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Strategies for reducing the ecological risks of hatchery programs: Case studies from the Pacific Northwest

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Abstract The Pacific Northwest state and federal agencies and tribes that operate salmon and steelhead (*Oncorhynchus* sp.) hatcheries are authorized to develop and implement strategies to reduce the risks the programs pose to wild fish populations. This paper reviews five case studies from the states of Oregon and Washington, USA, where agencies and tribes have implemented or proposed programs that were intended to reduce ecological risks due to hatchery programs. The case studies are for Oregon coho salmon, Select Area terminal fisheries programs for Chinook and coho salmon in the lower Columbia River, Hood Canal chum salmon in Puget Sound Washington, Siletz River steelhead on the Oregon coast, and Okanogan River Chinook salmon in eastern Washington. The five case studies address a diversity of management objectives and species. They demonstrate some of the science and risk reduction strategies used to alleviate the ecological effects of hatcheries, and they document some of the results and outcomes of taking action. Elements of four of the case studies have been in place for nearly 20 years. The available science and the conservation ethic toward hatchery programs evolved significantly over this period, and management decisions and strategies have been influenced by public policy as well as by scientific information. Therefore the case studies also document some of the history, the evolution of ideas, the uncertainty, and the political controversy associated with the management of this risk factor. The paper concludes with six principles to help guide the development of future risk reduction programs.

Keywords Hatchery · Ecological risk · Salmon and steelhead · Risk reduction

Introduction

Hatchery programs for Pacific salmon and steelhead (*Oncorhynchus* sp.) cause ecological risks to wild fish populations when the presence of hatchery fish detrimentally affects how wild fish interact with others of their own species, with their environment, or with other species (Kostow 2009). Some of the most commonly observed risks are direct predation of wild fish by hatchery fish (Parker 1971; Hargreaves and LeBrasseur 1986; Hawkins and Tipping 1999), competition between hatchery and wild fish (Nickleson et al. 1986; Nielsen 1994), attraction of other predator species, particularly when hatchery fish are concentrated in time and space (Collis et al. 1995; Nickelson 2003), density dependent effects triggered by large numbers of hatchery fish in freshwater and marine environments (Emlen et al. 1990; Kostow and Zhou 2006; Buhle et al. 2009), and disease transmission (Johnsen and

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Jensen 1986; Bartholomew and Reno 2002; Krkosek et al. 2005).

Management agencies and biologists in the Pacific Northwest began documenting ecological hatchery risks 30 years ago. Since that time, the science, the management, and the public ethic toward hatchery programs evolved significantly. In this paper, I present five case studies from the states of Oregon and Washington where managers acknowledged ecological risks and attempted to alleviate them. This management focus is rare. Hatchery risk management more often addresses interbreeding and genetics, and this perspective was particularly true in the early 1990s when four of the case studies began (see contemporary reviews by Hindar et al. 1991; Waples 1991). The actions taken in these case studies address a diversity of management objectives, problems, species, and jurisdictions.

It is important to emphasize that these case studies are histories of management, not examples of scientific experiments. Natural resource management is a process of taking action to deal with a complicated amalgam of environmental and social problems. Science has an important, but not a determinative, role in this process. Matters of law and public policy are also involved. The case studies are set in a context of multiple events and influences, including conflicting public interests and demands, human population growth, increasing urbanization, changes in harvest management, changes in public conservation ethic, habitat improvement and further degradation, natural environmental cycles, and scientific uncertainty. One clear fact in the Pacific Northwest is that salmon and steelhead abundances have declined for over a century, finally leading in the past decade to listings under the US Endangered Species Act (ESA) (16 U.S.C. §§ 1531–1544). Habitats deteriorated for a multitude of reasons while hatchery programs were implemented in lieu of curbing competing human demands (Lichatowich 1999; Taylor 1999). The genetic and ecological risks that hatchery programs pose to wild fish populations have been demonstrated by scientific studies (as reviewed by Araki et al. 2008; Fraser 2008; Naish et al. 2008; Kostow 2009), yet the roles and risks of hatchery programs remain contested (Brannon et al. 2004; Myers et al. 2004). While there is reason to believe that the ecological risks of hatchery programs contributed to the fish status problems addressed in these five case studies, this point could be debated. Ecological risks were demonstrated in only one of the case studies, Oregon coho salmon. In the other cases, risks were inferred from a reasonable survey of the available science and an assessment of the local circumstances. The scientific exploration of cause-and-effect often deteriorates in the public arena into blame-casting and simple answers that may be politically satisfactory but are not always scientifically sound or in the best interest of the fish (Taylor 1999). At some point, amid public policy debates and with only the information in hand, managers must decide what to do. Maintaining status quo is one possible decision and action. In the five case studies presented here the managers decided to do something else and took action to alleviate ecological hatchery risks that they believed were reasonably certain to be present.

In a recent paper (Kostow 2009), I reviewed some of the factors that contribute to increased ecological risks and listed 12 management strategies that have been used to alleviate these risks. This previous review was used to structure and compare the five case studies, which explore many of these strategies in more detail (summarized in Table 1). The case studies emphasize the kinds of ecological interactions originally reviewed by Kostow (2009). However, several of them also address risks due to mixed-stock harvests that target hatchery fish, due to disease transmission, or due to the effect of facility operations on the environment. These factors are also included in Table 1. Each case study presents a brief history, an analysis of the problem as it was originally perceived and as it evolved, a description of the strategies adopted to solve the problem, and a progress report on the outcome of the effort.

Case study 1: Oregon Coho Salmon

The case of Oregon Production Index (OPI) coho salmon (*O. kisutch*) is one of the best documented examples of the risks that large hatchery production and over-harvest pose to wild populations, and the political controversy that can obstruct management efforts to solve conservation problems. The OPI is a coho salmon harvest management unit that extends from the town of Ilwaco at the mouth of the Columbia River in Washington, south along the Oregon coast. Major production areas include the Columbia River and the Oregon coast (Fig. 1). OPI abundance has

Table 1 Strategies that were used in the five case studies to reduce the ecological risks of hatchery programs. All the case studies used multiple strategies (x) with a central theme that is indicated by bold capitals (**X**)

Strategies for reducing ecological hatchery risks (strategies 1–12 from Kostow 2009)	Case Study					
	Oregon Coho	Youngs Bay SAFE	Hood Canal Summer Chum		Siletz Summer Steelhead	Chief Joseph Hatchery
			Summer Chum	Programs for other species		
1. Operate hatchery programs within an integrated management context	x	x	x	x	x	x
2. Eliminate hatchery programs when they do not provide a benefit	**X**	x	x	x	x	
3. Reduce the number of hatchery fish that are released	**X**			x	x	x
4. Scale hatchery programs to fit carrying capacity					**X**	x
5. Limit the total number of hatchery fish that are released at a regional scale	**X**	**X**		x	x	
6. Only release juveniles that are actively smolting and will promptly out-migrate	x	x	x	x	x	
7. Release smaller hatchery fish, provided they are smolting						
8. Use acclimation ponds and volitional releases	x	x	x	x		x
9. Locate large releases of hatchery fish away from important natural production areas	x	**X**		x	x	**X**
10. Time hatchery fish releases to minimize ecological risks		x		**X**		
11. Restrict the number of hatchery adults allowed into natural production areas	x	x		x	**X**	x
12. Mark 100% of the hatchery fish and monitor the effects of hatchery programs	x	x	x		x	x
13. Reduce impacts on wild fish due to harvests that target hatchery fish	x	**X**		x		**X**
14. Address risks due to disease transfer		x	x	x		
15. Address risks due facility operations		x		x		
16. Additional strategies unique to the case study			**X**[a]	x[b]	**X**[c]	**X**[d]

[a] Release hatchery fry at a specific size window that facilitates niche separation and avoids competition for food, while also avoiding predation by hatchery fish on wild fish

[b] Restrict releases of hatchery trout to non-anadromous waters

[c] Restrict access of non-native salmonids from natural production areas

[d] Use hatchery supplementation to spread out the timing and spatial distribution of natural spawning to better utilize the available carrying capacity

been dominated by hatchery production since at least the 1960s but wild populations are also present. Harvest occurs in the ocean off southern Washington, Oregon and northern California, and in the Columbia River.

OPI coho abundance abruptly crashed in 1977. The cause of the crash was attributed to various factors, with substantial attention paid to an ocean regime shift in the late 1970s (Johnson 1984; Pearcy 1997). However, another observation made at the time of the crash was of the lack of a relationship between the numbers of hatchery fish released and adult returns (Fig. 2) (McGie 1980; Johnson 1984; Lichatowich and McIntyre 1987). Increasing numbers of hatchery coho smolts and pre-smolts were being released from Oregon and Washington state hatcheries in the Columbia River, federal hatcheries in the Columbia River, and state and private hatcheries on the Oregon coast (Fig. 3a, b), even while adult abundance

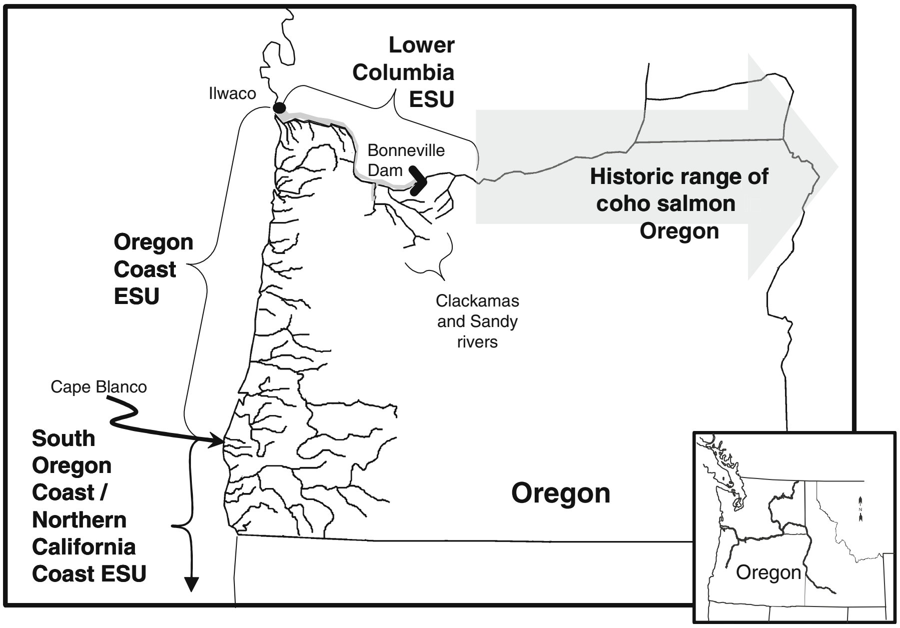

Fig. 1 Map of the range of the OPI coho harvest stock and wild coho populations in Oregon. The range of wild coho salmon currently includes basins in the lower Columbia River and along the entire Oregon coast. Coho became extinct in tributaries of the upper Columbia and Snake rivers in the 1980s. The remaining wild coho populations are divided into three ESUs

declined (Fig. 2). Most of the adults were accounted for in harvest as harvest rates averaged 82% during this period (Fig. 4). An index of wild coho salmon abundance, monitored since 1949 by a combination of spawning ground counts and dam counts, showed that wild Oregon coho salmon declined several years before the crash of the OPI (Fig. 5).

The State of Oregon adopted a coho salmon management plan in 1982, in response to the crash of the OPI (ODFW 1982). The plan attributed the crash to poor quality hatchery fish and environmental cycles and argued that there was no evidence of density-dependent effects of the large coho hatchery production in either freshwater or marine environments. The plan also defended the high harvest rates and supported the continuation or expansion of hatchery production. In particular, coho salmon in the Columbia River would "be managed primarily for hatchery production" and "underused natural production areas" would be "supplemented with surplus hatchery fish to increase and diversify the total production capabilities" (ODFW 1982). According to the plan "the greatest risk to the fisheries would be from a reduction in smolt numbers" (ODFW 1982). Subsequently, high smolt and pre-smolt releases continued through the 1980s (Fig. 3a, b).

