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Research, part of a Special Feature on Pathways to Resilient Salmon Ecosystems

Comparative Resilience in Five North Pacific Regional Salmon Fisheries

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ABSTRACT. Over the past century, regional fisheries for Pacific salmon (*Oncorhynchus* spp.) have been managed primarily for their provisioning function, not for ecological support and cultural significance. We examine the resilience of the regional salmon fisheries of Japan, the Russian Far East, Alaska, British Columbia, and Washington-Oregon-California (WOC) in terms of their provisioning function. Using the three dimensions of the adaptive cycle—capital, connectedness, and resilience—we infer the resilience of the five fisheries based on a qualitative assessment of capital accumulation and connectedness at the regional scale. In our assessment, we evaluate natural capital and connectedness and constructed capital and connectedness. The Russian Far East fishery is the most resilient, followed by Alaska, British Columbia, Japan, and WOC. Adaptive capacity in the fisheries is contingent upon high levels of natural capital and connectedness and moderate levels of constructed capital and connectedness. Cross-scale interactions and global market demand are significant factors in reduced resilience. Greater attention to ecological functioning and cultural signification has the potential to increase resilience in Pacific salmon ecosystems.

Key Words: *adaptive cycle; capital; connectedness; fisheries; history; North Pacific; resilience; salmon management*

INTRODUCTION

Pacific salmon (*Oncorhynchus spp.*) fisheries are integrated systems of people, fish, and the environment in specific places. They are complex, adaptive social–ecological systems that have taken different historical paths based upon the nature and diversity of and interaction among the components (Augerot 2000, Holling 2001). The distinct subsets of the North Pacific salmon fishery encompass social–ecological systems that interact with Pacific salmon in particular geographic areas, as regional salmon fisheries systems.

Salmon ecosystems provide a range of ecosystem services: ecological support, cultural services, and provisioning (Millennium Ecosystem Assessment 2005, Bottom et al. 2009). Contemporary salmon systems have adapted over time to focus primarily on provisioning, which is providing protein for the market and subsistence purposes (Lichatowich 1992, Augerot 2000). This parsing of ecosystem services is a human construct. Only recently have ecological support and cultural significance been assigned values and begun to be included in management considerations and priced in the marketplace. The market-driven provisioning function of wild Pacific salmon systems is not independent of ecological functionality. Ecological support elements of the Pacific salmon fisheries emerged as a modern fisheries management focus in the 1990s. With the U.S. emphasis on ecosystem-based management embedded in the Magnuson-Stevens Fishery Conservation and Management Act (1996, 2006) and the advent of the Canadian Wild Salmon Policy (Hyatt 1996, Irvine and Riddell 2007), management intentions have expanded from a concern solely with provisioning to evaluating additional ecosystem services. Prior to European colonization, tribal fisheries management included a broader suite of intentions and indicators, such as riparian conditions (Lake 2007). The status of the provisioning function can be readily measured by fisheries landings. Indicators for ecological functionality and cultural significance are being developed, but are not routinely monitored in most salmon fisheries (e.g., Nelitz et al. 2006).

In the five Pacific Rim salmon regions, we analyze how management and the historical pathways of

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these salmon ecosystems relate to resilience. We look at the effect of management straying from local and experiential knowledge and thereby reducing the resilience of the provisioning function of regional fisheries and of the salmon ecosystem as a whole (Ebbin 2002, Wilson 2006). Resilience is a measure of the magnitude of disturbance or surprise a social–ecological system can experience before shifting into a new state with different controls (Holling 1973, Gunderson and Pritchard 2002). Diminished resilience reduces adaptive capacity, the ability of a social–ecological system to cope with novel situations without losing options for the future (Folke et al. 2002). “A consequence of a loss of resilience, and therefore of adaptive capacity, is loss of opportunity, constrained options during periods of re-organization and renewal, and inability of the system to do different things. And the effect of this is for the social–ecological system to emerge from such a period along an undesirable trajectory” (Mantua et al. 2009).

Social–ecological systems accumulate capital and become increasingly connected as they mature (Holling 2001). By assessing the change in the regional fisheries systems, we can deduce each system’s potential resilience with respect to the provisioning function. These systems may appear very stable, but the degree and nature of their capital accumulation and connectedness makes them resistant to change. When internal or external shocks occur in tightly connected systems, disruption can spread quickly, either leading to adaptation or to systemic release and possibly collapse. Martin’s (2008) discussion of gillnetters coping with endangered species listings and Hanna’s (2008) review of Columbia Basin salmon recovery efforts in this special feature are examples of shocks leading to adaptation and release.

