COLUMN
PERSPECTIVE

The Failure of Wild Salmon Management: Need for a Place-Based Conceptual Foundation

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Salmon management has generally failed to rebuild depressed wild salmon populations or to manage many of them sustainably, despite a broad and growing scientific understanding of salmon ecology. We argue that to correct this failure, management policies and practices related to salmon need to become place-based. Key changes in management practices required to achieve place-based management include requiring that fishing occur closer to rivers of origin where particular populations can be identified with high precision, requiring that fishing gear be capable of releasing (with very low postrelease mortality) nontarget species and populations, and managing harvest to ensure that spawning escapements in most years exceed levels that would produce maximum sustainable yield. The scientific basis in support of place-based salmon management is clear, but implementing the required changes presents serious challenges that must be faced if the diversity and abundance of wild salmon are to be restored and if the world's wild salmon populations are to effectively cope with environmental changes imposed by climate change and continuing habitat degradation. Lessons from locations where management practices are based on a place-based conceptual foundation show how to successfully rebuild or maintain productive wild salmon populations.

Salmon management has generally failed to rebuild depressed wild salmon populations or to manage many of them sustainably despite a broad and growing scientific understanding of salmon ecology (e.g., Price et al. 2017). We argue that this failure is due to management policies and practices that are based on a flawed conceptual foundation that is incompatible with the current understanding of the diversity and complexity of salmon life history, population structure, and the locally adapted character of wild salmon. Lichatowich and Williams (2009:1011) characterized a conceptual foundation for fisheries management as

> "the set of principles, assumptions, and beliefs about how ecosystem processes influence or control fish productivity. A robust conceptual foundation therefore determines what problems (e.g., limitations on production) are identified, what information is collected, and how it is interpreted, and as a result, establishes the range of appropriate solutions."

A conceptual framework also broadly determines where the burden of proof lies when developing fishery management plans (Peterman 1990; Dayton 1998; Charles 2002; Gerrodette et al. 2002). Burden of proof in this context would identify what harm could result from a contemplated action and which party—the party proposing the action or the party opposing it—must demonstrate that the potential harm is or is not likely to occur. In contrast to the current widely used conceptual foundation, we describe an alternative that is firmly grounded in the current science of salmon ecology and that we refer to as "place-based." Alternative, place-based management policies and practices account for the complexity and local adaptation of wild salmon and require that we change where we fish, how many fish we catch, and how fish are produced in ways that run counter to current practices in many locations.

THE WILD SALMON CRISIS AND THE NEED FOR PLACE-BASED MANAGEMENT

Numerous wild Atlantic Salmon *Salmo salar* and Pacific salmon *Oncorhynchus* spp. populations are seriously depressed or declining relative to their historical abundances and current habitat capacities, despite often-stated public concern and billions of dollars spent to conserve and enhance wild populations (Montgomery 2003). This is a problem affecting most salmon regions of the globe. On the U.S. Pacific coast, 28 of 52 population aggregates have been managed for up to three decades under the Endangered Species Act, but none has recovered enough to be delisted (NMFS 2017). Many populations in British Columbia remain depressed after conservation and recovery actions (Price et al. 2017). In Korea, wild salmon no longer exist, and only a handful of small wild populations remain in northern Japan. Many of Norway's iconic wild salmon populations have radically declined since the mid-20th century, and the majority of populations in the British Isles and the European mainland are at all-time lows. The majority of Atlantic Salmon populations in North America and the Northeast Atlantic are either threatened with extinction or persist at low levels of abundance (NASCO 2016; Forseth et al. 2017). Overall, there are only a few exceptions to declining salmon abundance (e.g., some wild Pacific salmon populations in Alaska and the Russian Far East, particularly Kamchatka, and some wild Atlantic Salmon populations in northern Finland).

Somewhat paradoxically, substantial declines in wild salmon abundance and productivity have occurred coincident with a steady growth in scientific knowledge of the complexities of the life histories, ecology, and population genetics of wild salmon. A wide array of advanced tools for empirically estimating productivity and population trends, including detailed accountings of genetic structure, is now available on which to base risk-averse policies and management decisions (e.g., Lukacs and Burnham 2005; Pestal et al. 2012; Steele et al. 2013). Nonetheless, wild salmon generally are not being managed sustainably for use by commercial harvesters, indigenous people, and sport fishers, despite the efforts of tens of thousands of salmon scientists, managers, conservationists, and advocates worldwide.

