchukalo, V.I., A.F. Volkov, A. Ya. Efimkin, and N.A. Kuznetsova. 1995. Feeding and daily rations of sockeye salmon (*Oncorhynchus nerka*) during the summer period. (NPAFC Doc. 125). 9p. Pacific Research Institute of Fisheries and Oceanography (TINRO), Vladivostok, 690600, Russia.
- Davis, N.D. 2003. Feeding ecology of Pacific salmon (*Oncorhynchus* spp.) in the central North Pacific Ocean and central Bering Sea, 1991–2000. Ph.D. Dissertation, Hokkaido Univ., Japan. 190p.
- Davis, N.D., K.W. Myers, and Y. Ishida. 1998. Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. *N. Pac. Anadr. Fish Comm. Bull.* 1: 146–162.
- Davis, N.D., K.Y. Aydin, and Y. Ishida. 2000. Diel catches and food habits of sockeye, pink, and chum salmon in the central Bering Sea in summer. *N. Pac. Anadr. Fish Comm. Bull. No. 2:* 99–109.
- Davis, N.D., J.L. Armstrong, and K.W. Myers. 2004. Bering Sea salmon diet overlap in fall 2002 and potential for interactions among salmon. (NPAFC Doc. 779). 30p. School of Aquatic Fishery Sciences, Univ. Washington, USA.

- Dell, M.B. 1963. Oceanic feeding habits of the sockeye salmon, *Oncorhynchus nerka* (Walbaum), in Aleutian waters. M.Sc. Thesis, Univ. Michigan, Ann Arbor, USA. 40p.
- Dulepova, E.P., and V.I. Dulepov. 2003. Interannual and interregional analysis of chum salmon feeding features in the Bering Sea and adjacent Pacific waters of eastern Kamchatka. (NPAFC Doc. 728). 8p. Pacific Scientific Research Fisheries Centre, (TINRO-Centre), 4, Shevchenko Alley, Vladivostok, 690600, Russia.
- Elliott, J.M., and L. Persson. 1978. The estimation of daily rates of food consumption for fish. *J. Animal Ecol.* 47: 977–991.
- Farley, E.V., J.M. Murphy, A. Middleton, L. Eisner, J. Moss, J. Pohl, O. Ivanov, N. Kuznetsova, M. Trudel, M. Drew, C. Lagoudakis, and G. Yaska. 2004. Eastern Bering Sea (BASIS) coastal research (August–October 2003) on juvenile salmon. (NPAFC Doc. 816). 29p. Auke Bay Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 11305 Glacier Highway, Juneau, AK 99801-8626, USA.
- 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). 57p. Pacific Scientific Research Fisheries Centre (TINRO-Centre), Russia.
- Ito, J. 1964. Food and feeding habit of Pacific salmon (Genus *Oncorhynchus*) in their oceanic life. *Hokkaido Suisan Shikenjo Hokoku* 29: 85–97. (Translated from Japanese by Fish. Res. Board Can. Transl. Ser. No. 1309.)
- Kanno, Y., and I. Hamai. 1972. Food of salmonid fish in the Bering Sea in summer of 1966. *Bull. Fac. Fish., Hokkaido Univ.* 22: 107–128. (In Japanese with English abstract.)
- Karpenko, V.I. 1979. Feeding habits of juvenile Pacific salmon in the coastal waters of Kamchatka. *Soviet. J. Mar. Biol.* 5(5): 398–405.
- Karpenko, V.I. 1982a. Diurnal feeding rhythm of young salmon during the initial stage of marine life. *Vopr. Ichthyologii* 22(2): 131–134.
- Karpenko, V.I. 1982b. Biological peculiarities of juvenile coho, sockeye, and chinook salmon in coastal waters of east Kamchatka. *Soviet J. Mar. Biol.* 8(6): 317–324.