The effects on wild fish of the hatchery and harvest practices in the Oregon coho management plan

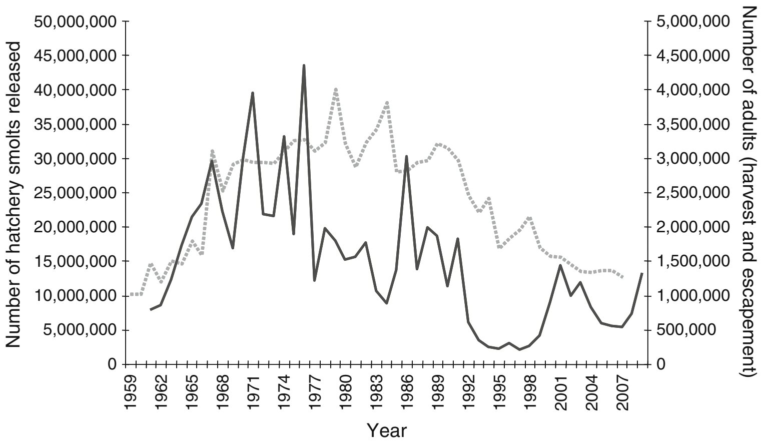

Fig. 2 Annual number of coho hatchery smolts released into the Columbia River and along the Oregon coast from 1960 to 2009 (*dashed line*), and the total number of coho adults (harvest plus escapement) produced by these releases (*solid line*). Data through 1981 previously reported by Lichatowich and McIntyre (1987)

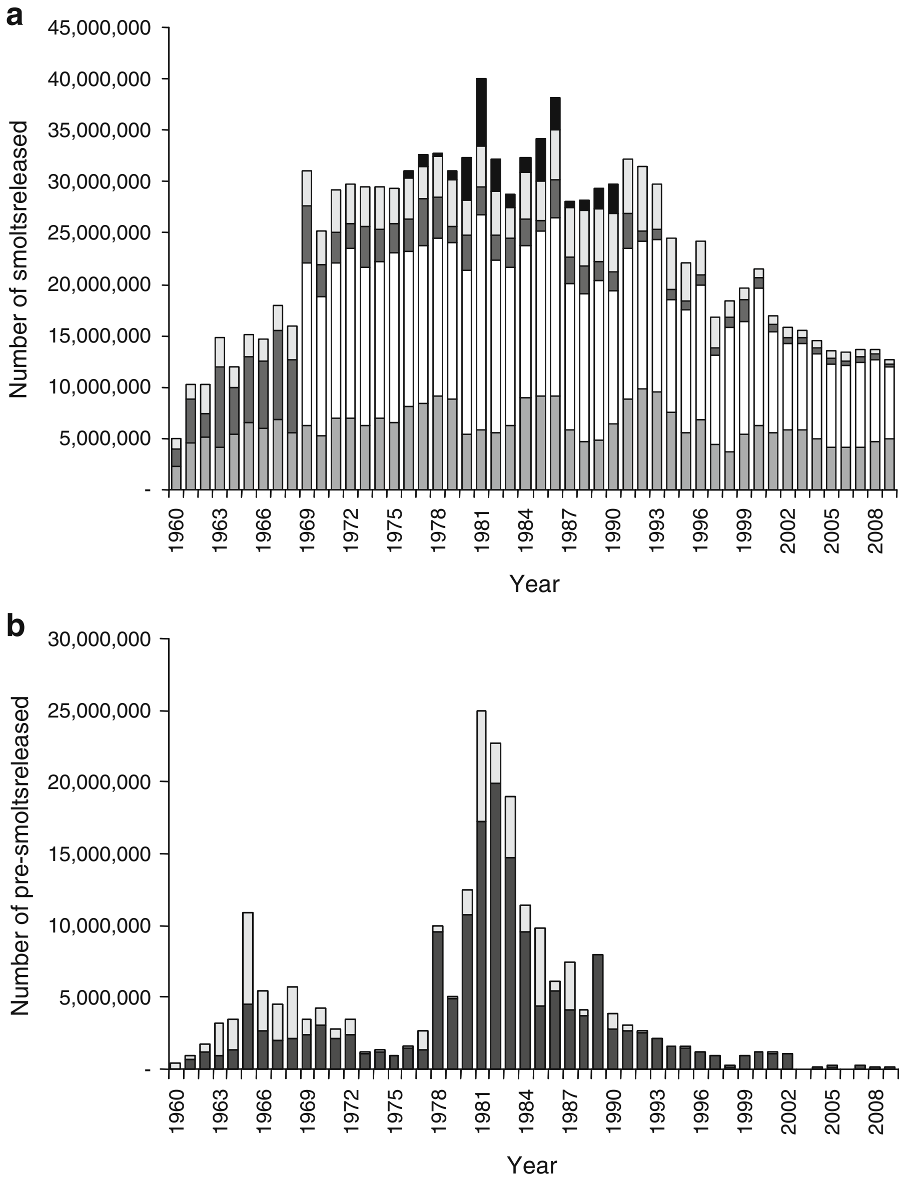

Fig. 3 (**a**) Break-out of the annual coho hatchery smolt releases from Fig. 2 by location and jurisdiction. Middle-grey bars are releases by ODFW into Oregon tributaries of the lower Columbia River, white bars are releases by WDFW into Washington tributaries of the lower Columbia River, dark-grey bars are releases into the lower Columbia River tributaries by federal hatcheries, pale-grey bars are releases by ODFW into Oregon coastal rivers, black bars are releases by private hatcheries into Oregon coastal rivers. (**b**) Annual number of coho hatchery pre-smolts released on the Oregon coast (*black bars*) and in the Oregon tributaries of the lower Columbia River (*grey bars*) (1960–2009). The pre-smolts require some freshwater rearing prior to out-migration. Historic coastal data from Willis (1979)

stimulated a series of publications about the risks of large hatchery production, over-harvest, density-dependent effects in freshwater and marine environments, and of out-planting hatchery fish into natural production areas (Lichatowich 1999). The first paper demonstrated how planting hatchery coho pre-smolts into natural habitats on the Oregon coast lowered wild fish productivity, most probably through competition (Nickelson et al. 1986). Lichatowich and McIntyre (1987) followed by demonstrating the association between increasing hatchery coho releases, decreasing coho harvest, and declining wild coho abundance in Oregon. Next, Emlen et al. (1990) provided evidence that large coho hatchery programs on the Oregon coast had density-dependent effects in the ocean. All three papers showed that, contrary to the arguments in the Oregon coho management plan, density dependent effects of the large hatchery releases were evident in both freshwater and marine environments. Natural environmental cycles in the marine environment likely contributed to optimistic returns of hatchery fish in good ocean years (Lichatowich 1999) and to more severe density dependent effects during the poor ocean years that started in the late 1970s (McGie 1984).

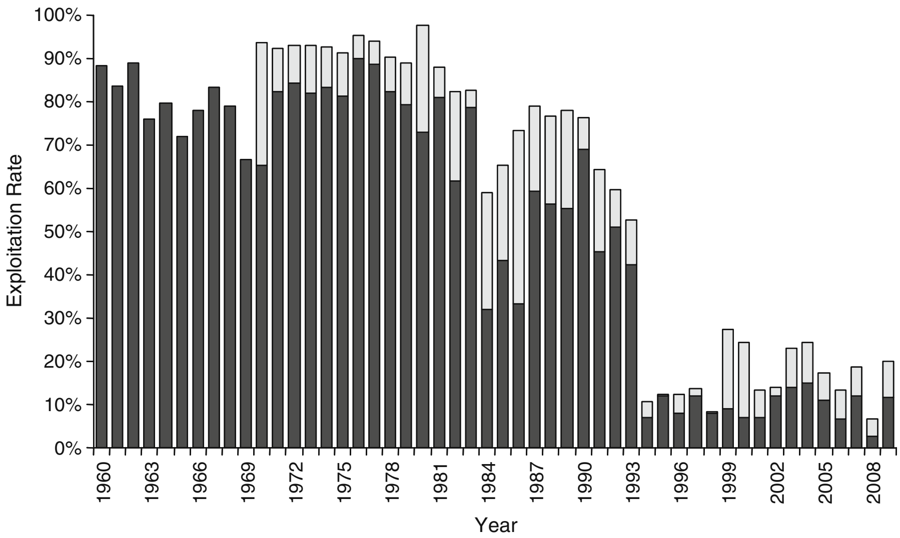

Fig. 4 Exploitation rates on OPI coho in the ocean (*black bars*) and lower Columbia (*grey bars*) (1960–2009). Coho were harvested in the lower Columbia prior to 1970, but were not separately enumerated

The science began to influence management by the early 1990s. Hatchery pre-smolt releases were curtailed state-wide (Fig. 3b) and all private hatchery programs on the Oregon coast were eliminated by 1991. However, state and federal agencies continued to release large numbers of hatchery smolts, particularly into the lower Columbia River (Fig. 3a). The result of managing the Columbia River "primarily for hatchery production" became evident. Wild coho salmon became extinct above Bonneville Dam (rkm 234) sometime in the 1980s (Kostow 1997). By 1995 spawning ground counts in Oregon tributaries below Bonneville Dam had dropped to near zero while fewer than 300 wild fish could be accounted for in the Clackamas and Sandy rivers. A review by Flagg et al. (1995) concluded that the combination of large hatchery releases and high harvest rates was driving lower Columbia River coho salmon to extinction.

Documentation of the impacts of the Oregon coho hatchery program continued into the 2000s. Nickelson (2003) found that releases of large numbers of hatchery coho smolts also depressed the productivity of wild coho salmon on the Oregon coast, probably through a combination of competition and predator attraction in estuaries. Finally adult hatchery coho were implicated when Buhle et al. (2009) did a retrospective analysis that demonstrated how large numbers of hatchery coho adults returning to natural spawning grounds on the Oregon coast had density-dependent effects on natural productivity.

As the literature documenting the risks of Oregon coho hatchery programs grew, status reviews in the 1990s demonstrated the fragile condition of Oregon's wild coho populations (Johnson et al. 1991; Nehlsen et al. 1991; Flagg et al. 1995; Kostow 1995; Weitkamp et al. 1995). Overall OPI abundance hit

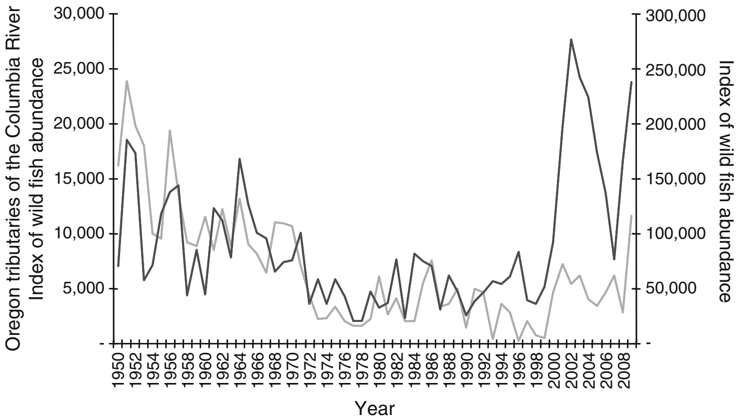

Fig. 5 Indices of wild coho abundance within the OPI area. The trend on the Oregon coast is shown by the black line, while the trend in Oregon tributaries of the Columbia River is shown by the grey line. Both indices include data from spawning ground surveys and dam counts

record lows in the mid-1990s (Fig. 2). After their initial decline in the early 1970s, coastal wild populations remained at low, relatively stable abundances for many years; but Columbia River wild populations continued to decline, reaching critical levels by the 1990s (Fig. 5). The two coho "Evolutionarily Significant Units" (ESUs) on the Oregon coast were listed as threatened species under the federal ESA in 1997 and 1998 (62 FR 24588; 63 FR 42587). However, National Marine Fisheries Service (NMFS) found that the coho ESU in the lower Columbia River was already extinct due to the history of extensive hatchery fish releases in the area (56 FR 29553). The State of Oregon disagreed with this finding based on the persistence of two weak but still extant wild coho populations in the Sandy and Clackamas rivers. In 1999, the State of Oregon listed lower Columbia River coho as a state endangered species (ODFW 2001; OAR 635-100-0190 through 0194).

Oregon Department of Fish and Wildlife (ODFW) began to address the impacts of the coho hatchery program in the mid-1990s. In 1992, Oregon adopted a new Wild Fish Management Policy (OAR 636-07-525) that emphasized wild fish protection and provided the authority to decrease hatchery risks. Various hatchery strategies were implemented, including those from Kostow (2009) indicated in Table 1. The main theme for decreasing hatchery risks to wild coho populations was to substantially decrease the number of hatchery fish that were being released. Some hatchery programs and stocks, including the Fall Creek hatchery stock in the Alsea River on the central Oregon coast and the Klaskanine hatchery stock in the lower Columbia River, were completely eliminated by the late 1990s.