The fundamental problem in many locations is that salmon management policies and practices have evolved in conflict with the current scientific knowledge of wild salmon, which recognizes that each specific population is uniquely adapted to its natal environment. The strong homing behavior of wild salmon results in the evolution of life histories that create and reflect a strong attachment to place—the spawning, rearing, and migratory habitats to which successful salmon populations must adapt. The attachment of wild salmon to particular places is evidenced most prominently by their locally adapted character (Taylor 1991; Eliason et al. 2011; Salvolainen et al. 2013) but extends more deeply to include the web of ecological relationships between wild salmon and other members of the biological community that interact with salmon, including humans (Lichatowich 2013). Under the place-based conceptual foundation, the burden is placed on those proposing a specific fishery management action to demonstrate (with sufficiently high probability) that the action assures that spawner escapement goals will be met and the associated ecosystem services provided by the exploited population(s) will not be impaired. The place-based nature of wild salmon has not been uniformly recognized or incorporated into management policies and actions that are designed to conserve or enhance wild salmon.

In contrast to the place-based character of salmon, the current widely used conceptual foundation is based upon an industrial, agricultural model that emphasizes intensive technological intervention in the natural life cycle of salmon in place of reliance on the inherent productivity of wild salmon in intact, functioning ecosystems. At its heart, this current conceptual foundation of many salmon management practices assumes that salmon runs can be effectively managed independently of one another and that human-induced losses of production capacity can be mitigated by actions to increase the number of smolts that reach the ocean, predominately by using artificial production of salmon in hatcheries. Although an extremely small number of hatchery fish may make it back to the hatchery of origin as adults (because of high mortality owing to poor competitive ability and environmental maladaptation resulting from being raised in hatcheries), these artificially produced fish have also lost connection with their wild or natural places of origin. Indeed, the current salmon management paradigm in the U.S. Pacific Northwest is driven by policies that assume wild salmon can be sustained in the presence of mixed-population fisheries in the ocean and that hatcheries and freshwater habitat enhancements can sufficiently mitigate losses of wild populations (Williams 2006). However, a robust body of salmon science strongly suggests that losses of wild populations will not be curtailed—let alone reversed—by these policies; a change in the conceptual foundation governing salmon management is needed (Lichatowich et al. 2017).

Some management policies do recognize the importance of locally adapted salmon populations (e.g., Canada's Wild Salmon Policy: DFO 2005; Norway's Nature Diversity Act of 2009: Forseth et al. 2013; Vøllestad et al. 2014), but such policies are often not fully implemented (Hutchings et al. 2012; Price et al. 2017). Additionally, a significant part of the problem can be attributed to the failure of management councils and agencies to follow scientists' recommendations to adopt precautionary policies (FAO 1995) that account for uncertainties involved in salmon harvest management. In many places, salmon management operates under a flawed conceptual foundation (Williams et al. 1999; Lichatowich and Williams 2009) that sets where we fish for salmon, how we decide how many to catch, and what we rely on to produce them (intact habitat in rivers and streams, or hatcheries) in ways that are at odds with what we know about salmon ecology.

We suggest that managers of wild salmon populations need to more rigorously choose actions that reflect the locally adapted, place-based character of wild salmon populations and adopt and adhere to targets for performance measures that reflect a place-based management regime (Box 1). Healthy wild populations reflect the evolution of life history complexity, especially diversity of age at maturity, as a hedge against environmental variation that occurs in their freshwater and marine habitats. One key characteristic of wild salmon is their high yet imperfect degree of homing fidelity to the rivers, streams, and within-stream locations of their birth. This characteristic allows for fine-scaled, local adaptations to their freshwater environments, resulting in high levels of genetic diversity both within and between populations (Lichatowich 2013).

Imperfect homing results in low background levels of straying that enable salmon to colonize newly available habitat. Straying gives new genotypes the opportunity to invade nearby populations (Bett et al. 2017), and depending on the abundance of that invaded population, may thereby help to maintain genetic diversity of local populations and enable them to adapt to different habitats within natal river systems. The resulting local adaptations mean that wild salmon must be managed as portfolios of local subpopulations with sufficient spawners in each to drive and maintain the high levels of genetic diversity and adaptive capacity that are essential if salmon populations are to thrive in the dynamic and complex environments in which they have evolved (Verspoor et al. 2007). For example, the huge and sustained runs of wild Sockeye Salmon *O. nerka* in Bristol Bay, Alaska, function as (and are managed as) an interactive portfolio of locally adapted populations. Large Sockeye Salmon runs into one part of that system have compensated for other runs that have been reduced by either harvesting (commercial or subsistence) or environmental variation during their life histories (Schindler et al. 2010). The key is to recognize and manage individual populations in the portfolio conservatively so that an appropriate abundance of spawners reaches the spawning grounds every year (Schindler et al. 2010).