- Karpenko, V.I. 1983. Influence of environmental factors on qualitative parameters of juvenile far-eastern salmon of the genus *Oncorhynchus* (Salmonidae) in Kamchatkan waters of the Bering Sea. *Vopr. Ichthyologii* 23(5): 93–101.
- Karpenko, V.I. 2003. Review of Russian marine investigations of juvenile Pacific salmon. *N. Pac. Anadr. Fish Comm. Bull.* 3: 69–88.
- Karpenko, V.I., and V.V. Maksimenkov. 1988. Preliminary data on the interactions between Pacific salmon and herring during early ontogeny. *Vopr. Ichthyologii.* 28(5): 136–147.
- Karpenko, V.I., and E.T. Nikolaeva. 1989. Daily feeding rhythm and rations of juvenile chum salmon, *Oncorhynchus keta*, during river and early marine part of their life cycle. *Vopr. Ichthyologii* 29(4): 75–82.
- Karpenko, V.I., and L.V. Piskunova. 1984. Importance of macroplankton in the diet of young salmon of Genus *Oncorhynchus* (Salmonidae) and their trophic relationships in the southwestern Bering Sea. *Vopr. Ichthyologii* 24(5): 98–106.
- Karpenko, V.I., V.G. Erokhin, and V.P. Smorodin. 1998. Abundance and biology of Kamchatkan salmon during the initial year of ocean residence. *N. Pac. Anadr. Fish Comm. Bull.* 1: 352–366.
- Koval, M.V., and V.I. Karpenko. 1998. Feeding of Pacific salmon during anadromous migrations in the Kamchatkan waters. (NPAFC Doc. 365). 11p. Kamchatka Fishery and Oceanography Research Institute (KamchatNIRO), Russia.
- Klovach, N., and A. Gruzevich. 2004. Results of 2003 salmon research cruise of the SRTMK “Sovremennik” (NPAFC Doc. 767). 32p. VNIRO, Russian Federal Research Institute of Fisheries and Oceanography Federal Fisheries Agency of Russia, Moscow, V. Krasnoselskaya, 17, Russia.
- Klovach, N.V., L.A. Rzhannikova, and S.B. Gorodovskaya. 1996. Biological characteristics of the chum salmon *Oncorhynchus keta* during the summer period of foraging in the sea. *Vopr. Ichthyologii* 36(8): 591–599.
- Machidori, S. 1968. Vertical distribution of salmon (Genus *Oncorhynchus*) in the Northwestern Pacific III. *Bull. Hokkaido Reg. Fish. Res. Lab.* 34: 1–11. (In Japanese with English summary.)
- Murphy, J., N. Davis, O. Ivanov, M. Rohr, S. Elmajjati, and W. Barber. 2003. Cruise report of the 2002 *Northwest Explorer* BASIS survey in the Bering Sea, September–October. (NPAFC Doc. 676 Rev. 1). 23p. NMFS, Auke Bay Laboratory, Juneau, AK; School of Aquatic and Fishery Sciences, University of Washington; Pacific Fisheries Research Centre (TINRO-Centre), Vladivostok; Alaska Quaternary Center, University of Alaska Fairbanks; Institute of Marine Science, University of Alaska Fairbanks.
- Myers, K.W., R.V. Walker, N.D. Davis, and J.L. Armstrong. 2004. High seas salmon research program, 2003. SAFS-UW-0402. 93p. Sch. Aquat. Fish. Sci, Univ. Washington, USA.
- Ney, J.J. 1990. Trophic economics in fisheries: Assessment of demand-supply relationships between predators and prey. *Rev. Aquat. Sci.* 2: 55–81.

- North Pacific Anadromous Fish Commission (NPAFC). 2001. Draft plan for NPAFC Bering-Aleutian Salmon International Survey (BASIS). (NPAFC Doc. 579). 27p. N. Pac. Anadr. Fish Comm., Canada.