The ESA listings of Oregon coho also had an effect on harvest rates. In 1999, the Pacific Fisheries Management Council (PFMC) adopted a harvest matrix based on escapement and marine survival to guide coho harvest in the ocean (PFMC 1999). Starting in 1994, harvest rates that historically exceeded 90% dropped to lower levels that were responsive to trends in wild coho abundance (Fig. 4). Later, ODFW adopted the matrix into its lower Columbia River coho recovery plan (ODFW 2001), its coastal coho recovery plan (ODFW 2007), and NMFS formalized a version of it in the 2008 Harvest Biological Opinion for the Columbia River (NMFS 2008).

ODFW's actions were scientifically supported by the papers from Nickelson et al. (1986), Lichatowich and McIntyre (1987), Emlen et al. (1990), and Flagg et al. (1995), as well as by a growing literature that documented the genetic risks of hatchery programs (Reisenbichler and McIntyre 1977; Reisenbichler 1988; Ryman and Laikre 1991; Waples 1991; Fleming et al. 1994; Berejikian 1995). However, the sound science was not enough to ward off controversy. In 1999, the combination of Oregon's elimination of the Fall Creek hatchery stock and the ESA listing of coastal coho triggered a political and legal controversy that challenged state and federal management authorities, questioned the role of hatchery fish, and upset all west coast salmon and steelhead ESA listings. At the heart of the suits was the argument that hatchery and wild fish were biologically equivalent and interchangeable so they should be treated the same way under the ESA. The plaintiffs' logic was that hatchery fish should be counted as contributing to fish abundance in ESA status reviews, and if this were done the fish would be abundant enough that ESA listings of most salmon and steelhead populations would not be warranted.

The Alsea Valley Alliance first went to state court to bar ODFW from eliminating the Fall Creek hatchery stock. The plaintiffs argued that the elimination of the hatchery stock was unlawful under state laws and regulations and asked for an injunction to prohibit the state from taking any action to stop adult hatchery coho from returning to spawn in the river or at the hatchery (Alsea Valley Alliance v Oregon Fish and Wildlife Commission Memorandum Opinion, Nov 11 1999 (Cir Ct Lincoln County OR)). The State of Oregon successfully defended itself, arguing that the best available science supported the decision to eliminate the Fall Creek hatchery stock; that decreased harvest rates lowered the demand for hatchery coho; and that the State of Oregon had the legal authority to make decisions to manage hatchery stocks, including the decision to eliminate them if appropriate (Alsea Valley Alliance v Oregon Fish and Wildlife Commission Avadavat of Douglas DeHart, Nov 11 1999 (Cir Ct Lincoln County OR); Alsea Valley Alliance v Oregon Fish and Wildlife Commission Brief of the State of Oregon Nov 11 1999 (Cir Ct Lincoln County OR)). The motion against Oregon was denied. The court found that state statutes authorize the state to decide "which fish will, and will not, be propagated in the waters of this state" (Alsea Valley Alliance v Oregon Fish and Wildlife

Commission Memorandum Opinion, Nov 11 1999, (Cir Ct Lincoln County OR)). Fall Creek Hatchery was closed and later reconstructed into a research facility.

The Alsea Valley Alliance then amended its complaint to challenge the federal ESA listing of the Oregon Coast Coho ESU and the NMFS hatchery policy (Alsea Valley Alliance v. Evans 161F. Supp.2d 1154 (D. Or. 2001)). Because NMFS had included some coho hatchery stocks in the coastal ESU (although, notably, not the Fall Creek stock), but had not extended ESA protection to the hatchery fish, the court found that NMFS had violated the ESA definition of "species" since "listing distinctions below that of a subspecies or a DPS[1] of a species are not allowed under ESA" (Alsea Valley Alliance v. Evans 161F. Supp.2d 1154 (D. Or. 2001)). The ESA listing of the Oregon Coast Coho ESU was voided. NMFS revised its hatchery policy (70 FR 37204) and re-reviewed and re-confirmed ESA listings for 27 salmon and steelhead ESUs/DPSs coastwide, finally also including the Lower Columbia River Coho ESU as a threatened species and re-listing the Oregon Coast Coho ESU (70 FR 37160; 70 FR 834; FR 73 7816). The new federal hatchery policy and ESA listing decisions were upheld by the Court of Appeals for the Ninth Circuit in 2009 (Trout Unlimited v. Lohn 559F.3d 946 (9th Cir. 2009)), finally concluding the case.

Oregon continued through the 2000s to decrease coho hatchery releases, eliminate coho hatchery stocks, and re-locate remaining coho hatchery production away from natural production areas (Fig. 3a, b). By 2009 the only remaining hatchery coho smolt programs on the Oregon coast were in the Nehalem, Trask (Tillamook Bay), Umpqua and Rogue rivers and the number of smolts released was only 5% of the number released in 1990. In the lower Columbia River, the 2009 hatchery coho smolt releases were down to 58% of the number released in 1990, reflecting decreases across all jurisdictions (Fig. 3a).

Oregon wild coho populations have increased in abundance since the lows of the 1990s, particularly on the Oregon coast where recent wild abundance has exceeded levels seen in the 1950s. Abundance of the Columbia River wild populations is also increasing, but more slowly (Fig. 5). Several factors probably contribute to the slower recovery of the Lower Columbia River Coho ESU. Some natural production areas in the lower Columbia were near zero abundance in the late 1990s and are just now being recolonized. Also, while the number of hatchery coho smolts released into the lower Columbia Basin declined, the remaining number, 12 million in 2009, is still substantial. Harvest rates on the lower Columbia River populations also remain higher because the populations experience both river and ocean fisheries (Fig. 4). Columbia River harvest managers adopted more protective protocols starting in 2006 and NMFS now constrains the ocean fisheries based on the status of the wild lower Columbia River populations (NMFS 2008). Abundance in the lower Columbia River continues to be concentrated in the Clackamas and Sandy rivers; however, naturally-produced coho are now present in Oregon tributaries from Youngs Bay to Hood River. Coho salmon also are being re-introduced into several basins within their historic range in the upper Columbia and Snake basins.

Case study 2: Youngs Bay SAFE program

The Select Area Fishery Enhancement Program, or SAFE program, is a terminal fishing program designed to allow harvest of known hatchery Chinook (*O. tshawytscha*) and coho salmon production while minimizing incidental affects of both harvest and hatchery activities on wild salmon and steelhead populations in the Columbia River. The Youngs Bay SAFE program is one of four current terminal fisheries programs located in off-channel areas near the Columbia River estuary in Oregon and Washington (Fig. 6). Youngs Bay joins the Columbia River estuary between rkms 16 and 24. The bay is the confluence of four small rivers with headwaters in the Oregon Coast Range: Youngs River, Klaskanine River, Walluski River, and Lewis and Clark River.

Hatchery-supported terminal fisheries in Youngs Bay date to the early 1900s when Klaskanine Hatchery was originally constructed. Bay fisheries were closed between 1931 and 1961, then reopened and expanded through the 1980s under a cooperative program between the State of Oregon and Clatsop County. The current SAFE program was established

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[1] "Distinct Population Segment" (DPS), language from the ESA referring to listable units under ESA; similar in concept to "ESUs".

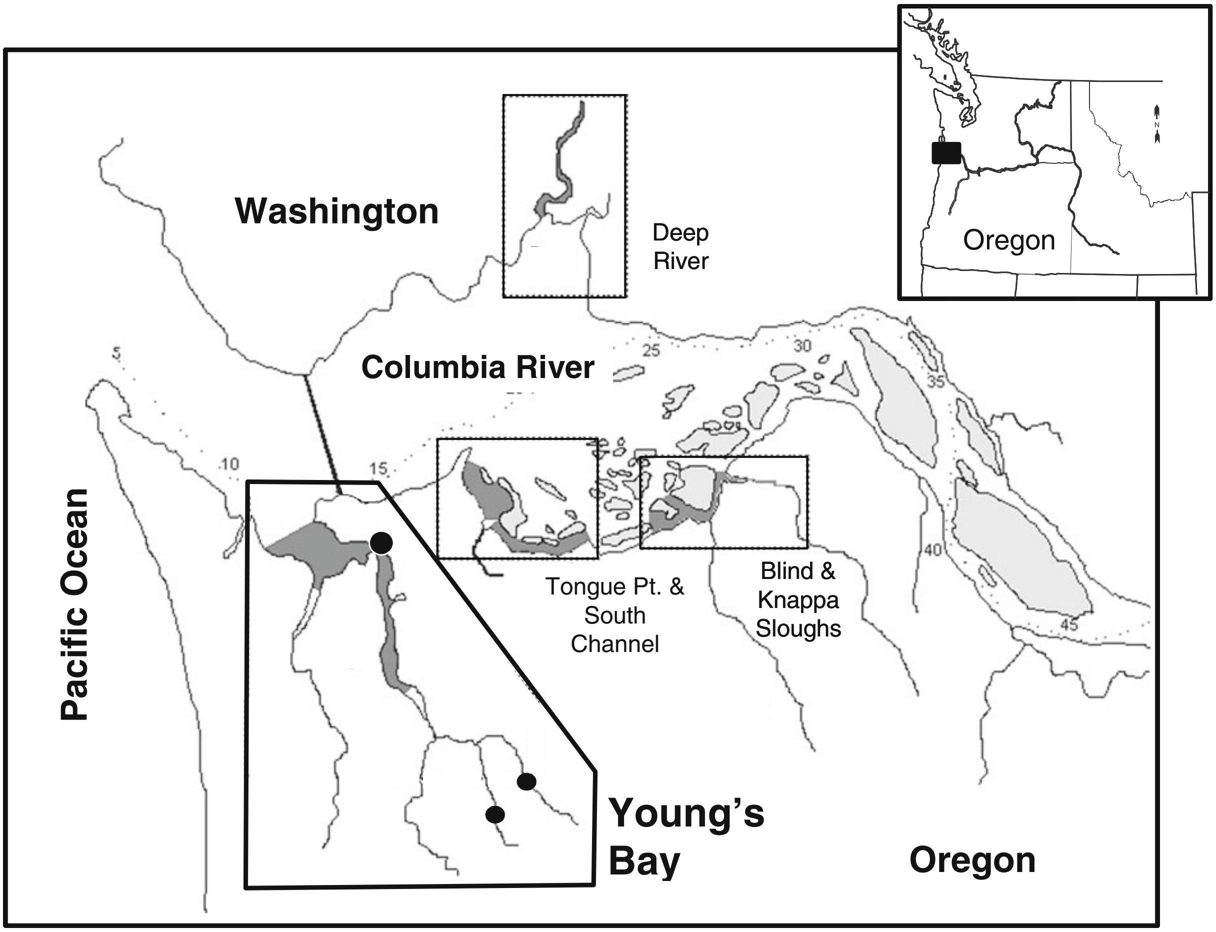


Fig. 6 Map of the current SAFE areas in the lower Columbia River including the Youngs Bay SAFE area. The terminal fishing zones are indicated in dark grey. The locations of the net pens and two hatchery facilities in Youngs Bay are shown as dots

in 1993 (North et al. 2006; Whisler et al. 2009). Three facilities release hatchery spring and fall Chinook and coho salmon to support the terminal fisheries in Youngs Bay, including the state-run Klaskanine Hatchery, the county-run South Fork Klaskanine Hatchery, and a complex of net pens located in the central bay that are supplied by production from other Columbia River basin hatcheries (Fig. 6). The SAFE programs include an intensive monitoring and evaluation program that annually assesses harvest rates on hatchery and wild fish and hatchery affects on natural fish production and on environmental quality in the bay (North et al. 2006; Whisler et al. 2009).

The concept of the SAFE programs is to concentrate hatchery fish releases and terminal fisheries on returning adults in a “dead-end” location away from important natural production areas. Important natural spawning areas on the Oregon side of the lower Columbia River are located upstream of the SAFE areas and include the mainstem Columbia, the Sandy, Clackamas, Scappoose and Clatskanie rivers plus other smaller tributaries of the lower Columbia, and the Willamette Basin. These basins produce wild spring and fall Chinook salmon, coho salmon, chum salmon (*O. keta*), and steelhead (*O. mykiss*), all of which are listed as threatened species under the federal ESA (70 FR 37160, 71 FR 834). Additional wild Chinook salmon and steelhead populations, some of which are also listed under ESA, pass through the lower Columbia River mainstem to spawning areas above Bonneville Dam.