The failure to implement a place-based conceptual foundation has contributed significantly to producing and maintaining the current depressed condition of many wild salmon populations. This failure arose from three sources. First, too often, emphasis has been placed on maximizing harvests from large, mixed-population stock aggregates in marine environments, which severely pressures the weak (i.e., smaller or less-productive) populations. Second, estimates of sustainable harvest rates are often based on maximum sustainable yield

BOX 1

WILD SALMON ECOSYSTEM VITAL SIGNS (I.E., TARGETS FOR PERFORMANCE MEASURES THAT REFLECT A PLACE-BASED MANAGEMENT REGIME). THESE MEASURES OF PERFORMANCE APPLY AT THE POPULATION OR POPULATION PORTFOLIO LEVEL OF ORGANIZATION (AS DETAILED BY LICHATOWICH ET AL. 2017).

- Sustained abundance (and size at maturity) of spawners to all spawning habitats in numbers that provide a biologically conservative state that takes into account environmental variation.
- Sustained habitat-specific density and growth of juveniles.
- High habitat connectivity and productivity in freshwater, estuarine, and ocean habitats.
- Natural or normative[a] seasonal flow patterns.
- Natural or normative seasonal temperature patterns.
- Productive and biodiverse food webs with strong riparian linkages and sustained inputs of marine-derived nutrients (i.e., salmon carcasses naturally deposited after spawning).
- High salmonid biodiversity (diverse life histories/portfolios).
- Natural or normative water chemistry (minimal pollution).
- No cultured stock escapements, introductions, or supplementations.

[a]"Normative" refers to amounts or patterns that are reasonably close to natural or historic attributes of salmon habitats (see Stanford et al. 1996); this is an especially important consideration given the certainty of climate warming in most salmon rivers.

(MSY), which assumes a relatively static environment, ignores uncertainties in estimation of population characteristics (such as productivity) and implementation of harvest regimes, and neglects the evolutionary response of salmon populations to harvest mortality (Enberg et al. 2009; Hutchings 2009; Kendall et al. 2009; Okomoto et al. 2009; Bromaghin et al. 2011). Third, there is a mistaken belief that large-scale hatchery production will enhance harvests and also lead to recovery of depressed wild stocks regardless of the extent of habitat degradation (Bottom 1997; Venditti et al. 2017).

To date, large-scale, marine mixed-stock commercial salmon fisheries have predominated in both Pacific and Atlantic fishing areas. Advances in boats and gear have allowed fishing across huge areas of the ocean and created the ability to completely clog estuaries and river mouths (Lichatowich 1999; Hooton 2011). As a result, entire populations have been extirpated or substantially depressed in one or a few fishing seasons. Currently, mixed-stock fisheries in the lower reaches of large rivers can also depress both target and nontarget salmon species and populations, leading to shortened seasons or closures (Walters et al. 2008). Harvest rates and spawning escapement goals based on MSY result in knife-edge management in which target harvest rates are frequently exceeded, and spawning escapement goals are therefore regularly missed because of high uncertainty and/or poor data with which to estimate stock dynamics.

Salmon hatcheries are not a solution because they create additional problems. For instance, large-scale hatcheries that utilize monocultural generic broodstocks allow salmon managers to postpone directly addressing the loss of freshwater and estuarine habitat due to dams, reservoirs, revetments, and water extractions (Lichatowich 1999). Salmon hatcheries also subsidize the growing commercial mixed-stock fisheries at the cost of ignoring the diversity and locally adapted character of the salmon (Lichatowich 1999). Stray or surplus hatchery fish interbreed with wild fish, reducing fitness (productivity) of the wild populations, even in one generation (Christie et al. 2014; see also Hatchery Scientific Review Group 2009:29–32). Though rarely quantified, the return on investment of hatcheries is stark in economic terms. For example, the roughly US$400 million in public funds spent annually on some 177 hatchery programs in the U.S. Columbia River basin (NMFS 2014) return far less than 1% per dollar invested, as measured in terms of the numbers and value of adult fish returning to the target areas (The Research Group 2008). The record for in-river habitat enhancements is no better (Bernhardt et al. 2005).