- Nishiyama, T. 1974. Energy requirement of Bristol Bay sockeye salmon in the central Bering Sea and Bristol Bay. *In Oceanography of the Bering Sea with emphasis on renewable resources. Edited by D.W. Hood and E.J. Kelley. Occas. Publ. No. 2. Inst. Mar. Sci., Univ. Alaska, Fairbanks, AK. pp. 321–343*
- Radchenko, V.I., and A.I. Chigirinsky. 1995. Pacific salmon in the Bering Sea (NPAFC Doc. 122). 80p. Pacific Scientific Research Fisheries Centre (TINRO-Centre), Russia.
- Radchenko, V.I., and O.A. Mathisen. 2004. Distribution, growth, and feeding of sockeye salmon in the western Bering Sea. *Trans. Am. Fish. Soc.* 133: 606–621.
- Shuntov, V.P., V.I. Radchenko, V.V. Lapko, and Yu.N. Poltev. 1993. Distribution of salmon in the western Bering Sea and neighboring Pacific waters. *Vopr. Ichthyologii* 33 (7): 48–62.
- Smorodin, V.P., M.V. Koval, O.B. Tepnin, and A.V. Morozova. 2004. The results of trawling survey in the southwest Bering Sea during September–October 2002 STR “Koryaksky”. (NPAFC Doc. 782). 48p. Kamchatka Research Institute of Fishery and Oceanography, 18, Naberezhnaya Street, Petropavlovsk-Kamchatsky, 683602, Russia.
- Sobolevskiy, E.I., V.I. Radchenko, and A.V. Startsev. 1994. Distribution and diet of chum salmon, *Oncorhynchus keta*, in the fall-winter period in the western part of the Bering Sea and Pacific Ocean waters of Kamchatka. *Vopr. Ichthyologii* 34(4): 92–101.
- Sobolevskiy, E.I., and I.A. Senchenko. 1996. The spatial structure and trophic connections of abundant pelagic fish of eastern Kamchatka in the autumn and winter. *Vopr. Ichthyologii*. 36(1): 30–39.
- Straty, R.R. 1974. Ecology and behavior of juvenile sockeye salmon (*Oncorhynchus nerka*) in Bristol Bay and the eastern Bering Sea. *In Oceanography of the Bering Sea with emphasis on renewable resources. Edited by D.W. Hood and E.J. Kelley. Occas. Publ. No. 2. Inst. Mar. Sci. Univ. Alaska, Fairbanks. pp. 285–320.*
- Tadokoro, K., Y. Ishida, N.D. Davis, S. Ueyanagi, and T. Sugimoto. 1996. Change in chum salmon (*Oncorhynchus keta*) stomach contents associated with fluctuation of pink salmon (*O. gorbuscha*) abundance in the central subarctic Pacific and Bering Sea. *Fish. Oceanogr.* 5(2): 89–99.
- Temnykh, O.S., A.N. Starovoytov, I.I. Glebov, G.V. Khen, A.Ya. Efimkin, A.M. Slabinsky, and V.V. Sviridov. 2003. The results of trawling survey in the epipelagic layer of the Russian economic zone in the Bering Sea during September–October, 2002. (NPAFC Doc. 682 Rev. 2). 39p. Pacific Scientific Research Fisheries Center (TINRO-Center), Vladivostok, Russia.
- Volkov, A.F., V.I. Chuchukalo, and A.Ya. Efimkin. 1995. Feeding of chinook and coho salmon in the northwestern Pacific Ocean. (NPAFC Doc. 124). 12p. Pacific Scientific Research Fisheries Centre (TINRO-Centre), Russia.
- Walker, R.V., K.W. Myers, N.D. Davis, K.Y. Aydin, and K.D. Friedland. 2000. Using temperatures from data storage tags in bioenergetics models of high-seas salmon growth. *N. Pac. Anadr. Fish Comm. Bull.* 2: 301–308.
- Windell, J. T. 1978. Digestion and the daily ration of fishes. *In Ecology of freshwater fish production. Edited by S.D. Gerking. Blackwell, Oxford. pp. 159–183.*