The SAFE program has dual goals. One goal is to provide a cost-effective and high-quality fishery in the terminal area. Hatchery stocks that produce adults with high market value at the terminal location are preferred. In the Youngs Bay program, hatchery spring Chinook salmon from the Willamette River and "bright" hatchery fall Chinook salmon originally from the Rogue River on the south Oregon coast are particularly desired because these stocks have delayed maturation after entering fresh water. Rearing and release strategies that optimize smolt-to-adult survival are also desirable in order to produce a high return of quality hatchery adults for the number of smolts released.

The second goal, of equal importance to the success of the program, is to decrease impacts of both hatchery production and harvest on wild fish. The hatchery strategies from Kostow (2009) that have been used in the SAFE programs in Oregon are indicated in Table 1. The central theme has been to decrease hatchery production at a regional scale and to locate most of the remaining releases away from important natural production areas. On Oregon's side of the lower Columbia River, including the Willamette Basin, regional releases of hatchery fall Chinook, coho and spring Chinook salmon declined by 60% from 1992 to 2008 (Fig. 7a). The largest decrease, by 74%, was of fall Chinook salmon releases. Releases declined in the Willamette Basin by 63%, including the complete elimination of non-native fall Chinook and coho salmon hatchery programs. Releases declined in other lower Columbia basins by 71%. Hatchery fall Chinook and coho salmon releases into the SAFE areas also declined, partly due to increased efficiency. Spring Chinook salmon releases into SAFE areas increased during this period (Fig. 7b).

Within Youngs Bay, further steps are taken to lower hatchery risks. All releases are of vaccinated, acclimated smolts either from net pens in the bay or from the two hatchery facilities. The smolts at the two hatchery facilities are released volitionally. The net pen smolts are released at night on out-going tides, which moves them quickly out of freshwater. This strategy is intended to lower the opportunity for hatchery juveniles to interact with other species and to improve hatchery fish smolt-to-adult survival by decreasing predator attraction. Predator attraction continues to be a problem because the predators (primarily birds) are adaptable as long as large concentrations of hatchery smolts are present. Additional strategies will be needed to control this risk.

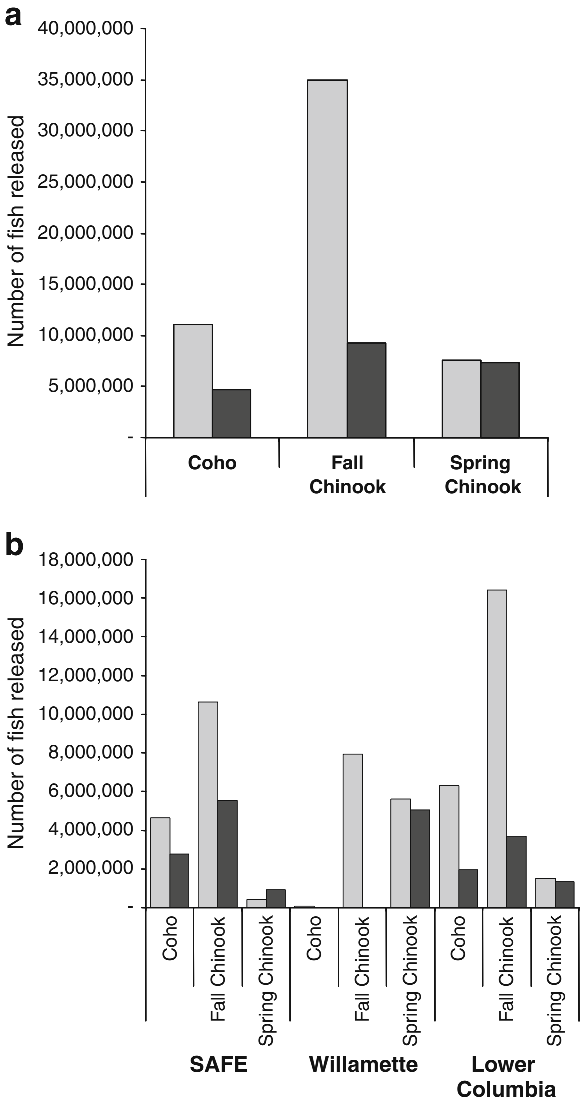


Fig. 7 (**a**) The number of hatchery coho, fall Chinook and spring Chinook salmon released regionally by ODFW and cooperators into Oregon tributaries of the lower Columbia River in 1992 (*grey bars*) compared to 2008 (*black bars*). Hatchery data are from Kostow (1995) and Chilton (2009). (**b**) Number of hatchery coho, fall Chinook and spring Chinook salmon by release area, comparing 1992 (*grey bars*) and 2008 (*black bars*). Hatchery data are from Kostow (1995) and Chilton (2009)

Hatchery adults are intended to be taken in fisheries and any straying outside of Youngs Bay is undesirable. Straying of hatchery adults from SAFE programs has been variable over the years. Some release locations have caused more problems than others, in particular the Deep River and original Tongue Point locations (Fig. 6). The release locations, timing and acclimation periods have been adjusted over the years to lower straying and continuous monitoring and adjustment is necessary to alleviate this risk. Managers are able to demonstrate that hatchery fish from the current SAFE programs stray less and only stray locally compared to releases from conventional hatchery programs. Based on recoveries of coded-wire tagged fish, hatchery fish from Youngs Bay releases are more often taken in commercial and recreational fisheries while fewer return to either hatchery racks or streams, compared to conventional releases of the same hatchery stocks elsewhere in the lower Columbia River (Fig. 8). Among the SAFE programs, the Youngs Bay releases produce the lowest number of strays into streams, and most of those are found in tributaries to Youngs Bay. The recovery of tags from streams does not provide enough information to estimate the percent of natural spawners that are hatchery fish. The estimate of hatchery fractions requires a good measurement of natural spawning abundance and differentiation of hatchery and wild fish on spawning grounds. Oregon managers are just beginning to conduct the systematic spawning ground surveys in the lower Columbia tributaries that eventually will provide this information.

The SAFE programs are also intended to decrease harvest impacts on wild salmon and steelhead. Harvest impacts to wild salmon and steelhead in mainstem fisheries are of substantial concern since the ESA listing of 13 ESUs/DPSs of sockeye (*O. nerka*), Chinook, coho, and chum salmon and steelhead in the Columbia Basin (70 FR 37160; 71 FR 834). All wild salmon and steelhead populations in the Columbia Basin move through the lower Columbia River mainstem during their spawning migrations. Historically, the Columbia River was host to a substantial indigenous, commercial, and recreational fishery (Craig and Hacker 1940; WDFW and ODFW 2002). Current commercial fisheries in the lower river use small boats fishing with gill nets or tangle nets, while recreational fisheries use hook-and-line gear. Harvest rates on the listed species are significantly reduced from historic levels and any mortality of wild fish is now considered an incidental impact in fisheries that target hatchery fish. An ESA Biological Opinion (NMFS 2008) places strict limits on these impacts. The SAFE programs are intended to optimize catch of the local hatchery stocks while minimizing incidental impacts on the listed species by locating fisheries away from important adult migration corridors. An example of this strategy and its effectiveness can be demonstrated by spring Chinook salmon. The allowed impact rate for non-tribal fisheries on ESA-listed spring Chinook salmon from above Bonneville Dam ranges from 0.5% to 2.7%, depending on abundance (NMFS 2008). Since 2002, the commercial catch of

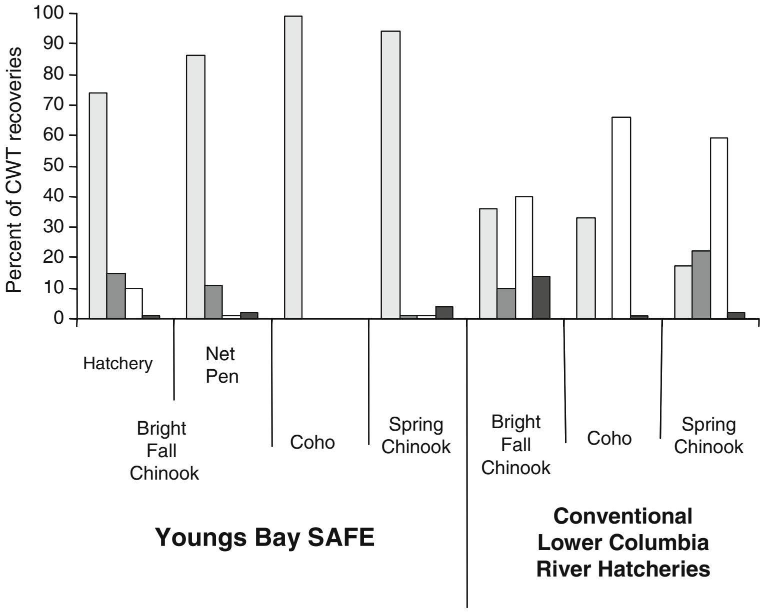


Fig. 8 Percent of coded wire tag (CWT) recoveries of Youngs Bay SAFE hatchery releases and conventional lower Columbia River hatchery releases of the same stocks in commercial fisheries (*light grey bars*), recreational fisheries (*dark grey bars*), at hatchery racks (*white bars*) and in streams (*black bars*). Recoveries are averages across all years with available data from 1990 through 2000 brood years. Data are from Whisler et al. (2009)

hatchery spring Chinook in the SAFE areas has been similar to the catch in the mainstem fisheries (Fig. 9a) while impact rates on wild upper Columbia River spring Chinook have been significantly lower (Fig. 9b). SAFE has provided an average of 52% of the total commercial catch, while imposing only 15% of the total impact on listed fish since 2002.

Although managers can demonstrate that regional hatchery and harvest risks are decreased by the SAFE programs, the biological benefits in terms of population responses are largely uncertain. Lower Columbia River wild coho abundance is increasing but population responses by other species, particularly wild lower Columbia fall Chinook, Willamette spring Chinook and chum salmon are not evident. The hatchery and harvest risks may not be decreased enough yet to benefit these species. For example, over 5 million hatchery spring Chinook smolts are still being released annually in the Willamette Basin (Fig. 7b) while the total exploitation rate on lower Columbia fall Chinook was still over 40% in the 2000s, primarily due to ocean fisheries (NMFS 2008). Also, decreasing harvest and hatchery impacts are only part of the overall recovery strategy. Extensive habitat rehabilitation will be needed in order to recover all lower Columbia and Willamette ESUs.