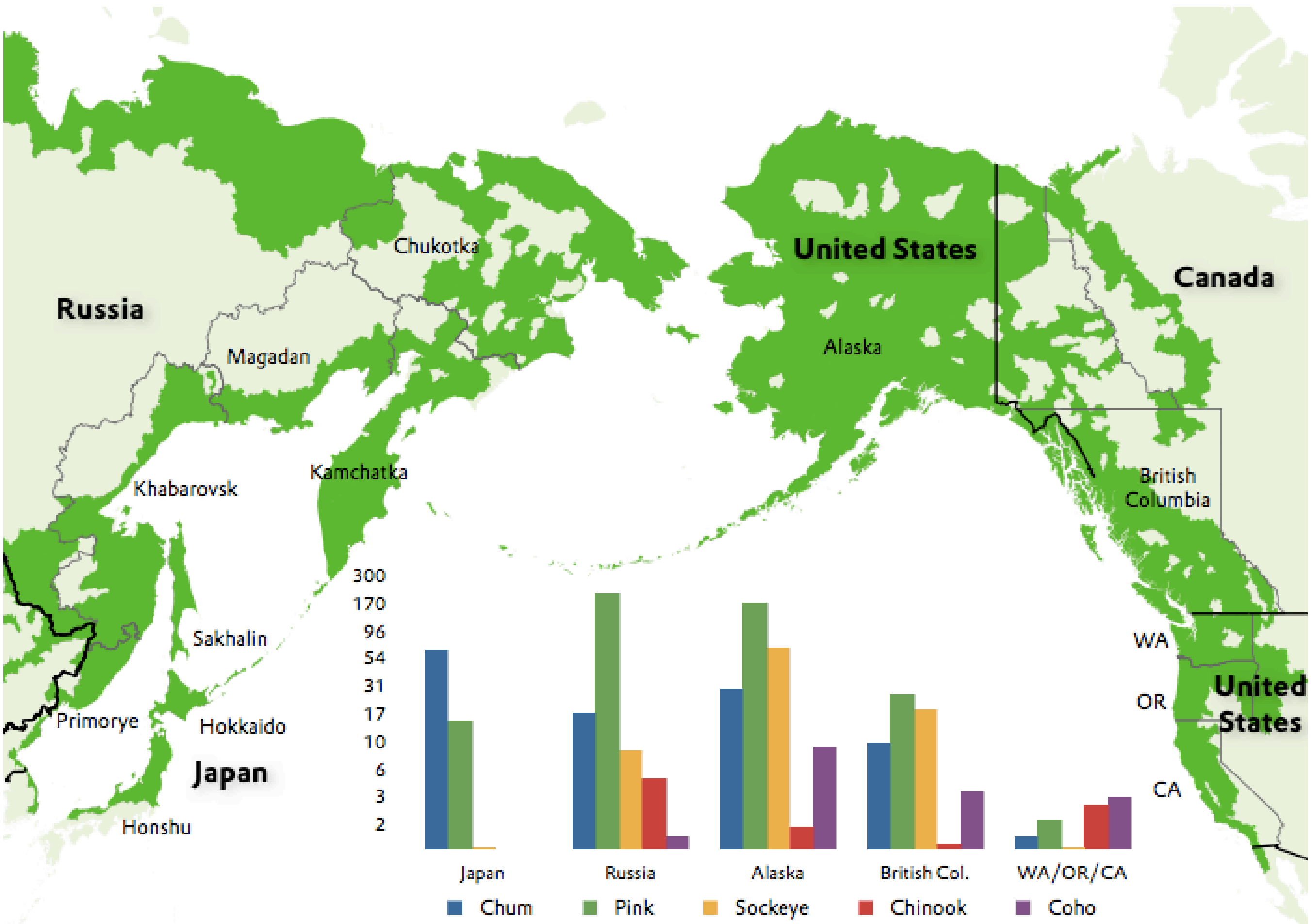
Because we cannot directly measure local and experiential knowledge in a broad comparative review of North Pacific salmon fisheries, we rely on proxy measures discernible at the regional scale. Institutions such as vertical integration of provisioning enterprises, globalized markets, and the interplay of management institutions representing a variety of sectors at various political scales lead to greater system brittleness over time. Brittleness increases the probability of entering the release phase where large amounts of capital are lost. With greater brittleness, it becomes more difficult to make structural changes in hierarchical systems that have long and complex contact links and highly structured and constrained feedback loops. For example, imagine the process required to make or change a federal rule or to get a bottom-up suggestion through a policy process. This brittleness reduces the resilience in social–ecological systems.

Regional salmon fisheries

Moving clockwise around the North Pacific are five distinct regional salmon social–ecological systems: Japan, Russia Far East, Alaska (USA), British Columbia (Canada), and Washington-Oregon-California or WOC (USA) (Augerot 2000). Each region has a different mix of native salmon species, at varying levels of abundance (Fig. 1, Table 1). These salmon-oriented systems interact through use of common marine rearing areas at sea, labor markets, global fisheries trade, and international geopolitics. Each regional system falls under a distinct national jurisdiction. Alaska and WOC are treated separately given their distinctness in geography, salmon species endowment, market position, regulatory systems, and historical pathways. We omit the small salmon fisheries of the Republic of Korea, Democratic Peoples’ Republic of Korea and the Peoples’ Republic of China (PRC), also countries of origin for anadromous salmon.

The adaptive capacity of salmon ecosystems varies with geography, the suite of potential habitats, climate patterns, and socioeconomic trajectory. The regional salmon fisheries have each adapted to environmental and economic change without fundamental shifts in the structure and function of the regional fishery systems. For example, Japan adapted its salmon fishery after the Russo-Japanese War, from which Japan gained extensive fishing concessions in Russia. The Japanese salmon fishery lost access to much of its natural capital and restructured with a high seas fishery and intensive hatchery production after losing access to Russian salmon at the end of the Second World War. It adapted once again with the closure of the high seas era in 1993, transitioning to the current coastal hatchery-based fishery. All of the regions have a shared trajectory of native fisheries giving way to colonization, industrialization, and sales to global markets. Global market pressures led to maximizing yields and overexploitation, loss of ecological function, and a weakening of the cultural significance of salmon.

