Preliminary Records of Otolith-Marked Chum Salmon found in the Bering Sea and North Pacific Ocean in 2006 and 2007

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Sato, S., M. Takahashi, N. Watanabe, S. Kitatsuji, D. Takasaki, T. Chiba, S. Imai, Y. Goda, Y. Katayama, M. Kagaya, M. Fukuwaka, B.A. Agler, and S. Urawa. 2009. Preliminary records of otolith-marked chum salmon found in the Bering Sea and North Pacific Ocean in 2006 and 2007. N. Pac. Anadr. Fish Comm. Bull. 5: 99–104.

Abstract: We examined otolith marks on chum salmon caught in the North Pacific Ocean and Bering Sea during the spring and summer of 2006 and 2007. Otolith marks were detected in 190 of 8,295 immature and maturing fish. Of these marked salmon, 13 fish were found in the North Pacific Ocean and 177 fish were found in the Bering Sea. Approximately 90% of the marked salmon were released from Japanese hatcheries. Other marked fish originated from hatcheries in Alaska, Russia, and the Republic of Korea. Our results suggest that otolith-marked chum salmon released from NPAFC countries are detectable in the Bering Sea and North Pacific Ocean. Our study demonstrated that otolith marking is a useful tool for identifying hatchery of origin of individual chum salmon in the ocean. We believe this technique will be useful for the international management of anadromous salmon stocks.

Keywords: chum salmon, otolith mark, distribution, Bering Sea, North Pacific Ocean

INTRODUCTION

Chum salmon (*Oncorhynchus keta*) are the most widely distributed salmon species in the Pacific Rim (Salo 1991). Chum salmon are also an important commercial fisheries resource in North Pacific countries. Determining the ocean distribution and origins of chum salmon will provide valuable information to help clarify stock-specific patterns of ocean migration for stock assessment.

Stock identification of chum salmon in the offshore waters of the Bering Sea and North Pacific Ocean has been attempted using a wide variety of techniques including tagging, identification of scale characteristics, otolith thermal marking, and/or genetic characters (e.g. Ishida et al. 1989; Ogura and Ito 1994; Wilmot et al. 1998; Seeb and Crane 1999; Urawa et al. 2000). Otolith thermal marking uses short-term temperature fluctuations to induce distinctive structural marks on the otoliths of incubating fish, and is a widely-used technique for identifying origins of hatchery-produced salmonids (Volk et al. 1999). Otolith mark/recovery experiments have provided significant new stock-specific information on the offshore ocean distribution and migration patterns of Pacific salmon (Farley and Munk 1997; Kawana et al. 1999; Carlson et al. 2000; Urawa et al. 2000; Myers et al. 2004). These recovery experiments have mainly focused on chum and pink salmon in the Gulf of Alaska. Urawa et al. (2009) indicated stock-specific chum salmon distribution in the Bering Sea and the adjacent North Pacific Ocean by combining genetic and otolith marking information.

In the spring and summer of 2006 and 2007, scientists from Japanese institutes surveyed salmon stocks in the Bering Sea and North Pacific Ocean (Fukuwaka et al. 2006, 2007; Morita et al. 2006, 2007). Approximately 8,000 chum salmon otolith samples were collected during these surveys. In this paper, we present the results from those surveys.

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MATERIALS AND METHODS

Fish Samples

Chum salmon were collected from the Bering Sea and North Pacific Ocean during research cruises of the R/V *Kaiyo maru* between April 24 and June 17, 2006 (41°01'N–55°29'N, 154°47'E–159°47'W; Fig. 1A), the R/V *Wakatake maru* between June 15 and July 14, 2006 (41°00'N–58°30'N, 179°00'E–180°; Fig. 1B) and between June 14 and July 12, 2007 (41°00'N–58°30'N, 176°00'E–178°00'W; Fig. 1C) (Fukuwaka et al. 2006, 2007; Morita et al. 2006). Cruises were also conducted by the R/V *Hokko maru* between June 30 and July 15, 2007 (Fig. 1D) and between July 22 and August 3, 2007 (52°38'N–59°23'N, 174°55'E–170°11'E; Fig. 1E) (Morita et al. 2007). Sagittal otoliths from 8,295 of 11,943 fish caught in the North Pacific Ocean and Bering Sea in 2006 and 2007 were collected onboard ship (Table 1). Otoliths were examined for the presence of an otolith mark at the laboratory of National Salmon Resources Center, Fisheries Research Agency, Japan. We also collected a scale from each sampled fish, and gonad weight was measured to