The SAFE programs also have several negative biological consequences. While they successfully decrease hatchery and harvest impacts on fish from elsewhere in the Columbia Basin, they concentrate the remaining impacts on any natural production that may occur in the local area. The concentrated impacts could impair salmon and steelhead recovery locally and basin-wide. Youngs Bay is within the range of historic spawning habitat for ESA-listed fall Chinook, coho and chum salmon. By the early 1990s, few wild

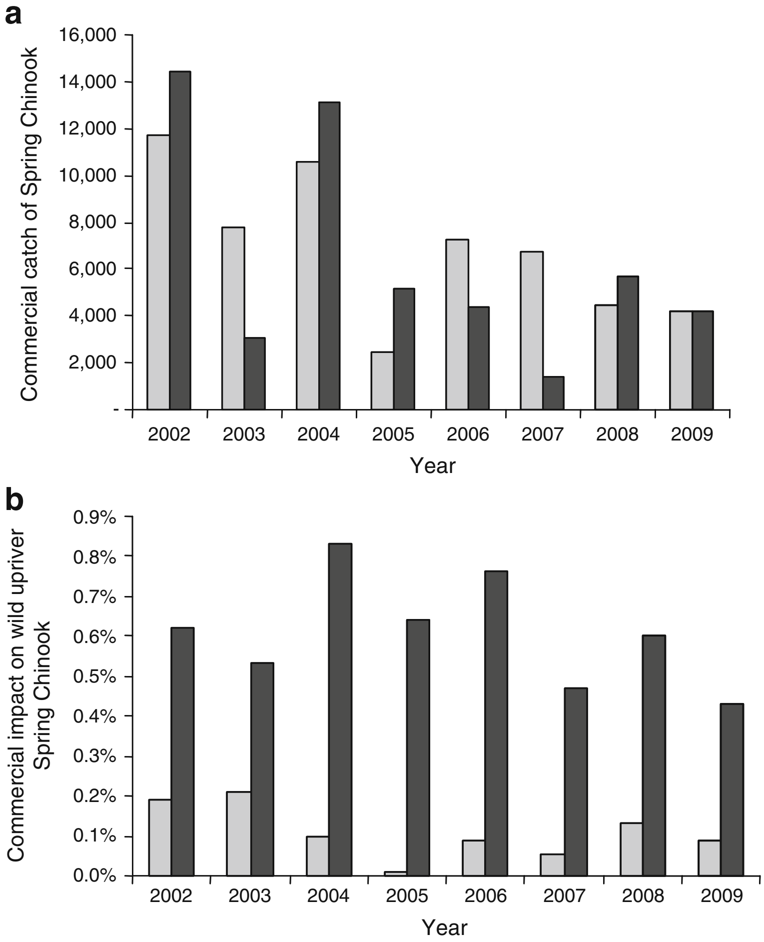


Fig. 9 (**a**) Comparison of commercial upriver spring Chinook salmon catch in the SAFE fisheries (*grey bars*) and mainstem Columbia River fisheries (*black bars*), 2002–2009. (**b**) Comparison of impacts on wild upriver spring Chinook salmon in the SAFE commercial fisheries (*grey bars*) and mainstem Columbia River commercial fisheries (*black bars*), 2002–2009. The mainstem commercial fishery is mark selective and impacts to wild fish are due to release mortalities

fish were spawning in bay tributaries and local habitats are degraded due primarily to historic forestry practices, but the basin has some recovery potential. Although the bay fisheries predominantly catch the local hatchery fish, any local wild fish that are present during the fishery are also encountered at a high rate. The fisheries close on October 31 so late returning species like chum salmon are not affected by them. But any early-returning wild fish, which includes some coho and fall Chinook salmon, remain vulnerable. Marked hatchery fish are regularly observed in the tributaries to the bay, while the number of wild (unmarked) fish on local spawning grounds remains very low (Whisler et al. 2009). Estuary rearing habitats are recognized as important for the recovery of salmon and steelhead populations throughout the Columbia Basin (Bottom et al. 2005) and Youngs Bay and the other SAFE areas cover a substantial portion of the Columbia River estuary. It is not known whether the SAFE programs have any effect on estuary rearing by wild out-migrants from elsewhere in the Columbia Basin. At this time, a trade-off has been accepted by regulators and the public as the SAFE programs are considered to provide public benefits while decreasing harvest and hatchery impacts on wild populations elsewhere in the Columbia Basin.

Case study 3: Hood Canal summer chum

Hood Canal in the state of Washington is a long fiord that adjoins North Puget Sound near its confluence with the Strait of Juan de Fuca (Fig. 10). The area is fed by numerous small river basins that drain either the high elevations of the eastern slopes of the Olympic Mountains (over 2000 m) or the low elevations of the Kitsap and Toandos peninsulas (less than 200 m). The Hood Canal summer chum is an independent ESU of *O. keta* that resides in Hood Canal and northward along the eastern Strait of Juan de Fuca (Johnson et al. 1997; Sands et al. 2009). Approximately 17 river basins in this area historically produced summer chum salmon, from the Dungeness River in the eastern Strait of Juan de Fuca to the Union River at the upper tip of Hood Canal (Fig. 10, Table 2). Unique characteristics of this ESU include the earliest adult migration timing among chum samon in the Puget Sound area. Adults migrate from late August to mid October and spawn soon after entering freshwater in the lowest reaches of their natal streams. Peak emergence occurs about the third week of March in Hood Canal and the first week of April in the Strait of Juan de Fuca, and sub-yearling smolt emigration through estuarine waters is complete by early May. The early adult migration timing creates a temporal separation from the more abundant fall chum salmon populations that spawn in the same geographic area, allowing for reproductive isolation and genetic distinction between the two life histories (Ames et al. 2000).

The Hood Canal Summer Chum ESU experienced a 30-year decline from historic escapements of over 40 000 fish in the 1960s to fewer than 1000 fish in 1990 (WDFW and WWTIT 1993). Summer chum salmon were likely extinct from two basins, Finch Creek and the Skokomish River, by the 1970s. Chum salmon in five additional basins had become extinct by 1990 (Table 2) (Ames et al. 2000). The abundance trend of the remaining summer chum salmon populations, including escapement and harvested fish, is shown in Fig. 11. The species received an ESA threatened listing in 1999 (64 FR 14508; 70 FR 37160).

Various factors are thought to have contributed to the summer chum salmon declines, including habitat degradation, climate-driven changes in hydrology, and incidental harvest in fisheries targeting other species (Johnson et al. 1997; Ames et al. 2000). Another contributing factor was thought to be the ecological effects of hatchery programs for other *Oncorhynchus* species. Fifteen hatchery facilities, including acclimation and broodstock collection sites, currently operate in Hood Canal, plus there is a complex on the Dungeness River (Fig. 10). The hatcheries are under multiple jurisdictions. The Washington Department of Fish and Wildlife (WDFW) operates several facilities and oversees additional cooperative programs with citizen volunteer groups and private operators. The Point No Point Treaty Tribes and the US Fish and Wildlife Service (USFWS) also have hatchery facilities in Hood Canal. By the early 1990s, these hatchery programs were producing fall chum salmon, steelhead, cutthroat trout (*O. clarki*), coho salmon, fall Chinook salmon, and odd-year pink salmon (*O. gorbuscha*). Small conservation programs for summer chum salmon were also beginning at this time. Each hatchery program was suspected of affecting wild summer chum salmon through various ecological

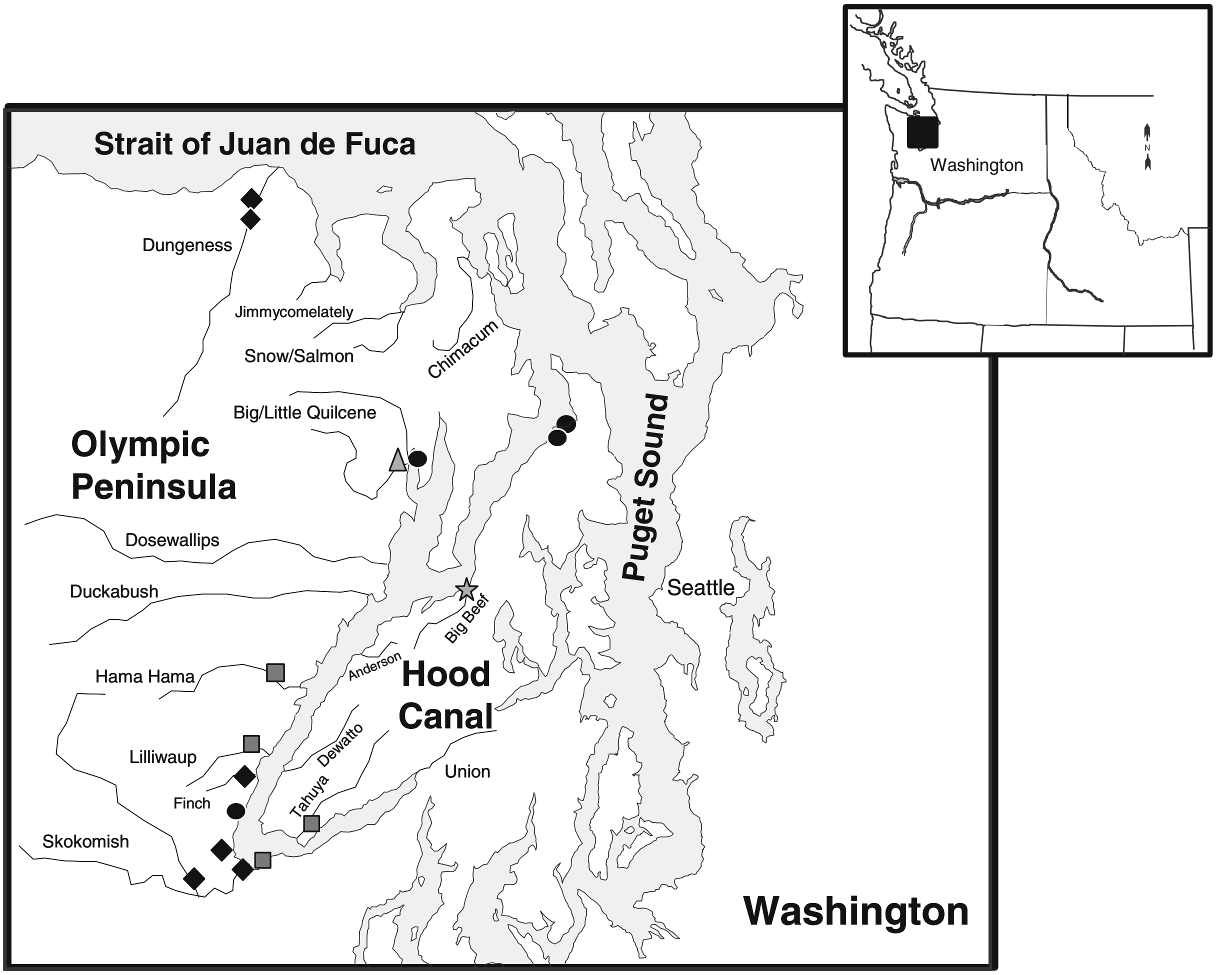


Fig. 10 Map of Hood Canal, Washington, showing the location of rivers currently or historically occupied by summer chum salmon (see Table 2), and the location of hatchery facilities by jurisdiction, including state (*diamonds*), tribal (*circles*), federal (*triangle*), private (*squares*) and university (*star*) hatchery facilities

mechanisms (Table 3). Piscivorous species, including coho salmon, steelhead, and cutthroat trout are direct predators on smaller juveniles such as wild summer chum salmon (Parker 1971; Hargreaves and LeBrasseur 1986; Hawkins and Tipping 1999). Large-sized hatchery fall Chinook and summer chum salmon also may prey on smaller wild summer chum. Other species, including fall Chinook salmon, pink salmon, fall chum salmon, and summer chum salmon are likely competitors for food (Hunter 1959) and may attract other fish, avian and mammalian predators when they are released in large numbers (Collis et al. 1995; Nickelson 2003).

The large fall chum salmon hatchery program in Hood Canal was particularly thought to pose risks to wild summer chum (Johnson et al. 1997; Ames et al. 2000). Artificial production in Hood Canal dates to the early 1900s, but the largest fall chum salmon program began in 1953 at the WDFW Hoodsport Hatchery on Finch Creek. Releases of hatchery fall chum salmon at the Hoodsport facility averaged over 30 million sub-yearling smolts a year, and peaked at over 50 million sub-yearling smolts in 1984 (Ames et al. 2000). Of the releases between 1977 and 1993, an average of 11 million hatchery chum a year was released prior to April 1, during the peak of wild summer chum salmon emergence in Hood Canal. About 10 million additional hatchery chum sub-yearling smolts were being released from federal, tribal, and volunteer hatchery programs by the early

Table 2 Escapement abundance and number of supplemented or reintroduced sub-yearling smolts released in Hood Canal summer chum salmon basins. Summer chum in Anderson, Dewatto, and Finch creeks and in the Skokomish River are considered to be extinct, while the presence of a population in the Dungeness River is uncertain. See Fig. 10 for locations of these basins

Region	River or creek	Status	Activity	Years when hatchery smolts were released		Total number of hatchery smolts released	Abundance (1990–94)	Abundance (2005–09)	Percent wild fish[a] (2001–04)
				Start Year	End Year				
Strait of Juan de Fuca	Jimmycomelately	Extant	Supplementation	1999	Continues	624 005	185	1275	38%
	Salmon	Extant	Supplementation	1992	2003	729 598	295	3025	62%
	Snow	Extant	Wild			0	15	455	60%
	Chimacum	Extinct	Reintroduction	1996	2003	434 633	0	1220	27%
Hood Canal	Little Quilcene	Extant	Wild			0	5	1385	85%
	Big Quilcene	Extant	Supplementation	1992	2003	3 635 163	330	3900	74%
	Dosewallips	Extant	Wild			0	250	2350	85%
	Duckabush	Extant	Wild			0	225	2115	78%
	Hamma Hamma	Extant	Supplementation	1997	2008	891 023	145	1655	73%
	Lilliwaup	Extant	Supplementation	1992	Continues	867 299	65	825	17%
	Union	Extant	Supplementation	2000	2003	267 327	320	1705	82%
	Tahuya	Extinct	Reintroduction	2004	Continues	662 443	0	490	0%
	Big Beef	Extinct	Reintroduction	1996	2004	884 280	0	735	3%

[a] Data from WDFW and PNPTT (2007)

1990s. It was thought that the combined numbers of wild and hatchery-produced chum smolts entering Hood Canal likely exceeded historic wild-only juvenile population levels, potentially triggering density-dependent effects on the wild summer chum (Ames et al. 2000). The growing fall chum salmon hatchery program correlated with the abundance decline of wild summer chum salmon (Johnson et al. 1997).