Fig. 1. The five salmon fisheries regions and log-transformed average total salmon run per year (catch and estimated total escapement, 1990–2000). Green shading indicates the geographic extent of Pacific salmon (Augerot and Foley 2005). Salmon run values include hatchery and wild salmon, but exclude catch by Japan in the Russian Exclusive Economic Zone. Masu is omitted because catch has just begun to be recorded regularly by Japan and Russia. Chinook and coho values are very preliminary. Data assembled by G. Ruggerone, Natural Resources Consultants, cartography D. Springmeyer.



Japan

Fishery Cooperative Associations (FCAs) are central to Japanese fisheries management, dating from the Fishery Law of 1901. Only cooperative members are allowed to fish, and village culture and tradition remain very strong in many communities. Historically, government subsidies to FCAs, e.g., national fish hatchery system and business loans, were high. The system is increasingly self-financing. The prefectural and national governments are minimally involved in coastal salmon management, aside from the salmon hatchery system. Government plays a key role in allocation for the high seas salmon fishery, which occurs beyond the territorial sea in the Japanese Exclusive Economic Zone (EEZ). Historically, most of Japan's catch was consumed in Japan, but today a significant portion is exported to the People's Republic of China for processing and resale abroad. Masu (*O. masou*) catch was for many decades counted with pink (*O. gorbuscha*) salmon both in

Table 1. Attributes of five salmon fishing regions.

	Japan	Russia Far East	Alaska	British Columbia	WOC
Native species (commercially dominant highlighted)	**Chum**, **pink**, masu	**Pink**, **chum**, **sockeye**, coho, Chinook, masu	**Pink**, **sockeye**, **chum**, coho, Chinook	**Chum**, **pink**, **sockeye**, Chinook, coho	**Chinook**, **chum**, **coho**, sockeye, pink
Dominant legal gear	Pound nets, gillnets for masu	Pound nets, beach seines	Gillnets, purse seines, troll	Purse seines, gillnets, troll	Troll, gillnets, purse seine
Main fishing area	terminal	terminal	coastal	coastal	coastal
Sport fishery	Marine; freshwater juvenile masu only	Modest freshwater fisheries	Marine and freshwater	Marine and freshwater	Marine and freshwater
Personal use fishery	No	Yes	Yes	No	No
Native fishery allocations	No	Yes	On federal lands	Yes	Yes
Major management authority	Fishery Cooperative Association, Japan Fisheries Agency for Russia treaty fishery	Federal Fisheries Agency	U.S.–Canada Salmon Commission, Alaska Department of Fish and Game	U.S.–Canada Salmon Commission, Canada Department of Fisheries and Oceans	U.S.–Canada Salmon Commission, Pacific Fisheries Management Council, interstate compact, tribes, states
Major markets	Domestic, plus China for reprocessing	Domestic, plus Japan, China reprocessing	Domestic, plus exports to Japan, China reprocessing	Export to US, Japan	Domestic

Japan and in Russia; therefore, it is not included in Fig. 1. Japanese consumers show an increasing preference for imported farm-reared filleted and portioned Atlantic salmon (*Salmo salar*), coho (*O. kisutch*) salmon, and wild-captured sockeye (*O. nerka*).

Russia

Pink and chum (*O. keta*) salmon are caught in terminal fisheries across the Russian Far East, but most of the sockeye, Chinook (*O. tshawytscha*), and coho are caught in shore-based fisheries on Kamchatka or in fisheries research institute gillnet fisheries offshore. Masu salmon are primarily a personal-use and sport target. Russian pound net and beach seine fisheries are run by private fishing companies, which require large crews of semi-skilled labor. Some companies are vertically integrated with processing and marketing elements, but most are catch operations only. Few sanctioned recreational and native subsistence fisheries or well-developed tourist sport fisheries exist. The boundaries of these fisheries and the well-financed illegal roe stripping fishery blur with the commercial system (Dronova and Spiridonov 2009). Government subsidies were historically high, but virtually non-existent in 2009. Since the collapse of the USSR in 1991, most community-based processing operations have closed, and processing is now centralized in regional port cities or distributed on floating processors. Salmon is a national resource, managed by a national agency with regional offices in conjunction with provincially based salmon councils.

North America

The United States (Alaska, WOC) and Canada are similar in terms of species and gear types, but the relative abundance of each species, except Chinook, is vastly greater in Alaska (Fig. 1, Table 1). Individually owned and operated mobile gear types predominate, along with some processor-owned boats (vertically integrated companies). Crews are small, and most catchers own a single boat. Alaska has large commercial fisheries for chum, pink, and sockeye salmon and smaller commercial fisheries for coho and Chinook. British Columbia fishers also catch the same five species. WOC's catch is dominated by Chinook. Chum and sockeye are caught commercially only in Washington State, at the northern extent of the WOC region. Coho and Chinook are generally sold fresh or frozen into the retail and restaurant trade in the domestic market. Frozen and canned sockeye are the highest value salmon products, followed by chum flesh and roe—sold fresh and frozen to North American, Japanese, and Chinese reprocessing markets (Knapp et al. 2007).

