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An overview of salmon enhancement and the need to manage and monitor natural spawning in Hokkaido, Japan

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Abstract The chum and pink salmon catches in Hokkaido, Japan have increased dramatically since the 1970s and the 1990s, respectively. In contrast, masu salmon catches have been steadily decreasing. Despite intensive hatchery development in Hokkaido, naturally spawning salmon populations persist based on results from a recent river survey. This paper focuses on the challenges of maintaining hatchery salmon populations while protecting natural chum, pink and masu salmon populations in Hokkaido. Two important initiatives related to meeting this ambitious goal are managing hatcheries in a way that minimizes negative interactions between natural and hatchery salmon populations, and initiating new efforts at restoring and rehabilitating degraded freshwater habitats. In addition, in order to maintain a balance of demand and supply in the domestic market through the exportation of extra salmon, Hokkaido has decided to enter full assessment to gain Marine Stewardship Council (MSC) certification of the Hokkaido chum salmon trap net fishery. This would involve a fundamental shift in fisheries management as practiced in Japan, specifically elevating the importance of managing the fishery in a way that conserves natural salmon populations. A key component of a new salmon management strategy is the establishment of a zone management framework based on the designation of stream units to spatially separate natural salmon from hatchery salmon to minimize negative effects of hatchery fish and to utilize effectively hatchery salmon for commercial fisheries. This effort is allied with similar initiatives in other Pacific Rim countries that are focusing on management reform to restore natural ecosystem function and maintain the coexistence of wild and hatchery salmon.

Keywords Natural spawning · Chum salmon · Pink salmon · Masu salmon

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Introduction

Chum salmon *Oncorhynchus keta*, pink salmon *O. gorbuscha* and masu salmon *O. masou* inhabit Japanese waters, and mainly reproduce in Hokkaido Island. Chum salmon are most abundant, followed by pink and masu salmon. Archaeological evidence found in Hokkaido showed that salmon were caught by "Eri", a kind of weir built in the streams. Salmon were eaten for subsistence during the Mid-Jomon period, beginning 5,500 years ago. Commercial fisheries using coastal trap nets for capturing salmon began in the 19 century in Hokkaido.

Salmon in Japan have been maintained by "Tanegawa No Seido", a kind of regulation to protect natural spawning in the streams in the Edo period created before the founding of the USA in 1776 (Kobayashi 1980). During this time, commercial fishing was not allowed in the Tanegawa's channels or streams so that chum salmon could naturally spawn. As fishing efforts increased using modern fishing gear, commercial catches decreased dramatically during the 1890s. As a result, Japan's salmon management approach gradually changed to hatchery-based management using modern techniques introduced from the USA. After low stocking effectiveness for long periods, hatchery returns of chum and pink salmon in Hokkaido have increased markedly in recent decades (see Kobayashi 1980; Nagata and Kaeriyama 2004; Morita et al. 2006b). Because improvements of hatchery techniques (such as pre-release feeding of juveniles, Kobayashi 1980) coincided with changes in ocean conditions (Kaeriyama 1999; Shimizu 2002), it is uncertain whether hatchery programs were primarily responsible for the net increase in total salmon production (Morita et al. 2006b). Recent papers suggested that wild pink salmon significantly contributed to the recent increase (Morita et al. 2006a) and we have recently documented that chum salmon naturally spawn in many streams around Hokkaido (Miyakoshi et al. 2011). On the other hand, masu salmon, which have a longer freshwater life prior to smolting, have decreased in Hokkaido. It is thought that this decrease is due to a combination of fishing pressure (Ando et al. 2002), low contribution of hatchery programs (Miyakoshi et al. 2001a, b), negative impacts of captive broods (Edpalina et al. 2004), and loss of freshwater environments for natural spawning and rearing (Nagata et al. 2002; Fukushim 2005). Therefore, it is important not only to maintain the hatchery programs but also to conserve natural spawning to encourage the development of sustainable salmon fisheries resources in Hokkaido.

There is increased interest in Japan for fisheries to undergo third-party assessments to gain ecolabel certification based on ecological and economic justifications. The leading global seafood certifier is the Marine Stewardship Council (MSC) based in London, UK (www.msc.org). MSC certification requires evidence that a fishery is managing in a way that protects wild populations and minimizes impact on non-target species and the ecosystem (SCS 2007). MSC was formed by the World Wildlife Fund (WWF) and Unilever in 1997 and developed an environmental standard for sustainable, well managed fisheries and a supply chain standard which ensures sustainably fished seafood is tracked from wild catch to dinner plate (see http://www.msc.org). The three MSC principles for sustainable fishing were developed on the basis of the FAO Code of Conduct for Responsible Fisheries (FAO 1995). One of the principles is to maintain or re-establish healthy populations of targeted species. MSC criteria for salmon fishery certification focuses specifically on wild salmon management. Currently, MSC considers two components to a fished stock in their assessments: a hatchery component and a natural reproductive component. The natural reproductive component, according to MSC guidelines, must be able to maintain itself without having to be restocked every year. Further, the stocking cannot form a major part of the current rebuilding plan for depleted stocks (MSC 2009). The Technical Advisory Board of MSC informed the Hokkaido Federation of Fisheries Cooperative Association (HFFCA) as a client that the Hokkaido chum salmon trap net fishery is in transitional scope because of a lack of clear evidence of wild salmon management (HFFCA, pers. comm.). Before entering the full-assessment, wild salmon policy and management (including the establishment of escapement goals) are needed in the Hokkaido chum salmon trap net fishery.

Therefore, there are now strong ecological and economic incentives to reform salmon fishery management in Hokkaido. In this paper, we first review the effects of hatchery programs, the current status of natural or wild salmon and their habitat, and salmon management issues related to the MSC assessment. Finally we conclude with some ideas concerning management reform to restore natural ecosystem function of Hokkaido salmon rivers and to maintain the coexistence of wild and hatchery salmon in this region.

Definition of terms and data sources

For the purposes of this paper, we distinguish three different categories of salmon in Hokkaido: 1) Hatchery-origin salmon (or hatchery salmon) are salmon that are raised in hatcheries and released into the stream as juveniles, 2) Natural-origin salmon (or natural salmon) are salmon that originate from naturally spawning parents (i.e. hatch from eggs deposited into gravel in a stream), and 3) Wild salmon are salmon that have not been significantly influenced (genetically and ecologically) by hatchery activities. By this definition, type 3 salmon is a special case (a subset) of type 2 salmon. At this time, MSC does not distinguish type 2 and 3. Hence, wild salmon, as defined by MSC, are salmon that are produced by spawning in natural habitat.

Further, we distinguish four different types of streams in Hokkaido: 1) streams where hatcheries are located and hatchery salmon are released and returning hatchery salmon are captured as brood stock, 2) streams that receive hatchery plants but have no hatchery facilities and returning adult salmon are not taken as brood stock, 3) streams that have received hatchery releases in the past but currently do not receive any hatchery releases, and 4) streams that have never received hatchery plants. These categories are the same as those used by Miyakoshi et al. (2011).