In 2000, the State of Washington and the Point No Point Treaty Tribes jointly adopted a Summer Chum Salmon Conservation Initiative to protect and restore wild summer chum salmon in Hood Canal and the

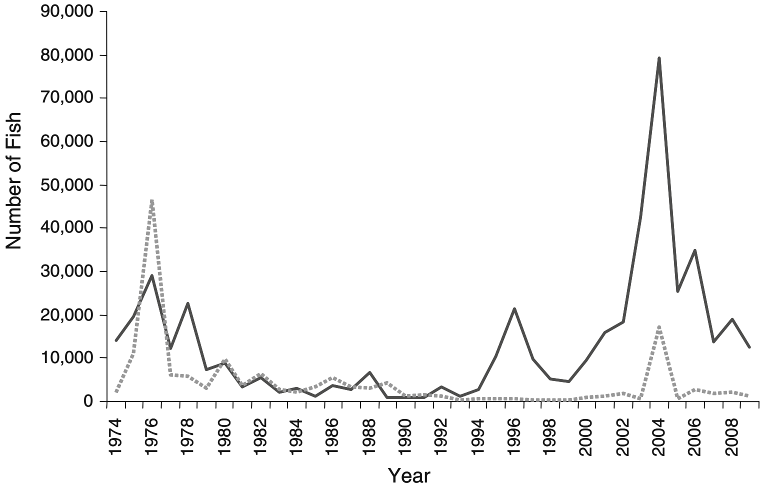


Fig. 11 Total escapement of adult Hood Canal summer chum salmon (*solid line*) and number of fish that were harvested (*dashed line*) (1974–2009)

Table 3 Hatchery stocks released into Hood Canal that are suspected of impacting wild summer chum salmon, including their likely ecological interactions and primary measures adopted to alleviate risks

Hatchery stock	Ecological interaction	Primary risk reduction measure (also see Table 1)
Fall Chum	Competition Predator attraction	Delay releases until after April 1
Steelhead	Predation	Delay releases until after April 15
Cutthroat	Predation	Eliminate releases in anadromous areas
Coho	Predation	Delay releases until after April 15
Fall Chinook	Predation Competition	Delay releases until after April 15
Odd-year Pink	Competition	Delay releases until after April 1
Summer Chum	Competition Predator attraction Predation	Release summer chum at an average size window of 45–50 mm

Strait of Juan de Fuca (Ames et al. 2000). The USFWS and several regional public groups including Long Live the Kings are also cooperators. The plan includes summer chum supplementation and reintroduction programs, and risk abatement strategies to decrease ecological risks caused by hatchery programs for other species. The comprehensive plan also includes habitat protection and rehabilitation strategies, harvest restrictions in fisheries that incidentally affect summer chum salmon, and an extensive monitoring and evaluation program. These actions in combination are expected to benefit wild summer chum recovery.

The intent of the summer chum salmon supplementation program is to quickly boost abundance in some remaining populations and thereby reduce short term extinction risks. The program targets four basins in Hood Canal, including the Big Quilcene, Lilliwaup, Hamma Hamma and Union rivers, and two basins in the Strait of Juan de Fuca, Salmon and Jimmycomelately creeks. The annual number of subyearling smolts released and the adult abundance trend in these basins are shown in Fig. 12a. Supplementation is limited to a three generation maximum duration period (12 years) or until adult abundance targets are met, with some exceptions for catastrophic circumstances. The first supplementation programs started in 1992 and four of the six programs were terminated by 2008. One of the continuing programs, on the Lilliwaup, has exceeded the 12 year limit but continues because the extinction risk remains high in this basin. The total number of supplemental summer chum salmon released to date by basin is given in Table 2.

The reintroduction programs are intended to quickly reseed vacant habitats. The program targets three basins where summer chum salmon are extinct, including Big Beef Creek and Tahuya River in Hood Canal and Chimacum Creek in North Puget Sound. The annual number of sub-yearling smolts released and the adult abundance trend in these basins are shown in Fig. 12b. The first reintroduction programs started in 1996 and two of the three programs were terminated by 2008. The total number of reintroduced summer chum salmon released to date is given in Table 2.

The Duckabush and Dosewallips rivers were left as wild-only production as a risk aversion strategy. The Little Quilcene River in Hood Canal and Snow Creek in the Strait of Juan de Fuca also were not directly supplemented although they adjoin supplemented areas and adult hatchery fish returned to these basins and added to their total abundance (Table 2). The annual adult abundance trend in these basins is shown in Fig. 12c.

The supplementation and reintroduction programs include specific strategies to avoid ecological risks to wild summer chum salmon, including many of the strategies in Kostow (2009), but also some novel strategies as indicated in Table 1. The primary risk avoidance strategy is to release the hatchery summer chum smolts at an average size window of 45–50 mm, and no larger than 53 mm. This size window is larger than the wild juveniles, which are 37–41 mm, and was selected because it is considered large enough to facilitate niche separation between hatchery and wild fish to decrease competition for food, while also avoiding hatchery fish predation on the wild

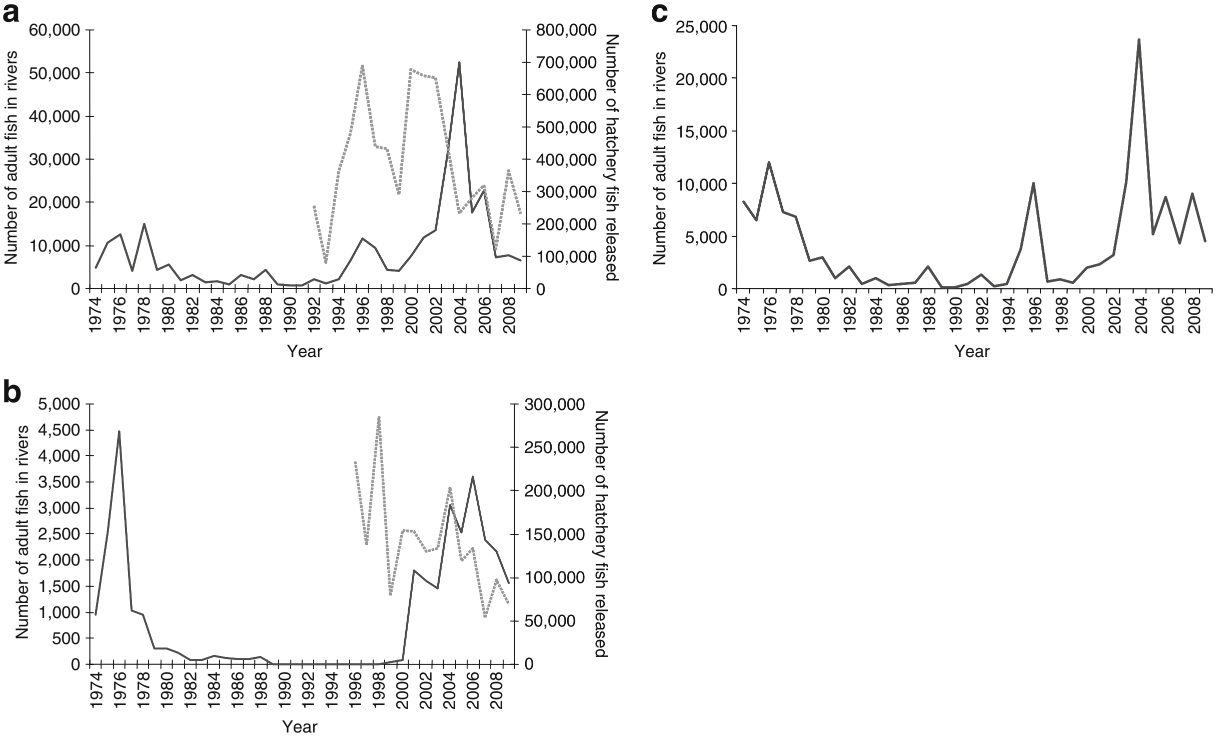


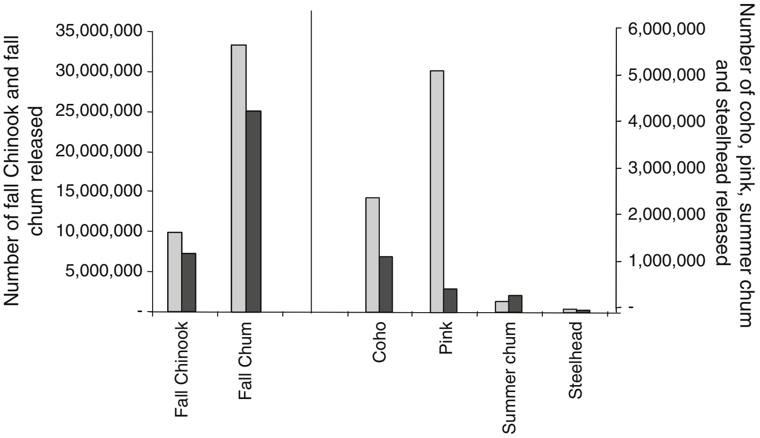
Fig. 12 (**a**) Abundance of adult Hood Canal summer chum salmon in supplemented basins (*solid line*) and the annual number of hatchery summer chum released into the areas (*dashed line*) (1974–2009). (**b**) Abundance of adult Hood Canal summer chum salmon in basins with reintroductions (*solid line*) and the annual number of hatchery summer chum released into the areas (*dashed line*) (1974–2009). (**c**) Abundance of adult Hood Canal summer chum salmon in basins that are unsupplemented (1974–2009)

juveniles. Disease monitoring guidelines are in place to decrease the risk of transmitting fish pathogens to wild populations. Unique otolith marks are used on the hatchery fish to facilitate monitoring, including evaluation of hatchery fractions on spawning grounds, adult reproductive success, and straying. Otherwise, release timing and locations are selected to facilitate rapid out-migration while mimicking wild juvenile timing and behavior (Ames et al. 2000).

The hatchery programs for other species were subjected to a risk assessment as part of the development of the initiative. The risk assessment for each hatchery program considered the impacts of hatchery operations (such as trap operation or the effect of hatchery effluents), of direct predation, of predator attraction, of competition (by juveniles and adults), of behavioral modification (by juveniles and adults) and of disease transfer (Ames et al. 2000). Likely hatchery risks were identified, and risk abatement strategies were developed (Table 3). The hatchery strategies described in Kostow (2009) that are used for the other species are indicated in Table 1. The central theme across all species is to delay releases of hatchery juveniles until after summer chum emergence and out-migration, and to avoid releasing fish that would residualize. The release of species most likely to be direct predators on summer chum is delayed until after April 15. The release of primary competitors is delayed until after April 1 (Table 3). Future resident trout releases are restricted to non-anadromous waters only. Additional strategies include the use of acclimation facilities and volitional releases, the elimination of some releases, and the 100% removal of returning hatchery adults from some fall chum, pink and Chinook programs to avoid redd superimposition in summer chum salmon spawning streams (Ames et al. 2000).