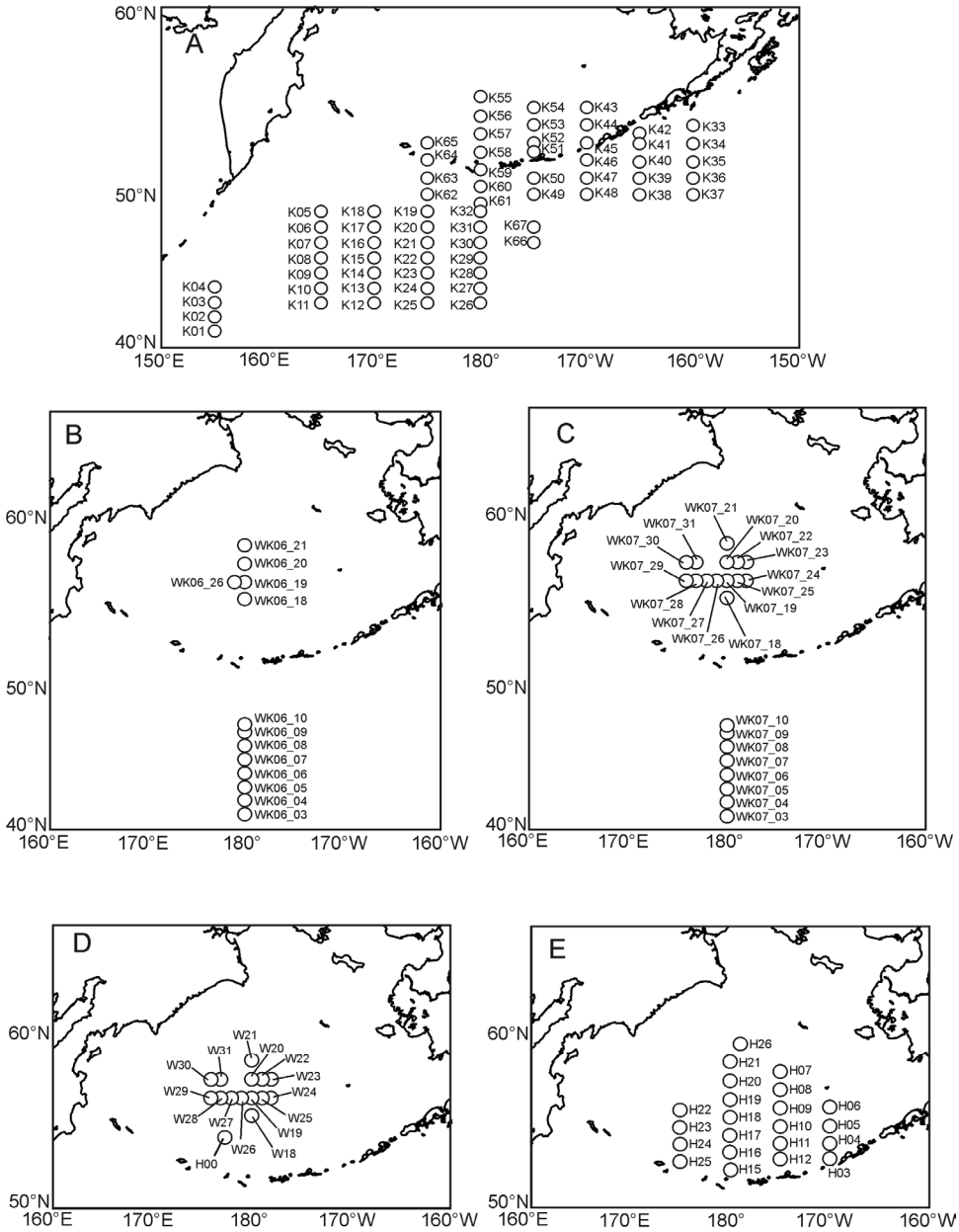

Fig. 1. Sampling locations of chum salmon in the North Pacific Ocean and Bering Sea during Japanese research cruises of R/V *Kaiyo maru* between April 24 and June 17, 2006 (A), R/V *Wakatake maru* between June 15 and July 14, 2006 (B), and between June 14 and July 12, 2007 (C), R/V *Hokko maru* between June 30 and July 15 (D), and between July 22 and August 3, 2007 (E).

the nearest gram. Fish age was determined by counting scale annuli, and maturity was determined from gonad weights (Takagi 1961). The criteria used to categorize maturity by gonad weight are shown in Table 2.

Detection of Otolith Thermal Marks

One otolith from each pair was mounted on a glass slide using Thermoplastic Cement (Buehler Ltd., Lake Bluff, IL) and then ground to expose the primordia using Doctor-Lap (MARUTO Instrument Co. Ltd., Tokyo, Japan) and Fibermet Discs (0.3, 1, 3, 9, and 12 µ, Buehler Ltd.). If a sample was overground, the other sagittal otolith was used. Otolith microstructure was examined under a compound microscope and compared to the mark patterns of voucher specimens archived on the NPAFC website (http://npafc.taglab.org). All otoliths were read independently by two readers (a beginner and an experienced reader). When disagreements between otolith readers occurred, they accessed the NPAFC database and re-checked the details of the mark pattern. After discussion, the experienced reader made the final decision.

RESULTS