Based on this scheme, streams in Hokkaido can be clearly categorized, but distinguishing between the three different salmon "types" is very uncertain given the limited marking programs and uncertainty about the scale of straying, introgression and ecological interactions occurring. Currently, the ratio of otolith-marked chum and pink salmon to total hatchery releases is very low (<15%, National Salmon Resources Center 2009). No mass marking programs currently exist for the other salmon species. Given this uncertainty, we identify in this paper only hatchery-origin and natural-origin salmon, acknowledging that the latter type includes an unknown proportion of wild salmon that we are unable to estimate at this time.

We used data of commercial catch numbers in the sea and stream catch numbers for hatchery programs of chum and pink salmon (Hokkaido Salmon Hatchery 1971–1998; National Salmon Resources Center 1999–2009). Chum salmon and pink salmon are caught by trap (set) net fishing in the coastal waters from late August to mid December and from late July to early October, respectively. This represents a period just prior to entry into their natal streams for spawning. We also report data on commercial catch in the sea and hatchery brood stock take in streams by hatcheries releasing masu salmon in Hokkaido (Hokkaido Fish Hatchery 1983–2007; Hokkaido Salmon Hatchery 1971–1998; National Salmon Resources Center 1999–2009). Masu salmon are caught by several types of fishing gear, including trap nets, gill nets, and angling, mainly during January to May in the coastal waters. Masu salmon return to their natal streams earlier in the season (spring to early summer) compared to chum salmon and pink salmon, and reside in streams several months before spawning in autumn. We characterized the chum salmon fishery using a variety of data sources, including commercial catch weight (metric tons), economical yield (Japanese yen) and Ex-vessel price (Japanese yen per kg) (Hokkaido Fishing Zone Coordination Commission 1986–2008). HFZCC collect these data from each of the local fisheries cooperative associations at 10 day intervals during the fishing season. In addition, we report export figures of chum salmon (Hokkaido Trap Net Fishery Association 2010).

To characterize hatchery activities, we obtained hatchery release data for chum salmon and pink salmon juveniles (Hokkaido Salmon Hatchery 1971–1998; National Salmon Resources Center 1999–2009) and masu salmon juveniles (Hokkaido Salmon Hatchery 1971–1998; National Salmon Resources Center 1999–2004; Hokkaido Fish Hatchery 1971–2004).

Hokkaido salmon status

Chum salmon Hatchery programs of chum salmon in Hokkaido began during the late 1880s to provide salmon for harvest in commercial fisheries. The number of chum salmon juvenile releases has increased since the 1970s, and has reached ca. 1 billion juveniles per year (Fig. 1A). These juveniles are released into 139 streams (Fig. 1B) and held in 80 marine net pen sites before release. Although the effectiveness of hatchery releases has not been explicitly examined, commercial chum salmon catches have increased dramatically since the 1970s (r=0.910, p<0.001) and has shown strong coherence with the amount of brood stock take in hatchery streams (Fig. 1A). The number of coastal trap nets also increased from ca. 400 to ca. 1,000 after 1968, commensurate with the total commercial catch (Morita et al. 2006b). This increase in fish abundance coincided with improvements in hatchery techniques (Kobayashi 1980) and improvement in marine survival as a result of shifts in ocean conditions (Kaeriyama 1999; Kaeriyama et al.

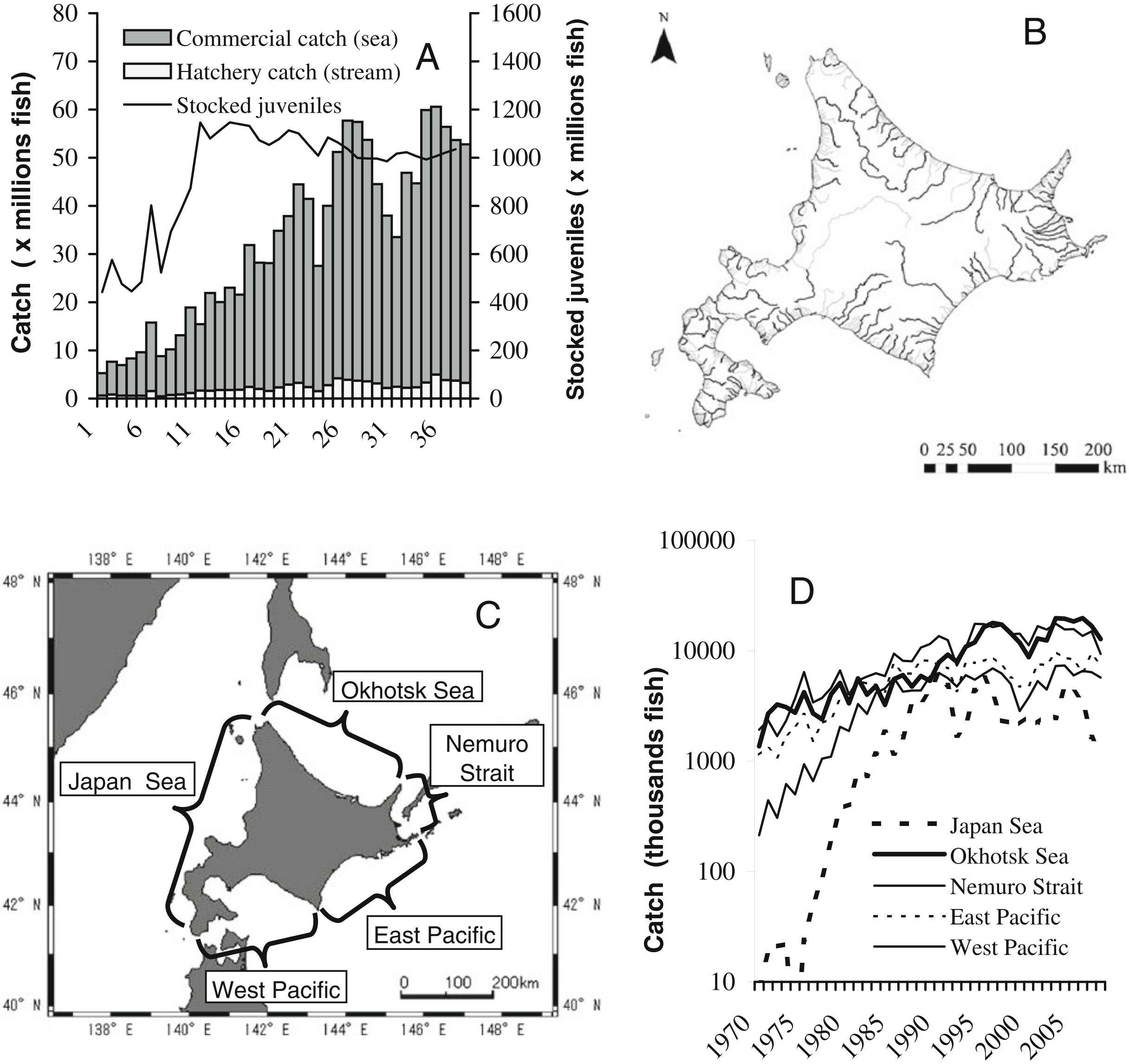

Fig. 1 Long term changes in annual commercial catch, hatchery catch and stocked juveniles of chum salmon in Hokkaido Island (**A**), location (*solid line*) of streams stocked juveniles (**B**) and commercial catch for each region in Hokkaido, Japan (**C**, **D**)