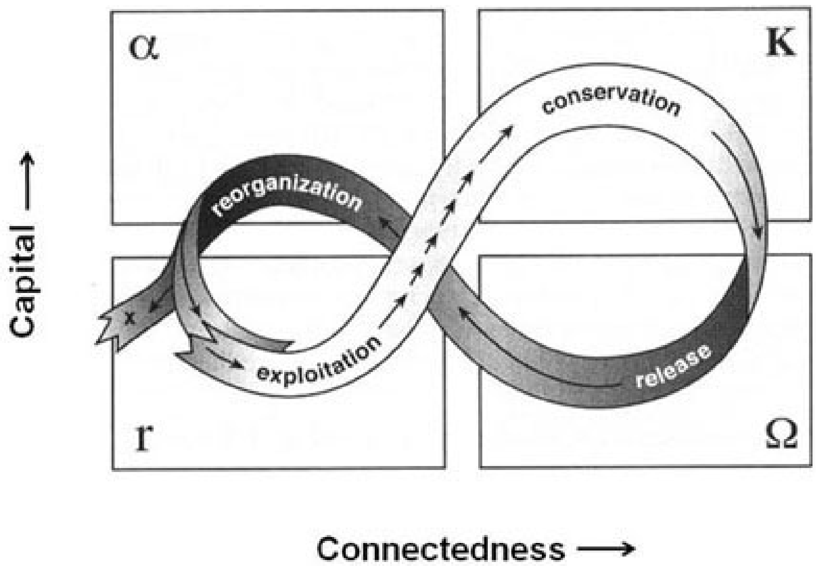
Fisheries in all three North American regions are managed in part through allocations set by the Pacific Salmon Commission under the U.S.–Canada Salmon Treaty. Alaskan salmon fisheries are managed by the Alaska Department of Fish and Game for long-term sustainability, as mandated in the state's constitution. Canada exercises national management and is highly engaged in the Pacific salmon fisheries under the 2005 Wild Salmon Policy. The Canada Department of Fisheries and Oceans allocates salmon to First Nations for commercial, ceremonial, and subsistence purposes. Salmon fishery management in WOC is split across multiple authorities: the federal Pacific Fishery Management Council, state fish and wildlife agencies, the treaty tribes, and subregional compacts and commissions. An additional level of federal authority is exercised for salmon populations listed as threatened or endangered under the U.S. Endangered Species Act. Government subsidies in all three regions have had a consistent emphasis on hatchery salmon production and variable emphasis on habitat protection, restoration, and supporting catcher livelihoods.

METHOD FOR ESTIMATING RESILIENCE

Resilience in complex social–ecological systems tends to follow a common set of cyclical patterns related to production and connectedness (Holling 2001, Gunderson and Pritchard 2002). Gunderson, Holling and colleagues cast this as the renewal cycle (Gunderson et al. 1995). The renewal cycle is based on three dimensions—potential (also referred to as productivity) and connectedness are in the x–y plane. The two-dimensional view of the renewal cycle has four phases: exploitation, conservation, release, and reorganization (Fig. 2). Exploitation (r) has increasing capital accumulation and limited connectedness. As the conservation phase (K) proceeds from exploitation, capital accumulation rises to a maximum and stops growing. The system becomes increasingly connected, and connections are more brittle. During release (Ω), brittle connections are broken, and capital that has accumulated with rising productivity is released. During reorganization (α), productivity is low as a new order for the system is sought and connections are renewed. Social–ecological systems are at maximum productivity during the peak of the conservation phase, but the number and nature of connections induce brittleness and diminished resilience. Resilience is in the z plane and is lowest just before and during the release phase, often called the "back loop" of the renewal cycle (Berkes and Folke 2002).

As users develop extractive resources, by fishing, logging, grazing, or something else, initial production rates grow rapidly in the exploitation phase. Early in the exploitation phase, innovation opens use of a new resource. Later in the exploitation phase, little skill or investment allows operation of a profitable business. As the number of users attracted to the sector increases and more pressure is placed on the resource, the natural capital begins to diminish, and constructed capital accumulation increases—larger boats with more powerful engines and improved technologies, vertically integrated fishing companies with processing capacity, multiple processing plants, and diversified product lines. Active management usually occurs during this, the conservation phase in which the goal is to maintain continued levels of production. The objective becomes to maximize current catch without jeopardizing future system productivity—in fisheries management, this is referred to as maximum sustainable yield.

Fig. 2. Adaptive cycle showing the increase in capital accumulation (potential) and connectedness from the exploitation to conservation phases. From Panarchy: Understanding Transformations in Human and Natural Systems edited by Lance H. Gunderson and C.S. Holling. Copyright © 2002 Island Press. Reproduced by permission of Island Press, Washington, DC.



As the social–ecological system becomes increasingly capitalized, it also becomes more tightly interconnected institutionally and ecologically. Systems that are highly institutionally connected become brittle and inflexible to change (Gunderson and Holling 2002). If regional salmon fisheries become more closely coupled ecologically due to simplification of fish assemblages, salmon populations, and habitats, they become more vulnerable to internal or external change. Events like a court ruling, a poor season, ecological disturbance, or absence of financial credit may then rapidly cascade through the system, destroying capital and connectedness. When a system has sufficient adaptive capacity, these events will likely lead to "small loops" in the conservation portion of the adaptive cycle, without systemic release and collapse. However, if the system has become very brittle, even a relatively small perturbation may lead to systemic release. Depending on the social and ecological resources remaining, the system may reorganize for a new exploitation phase, with a modified structure and perhaps an altered function.

As we are concerned with social–ecological systems, potential is stored in two types of capital: natural and constructed capital. Constructed capital is the capital developed by the human components of the social–ecological system, whereas natural capital refers to natural resources. Likewise, connectedness has natural and constructed components.

Relative ranks specify capital accumulation and connectedness in the five regional salmon fisheries. We locate rankings on the adaptive cycle and infer the relative resilience at that point in the renewal cycle. We use a qualitative three-tiered ranking of high, medium, and low, based on the authors' judgment regarding the regional fisheries, and we indicate this with an arrow if the trend is up or down.