Otolith marks were detected in 190 of 8,295 chum salmon (2.29%) caught in the Bering Sea and North Pacific Ocean in 2006 and 2007 (Table 1). Of the marked salmon, 13 of 1,885 fish (0.69%) were found in the North Pacific Ocean during the spring of 2006 and five of 335 fish (1.49%) were recovered in the early summer of 2006. Twelve of 847 fish (1.41%) were found in the Bering Sea during the summer of 2006. In the summer of 2007, 160 of 4,899 fish (3.3%) were recovered in the Bering Sea. These latter samples included two alizarin complexone (ALC) marked fish. Most of the marked chum salmon that we recovered were from Japanese hatcheries (Table 1).

Bering Sea Recovery

During early summer of 2006, five Japanese maturing chum salmon originally from the Chitose, Shari, Ichani, and Shizunai hatcheries in Hokkaido were caught in the central and eastern waters of the Bering Sea. In the summer of 2006 and 2007, 28 marked maturing fish were also recovered in the Bering Sea basin (Table 1). Those marked fish were released from eight Japanese hatcheries (Ichani, Shari, Nijibetsu, Shizunai, Tokushibetsu, Tsurui, Tonbetsu, and an unspecified hatchery in Hokkaido), the Paratimsky Hatchery in Kamchatka and an unidentified hatchery in either Russia or Alaska (Table 1).

We found a total of 144 immature otolith-marked chum salmon in the Bering Sea (Table 1). Of these marked fish, the origins of 137 fish were identified as follows: 130 from 13 Japanese hatcheries (Tokushibetsu, Shari, Nijibetsu,

Table 1. Number of chum salmon caught (Catch), sampled (OT), and number of otolith-marked chum salmon detected in the Bering Sea (BS) and North Pacific Ocean (NP) on the Japanese research vessels *Kaiyo maru*, *Wakatake maru*, and *Hokko maru* in 2006 and 2007. M, maturing fish; I, Immature fish; T, surface/midwater trawl; H, hook-and-line; G, gillnet; UI, unidentified origin.