2011). However, there is continued concern about diminishing salmon carrying capacity in the North Pacific Ocean (Kaeriyama 2004). Hokkaido chum salmon are divided into five genetic strains (Japan Sea, Okhotsk Sea, Nemuro Strait, eastern, and western Pacific Ocean, Fig. 1C) based on microsatellite DNA analysis (Beacham et al. 2008). Chum salmon catch shows different trends for each strain (Fig. 1D). While chum salmon catches at the Nemuro Strait and the Pacific Ocean regions of Hokkaido increased since the 1970s–1980s, chum salmon catches in the Okhotsk Sea did not exhibit a marked increase until the 1990s. In contrast, chum salmon in the Japanese Sea have tended to decrease since the 1990s. Because releases of Hokkaido chum salmon have been relatively stable from year to year (ca. 200 million individuals in each region), these different fluctuations may be the result of dynamic coastal water conditions during their early ocean life that can affect food production and predation

(Nagata et al. 2007). Therefore, it is important to research not only the carrying capacity in the offshore ocean but also production dynamics in the coastal environments (Nagata et al. 2007; Kaeriyama et al. 2011). While genetic diversity of chum salmon populations in Hokkaido was reported to be lower than those of Russian and North American chum salmon populations (Altukhov et al. 2000), recent DNA analyses could not confirm low genetic diversity of chum salmon populations in Hokkaido (Sato et al. 2004; Beacham et al. 2008).

Commercial catches of chum salmon consisted of approximately 10 million individuals in the early 1900s when there were almost no hatchery programs operating (Kobayashi 1980). During this era chum salmon were supported by natural spawning (wild salmon) in many streams around Hokkaido. When hatchery programs became active and wild salmon declined following 1960, the number of salmon streams supporting natural spawning was estimated to be at least 107 (the total number of surveyed streams is unknown). These streams were distributed across Hokkaido: 29 streams in the Okhotsk and Nemuro regions, 41 streams in the Pacific Ocean regions, and 37 streams flowing into the Japan Sea (Hokkaido Salmon Hatchery 1964). Preliminary results from a river survey conducted in 2008 and 2009 showed that natural spawning still occurs in 104 and 89 streams observed in 2008 and 2009, respectively, out of a total of 239 surveyed streams in both years (Miyakoshi et al. 2011). Moreover, the spawning period of naturally spawning salmon in the Uebetsu River (a natural salmon stream near the Shiretoko World Natural Heritage Site in northeastern Hokkaido) extended from mid September to late December. This natural spawning period was more protracted than that observed for returning hatchery chum in the same river system (Hokkaido Fish Hatchery 2010). In addition, the majority of upriver spawners were determined to be of natural-origin based on otolith marks (Hokkaido Fish Hatchery 2010). These differences in spawning or run timing between natural and hatchery spawners may be caused by protocols of selective breeding used by the hatchery programs to conform better with the established commercial fishing seasons. Therefore, the challenge is to maintain commercial yield of hatchery salmon while not disrupting the locally adapted salmon populations, currently representing a mixed population of hatchery-origin, natural-origin and wild salmon. In order to manage natural-origin and wild salmon, we need to establish escapement goals in the wild and natural salmon streams and to estimate and control straying from other hatchery systems. This will require a monitoring survey that includes hatchery marking and quantitative escapement surveys of natural spawning grounds. Unfortunately few data exist from quantitative surveys of escapement (Miyakoshi et al. 2011).

Pink salmon Pink salmon in Hokkaido are mainly distributed and caught around the Okhotsk Sea (Morita et al. 2006b). The number of hatchery juveniles released per year has increased since the early 1980s and reached ca. 140 million in the late 1980s (Fig. 2A). These juveniles are now released into 42 streams (Fig. 2B) and held in marine net pen sites before release in the Okhotsk Sea and Nemuro regions of Hokkaido. While pink salmon commercial catches in Hokkaido remained at a low level until the 1980s, since the early 1980s they have increased sharply in odd years (r=0.829, P<0.001) and even years (r=0.859, P<0.001, Fig. 2A). The even-year runs have experienced a decrease after 2004 (Fig. 2A). Hatchery pink salmon catches in streams also gradually increased since the 1980s (Fig. 2A). The total number of coastal small trap nets since 1968 was relatively constant at ca. 1,400 to ca. 1,800 nets (Morita et al. 2006b). Shimizu (2002) reported that the return rate for pink salmon from the 1967 to the 1995 brood years in the Okhotsk coastal region was negatively correlated with the concentration of sea ice, especially evident since the 1990 brood year that exhibited high survival during a period characterized by much less sea ice. Morita et al. (2006a) concluded that the recent increase in pink salmon abundance could be largely explained by natural reproduction and climate change, with increased hatchery releases having little effect. This assertion was based on three arguments: (1) pink salmon catch showed a biennial oscillation in spite of a constant number of juveniles releases indicating a substantial contribution of naturally spawned fish, (2) population trends of pink salmon are linked to climate variables such as autumn rainfall and winter storms that could be controlling reproduction of naturally spawning pink salmon in freshwater, and (3) the recapture rates of thermally marked pink salmon were very low, suggesting

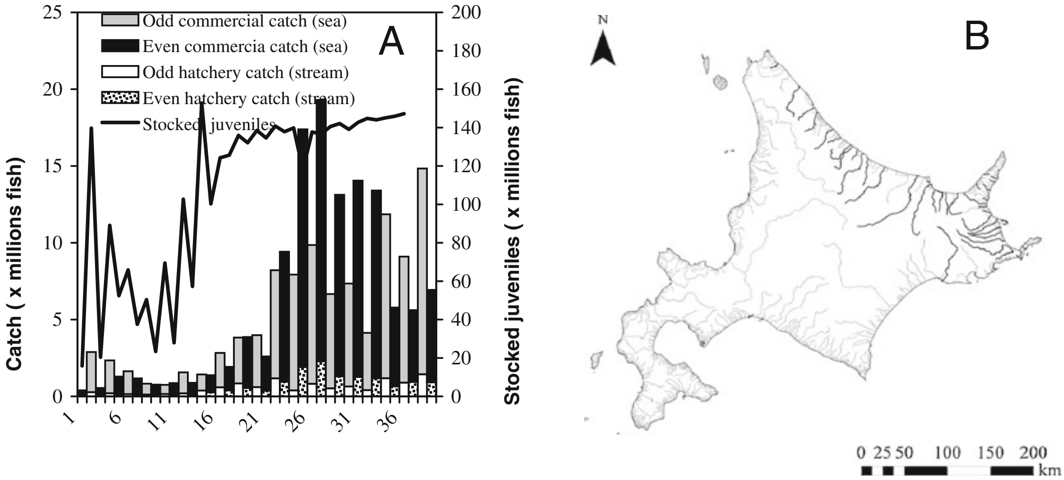

Fig. 2 Long term changes in annual commercial catch, hatchery catch and stocked juveniles of pink salmon in Hokkaido Island, Japan (**A**), and location (*solid line*) of streams stocked juveniles (**B**)