Natural capital

As regional salmon fisheries systems enter the conservation phase, they draw down natural capital and begin to substitute and rely more heavily on constructed capital. This is referred to as the "fishing down process" (The H. John Heinz Center for Science, Economics and the Environment 2000).

Natural capital is energy, which may be represented in the form of river discharge, biomass, carbon, or other nutrients. In this case, the key elements of natural capital are salmon biomass, salmon species and life-history diversity, and habitat quality, quantity, and diversity. Salmon ecosystems are most robust when catchment populations are abundant and contain a variety of species and life-history elements, and salmon use freshwater and marine habitat that is abundant, diverse, and of high quality. Species and within-species life-history diversity within a salmon catchment or local fishery serve as a form of risk spreading. In any given string of years with varying weather patterns, some proportion of the salmon in the system should perform well, providing nutrients to the aquatic and riparian flora and fauna (Healey 2009). Salmon biomass is the most straightforward measure of natural capital when management is focused primarily on the provisioning function.

Constructed capital

We use the term "constructed capital" to refer to infrastructure, institutional capital such as fishing rights, and human capital. First, hatcheries are built to augment the stock of natural capital, but then replace it with engineered or constructed capital (Lichatowich 1999). The infrastructure category includes coastal fishing ports, cold storage, fish processing capacity, and transportation networks. Human capital represents the availability of trained fisheries-sector workers and positive attitudes toward work.

Natural connectedness

Social–ecological systems abound in connections linking disparate parts of the system through flows of energy, nutrients, water, and information. At the regional scale, the key natural connectedness elements are large-scale temporal and spatial phenomena: three-dimensional free-flowing rivers, and marine and freshwater conditions. The first refers to the normative river concept: the "functional norm which ensures that we provide the essential ecological conditions and processes necessary to maintain diverse and productive salmonid populations" (Lichatowich et al. 2005). To support habitats for salmon requires sufficient exchange of water, nutrients, energy, and other materials in a river basin. The optimal state will occur in an undammed river, a full-range of predator–prey relationships, complex trophic interactions, unconstrained by transportation routes, absence of urban development on the floodplains that are also unaltered by extensive mining, agriculture, or logging.

Marine climate connectedness refers to the spatial and temporal links in the sequence of marine habitats through which salmon migrate and feed during their life cycle, whereas freshwater climate condition refers to the synchrony of climate sequence within river basins. Due to the interacting effect of climate cycles and human perturbation, the sequence of habitats in the marine or freshwater environment may not synchronize with salmon population needs in a particular region. The freshwater and marine conditions may also be out of phase with one another for a given salmon population. Our qualitative assessments for marine and freshwater climate connectedness represent broad generalizations at the regional fisheries scale, informed by the MALBEC Project (Mantua et al. 2007).

Constructed connectedness

Institutions connect humans with their ecology (Hanna 2008). Institutional connections evolve over time to address problems and opportunities faced by actors in the regional fishery systems. Finley's (2009) discussion of the political and legal ramifications of the scientific concept of maximum sustainable yield in this volume is an example. To assess constructed connectedness, we use four external elements: degree of vertical integration, regulatory interconnectedness, cross-sectoral integration, and global market involvement.

First, we review vertical corporate integration extending beyond the region, which results in deep, hierarchical structures that often span fisheries for multiple species, include processing and distribution, and may extend into the retail and restaurant operations. Second is governmental regulation, standards, coordination, and oversight, which add layers of decision-making authority and concurrence to regional salmon fisheries systems, both at the same level of organization (horizontal; e.g., state) or at different levels (vertical; e.g., state–federal). We refer to this attribute as regulatory interconnectedness, although it could be referred to as institutional interplay (Ebbin 2002, Young 2002). This form of interconnectedness is not inherently positive or negative, but when levels of interconnectedness are high, creative decision making is limited by regulations, and any regulatory change takes a long time to work through the system.

Third, cross-sectoral habitat mandates cross resource-use subsystems (i.e., fisheries, forestry, land use, mining) and constitute a distinct form of constructed connectedness. These mandates represent an attempt to address competing demands for natural resources through governance, rather than the market place. Natural capital and connectedness may be protected by these mandates, but they also increase system brittleness through regulatory prescriptions and concurrence processes.

Market relationships are a fourth form of constructed connectedness. We assess the relative interregional or global market connectedness. Distant demand is frequently out of proportion to local fisheries systems' productive capacity, whereas market prices reflect gross availability across all sources for salmon. These price distortions may lead local fishers to capture more fish, eating into their natural capital, to compensate for low prices or to profit from high global market prices.

RESULTS

The five regional fisheries are our units of analysis. We have mapped our perception of the interacting social–ecological hierarchy in Fig. 2 (adapted from Folke et al. 2003). Each regional fishery is influenced by a national entity, and habitat areas are affected by competing demands for natural resources and by climate cycles such as the Pacific Decadal Oscillation (Mantua and Francis 2004). Many slow variables may express themselves over the regional extent: political regime change, climate effects on marine and freshwater habitat condition, species and life-history diversity, and long-term economic cycles. Global markets, geopolitics (i.e., as reflected in treaties and agreements), and the global climate system span all spatial extents.

The regional focus provides a very coarse spatial scale for examination of social–ecological dynamics in salmon fisheries around the North Pacific. Each regional fishery is a linked social–ecological system operating at range of spatial and temporal extents (Holling et al. 2002). Variables that change more rapidly may occur over spatial extents as small as a sub-basin and affect salmon biomass and habitat quality. For the purpose of this analysis, the elemental units, those with the smallest spatial, temporal, and institutional scale in the social–ecological system, are the local fishing community and associated catchment or sub-basin.