Year/season	Sampling date	Research vessel	Survey area (stations)	Gear	Catch	OT	Number of otolith-marked fish by country of origin											
							Japan		Korea		Russia		Alaska		UI		Total	
							M	I	M	I	M	I	M	I	M	I	M	I
2006 spring	April 24 - May 15	*Kaiyo maru*	NP (K01-32, 66-67)	T, H	1,294	1,022	4	3	0	0	0	0	0	0	0	3	4	6
2006 early summer	May 26 - June 17	*Kaiyo maru*	NP (K33-42, 46-50, 59-64)	T	978	863	1	0	0	0	1	0	1	0	0	0	3	0
	May 26 - June 17	*Kaiyo maru*	BS (K43-45, 51-58, 65)	T	360	335	5	0	0	0	0	0	0	0	0	0	5	0
2006 summer	June 15 - 22	*Wakatake maru*	NP (WK06_03-10)	G	123	102	0	0	0	0	0	0	0	0	0	0	0	0
	July 10 - 14	*Wakatake maru*	BS (WK06_18-21, 26)	G	1,173	847	1	7	0	0	0	0	0	0	1	3	2	10
	June 14 - 21	*Wakatake maru*	NP (WK07_03-10)	G	250	227	0	0	0	0	0	0	0	0	0	0	0	0
2007 summer	June 29 - July 12	*Wakatake maru*	BS (WK07_18-31)	G	1,175	1,079	8	27	0	1	1	0	0	1	0	0	9	29
	June 30 - July 15	*Hokko maru*	BS (H00, W18-31)	T	2,740	1,802	16	59	0	0	0	0	0	1	0	2	16	62
	July 22 - August 3	*Hokko maru*	BS (H03-26)	T	3,850	2,018	1	37	0	0	0	0	0	4	0	2	1	43
Total					11,943	8,295	36	133	0	1	2	0	1	6	1	10	40	150

Table 2. Criteria used to categorize maturity by gonad weight of chum salmon (modified from Takagi (1961)).

Sex	April - late May	June			July		
		Early	Mid	Late	Early	Mid	Late
Female	≤ 10 g	< 15 g	< 15 g	≤ 20 g	< 25 g	< 25 g	< 25 g
Male	≤ 1 g	≤ 2 g	≤ 3 g	≤ 3 g	≤ 3 g	≤ 5 g	≤ 5 g

Tokachi, Yakumo, Tonbetsu, Ichani, Shizunai, Chitose, Teshio, Tsurui, and unspecified hatcheries in Hokkaido and Katagishi Hatchery on the Pacific coast of Honshu); one from the Yang-Yang Hatchery in the Republic of Korea; six from four Alaskan hatcheries (Macaulay, Wally Noerenberg, Port Armstrong, and Haines). One otolith-marked fish (age 0.1, male, 334 mm in fork length) was caught at station WK07-31 (56°30'N, 176°00'E; Fig. 1C) on July 12, 2007 and is the first record of a Korean chum salmon found on the high-seas.

North Pacific Ocean Recovery

In the North Pacific Ocean during the spring of 2006, seven maturing otolith-marked chum salmon were collected: five Japanese fish were caught in the central and eastern North Pacific Ocean (175°E, 180°, and 165°W) and one Russian and one Alaskan fish were both caught at station K46 (52°08'N, 170°04'W) in the eastern North Pacific Ocean. Those fish originated from four Japanese hatcheries (Chitose, Nijibetsu, Tsurui, and Shizunai in Hokkaido), the Ozerkovsky Hatchery in western Kamchatka, and the Macaulay Hatchery in southeast Alaska. No maturing fish were recovered in the central North Pacific Ocean during the summers of 2006 and 2007.

Six immature otolith-marked chum salmon were found in the North Pacific Ocean in the spring of 2006. Three of those fish were released from two Japanese hatcheries (Nijibetsu and Ichani in Hokkaido), but the hatchery origins of the other three marked fish could not be identified. These samples were collected from the central North Pacific Ocean (43°00'N–45°06'N, 174°50'E–179°48'W). In the summer of 2006 and 2007, no otolith-marked immature fish were detected in the central North Pacific Ocean.

DISCUSSION

This study demonstrated that otolith marks were detected in 190 of 8,295 immature and maturing fish in the survey areas of North Pacific Ocean and Bering Sea during 2006 and 2007. Of these marked salmon, 13 fish were found in the North Pacific Ocean and 177 fish were found in the Bering Sea. Approximately 70–90% of the otolith-marked immature chum salmon originated from Japanese hatcheries, and they were mainly found in the central Bering Sea.