hatchery contribution to overall adult abundance was small (% of fry marked at release, 42% and 62% in the Tokushibetsu and Ichani Rivers, respectively;% of adults marked on return, 1% and 4%, respectively) (National Salmon Resources Center 2004). However, it does not appear that a biennial oscillation of pink salmon in Hokkaido is conspicuous because of temporal shifts from odd-year dominance to even-year dominance (Fig. 2). Further, pink salmon commercial catches increased sharply in the early 1990s along with chum salmon hatchery returns from the Okhotsk Sea, suggesting that hatcheries efforts likely contributed to overall abundance in both species (Fig. 1). Moreover, the increases of both species in the early 1990s might have resulted from favorable ocean conditions during their early ocean life (Shimizu 2002; Miyakoshi et al. 2007), not freshwater environments. In addition, a recent study showed high recapture rates of marked hatchery pink salmon in the Tohoro River of the Nemuro Strait (% of otolith-marked fry at release, 100%;% of marked adults on return, 63%), and wide straying (1–5%, marked adults in the total catch) in streams up to 60 km from the Tohoro R. (Hokkaido Fish Hatchery 2010). These results differ from the low recapture rates observed in the Tokushibetsu and Ichani Rivers (National Salmon Resources Center 2004). Thus, there is a lack of compelling evidence that trends in pink salmon are driven strongly by natural reproduction. Therefore, the stocking effectiveness of hatchery pink salmon and the accurate number of naturally spawning pink salmon around Hokkaido have to be determined through more direct quantitative surveys of natural escapement and reproductive success of natural spawners. To properly manage both hatchery-origin and natural-origin pink salmon in Hokkaido, these surveys need to involve mass release of otolith-marked juveniles, enumeration and identification of naturally spawning adults, and an evaluation of natural recruitment dynamics to establish meaningful escapement goals (Yokoyama et al. 2010).

Masu salmon Masu salmon are generally anadromous in Hokkaido, but mature male parr also occur (Kato 1991). Sea run masu spend only 1 year in the Okhotsk Sea and coastal waters around Hokkaido, but they live in streams for more than 1 year before their seaward migration. This life history trait distinguishes them from chum and pink salmon, which go to the sea soon after emergence. As masu adults return to natal streams in spring and early summer, the fishing season in the sea extends from winter to spring. In contrast to Japanese chum and pink salmon, which have shown increases in numbers, masu salmon commercial catches have consistently decreased after 1970 (r=−0.847, P<0.001), especially in the Japan Sea despite many costly efforts to reverse this trend, including increased hatchery activity and rehabilitation of freshwater environments (Fig. 3A and B). However, brood stock catches of masu salmon in the streams have shown no clear trend, but have exhibited high year-to-year variability. One explanation to

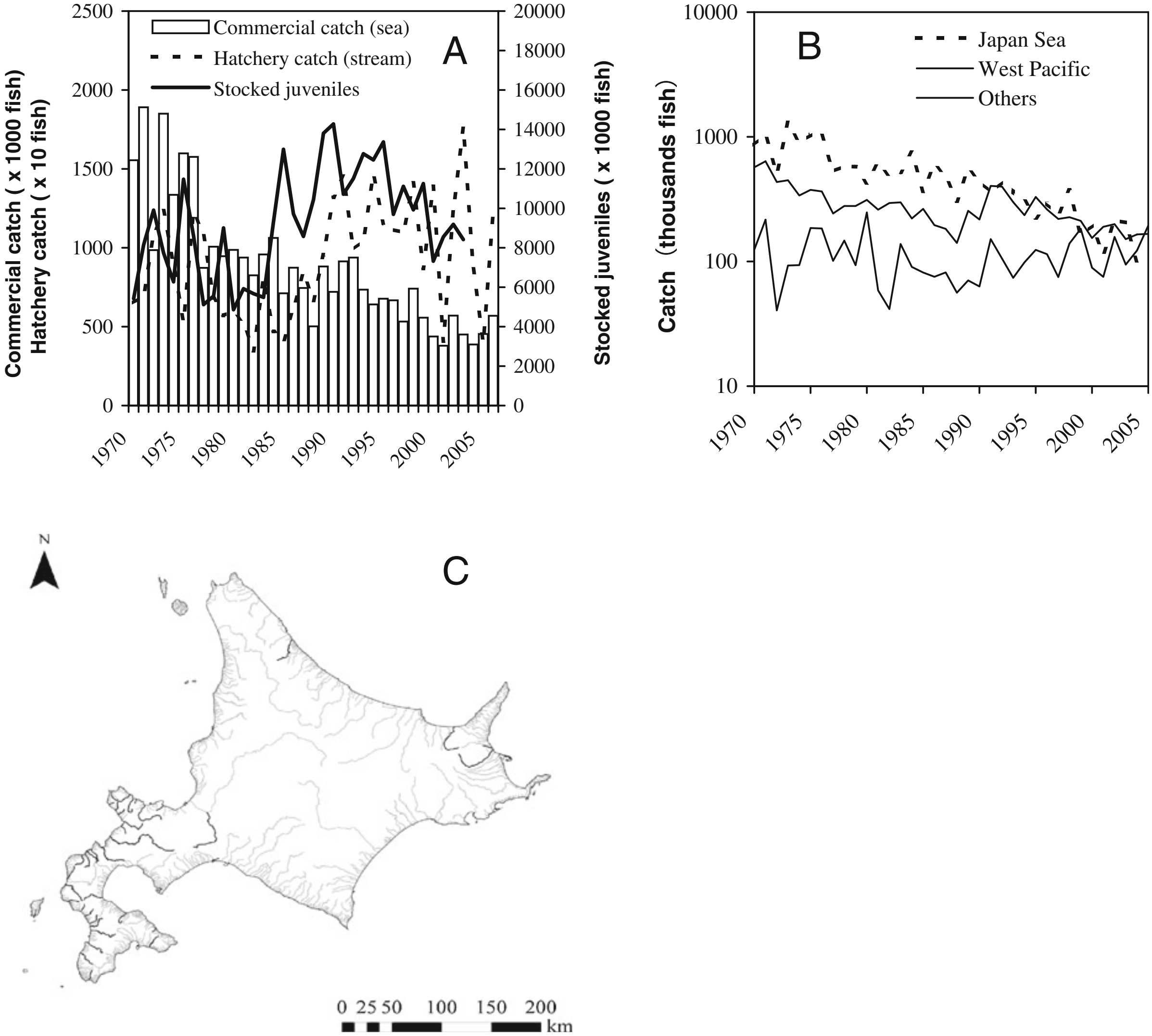

Fig. 3 Long term changes in annual commercial catch, hatchery catch and stocked juveniles of masu salmon in Hokkaido Island, Japan (**A**) and commercial catch in Japan Sea, West Pacific Ocean and others (**B**) and location (*solid line*) of streams stocked juveniles (**C**)