Natural capital

The northern salmon regions in the North Pacific have more natural capital than the southern ones. Russia and Alaska have the richest suite of natural capital in their regional fisheries systems. Alaska ranks high for biomass, diversity, and habitat, whereas Russia ranks high for biomass and habitat, but is medium with respect to species diversity (Table 2). This reflects Russia's uneven salmon distribution, with commercial aggregations of coho and Chinook found only in Kamchatka Territory (Augerot 2005). Alaskan salmon biomass at the regional level is near record highs, although biomass declines are noted for the Yukon–Kuskokwim area (Eggers 2009). Gresh et al. (2000) estimated Alaskan salmon runs to be near 110% of historical abundance.

Japan and WOC salmon systems both have impoverished natural capital. In Japan, salmon biomass is much greater than historical values due to chum and pink salmon hatcheries and many decades of productive marine rearing conditions. However, less than 2% of Japan's chum and roughly 40% of pink salmon returns are naturally spawning fish (Kaeriyama 1999, Morita et al. 2006*a*, *b*). Japan ranks low for wild salmon biomass, species and life-history diversity, and habitat quality, quantity, and diversity. WOC ranks low for salmon biomass, but moderately for species and life-history diversity. Current salmon runs are at best 5% of historical run sizes across Washington-Oregon-California (Gresh et al. 2000). Many sockeye, coho, chum, and Chinook runs have been intermittently or permanently closed to fishing. The historic fisheries in the large and ecologically diverse Columbia and Sacramento–San Joaquin river systems hosted a diversity of salmon species and life histories, and many of these remain as remnant populations (Gustafson et al. 2007). Habitat quality, quantity, and diversity have deteriorated significantly across most of WOC and we rank this attribute as low.

Table 2. Capital rankings for the five salmon fishing regions. H is for high rankings, M is medium, and L is low.

Capital	Japan	Russia	Alaska	British Columbia	WOC
Natural					
Salmon biomass	L	H	H	M	L
Species and life history diversity	L	M	H	H	M
Habitat quality, quantity & diversity	L	H	H	M	L
Constructed					
Hatcheries	H	L	M	H	H
Fishing rights (institutional)	H	M	H	H	H
Human capital	L	L	M	L	L
Infrastructure	H	L	M	M	M

British Columbia is an intermediate case with respect to natural capital, with high species and life-history diversity, and contemporary salmon runs at approximately 40% of historic levels (Gresh et al. 2000). Habitat quality, quantity, and diversity are in moderate condition across the region, extensively affected by extractive industries such as mining and logging, and intensively altered by agriculture and urbanization in southern British Columbia (Hartman et al. 2007).

Constructed capital

Japan has the most constructed salmon fishery capital (H), with a dense hatchery system, clearly defined community-based fishing rights, and very well-developed local port, cold storage, and other fishing infrastructure. All of these attributes receive a high ranking (Table 2). However, human capital is rapidly eroding in Japan, as the rural fishing population ages and the younger generation moves out (U.S. Department of Agriculture 2006). We rank human capital in Japan's salmon fishery as low.

The Russian Far Eastern salmon fishery is low (L) in constructed capital. Small port, cold storage, and processing infrastructure is rare, although increasing, particularly in Sakhalin and Kamchatka territories where most of the salmon are caught. Road and rail infrastructure are poor across most of the Russian Far East, and all interregional air and sea freight must travel through a limited number of major air and seaports (Clarke 2007). Although ranking this form of capital as low, we acknowledge that Russia has a current campaign to improve coastal infrastructure as a component of the Federation's economic stimulus plan. Human capital is also poorly developed in the salmon fishery; after the collapse of the Soviet Union, the average training and preparedness of fishery-sector labor diminished greatly, and many trained people were forced by economic necessity to shift to other work when centralized government-run companies ceased to operate, thus the rank is low (L).

Hatcheries are sparsely distributed across the Russian Far East with the exception of Sakhalin Territory, where hatcheries are numerous and modern. We rank this form of constructed capital as low. On Sakhalin Island, hatcheries appear to have successfully increased pink salmon populations, but perhaps more importantly, have served to anchor fishing rights, giving the emerging regulatory system a medium (M) rank. Russia recently adopted a system of long-term leases, linking each river basin to a fishing company (Beliaev and Zviagintsev 2007). This system is an improvement over the year-to-year allocation of fishing quota to qualifying companies and should provide improved within-season catch management and year-to-year stability, facilitating more investment in natural and constructed capital.

Alaska's constructed capital is well-developed, with a robust hatchery system (M), clearly designated and enforced fishing rights (H), good but eroding availability and training of human capital (M), and good but declining port, processing, and storage capacity (M), associated with corporate consolidation. An increasing proportion of Alaskan salmon, as well as Japanese and Russian catch, is exported minimally processed to the Peoples' Republic of China, where it is converted to value-added products and re-exported around the world (Clarke 2007, Asia Business News Newswire 2007).

The British Columbia salmon fishery system is heavily invested in an extensive network of hatcheries and spawning channels (H) and has a well-developed and stable fishing rights system (H). Human capital has declined in preparedness and availability (L), in part related to the export of processing jobs to the WOC and China. Government programs to reduce fishing capacity and the ensuing increase in market prices for licenses, in tandem with global market dynamics, led to falling profitability and an exodus of fishers (Scholz et al. 2004). Likewise, local ports and processing and cold storage plants have closed due to corporate mergers in the fishery sector, leading to a moderate infrastructure ranking (M; Newell 1988).