Our study indicated that the recovery number and percentage of otolith-marked samples were very low (0.69–3.3%). The number and percentages of otolith-marked fish released were approximately 19–146 million (1.0–7.9%) from Japan, 7–49 million (2.5–13.7%) from Russia, 267–477 million (58.9–96.4%) from Alaska, and 0.6–1.4 million (11.5–23.8%) from Washington, Oregon, California, and Idaho, between 2001 and 2006 (data from NPAFC website: www.npafc.org). However, about 89% of the recovered otolith-marked chum salmon were released from Japanese hatcheries.

The survey areas in our study were limited. Particularly, in the summer of 2006 and 2007, otolith samples were collected from limited areas of the central North Pacific Ocean and central (high-seas) Bering Sea. Previous tagging and genetic studies indicated that Asian (Japanese and Russian) stocks were widely distributed in the Bering Sea and North Pacific Ocean (Sato et al. 2009; Urawa et al. 2009). It may be that the limited survey design influenced the number and percentages of otolith-marked chum salmon recovered.

Why did Japanese otolith-marked fish dominate the recovery from the survey areas of the central Bering Sea? Almost all Japanese stocks migrate into the central Bering Sea during the summer (Urawa et al. 2009). United States stocks from central Alaska, southeast Alaska, Washington, and Oregon were mainly distributed in the Gulf of Alaska and central North Pacific Ocean, while the Russian stocks are mainly distributed in the western Bering Sea and northwest Pacific Ocean (Myers et al. 1996). Further, most of the otolith-marked fish originating in United States and Russia are released from Prince William Sound and southeast Alaskan hatcheries and Sakhalin Island hatcheries, respectively (NPAFC website: www.npafc.org). Therefore, it seems logical that we did not recover any otolith-marked fish released from United States or Russian hatcheries.

Our present study indicates that 10 maturing Japanese chum salmon were collected from the survey areas of the North Pacific Ocean (175°E, 180°, and 165°W) and southern Bering Sea in the spring and early summer, and 26 maturing fish originating in Japan were caught in the survey areas of the central Bering Sea during summer. On the other hand, 130 immature fish originating from Japanese hatcheries were caught in the survey areas of the Bering Sea during summer. Urawa et al. (2009) estimated that maturing Japanese chum salmon in Gulf of Alaska migrate into the Bering Sea during June, followed by young chum salmon from the western North Pacific Ocean and by immature Japanese fish from the Gulf of Alaska. Maturing chum salmon migrate out of the Bering Sea by August, while immature fish remain there to feed (Urawa et al. 2009). Our results reflect the migration patterns of maturing and immature Japanese chum salmon.

Hatcheries in southeast Alaska and Prince William Sound annually released approximately 270–460 million otolith-marked chum salmon from 2001 to 2006; the Japanese released 19–146 million otolith-marked fish from 2001 to 2006 (NPAFC website: www.npafc.org). Neave et al. (1976) estimated that immature chum salmon of North American stocks migrate to the north and west in the Gulf of Alaska during spring and early summer, and that they remain in the Gulf of Alaska (primarily south of 50°N and east of 155°W) during the late summer and winter. A previous tagging study also indicated that immature chum salmon released from Prince William Sound and southeast Alaskan hatcheries were distributed in the Gulf of Alaska and central North Pacific Ocean and adjacent Bering Sea waters during summer (Myers et al. 1996). Previous genetic and otolith mark analyses suggested that Prince William Sound and southeast Alaska immature chum salmon are distributed in the northern Gulf of Alaska and southern Bering Sea during summer (Urawa et al. 2009). Our otolith mark recoveries suggest that the Prince William Sound and southeast Alaska fish are mainly distributed in the Gulf of Alaska and central North Pacific Ocean, and that some of these fish may extend into the survey areas in the central Bering Sea.