explain why masu salmon abundance has not expanded is the rise in recreational catch of juveniles (Ando et al. 2002). Recreational fishing for juvenile masu is very popular in Hokkaido because of the traditional food culture as well as a rising interest in masu fishing as a rewarding recreational activity. Therefore, people are not prohibited from fishing masu juveniles except in the spring season when masu salmon smolts migrate to sea. In addition, recreational fishing is prohibited all year in 32 conservation streams and 12 resources conservation streams (except in the winter season). These regulations were established by the national government and the Hokkaido government, respectively, as a means to conserve naturally spawning masu salmon in Hokkaido. Masu salmon hatchery releases have increased from 6 million to more than 10 million per year since the 1980s. In recent years, however, masu salmon hatchery releases have decreased to ca. 8 million per year (Fig. 3A). Masu salmon juveniles, including smolts, have been released into 38 steams, mainly coastal streams in southern Japan Sea (Fig. 3C). Because of a shortage of egg production for hatchery programs, two types of masu salmon stocks have been used for artificial propagation. The first type is from spawners that spend time in the ocean and are captured in natural streams, representing a natural brood stock. The other type is from spawners that have been cultured for successive generations in artificial, freshwater ponds, representing a captive brood stock. Captive brood stocks of masu salmon used for hatchery programs are reported to be divergent from wild masu salmon populations with respect to genetic markers (Edpalina et al. 2004; Yu et al. 2011) and smolt timing (Koyama et al. 2007). Therefore, recent programs have used captive brood stock that have experienced no more than one full generation in captivity in an effort to limit the effect of domestication.

Large scale release of fin-clipped juveniles and smolts was implemented to evaluate the stocking effectiveness of masu salmon (Miyakoshi et al. 2001a, b). On the basis of the recapture data in the fish-markets, average recovery rates of juveniles (0.6–1.0 g body weight) and smolts (14.8–38.2 g body weight) by commercial fisheries were 0.41% and 2.12%, respectively (Miyakoshi 2006). The contribution of adult hatchery masu salmon to commercial catches was estimated to be 14–26% in Hokkaido (Miyakoshi 2008). These estimates suggest that wild masu salmon may also contribute substantially to commercial fisheries, but the origin of these fish is unclear. Historically it has been difficult to capture brood stock of masu salmon given the difficulties of maintaining a weir under the high stream discharge regimes that prevail during their early, spring spawning migration. This results in substantial natural escapement of masu salmon to many streams in Hokkaido. As a result, natural spawning masu salmon may represent an important contributor to the commercial and recreational fishery in this region, and thus should remain a high priority for conservation. According to several reports on natural spawning of masu salmon in small mountain streams, masu salmon particularly favor the middle and upper part of the mainstem river and tributaries (Yanai et al. 1996; Omori 1998; Sugiwaka et al. 1999; Urabe et al. 2004). As documented above for chum and pink salmon, very few quantitative surveys have been conducted to enumerate natural escapement for masu salmon in Hokkaido streams. Riverine environments of Hokkaido have become degraded due to anthropogenic disturbances such as damming (Fukushim 2005), channelization (Nagata et al. 2002; Nagayama et al. 2008), and agricultural land use (Nagasaka et al. 2005). Impacts from these activities have been especially pronounced on masu salmon as a result of their relatively long freshwater life history stage. Therefore, in order to conserve wild salmon, rehabilitation of watershed environments have been implemented to improve adult passage to upstream spawning areas around Hokkaido since 1974 (Hokkaido Department of Fisheries 1992). As a condition to the inscription of the Shiretoko peninsula as a UNESCO Natural World Heritage Site in 2005, many dams on mountain streams have been removed or modified to improve passage to upstream spawning grounds in this region (Nakamura and Komiyama 2010). There are a number of other cases where habitats for adults and juveniles have been restored (Nagata et al. 2002; Kawaguchi et al. 2005). In a recent case, cooperation between a private paper company in Japan (Oji Paper, Inc.), a local conservation organization (Itou no Kai), and a non-profit conservation organization based in the USA (Wild Salmon Center) has resulted in the establishment of a new protected area, the Sarufutsu Environmental Conservation Forest in the Soya region of Hokkaido. Planned activities include improving adult fish passage to spawning ground by upgrading culverts with the aim of increasing production of naturally spawning salmon in this important river system. This represents a new approach in Japan that helps ensure that intact, productive freshwater habitat for a variety of species, including pink, chum and masu salmon in the Sarufutsu River, is conserved for the future.

Economic status of salmon

While Hokkaido chum salmon catches have increased over time, economic yields of chum salmon decreased during 1994–2003 (Fig. 4) as a result of depressed prices resulting from a dramatic increase in the supply of global salmon to Japan, particularly imported wild salmon from Alaska and farmed salmon from Norway and Chile (Morita et al. 2006b). In recent years, however, the HFFCA began to export surplus chum salmon to China in order to improve the domestic demand in Japan. As a result of this effort, ex-vessel price of chum salmon in the domestic market has recovered (Figs. 4 and 5). In China, imported chum are processed and packaged, and re-exported to markets in Europe and North America. However,

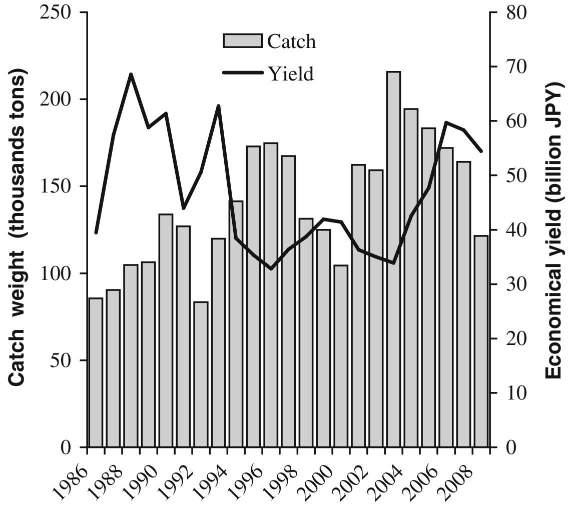

Fig. 4 Long term changes in commercial catch weight and economical yield of chum salmon in Hokkaido Island, Japan. Total catch and yield data are from Hokkaido Fishing Zone Coordination Commission (1986–2008)

Alaskan MSC-certified salmon are also being exported from Alaska to the China market (Shimizu 2007; NOAA 2010). Many global markets, particularly in Europe, are sourcing seafood exclusively from certified sustainable sources, including MSC certified fisheries. This has created an incentive for HFFCA to enter MSC assessment in order to earn increased share of this important emerging market. In order for the Hokkaido chum salmon trap net fishery to be considered for certification, a new wild salmon policy and management approach is needed.