The situation in WOC parallels that in the British Columbia salmon fishery. An extensive hatchery network is supported mainly with government funds (H). Fishing rights are clearly defined (H; Lichatowich 1999). However, human capital is declining in quantity and quality (L), with processing jobs exported overseas and many fishers leaving their boats at the docks, due to either poor markets or fishery closures due to wild fish declines (Smith and Gilden 2000). A great deal of small port infrastructure and processing capacity has been lost (M), due to corporate consolidation in the seafood processing, trade, and grocery sectors (Wisdom 2008).

Natural connectedness

Corresponding with natural capital, the Russian Far East and Alaska have the greatest natural connectedness and rank highly on all three attributes (Table 3). Marine climate conditions have been favorable for salmon from both regions for the better part of three decades, whereas freshwater conditions have been somewhat more variable geographically over that time period, leading to local declines in production in the Yukon, Kuskokwim, and Amur rivers at different times in the recent past. Both Russia and Alaska abound in free-flowing rivers, unconstrained by roads, settlements, agriculture, or other forms of development. Mining is the major sector affecting river function and connectivity in both regions.

WOC is the most impoverished in terms of natural connectivity, ranking low across the board. Marine conditions have been unfavorable for most years since about 1980, with only two short sequences (2–3 years) of favorable marine habitat connectivity. Recent climate patterns, with associated shifts in the type and quantity of precipitation and altered seasonal hydrographs, have led to fragmented sequences of freshwater habitat. Most rivers have been significantly altered by transportation routes that constrain floodplains, and by dams, agriculture, settlements, logging, and mining. Disruptions in freshwater connectivity have led to unfavorable changes in trophic interactions over time.

British Columbia is an intermediate case, due in part to its geography. Whereas the marine climate effects of the Pacific Decadal Oscillation are clearly observable on salmon populations in WOC and Alaska, British Columbia is on a shifting boundary between the two regions. Warm periods improve the entire series of ocean habitats used by Alaskan salmon, but elevate ocean temperatures along the North American continental shelf above optimal levels for WOC fish, or they may be indicative of broader ecological changes that are dangerous to salmon independent of the direct physiological effects of temperature alone (http://jisao.washington.edu/pdo/). Ocean temperature patterns along the British Columbia coast may vary year to year, creating much greater variability in salmon productivity. Freshwater climate conditions are affected by continental high pressure systems and may be out of synchrony with favorable marine climate trends for salmon, particularly for basins such as the Fraser River, extending inland beyond

Table 3. Connectedness rankings for the five salmon fishing regions. Hi is for high rankings, M is medium, and L is low.

Connectedness	Japan	Russia	Alaska	British Columbia	WOC
Natural					
Climate condition – marine	H	H	H	M	L
Climate condition – freshwater	L	H	H	M	L
3-D free flow rivers	L	H	H	M	L
Constructed					
Vertical integration	M	M	H	H	M
Regulatory interconnectedness	L	M	M	M	H
x-sectoral habitat protection mandates	L	M	H	H	M
Global markets	H	M	H	H	H

the coastal mountains. Many rivers are significantly constrained by transportation routes and some by dams. Human settlements, agriculture, and mining have most significantly altered regional rivers, with the most severe effects concentrated in the Fraser River basin and on Vancouver Island. We rank British Columbia medium for natural connectivity, across all three attributes.

Unlike the other regions, Japan is not homogenous in its rankings. As for Russia and Alaska, marine conditions have been largely favorable since about 1980 (H). Freshwater climate conditions are almost irrelevant, given the dominance of hatchery production. However, based on recent studies by Morita et al. (2006*b*), pink salmon abundance is highly correlated with freshwater climate effects, which have created series of favorable and unfavorable years for naturally spawning pink salmon over the past decades. We rank freshwater climate connectivity as low, given its highly altered nature and limited role in salmon reproduction due to the hatchery program. Japanese rivers are highly affected by dams and channelization, with very few remaining free-flowing rivers (Fukushima et al. 2007).

Constructed connectedness

Vertical integration is reflected in Japanese salmon pound net fisheries that are owned and operated by local FCAs. Salmon are subsequently sold to trading companies. Strong vertical integration is a characteristic of marketing in Japan, and we scored it as medium. After the collapse of the Soviet Union, Russia's hierarchically structured, government-owned salmon fishery splintered into numerous small, poorly capitalized, and inexperienced businesses. Significant business consolidation has occurred over the past 18 yrs, and many salmon fisheries are now carried out by companies that may operate hatcheries and processing plants, and engage in foreign trade. We also rank vertical integration in Russia as medium.

Vertical integration is high in Alaska and British Columbia. WOC is characterized by many small, independent, seasonal fishers with less vertical integration between catchers and a very centralized processing to market linkage.

Government regulatory interconnectedness is distinctly different in Japan. Japan exercises prefectural oversight over management plans developed by the FCAs, but no federal or prefectural regulation over commercial fisheries (Augerot 2005). The principal bridging organizations are the prefecture-level and federal-level cooperative associations: Dogyoren for Hokkaido and Zengyoren for all of Japan. We rank Japan as low for this form of connectedness.

Russian Pacific salmon fisheries are moderately interconnected institutionally and are becoming more so (Beliaev and Zviagintsev 2007). Historically, Russian salmon management has been top-down, from Moscow to the regions. After the collapse of the Soviet Union, regional authority increased, particularly the role of gubernatorial administrations and regional salmon councils. Regional divisions of federal agencies are the principal vertical and horizontal bridging entities, e.g., KamchatNIRO and Sevvostrybvod on Kamchatka.