During the implementation of the initiative some of the hatchery programs for fall chum, fall Chinook, coho and pink salmon were down-sized or eliminated beyond what was originally anticipated (WDFW and PNPTT 2007). Changes in total numbers released by

Fig. 13 Changes in the number of hatchery fish released in Hood Canal and the Dungeness River by species comparing average releases in 1986–1994 (*grey bars*) (data from Ames et al. 2000) to 2009 releases (*black bars*)



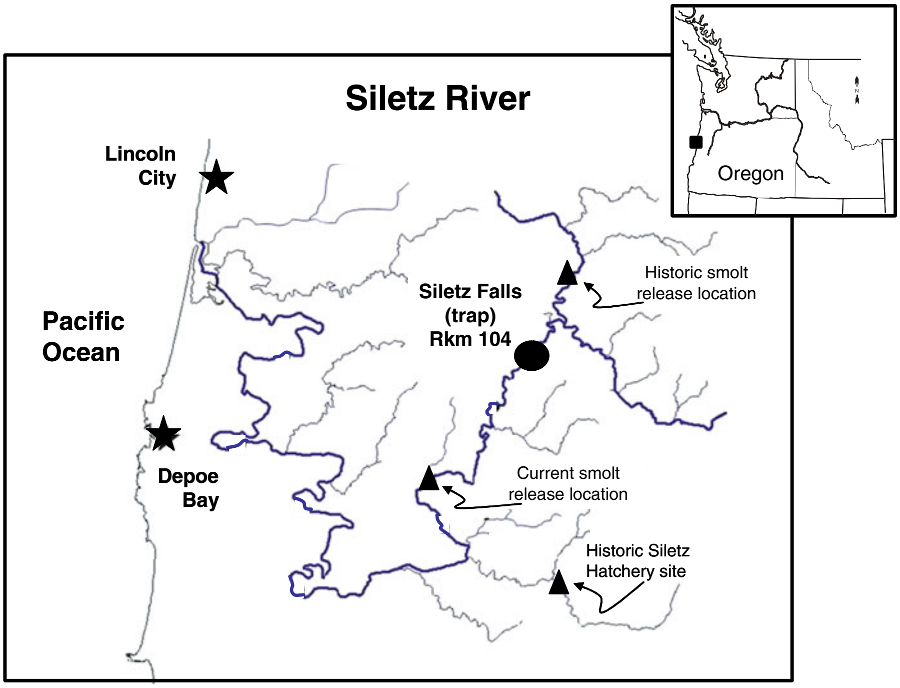
species are shown in Fig. 13. While some of these reductions were unrelated to the initiative, they provide benefits to wild summer chum salmon by decreasing the number of hatchery fish released at a regional level, which further alleviates ecological risks.

Total summer chum salmon abundance has increased since the early 1990s with a recent average escapement of over 21 000 fish and an additional 1700 fish harvested (Fig. 11). Recent 5-year average abundances in individual basins are given in Table 2, compared to abundances in the early 1990s. Abundance has increased in all basins; however, the supplementation and reintroduction programs continue to contribute hatchery adults. In the mid-2000s, about 30% of the adult summer chums on Hood Canal spawning grounds were hatchery fish, while about 45% of the adult summer chums on Strait of Juan de Fuca spawning grounds were hatchery fish (WDFW and PNPTT 2007). The percent wild (or naturally-produced) fish in individual basins in recent years, based on the recovery of marked fish on the spawning grounds, is given in Table 2. The percent wild in the reintroduction basins remained particularly low through the mid-2000s, but this is expected given that the local populations are extinct and the reintroductions are only recently implemented. More recent unpublished data indicates that the Chimacum and Big Beef creeks are now over 90% naturally-produced (personal communication Thom Johnson, WDFW). The supplemented basins vary from a low of only 17% wild in the Lilliwaup to over 80% wild in the Union River. The unsupplemented basins, like the Duckabush and Dosewallips, also contained a high proportion of hatchery adults in the mid-2000s due to straying from adjacent supplemented basins, although the proportions are decreasing. Migration among adjacent basins within a geographic area like Hood Canal may be a natural population dynamic of summer chum salmon (Sands et al. 2009). Current monitoring indicates that the hatchery adults on the natural spawning grounds are reproducing at levels typical of other first-generation, local-origin hatchery programs, at about 83% of wild fish reproductive success (Berejikian et al. 2009). Hatchery fractions will decline as the supplementation programs terminate and the last hatchery adults return. Future monitoring will determine if the number of wild fish stabilizes and becomes self-sustaining at the higher abundance levels.

Case study 4: Siletz summer steelhead

The Siletz River is located on the central coast of the state of Oregon. It drains an area of about 585 km^2, with headwaters in the Oregon Coast Range and entry to the Pacific Ocean near the town of Lincoln City, Oregon (Fig. 14). Siletz Falls, a 9 m boulder cascade, is located on the mainstem of the river at rkm 104. The steep gradient and high winter flows at the falls create a natural velocity barrier that historically blocked the passage of most salmon and steelhead into the upper basin. Winter-migrating species native to the lower Siletz basin, including winter steelhead, fall Chinook salmon, and coho salmon, are thought to have been excluded from passing the falls. Summer-migrating species, particularly summer steelhead

Fig. 14 Map of the Siletz River, Oregon, showing the location of Siletz Falls and the historic and current release locations for summer steelhead hatchery smolts



which have a peak passage time in July, were able to negotiate the falls during low summer flows. Spring Chinook salmon and sea-run cutthroat trout, which are native to the lower Siletz basin and have summer migration timing, may have also passed the falls. Resident cutthroat trout are native to the basin above the falls.

The summer steelhead population in the Siletz River is a rare life history on the Oregon coast. Most coastal *O. mykiss* populations have winter-run life histories. The Siletz population is the only summer-run population in a coastal river that drains exclusively from the Oregon Coast Range. Summer steelhead populations are present in only two other Oregon coastal rivers: the larger Umpqua and Rogue rivers that transect the Coast Range and drain the southern Cascade Mountains (Kostow 1995; Busby et al. 1996). The presence of this unique life history in the Siletz River was probably facilitated by the falls selecting for summer migration times and eliminating competition by the other species and life histories.

A fish ladder was constructed around Siletz Falls between 1949 and 1952. The ladder opened passage to winter steelhead, coho salmon and fall Chinook salmon. Hatchery programs were already established in the basin. Siletz Fish Hatchery, located on Rock Creek in the lower basin (Fig. 14), began operation in 1937 and released hatchery coho salmon, fall Chinook salmon and winter steelhead (Wallis 1963). A summer steelhead hatchery broodstock was collected at Siletz Falls, starting in 1956. The first smolt releases occurred in 1959. All summer steelhead hatchery smolts were released into natural habitats above the falls until 1964 when part of the releases were moved to the lower basin. Hatchery cutthroat trout were released both above and below the falls (Weber and Fortune 1974). The number of hatchery fish released annually into the Siletz Basin since 1970 is shown in Fig. 15.

The abundance of adult summer steelhead was monitored at the fish ladder from 1969 to 1972 (Fig. 16) (Weber and Fortune 1974). By this time, the summer steelhead hatchery program had been in place for a decade and releases into the Siletz basin had increased from 25 000 smolts to 80 000 smolts annually. The number of wild summer steelhead adults passing the falls averaged 624 fish during the 1969–1972 monitoring period. The number of hatchery adults averaged 1,977 fish, or about 76% of the total number of summer steelhead passing the ladder. Other species were not monitored during this period, and all enumeration of adults at the ladder ceased after 1972.

Monitoring at the fish ladder started again in 1994 and was comprehensive for all species passing the

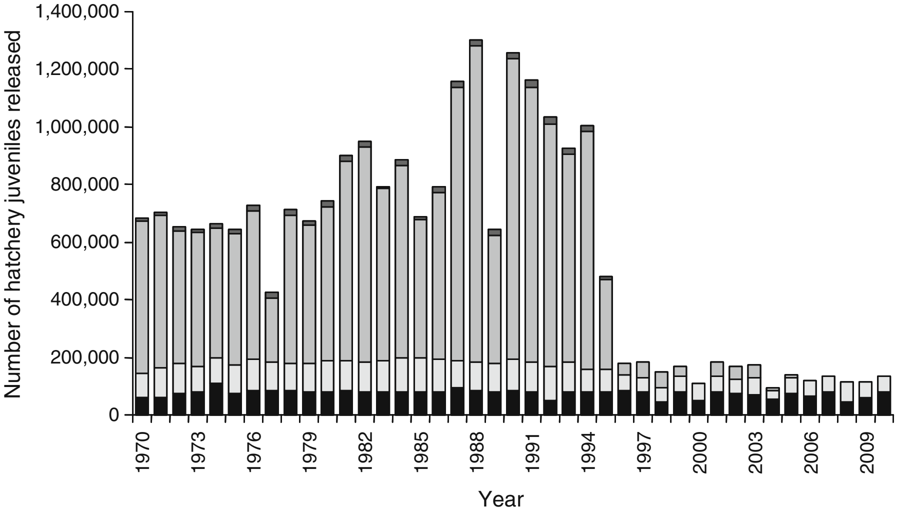


Fig. 15 Number of hatchery juveniles released into the Siletz Basin, 1970 through 2010. Black bars are summer steelhead, light grey bars are winter steelhead, middle grey bars are coho salmon and dark grey bars are cutthroat trout. All releases since 1994 were located below Siletz Falls

falls except cutthroat trout. Over the first several years the average abundance of wild summer steelhead was less than 100 fish (Fig. 16). A wild spring Chinook salmon population was also present with an average abundance of about 190 fish. The wild summer steelhead population was only 3% of the total number of fish counted in the fish ladder, while the wild spring Chinook population was only 5%. The rest, 92% of the total fish present, were either hatchery summer steelhead (69% of the total), or other salmonid species including winter steelhead (22% of the total), coho salmon and a few fall Chinook salmon. Cutthroat trout also passed the ladder but escaped the trap and were not enumerated.

ODFW started a program to recover the wild summer steelhead population in 1994. The plan was formally adopted as part of the state's Siletz Basin Plan in 1998 (ODFW 1998). The strategies from Kostow (2009) used in the recovery program are indicated in Table 1. The overall theme of the program focused on the ecological effects of the other salmonid species and on the high proportion of hatchery summer steelhead adults entering the natural production area above Siletz Falls. The hatchery summer steelhead were thought to

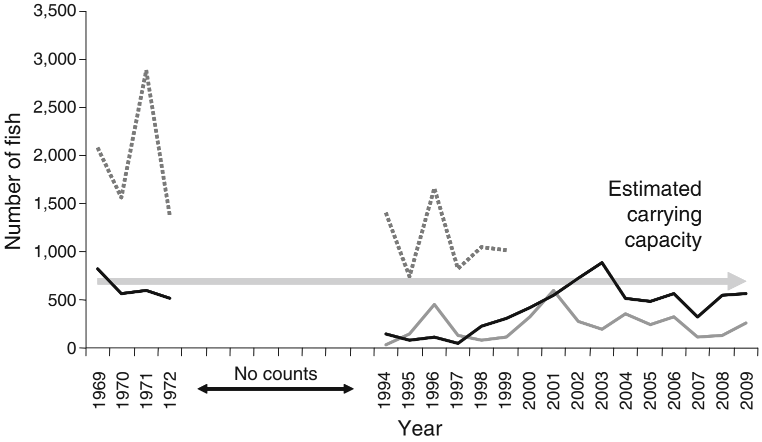


Fig. 16 The number of wild (*solid line*) and hatchery (*dashed line*) adult Siletz summer steelhead passing the fish ladder at Siletz Falls from 1969 to 1972 and from 1994 to 2009 (historic data from Weber and Fortune 1974). No monitoring occurred between 1973 and 1993. The arrow indicates the estimated carrying capacity for summer steelhead. The number of wild adult spring Chinook passing the falls since 1994 is also shown (*grey line*)

pose genetic and competition risks to the wild steelhead, while the other salmonids were suspected of competing with the wild population. The habitat above Siletz Falls, although limited in area, was stable or improved since the 1970s, and consumptive harvest was already mark-selective for hatchery fish; thus these factors were not considered to have caused the summer steelhead population decline.

The recovery strategy was to eliminate hatchery smolt releases above the falls and to convert the fish ladder at Siletz Falls into a fish trap that could be used to control adult fish passage. All adult winter steelhead, coho and fall Chinook salmon were removed at the trap, starting in 1994. Wild fish of these species, about 10% of the fish removed, were placed into natural habitats within their own historic range in the lower Siletz Basin. Releases of hatchery coho salmon and cutthroat trout in the Siletz Basin were initially reduced, and then eliminated, and all the remaining hatchery steelhead smolt releases were moved to below Siletz Falls (Fig. 15).