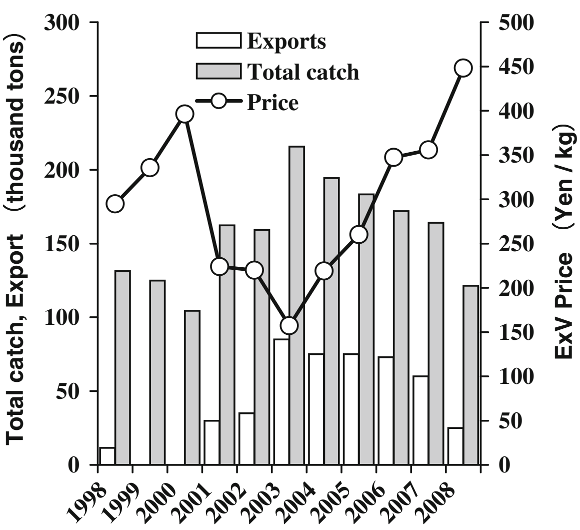

Fig. 5 Recent changes in commercial catch weight, exported amount and Ex-vessel price of chum salmon in Hokkaido Island, Japan. Values of exports are included in total catch

Salmon management and future perspective

We acknowledge that current efforts at managing natural reproduction of salmon are insufficient and the state of salmon streams in Hokkaido is inadequate to establish a sustainable commercial fishery as it is currently defined by MSC. In order to manage hatchery programs in a manner that minimizes risk to natural-origin and wild salmon while providing continued benefits to the commercial fishery, we need to establish a new policy of salmon management by striking a balance between wild salmon conservation and hatchery-based management. It is interesting to note that Hokkaido, since the 1950s, has been managing for natural reproduction of chum, pink and masu salmon by legally prohibiting commercial and recreational fishing for salmon adults in all Hokkaido streams under the Fisheries Law, the Fisheries Resources Protection Law and the Regulation of Inland Fisheries Adjustment in Hokkaido. Unfortunately, the aim of this management effort was to meet goals of hatchery brood stock take, not natural escapement. While records exist for brood stock take in salmon streams (Figs. 1B, 2B and 3A), there has been no concerted effort during this period to quantify status or trends of naturally spawning salmon in Hokkaido comparable to programs established in other countries. Because of this, it has not been possible to develop sustainable natural escapement goals in Hokkaido. Therefore, we recommend the Hokkaido government agencies and the private sector work together to develop a new wild salmon policy that builds on the existing hatchery management policy in Hokkaido. The Hokkaido Government has now made preliminary strides in developing this new framework for chum salmon. This policy may include implementing fishing regulations in the sea enforced by the government to ensure sufficient numbers of adult salmon enter the streams. This will require close collaboration with the private sector, including local fisheries cooperative associations and local salmon enhancement program associations (see Makino and Matsuda 2005; Makino et al. 2008). We recommend a framework be established to allow sufficient numbers of fish to escape the trap net fishery to achieve established natural escapement goals. As in the hatchery programs, this natural escapement program would be managed autonomously by the private sector. Kaeriyama and Edopalina (2004) emphasized the importance of establishing a system that allows natural- and hatchery-origin salmon to coexist by managing separate zones in freshwater environments. This would help to minimize the negative impacts such as competition, disease and genetic problems that can arise from hatchery programs (National Research Council 1996; Naish et al. 2007). Our preliminary stream surveys in Hokkaido reveal that many streams currently support natural spawning of chum salmon (Miyakoshi et al. 2011). Therefore, we need to implement zone-management based on coastal stream units or tributary units in large rivers to maintain natural salmon reproduction and to manage the hatchery system to minimize negative effects. As evidence of active reform, the private sector in the Okhotsk region in 2010 conducted quantitative surveys of adult chum salmon in 12 index streams supporting natural reproduction (Hirokazu Urabe et al. personal comm.). The overall aim of this initiative is to evaluate natural reproduction of chum salmon and the status of the natural stream environments under the guidance of the Salmon and Freshwater Fisheries Research Institute. An important component of this project is to quantify the ratio of natural-origin and hatchery-origin chum salmon in the spawning population based on an otolith-marking program conducted by the National Salmon Resources Center. As the marking program develops further, it is hoped that this work will ultimately lead to the establishment of escapement goals based on natural recruitment processes (Van Alen 2000) and a rigorous evaluation of hatchery straying (Brenner and Moffitt 2011). We hope that this approach to wild salmon management will extend to pink and masu salmon in the near future.

In addition to the establishment of new policies regarding wild salmon, it is also critical to establish stream restoration programs to rehabilitate freshwater environments to create more productive salmon habitat. Freshwater environments around Hokkaido Island have deteriorated and have become fragmented due to instream construction (e.g. dam construction, channelization and bank protection), logging, agriculture and other developments since the 1950s. These activities have degraded wild salmon habitat, especially masu salmon because they rely on upstream and tributary habitat and spend more than 1 year in freshwater before seaward migration (Fukushima and Kameyama 2006). However, more attention is now being paid to the importance of rebuilding the natural ecosystem since the passage of the River Act (amended in 1997) to help conserve and restore freshwater environments throughout Japan. While this work is intended to restore rivers to their original state, rehabilitation can be defined more broadly as the action of restoring habitat to a previous condition or status, not necessarily to some pristine, original state (Bradshaw 1996). Therefore, rehabilitation as implemented in Hokkaido could focus to recover naturally functioning streams that can support natural reproduction of salmon without returning the stream to a pristine state. Many programs in Hokkaido have been implemented to improve the freshwater environments for salmon. Before doing rehabilitation, it is important to first identify target species, then describe the current condition of fish habitat, and finally recommend fish habitat rehabilitation or restoration methods (Johnston and Slaney 1996; Cowx and Welcomme 1998). In the rehabilitation of the Shakotan River (Nagata et al. 2002), we described masu salmon fish habitat in this stream and evaluated fish habitat condition on the basis of recent studies. An accurate and precise description and evaluation of channelization impacts in the Shakotan River allowed us to propose fish habitat rehabilitation methods and procedures that could be applied to specific stream management sections. Fragmentation by dams has caused reduction of spawning habitat of salmon (Fukushima and Kameyama 2006). Although fish ladders have been installed since the 1970s in Hokkaido (Hokkaido Department of Fisheries 1992), recent efforts have focused on modifying existing dams to improve fish passage and allow greater movement of gravel and sediments that serve to maintain natural ecosystem function (Nakamura and Komiyama 2010). In addition, in order to recover both structure and function of these stream ecosystems, a channelized river has been restored to a more natural, meandering state using the isolated old channel (Akita et al. 2006). Therefore, it is important to improve our understanding of physical and biological components of streams and rivers, and how they interact to create and maintain salmon habitat (Stanford et al. 2005). By involving biologists and engineers in this cooperative investigation, we will be able to implement structural modifications to streams which have been demonstrated to benefit salmon.

Furthermore, because of limited information from biological and engineering disciplines, rehabilitation and restoration programs should be performed in the context of adaptive management.