Russian hatcheries released approximately 306–387 million chum salmon from 2001 to 2006. Of these, approximately 7.9–49 million fish (2.5–13.7%) were otolith-marked. Previous genetic stock identification studies estimated that Japanese and Russian stocks were dominant in the Bering Sea basin during summer and fall, and that their abundances were almost equivalent (Sato et al. 2009; Urawa et al. 2009). However, in our study the number of otolith-marked fish of Russian origin was much lower than those of Japanese origin. In Russia, wild populations are the basis of most of the salmon harvest (Zaporozhets and Zaporozhets 2004). A previous study of wild and hatchery fish production and recruitment in the Tym River, one of the largest rivers on Sakhalin Island, indicated that returning numbers of wild chum salmon were five times greater than those of hatchery origin during 1960–1998 (Kovtun 2000). The low recovery of Russian otolith-marked fish in the high-seas ocean samples suggests that Russian chum salmon stocks include a considerable number of wild fish.

An otolith-marked fish released from the Yang-Yang Hatchery in the Republic of Korea was collected in the central Bering Sea during the summer of 2007. This was the first record of recovery of a Korean otolith-marked salmon on the high seas. This finding suggests that Korean chum salmon may migrate to the Bering Sea during the summer as do other Asian stocks.

In conclusion, we have demonstrated that otolith-marked chum salmon released from the NPAFC countries were widely distributed in the Bering Sea and North Pacific Ocean. Otolith marking is a useful tool for identifying the hatchery of origin of individual chum salmon in the ocean. We believe this technique will be useful for the international management of anadromous salmon stocks in the North Pacific Ocean.

ACKNOWLEDGMENTS

We express our thanks to the captains, officers, and crews of R/Vs *Kaiyo maru*, *Wakatake maru*, and *Hokko maru* for their efforts to collect high-seas samples. We also thank Dr. Kentaro Morita, Hokkaido National Fisheries Research Institute, Fisheries Research Agency, for his help in sample collection on the *Kaiyo maru* and *Hokko maru*. The present study was supported by the Promotion Program of International Fisheries Resources Survey of the Fisheries Agency of Japan.

REFERENCES

Carlson, H.R., E.V. Farley, Jr., and K.W. Myers. 2000. The use of thermal otolith marks to determine stock-specific ocean distribution and migration pattern of Alaskan pink and chum salmon in the North Pacific Ocean 1996–1999. N. Pac. Anadr. Fish Comm. Bull. 2: 291–300. (Available at www.npafc.org).

Farley, E.V., Jr., and K. Munk. 1997. Incidence of thermally marked pink and chum salmon in the coastal waters of the Gulf of Alaska. Alaska Fish. Res. Bull. 4: 181–187.

Fukuwaka, M., and N. Watanabe. 2006. International salmon research aboard the R/V *Wakatake maru* in the central North Pacific Ocean and Bering Sea during the summer of 2006. N. Pac. Anadr. Fish Comm. Doc. 959. 17 pp. (Available at www.npafc.org).

Fukuwaka, M., N. Davis, M. Kuwaki, S. Imai, and K. Toge. 2007. International salmon research aboard the R/V *Wakatake maru* in the central North Pacific Ocean and Bering Sea during the summer of 2007. N. Pac. Anadr. Fish Comm. Doc. 1046. 19 pp. (Available at www.npafc.org).

Ishida, Y., S. Ito, and K. Takagi. 1989. Stock identification of chum salmon *Oncorhynchus keta* from their maturity and scale characters. Nippon Suisan Gakkaishi 55: 651–656.

Kawana, M., S. Urawa, G. Anma, Y. Kamei, T. Shoji, M. Fukuwaka, K. Munk, K.W. Myers, and E.V. Farley, Jr. 1999. Recoveries of thermally marked maturing pink salmon in the Gulf of Alaska in the summer of 1998. Bull. Nat. Salmon Resources Center 2: 1–8. (Available at http://salmon.fra.affrc.go.jp/english/eng2_BNSRC.htm).

Kovtun, A.A. 2000. Wild and hatchery production and recruitment of autumn chum salmon (*Oncorhynchus keta* Walbaum) in the Tym River, Sakhalin, 1960–1998. N. Pac. Anadr. Fish Comm. Bull. 2: 255–261. (Available at www.npafc.org).