FEATURES OF PLACE-BASED MANAGEMENT

Salmon management policies and actions that are place-based and founded on the current understanding of salmon science would look quite different from what occurs today in many regions. Place-based management requires a different set of performance metrics than are used in the current commodity-based conceptual foundation (Lichatowich et al. 2017). The current conceptual foundation emphasizes metrics related primarily to harvest and artificial production, including harvest by species and hatchery performance (number of smolts released, hatchery returns, escapement to meet broodstock needs, etc.). In contrast, indicators relevant to place-based management would include population-level and habitat performance measures, such as genetic diversity, life history diversity (and the re-emergence of lost life history patterns), spawning and egg escapements to specific rivers or watersheds, habitat connectedness, and natural seasonal flow and temperature patterns (Box 1). Canada's Wild Salmon Policy (DFO 2005) and the wild salmon management policies of Norway's Nature Diversity Act (Forseth et al. 2013; Vøllestad et al. 2014) are examples of broad, overarching policy frameworks that are relatively consistent with this new conceptual foundation (Boxes 2, 3).

Implementation of place-based salmon management would require emphasis on at least three activities for each local salmon population. First, documentation of population structure (genetic and life history diversity) would help (to the extent possible) tune the spatial scale of the fishery to the spatial scale at which the target population reproduces (affecting where we fish). Second, the use of on-site and remote sensing tools in conjunction with advanced population models would contribute to robust estimates of potential production per unit habitat for all fished populations (guiding choices of how many fish we harvest). Third, management for robust annual spawning escapements and associated levels of egg deposition by wild salmon that are greater than MSY point estimates will increase the probability of maintaining the life history diversity and adaptive capacities of each wild population affected by fishery interceptions (influencing what we rely on to produce the fish and how we determine how many to harvest). All three types of action recognize and reflect the place-based character of salmon populations.

To recover and sustainably manage currently depressed wild salmon populations, we need to fish as close as practical

BOX 2
A SUBSET OF FEATURES OF CANADA'S WILD SALMON POLICY. QUOTES ARE DRAWN FROM THE DEPARTMENT OF FISHERIES AND OCEANS CANADA (DFO 2005).

Among other things, Canada's Wild Salmon Policy (WSP) is intended to provide guiding principles to inform management decisions that will help meet various goals and objectives. For instance, the overarching "goal of the WSP is to restore and maintain healthy and diverse salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity." The following three objectives combine to meet that goal. The first objective is to safeguard the genetic diversity of wild Pacific salmon through protection of conservation units (CUs): "A CU is a group of wild salmon sufficiently isolated from other groups that, if extirpated[,] is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations." Thus, "persistence of salmon within the CU, and its associated production, demand responsible management of its population structure and habitats, as well as the ability of fish to move among habitat areas (connectivity)." The second objective of Canada's WSP is to maintain habitat and ecosystem integrity through "a cooperative and collaborative approach among the various levels of government so that land and water use activities and decisions better support the needs of salmon." The third objective is to manage fisheries for sustainable benefits for "First Nations, harvesters, environmental groups, and community interests in the resource." As noted earlier, full implementation of all elements of such policies is required to produce the desired benefits.

BOX 3
KEY FEATURES OF NORWAY'S WILD SALMON MANAGEMENT PURSUANT TO THE NATURE DIVERSITY ACT (2009).

Wild salmon management in Norway is based on the establishment of conservation limits and targets for each of 439 known individual populations. Conservation limits are estimated from stock-specific data or extrapolated from the former to populations with similar riverine habitat conditions. Limits are determined by a group of scientists from research institutions in Norway and are reviewed by local-country government fisheries managers. Limits are quantified as the egg deposition needed to achieve maximum smolt recruitment, are translated into adult female spawner escapement levels based on age structure and the average eggs per female per age, and are expressed as numbers of eggs per square meter of adult spawner-accessible river habitat. "The main purpose for implementing management according to conservation limits was to ensure average maximum recruitment in all Norwegian populations" (Forseth et al. 2013). The management targets for each population are defined as attainment of the conservation limits in 3 out of 4 years. Importantly, harvest is managed to attain conservation limits regardless of smolt-to-adult survival (which has been at historic lows for most of the past decade or longer). Harvest is restricted or closed entirely when adult escapement is estimated to be below the levels required to attain the egg deposition targets. The employment of independent research scientists with the authority to establish scientifically credible, data-driven estimates of conservation limits is a key feature of this approach.