Concluding remarks

Japan faces many challenges in developing new policies to support naturally reproduced salmon as a key component of a sustainable recreational and commercial fishery. In addition to the challenges we outlined in this paper, one of the paramount future challenges is addressing changes in marine carrying capacity and the uncertainty related to climate change. Hatchery programs will play an important role in meeting the food demands of an expanding human population in the 21st century. However, we have to conserve not only the genetic diversity of hatchery salmon but also maintain the wild and natural salmon populations that support our fisheries, provide important ecosystem services and contribute to our regional biodiversity. Therefore, it is imperative that we focus on the biological interactions between wild and hatchery salmon to avoid negative impacts. Harmony with the ecosystem and coexistence of wild and hatchery populations are extremely important issues for the North Pacific Rim nations. We hope this paper will motivate additional work to establish a new wild salmon management policy and restore, rehabilitate and protect salmon habitat throughout Hokkaido. To advance such basic ideas, in Japan we are taking preliminary steps to monitor natural reproduction of salmon, develop a new framework of zone management to separately manage wild, natural and hatchery salmon populations in freshwater, and rehabilitate wild salmon populations and natural ecosystems.

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References

Altukhov Y, Salmenkova EA, Omelchenko VT (2000) Salmonid fishes: population biology, genetics and management. Blackwell, Oxford

Akita M, Makiguhci Y, Nii H, Nakao K, Sandahl JF, Ueda H (2006) Upstream migration of chum salmon through a restored segment of the Shibetsu River. Ecol Freshwat Fish 15:125–130. doi:10.1111/j.1600-0633.2006.00153.x

Ando D, Miyakoshi Y, Takeuchi K, Nagata M, Sato T, Yanai S, Kitada S (2002) Estimates of numbers of juvenile masu salmon *Oncorhynchus masou* caught by recreational anglers in an urban stream. Nippon Suisan Gakk 68:52–60, In Japanese with English abstract

Bradshaw AD (1996) Underlying principles of restoration. Can J Fish Aquat Sci 53(Suppl):3–9

Beacham TD, Sato S, Urawa S, Lei KD, Wetklo M (2008) Population structure and stock identification of chum salmon *Oncorhynchus keta* from Japan determined by microsatellite DNA variation. Fish Sci 74:983–994. doi:10.1111/j.1444-2906.2008.01616.x

Brenner RE, Moffitt SD (2011) Hatchery salmon straying studies in Prince William Sound, Alaska. Environ Biol Fish

Cowx IG, Welcomme RL (1998) Rehabilitation of rivers for fish. Rome FAO

Edpalina RR, Yoon M, Urawa S, Kusuda S, Urano A, Abe S (2004) Genetic variation in wild and hatchery populations of masu salmon (*Oncorhynchus masou*) inferred from mitochondrial DNA sequence analysis. Fish Genet Breed Sci 34:37–44

FAO (1995) Code of conduct for responsible fisheries. Rome, FAO

Fukushim M (2005) The dam-related decline of freshwater fish diversity-analysis of the data collected from Hokkaido during the last half century. Jap J Ecol 55:349–357, In Japanese with English abstract

Fukushima M, Kameyama S (2006) The effect of damming on masu salmon and the Sakhalin taimen and the association of their conservation areas based on predictive habitat model. Ecol Civil Eng 8:233–244, In Japanese with English abstract

Hokkaido Department of Fisheries (1992) Hokkaido fisheries today, Hokkaido White Paper of Fisheries. Hokkaido Department of Fisheries, Sapporo, In Japanese

Hokkaido Fish Hatchery (1971–2007, 2010) Annual report. Hokkaido Fish Hatchery, Eniwa, Japan (In Japanese)

Hokkaido Fishing Zone Coordination Commission (1986–2008) Ten-days report of commercial catch for chum and pink salmon in Hokkaido. Hokkaido Fishing Zone Coordination Commission, Sapporo, Japan (In Japanese)

Hokkaido Salmon Hatchery (1964, 1971–1998) Annual report. Hokkaido Salmon Hatchery, Sapporo, Japan (In Japanese)

Hokkaido Trap Net Fishery Association (2010) Report of salmon market trends. (In Japanese)

Johnston NT, Slaney PA (1996) Fish habitat assessment procedures. Watershed Restoration Technical Circular 8, Ministry of Environment, Land and Parks and Ministry of Forests

Kaeriyama M (1999) Hatchery programmes and stock management of salmonid populations in Japan. In: Howell BR, Mokesness E, Svasand T (eds) Stock enhancement and sea ranching. Blackwell Science, London, pp 153–167

Kaeriyama M (2004) Evaluation of carrying capacity of Pacific salmon in the north Pacific Ocean for ecosystem-based sustainable conservation management. NPAFC Tech Rep 5:1–4

Kaeriyama M, Edopalina RR (2004) Evaluation of the biological interaction between wild and hatchery populations for sustainable fisheries management of Pacific salmon. In: Leber KM, Kitada S, Blankenship HL, Svåsand T (eds) Stock enhancement and sea ranching, 2nd edn. Blackwell Science, Oxford, pp 247–259

Kaeriyama M, Seo H, Kudo H, Nagata M (2011) A review of ecological interaction between wild and hatchery-derived populations of Pacific salmon in the North Pacific. Environ Biol Fish (submitted to this special issues)

Kato F (1991) Life histories of masu and amago salmon. In: Groot C, Margolis L (eds) Pacific salmon life histories. UBC Press, Vancouver, pp 447–520

Kawaguchi Y, Makamura F, Kayabe Y (2005) Effects of a re-meandering project on the physical habitats and fish in the Shibetsu River. Ecol Civ Eng 7:187–199

Kobayashi T (1980) Salmon propagation in Japan. In: Thorpe JE (ed) Salmon ranching. Academic, London, pp 91–107

Koyama T, Nagata M, Miyakoshi Y, Hayano H, Irvine JR (2007) Altered smolt timing for masu salmon *Oncorhynchus masou* resulting from domestication. Aquaculture 273:246–249. doi:10.1016/j.aquaculture.2007.10.006

Makino M, Matsuda H (2005) Co-management in Japanese coastal fisheries: institutional features and transaction costs. Mar Policy 29:441–450. doi:10.1016/j.marpol.2004.07.005

Makino M, Matsuda H, Sakurai Y (2008) Expanding fisheries co-management to ecosystem-based management: a case in the Shiretoko World Natural Heritage area, Japan. Mar Policy 33:207–214. doi:10.1016/j.marpol.2008.05.013

Marine Stewardship Council (2009) Enhanced fisheries—scope of application of the MSC Principles and Criteria. MSC TAB d-001 v2. Marine Stewardship Council–Technical Advisory Board, London, UK

Miyakoshi Y, Nagata M, Sugiwaka K, Kitada S (2001a) Commercial harvest of hatchery-reared masu salmon *Oncorhynchus masou* estimated by a coast-wide sampling program in Hokkaido, northern Japan, and the two-stage sampling schemes of landings. Fish Sci 67:126–133

Miyakoshi Y, Nagata M, Takeuchi K, Sugiwaka K, Kitada S (2001b) Effectiveness of stocking masu salmon *Oncorhynchus masou* fry as a means of increasing commercial catches. Fish Sci 67:1184–1186