Managers were concerned that the low numbers of wild summer steelhead posed a potential genetic and demographic risk, particularly given the uniqueness and geographic isolation of the population. Therefore, a short-term supplementation program was designed for the summer steelhead population using the broodstock that was founded at Siletz Falls in the 1950s. Three factors were considered in the design of the supplementation program. First was the anticipated reproductive success of the hatchery summer steelhead. The hatchery broodstock, although locally founded and periodically augmented by the addition of unmarked fish captured at the falls, had been artificially propagated for over 35 years. The reproductive success of the hatchery adults was anticipated to be about 30% of that of the wild population, based on the literature available in the early 1990s (Reisenbichler and McIntyre 1977; Leider et al. 1990; also reviewed by Berejikian and Ford 2004). Second was the estimated carrying capacity of the natural production area. Carrying capacity was estimated to be able to support the production from about 700 adult summer steelhead, based on the available habitat and the historic run size. The number of hatchery adults passed to supplement the wild population was set above the estimated carrying capacity (Fig. 16). It was thought this approach would give the quickest boost to the abundance of naturally-produced fish given the expected poor reproductive success of the hatchery fish. The rest of the summer steelhead hatchery adults were removed at the trap. The third factor was the duration of the supplementation program, which was set at one generation, or 6 years, from 1994 through 1999.

Starting in 2000, all summer steelhead hatchery adults, along with all winter steelhead, coho and fall Chinook salmon, were removed at the trap, amounting to about 3,000 adult fish annually. This action is expected to continue into the future. Wild summer steelhead and spring Chinook salmon continue to be passed and monitored at the ladder. Coastal cutthroat trout also continue to pass the ladder and falls.

The wild Siletz summer steelhead population increased and apparently stabilized since the record low of 44 fish in 1997. The population has averaged 560 fish since 2000, slightly below the originally estimated carrying capacity (Fig. 16). It is uncertain whether the supplementation program contributed to the population rebound; however, the ecological risks from hatchery and non-native fish have been eliminated and the program accomplished its recovery objectives.

Case study 5: Chief Joseph hatchery

Unlike the previous four case studies which have been under implementation for many years and were largely initiated to solve an existing problem, Chief Joseph Hatchery is only in the planning stage. It is a unique case study in the sense that it is a completely new hatchery program and demonstrates that hatchery risks can be anticipated and risk reduction actions can be designed into the program in advance of implementation. A master plan was completed in 2004 (CTRC 2004) and the first stages of construction and implementation began in 2010. The proposed program involves the redistribution of Chinook salmon hatchery production in the Okanogan River and mainstem Columbia River and the construction of a new hatchery facility, Chief Joseph Hatchery, at the base of Chief Joseph Dam. Chief Joseph Dam is located at rkm 877 on the mainstem Columbia River, Washington. The dam has no fish passage facilities, and like the older Grand Coulee Dam, which is located about 84 km further upriver, Chief Joseph Dam forms a complete blockage to fish migration.

The Okanogan River is a transboundary river that drains about 23 000 km^2 in the United States and

Canada and enters the Columbia River about 25 km below the dam (Fig. 17). The Okanogan is the uppermost tributary of the Columbia River that is still available to anadromous fish. Wild populations of summer/fall Chinook salmon, sockeye salmon and summer steelhead are still present in the Okanogan River, while spring Chinook salmon are extinct. The summer steelhead population is an ESA threatened species (74 FR 42605) and the Okanogan Basin is within the historic range of ESA endangered spring Chinook salmon (70 FR 37160). The habitat in the Okanogan Basin has been impacted by water diversions and other local alterations. However, the most significant factor limiting wild production in the basin is passage mortality through nine hydroelectric dams as the fish navigate the mainstem Columbia River to reach the Pacific Ocean (CTRC 2004). The abundance of the extant wild populations is thought to be kept well below the basin's carrying capacity due to the high mortality during migration.

The proposed hatchery program will include a series of supplementation and reintroduction programs for spring and summer/fall Chinook salmon in the Okanogan River, and will support a terminal mark-selective fishery on hatchery summer/fall Chinook in the dead-end reach of the Columbia mainstem below Chief Joseph Dam.

The supplementation program for summer/fall Chinook salmon in the Okanogan is intended to diversify adult run timing and spawning distribution in the basin in an effort to better use the available carrying capacity. The current population is thought to be at about 33% of the available carrying capacity. The distribution of current natural spawning activity is concentrated in 14 km of one tributary, the Similkameen River, where an average of 57% of the natural spawners are hatchery-origin fish produced from a WDFW hatchery facility at Similkameen Pond. Redd densities in this reach have been as high as 400 redds/km, resulting in substantial redd superimposition (CTRC 2004). The new hatchery program

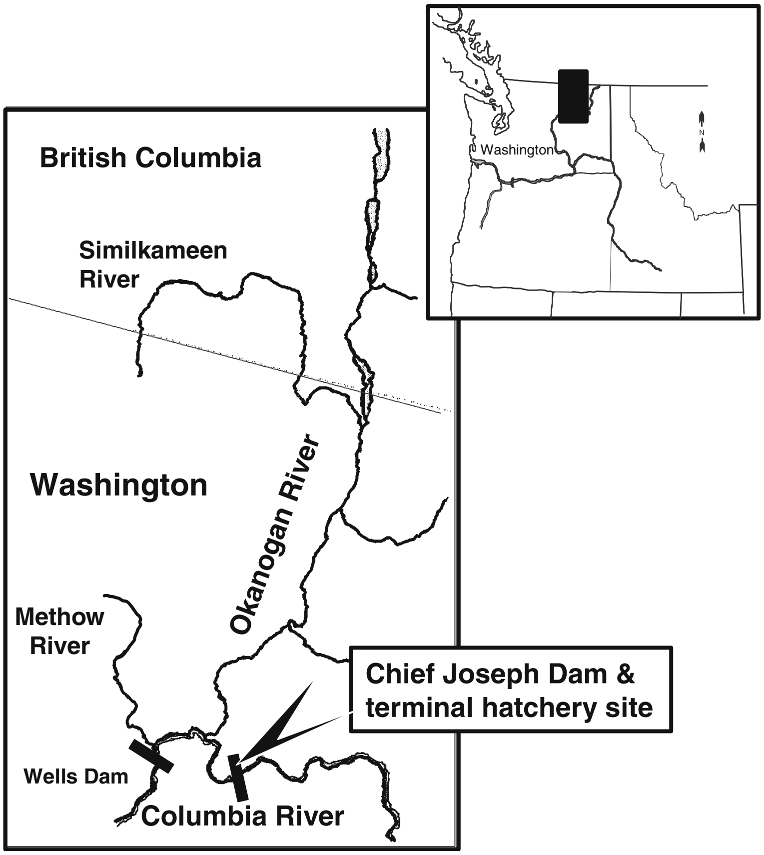


Fig. 17 Map of the upper Columbia and Okanogan rivers, showing Chief Joseph Dam. The Chief Joseph Hatchery is being constructed adjacent to the dam. The terminal fishery area will be located in the mainstem Columbia River immediately below the dam. Supplementation and reintroduction programs will occur in the Okanogan River

will use a new local Okanogan broodstock that has a broader summer/fall run timing distribution than the old broodstock. Hatchery juveniles are to be released across four acclimation sites in the basin. The intention is to establish other natural spawning areas throughout the basin. The number of hatchery adults allowed into the basin will be decreased as improved spawning distribution objectives are accomplished.

The eventual reintroduction program for spring Chinook salmon is expected to use a broodstock from the adjacent Methow River. Details of the reintroduction program have yet to be developed.

The fisheries program is designed to be a terminal, mark-selective fishery on hatchery summer/fall Chinook salmon located in the dead-end tail race of Chief Joseph Dam. The purpose of the fisheries program is to increase and stabilize a tribal ceremonial and subsistence fisheries for members of the Confederated Tribes of the Colville Reservation (Colville Tribes or CTCR) and to provide a local recreational fishery. The Colville Tribes traditionally fished for salmon and steelhead in the reaches of the Columbia River that were lost due to the completion of Grande Coulee Dam in 1942. An important aspect of the fishery program will be the development of terminal fishing gear that would impose a low release mortality rate on any wild fish that are encountered in the fishery.

The strategies from Kostow (2009) that are currently planned for use in the Chief Joseph Hatchery program are indicated in Table 1. The theme for the supplementation program is to use hatchery supplementation to expand the timing and spatial distribution of natural spawning activity in the basin. This strategy is intended to alleviate the problem of redd superimposition and better utilize the available carrying capacity. The central theme for the fisheries program is to isolate the production releases in the Chief Joseph Dam tail race, away from important natural production areas in the Okanogan basin, while also using the fisheries to control the number of hatchery adults entering natural production areas. An additional strategy is to measure the success of the program based on the achievement of natural abundance goals. Initially, the program will increase the number of hatchery fish released into the Okanogan River. However, if specific wild fish abundance thresholds are not being met, or if the selective fisheries are not able to remove enough hatchery adults to control the number of them in natural production areas, the level of hatchery production would be decreased. It is anticipated that additional strategies to reduce ecological risks, including potential risks to other species, may be adopted as the program proceeds through implementation (CTRC 2009).

Conclusions

The five case studies presented in this paper describe how strategies to reduce the ecological risks of hatchery programs have been planned and implemented to accomplish various management program goals. Managers are primarily interested in seeing wild fish abundance improve and public needs met; therefore, the currency of success in these case studies has been whether these two objectives have been accomplished. The results to date are mixed. Some wild population sizes have increased, others have not yet, or it is premature to be certain that increased abundances will be sustained. Meanwhile, public demand is rarely satiated.

It could be debated whether any of the actions taken in these case studies demonstrably improved wild population status even when hatchery risks were certainly eliminated and wild fish abundance improved. Obviously there is no single cause of fish population declines, and there will not be any simple, single-factor solution to the problem. The recovery of Pacific Northwest salmon and steelhead can only result from the cumulative resolution of multiple risk factors, including the risks caused by the ecological effects of hatchery programs. The chroniclers agree that Pacific Northwest salmon and steelhead remain in crisis (Lichatowich 1999; Taylor 1999; Blumm 2002). Public opinion and a preoccupation with uncertainty and “more studies” cannot justify indecision or paralysis in management, particularly when wild populations are sliding toward extinction. It is hoped that these case studies will serve as encouragement and examples to other managers. Several general principles are evident:

1. *Management context*: The risk reduction strategies need to be set in a management context. A management plan establishes authority, sets objectives and priorities, coordinates, and confirms agreement among co-managers and partners,

helps provide funding and other resources, and establishes a commitment to implement the programs over the long term. Integrated management plans also place risk reduction strategies for hatchery and harvest programs in context with other recovery actions since a variety of factors contribute to wild population declines. The plans may include formal policy and regulatory components such as a state administrative rule or a formal memorandum of agreement, and may benefit from formal scientific and public review. However the process and development of management plans should not become a reason for inertia or delayed action once problems are identified. In several of the case studies, the final plans were adopted several years after the first actions were taken and the plans essentially formalized actions that had already proved successful.

2. *Multiple Strategies:* Most programs to alleviate ecological risks will utilize multiple strategies, although they may have a central theme. The strategies provided by Kostow (2009) can serve as a shopping list of ideas; however, unique and innovative actions should be considered so that the solutions are customized to address specific problems.
3. *Large geographic scope*: The most successful programs will have a large geographic scope. Ecological impacts may occur anywhere within the range of a population or ESU, so a large geographic scope is necessary to effectively lower risk. Strategies should be designed over at least an entire river basin or across the entire range of the target population. Several of the case studies extended across entire ESUs. Even wider regional programs may be needed to address risks in shared migration corridors or in the ocean. A consequence of a broad geographic scope is that multiple jurisdictions may need to cooperate in the program. The case studies in this review demonstrate that the involvement of multiple jurisdictions need not hinder implementation and success.
4. *Multiple species*: Many risk reduction programs will need to address multiple hatchery programs and multiple species within a geographic area. This is an expected consequence of solving the problem of ecological hatchery risk since a wild population can be affected by hatchery programs for other species.
5. *Long-term implementation*: Given the complexities of multiple jurisdictions, multiple strategies, large geographic scope and multiple hatchery programs for multiple species, managers can expect that programs to reduce ecological risks will take many years to reach full, effective implementation. Some strategies may need to be implemented in gradual steps to allow public opinion to adjust to them. In some cases established protocols will need to be continued into the indefinite future.
6. *On-going evaluation:* Management actions will require continuous evaluation and attention to expected outcomes, and remain flexible enough to allow periodic readjustments. The ultimate goal and general approach needs to be firmly established at the outset, but the details of successful strategies are refined through trial and error. Periodic reassessment and readjustments are needed to keep the programs moving in the intended direction and ensure long-term success.

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