to the rivers of origin of the target populations (e.g., the Bristol Bay Sockeye Salmon fishery; the Cook Inlet [Alaska] set-gillnet fishery for Sockeye Salmon; the First Nation Sockeye Salmon fishery in Babine Lake, British Columbia; many North American Atlantic Salmon fisheries; and the in-river fishery in Finland's Teno River; ICES 2007; Vaha et al. 2008). We also need to employ selective fishing methods and gear that are capable of releasing non-target individuals with no or very low postrelease mortality (e.g., the cooperative Lummi Island Wild reef-net fishery: Lummi Island Wild 2017; and pound nets [fish traps]) and to manage salmon populations so as to ensure annual spawning escapements greater than MSY point estimates. Where this approach has been applied, rapid recovery of substantially depressed runs has occurred, as exemplified in the USA (Okanagan River Sockeye Salmon; McMillan 2013), Cascapedia River (Quebec, Canada) salmon (Mark Anton, Cascapedia River Society, personal communication), several Irish rivers (O'Maoileidigh et al. 2004), and Finland (Teno River; Venditti et al. 2007; NASCO 2014). Recent implementation of place-based management of the harvest of locally adapted populations in Norway exhibits promising results (Forseth et al. 2013). In general, Atlantic Salmon management rangewide over the past 20 years has largely moved away from (or never implemented) in-river hatchery production and has considerably reduced open-ocean and nearshore mixed-stock fisheries that encounter multiple independent populations. However, the legacy of previous management practices, such as high harvest rates, has likely delayed—if not prevented—the recovery of those wild Atlantic Salmon populations, the majority of which remain depressed and of conservation concern (Gibson et al. 2006; NASCO 2016). Moreover, widespread culturing of Atlantic Salmon in estuarine net pens is especially problematic owing to diseases and escapements that impact wild populations (Glover et al. 2012; Karlsson et al. 2016; Forseth et al. 2017). This problem is paramount in the USA and British Columbia (Morton and Volpe 2002; Fisher et al. 2013).

RECOMMENDATION

The current conceptual foundation guiding salmon management is responding to an overarching policy that emphasizes the production of commoditized salmon in support of commercial, tribal, and sport fisheries (Lichatowich et al. 2017). To put wild salmon on the path to recovery using the latest scientific knowledge, a policy of commodity production cannot remain the major focus of management programs. We recommend an alternative overarching policy that gives managers a statutory mandate to shift their attention to the ecological underpinnings that sustain wild salmon. That alternative policy is based on an ancient legal tradition called the public trust doctrine. Wild Pacific salmon are a prime candidate for protection and restoration under that doctrine. The doctrine obligates the trustees—the management agencies—to act prudently and restore damaged parts of the trust (Wood 2014). To ensure that the trust responsibility as an overarching policy is implemented, it should be added to existing statutes governing the management agency's operations. In meeting this trust responsibility, the government agencies acting as trustees must let future generations experience, to the extent possible, wild salmon in their natural setting and not as the impoverished remains of our current approach to management and recovery. In essence, broad, overarching salmon management policies should be developed that are based on and continuously updated by the latest scientific knowledge about the population dynamics of salmon, changes in their habitats, and harvesting processes.

Change is urgently needed because wild salmon populations in very productive rivers, such as those in Iceland, Kamchatka, Russia's Kola peninsula, and Alaska's Bristol Bay, among a few others, remain robust but can be quickly compromised by conventional policy and management approaches, such as the use of hatcheries, driven by the current conceptual foundation. Climate warming and density-dependent competition for food in the ocean between wild and hatchery salmon are also sources of pressure on wild salmon that require more thorough consideration by salmon managers (Ruggerone et al. 2010). Historical precedents, our professional experience, and current scientific understanding of salmon ecology all lead us to forecast that the recovery of wild salmonids and their ecosystems will remain elusive unless salmon management practices shift to a place-based foundation. The biggest obstacle to salmon recovery is not a lack of science or a lack of scientists; rather, it is persuading management agencies to adopt a conceptual foundation that is consistent with current science and incorporates the precautionary dictates inherent to a place-based management approach.

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