Miyakoshi Y (2006) Evaluation of stock enhancement programs and stock assessment for masu salmon in Hokkaido, northern Japan. Sci Rep Hokkaido Fish Hatchery 60:1–64, In Japanese with English abstract

Miyakoshi Y, Saitoh S, Matsuoka A, Takada M, Asami H, Fujiwara M, Nagata M (2007) Comparison of release timing of hatchery-reared juveniles chum salmon (*Oncorhynchus keta*) to spring coastal sea surface temperature during high and low survival period. In: Nishida T, Kailola PJ, Caton AE (eds) GIS/spatial analysis in fishery and aquatic sciences (vol. 3). Fishery and Aquatic GIS Research Group, Saitama, pp 227–240

Miyakoshi Y (2008) Effectiveness of stocking and enhancement programs as a case study of masu salmon in Hokkaido. In: Kitada S, Kaeriyama M, Hamasaki K, Taniguchi N (eds) Enhancement and conservation for fisheries resources. Seizando-Shoten Publishing, Japan, pp 48–65, in Japanese

Miyakoshi Y, Urabe H, Saneyoshi H, Aoyama T, Sakamoto H, Ando D, Kasugai K, Mishima Y, Takada M, Nagata M (2011) The occurrence and persistence of naturally spawning chum salmon populations in northern Japan. Environ Biol Fish

Morita K, Morita SH, Fukuwaka M (2006a) Population dynamics of Japanese pink salmon (*Oncorhynchus gorbuscha*): are recent increase explained by hatchery programs or climatic variations? Can J Fish Aquat Sci 63:55–62

Morita K, Saito T, Miyakoshi Y, Fukuwaka M, Nagasawa T, Kaeriyama M (2006b) A review of Pacific salmon hatchery programmes on Hokkaido Island, Japan. ICES J Mar Sci 63:1353–1363. doi:10.1016/j.icesjms.2006.03.024

Nagasaka A, Yanai Y, Sato H, Hasegawa S (2005) Soil erosion and gally growth associated with cultivation in southwestern Hokkaido. Ecol Eng 24:503–508

Nagata M, Omori H, Yanai S (2002) Restoration of spawning and rearing habitats for masu salmon, *Oncorhynchus masou* in a channelized stream. Fish Sci (Supple. II): 1707–1710

Nagata M, Kaeriyama M (2004) Salmonid status and conservation in Japan. In: Gallaugher P, Wood L (eds) The proceedings of world summit on salmon, Simon Frazer University. B.C. Canada pp 89–97

Nagata M, Miyakoshi Y, Ando D, Fujiwara M, Sawada M, Shimada H, Asami H (2007) Influence of coastal seawater temperature on the distribution and growth of juvenile chum salmon, with recommendations for altered release strategies. N Pac Anadr Fish Comm Bull 4:223–235

Nagayama S, Kawaguchi Y, Nakano D, Nakamura F (2008) Methods for and fish responses to channel remeandering and large wood structure placement in the Shibetsu River Restoration Project in northern Japan. Landsc Ecol Eng 4:69–74

Naish KA, Taylor Iii JE, Levin PS, Quinn TP, Winton JR, Huppert D, Hilborn R (2007) An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon. Adv Mar Biol 54:61–194

Nakamura F, Komiyama E (2010) A challenge to dam improvement for the protection of both salmon and human livelihood in Shiretoko, Japan's third Natural Heritage Site. Landscape Ecol Eng 6:143–152. doi:10.1007/s11355-009-0083-6

National Research Council (1996) Upstream. National Academy Press, Washington, p 452

National Salmon Resources Center (1999–2009) Annual report. National Salmon Resources Center, Sapporo, Japan. (In Japanese)

NOAA (2010) Cumulative trade data by product, 2008–2009. NOAA Fisheries, Office of Science and Technology, Fisheries Statics Division. (http://www.st.nmmfs.noaa.qov/st1/trade/cumulative_data/TradeDataProduct.html)

Omori H (1998) Effect of rearing habitat restored for masu salmon in Shakotan River. In: A study on restoration of riparian environments in agricultural zone. Annual report of joint research program, pp 74–80. Hokkaido Forestry Research Institute, Hokkaido Fish Hatchery and Hokkaido Agricultural Research Institute. (In Japanese)

Sato S, Kojima H, Ando J, Ando H, Wilmot RL, Seeb LW, Efremov V, LeClair L, Buchholz W, Jin DH, Urawa S, Kaeriyama M, Urano A, Abe S (2004) Genetic population structure of chum salmon in the Pacific Rim inferred from mitochondrial DNA sequence variation. Environ Biol Fish 69:37–50

SCS (2007) The commercial Alaska salmon fisheries managed by the Alaska Department of Fish and Game, a 5-Year re-assessment based on the marine stewardship council program. Final report, 301 pp. Scientific Certification Systems, Inc, USA

Shimizu I (2002) Sea ice and return of pink salmon. In: Takahashi M, Shirasawa K (eds) Ecosystem of sea ice. Kaiyo Monthly 30: 178–186. (In Japanese)

Shimizu I (2007) Export issues of Japanese domestic salmon revealed by the market research of Chinese seafood. FRA Salmon Research Report 1:9–11, In Japanese

Stanford JA, Lorang MS, Hauer FR (2005) The shifting habitat mosaic of river ecosystems. Verh Internat Verein Limnol 29:123–136

Sugiwaka K, Takeuchi K, Suzuki K, Nagata M, Miyamoto M, Kawamula H (1999) Distribution and structure of spawning redds of masu salmon in the Atsuta River. Sci Rep Hokkaido Fish Hatch 53:11–28, In Japanese with English abstract

Urabe H, Murakami Y, Nakatsugawa M (2004) Evaluation of spawning habitat for masu salmon. Mon Rep Civ Eng Res Inst 613:32–44, In Japanese

Van Alen BW (2000) Status and stewardship of salmon stocks in southeast Alaska. In: Knudsen EE, Steward CR, MacDonald DD, Williams JE, Reiser DW (eds) Sustainable fisheries management. CRC Press. pp 161–193

Yanai S, Nagata M, Shakotan Research Group (1996) Various factors affecting the habitats of masu salmon (*Oncorhynchus masou* Brevoort) in an artificially regulated river, Central Hokkaido (III)- influence of civil engineering works on the spawning habitat of masu salmon. Trans Meet Hokkaido Branch Jap Soc 44:55–57, In Japanese

Yokoyama Y, Koshino Y, Miyamoto K, Kudo H, Kitada S, Kaeriyama M (2010) Estimating the spawning escapement of pink salmon *Oncoryhnchus gorbuscha* using the area-under-the-curve method in the Rusha River of the Shiretoko Penisula, Hokkaido Island. Nippon Suisan Gakk 76:383–391, In Japanese with English abstract

Yu J-N, Auma N, Abe S (2011) Genetic differentiation between collection of hatchery and wild masu salmon (*Oncorhynchous masou*) inferred from mitochondrial and microsatellite DNA analyses. Environ Biol Fish