Morita, K., S. Sato, T. Kaga, D. Takasaki, T. Chiba, A.F. Volkov, K. Cieciel, S.K. Kang, N. Tanimata, Y. Kameza-

wa, M. Katsumata, and T. Azumaya. 2006. The 2006 spring international cooperative salmon research cruise of the R/V *Kaiyo maru*. N. Pac. Anadr. Fish Comm. Doc. 958. 9 pp. (Available at www.npafc.org).

Morita, K., S. Sato, M. Kagaya, Y. Katayama, Y. Goda, T. Chiba, and K. Makino. 2007. The 2007 summer Japanese salmon research cruise of the R/V *Hokko maru*. N. Pac. Anadr. Fish Comm. Doc. 1044. 8 pp. (Available at www.npafc.org).

Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M. L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956–1995. N. Pac. Anadr. Fish Comm. Doc. 192. 227 pp. (Available at www.npafc.org).

Myers, K.W., R.V. Walker, K. F. Van Kirk, and M. Kaeriyama. 2004. Thermal otolith mark recoveries from salmon in international waters of the Gulf of Alaska in 2002. N. Pac. Anadr. Fish Comm. Doc. 805. 10 pp. (Available at www.npafc.org).

Neave, F., T. Yonemori, and R.G. Bakkala. 1976. Distribution and origin of chum salmon in offshore waters of the North Pacific Ocean. Int. North Pac. Fish. Comm. Bull. No. 35. 79 pp.

Ogura, M., and S. Ito. 1994. Change in the known ocean distribution of Japanese chum salmon, *Oncorhynchus keta*, in relation to the progress of stock enhancement. Can. J. Fish. Aquat. Sci. 51: 501–505.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. UBC Press, Vancouver. pp. 233–309.

Sato, S., S. Moriya, T. Azumaya, H. Nagoya, S. Abe, and S. Urawa. 2009. Stock distribution patterns of chum salmon in the Bering Sea and North Pacific Ocean during the summer and fall of 2002–2004. N. Pac. Anadr. Fish Comm. Bull. 5: 29–37. (Available at www.npafc.org).

Seeb, L.W., and P.A. Crane. 1999. Allozymes and mitochondrial DNA discriminate Asian and North American populations of chum salmon in mixed-stock fisheries along the south coast of the Alaska Peninsula. Trans. Am. Fish. Soc. 128: 88–103.

Takagi, T. 1961. The seasonal change of gonad weight of sockeye and chum salmon in the North Pacific Ocean, especially with reference to mature and immature fish. Bull. Hokkaido Reg. Fish. Res. Lab. 23: 17–34. (In Japanese with English abstract).

Urawa, S., M. Kawana, G. Anma, Y. Kamei, T. Shoji, M. Fukuwaka, K.M. Munk, K.W. Myers, and E.V. Farley, Jr. 2000. Geographic origin of high-seas chum salmon determined by genetic and thermal otolith markers. N. Pac. Anadr. Fish Comm. Bull. 2: 283–290. (Available at www.npafc.org).

Urawa, S., S. Sato, P.A. Crane, B. Agler, R. Josephson, and T. Azumaya. 2009. Stock-specific ocean distribution and migration of chum salmon in the Bering Sea and North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull. 5: 131–146. (Available at www.npafc.org).

Volk, E.C., S.L. Schroder, and J.J. Grimm. 1999. Otolith thermal marking. Fish. Res. 43: 205–219.

Wilmot, R.L., C.M. Kondzela, C.M. Guthrie, and M.S. Masuda. 1998. Genetic stock identification of chum salmon harvested incidentally in the 1994 and 1995 Bering Sea trawl fishery. N. Pac. Anadr. Fish Comm. Bull. 1: 285–299. (Available at www.npafc.org).

Zaporozhets, O.M., and G.V. Zaporozhets. 2004. Interaction between hatchery and wild Pacific salmon in the Far East of Russia: a review. Rev. Fish Biol. Fish. 14: 305–319.