Alaskan salmon management and oversight involve fewer governmental entities as the state has clear jurisdiction and authority over sport and commercial salmon fisheries, with federal authority only over subsistence on federal lands. Alaska actively participates in the North Pacific Anadromous Fish Commission, U.S.–Canada Salmon Commission and the Pacific States Marine Fisheries Commission, representing international and interstate collaboration. There is no federal concurrence or oversight in Alaska's salmon fisheries. We rank Alaska's salmon fishery medium (M) for intergovernmental connectedness.

British Columbia (BC) is also moderately interconnected in this regard, as the provincial government does not share harvest authority for salmon. Many First Nations are negotiating treaty rights and have formal, negotiated co-management relationships with Canada's Department of Fisheries and Oceans. Since the mid 2000s, vertical bridging organizations have also been introduced to BC salmon fisheries: the Pacific Fisheries Resource Conservation Council, the Fraser Basin Council, and the Commercial Salmon Advisory Board.

WOC has the most complex set of fisheries management regulations and number of entities engaged in salmon fishery management and oversight, due to spatially defined state, federal, and tribal authority, and an array of treaty, compact, and salmon recovery organizations designed to manage shared fisheries across states and tribes. We rank WOC highly for this form of connectedness (H).

Cross-sectoral habitat mandates vary greatly across the salmon fishery regions, from virtually non-existent upland habitat regulations in Japan (L) to extensive interventions and coordination in WOC, when salmon populations are listed under the U.S. Endangered Species Act. WOC receives a moderate ranking (M) in Table 3, due to the difficulty of effecting cross-sectoral habitat mandates on its extensive private lands.

Russia's Forest and Water Codes each include strong salmon habitat protections, dating to the Soviet era. These protections are slowly eroding, and the disincentives for rule breaking are minor and enforcement capacity is low. The Russian Federation owns all lands and waters, and to date, this has slowed natural resource development pressures. The current trend toward privatization of resource rights under long-term leases may lead to weakened cross-sectoral habitat protection mandates. We rank this attribute for Russia as moderate.

Alaska also has strong cross-sectoral habitat protection mandates in place (H), although they are frequently challenged by the mining, oil, and gas sector. Several Alaska-based environmental organizations watch-dog the enforcement of cross-sectoral habitat mandates, supporting the enforcement of habitat regulations. British Columbia ranks high on this attribute because its federal Fisheries Act requires no net loss of salmon habitat and mandates mitigation, and most of the lands are in provincial government ownership.

Historically, most of Japan's chum, pink, and masu salmon did not reach global markets. They were consumed within Japan, and additional Pacific salmon was imported from other regional salmon fisheries. Japanese salmon imports have long dominated the global salmon trade, although this may be changing with the emergence of the Peoples' Republic of China as a global fisheries reprocessing center (Clarke 2007). Cultural and economic changes drawing more women into the workforce have resulted in less demand for headed and gutted Japanese catch and more for imported, farm-raised and filleted salmon (*Salmo salar*) and coho. Japan is exporting an increasing proportion of its chum catch for reprocessing in China, destined for global markets. We rank Japan's market connectedness as high (H).

During the Soviet era, most of the Russian salmon catch was consumed internally, although a portion of the sockeye catch was exported to Japan. Some of the less abundant species, including Chinook and masu, were destined for Western Russian markets and rarely seen by local Russian Far Eastern consumers. Most fish was sold as blocks by weight, chopped from frozen blocks of headed and gutted salmon. With the privatization of the fisheries and the end of the government export monopoly, an increasing volume of salmon is exported to Japan, Republic of Korea, and the Peoples' Republic of China (Dronova and Spiridonov 2009). The Russian salmon fishery is moderately (M) connected to global markets, and those connections are increasing.

Alaska and British Columbia are highly integrated into the global salmon market, exporting a large proportion of their catch (Knapp et al. 2007). WOC market integration has declined from historical levels in the cannery era, with most of its current catch sold as fresh-frozen fish to high-end retail and restaurant trade within the United States. During the heyday of WOC fisheries, markets for its canned salmon were global. Most fishing vessels are still individually owned, but in practice their movement and effort is dictated by prices offered by integrated processing, distribution, and marketing companies and by competition from the international pen-reared salmon industry. All three rank highly for global market connectedness, although this attribute may be declining for WOC salmon fisheries.

RESILIENCE

We converted our qualitative ranking of the regional fisheries for capital accumulation and connectedness to numerical scores to reflect regional fishery system capital accumulation and connectedness (Table 4) and plotted them on the three-dimensional adaptive cycle (Fig. 3). The results provide a characterization of the resilience of the provisioning function for the five regional systems. Resilience provides the elements necessary for adaptive capacity—the structural and functional diversity of ecological systems and institutions essential for renewal and reorganization (Berkes 2002, Gunderson and Holling 2002, Mantua et al. 2009).

Japan's salmon fishery appears to be one circuit ahead of the other four regions through the adaptive cycle. By the 1960s, the Japanese system had substituted constructed capital (hatcheries) and high seas interception fisheries for its own natural capital. The only strong remaining element of natural connectedness for Japan's regional salmon fishery is marine habitat connectivity. The constructed capital afforded by historical government subsidies and the institutional capital associated with FCAs creates a strong social safety net for salmon fishers. The system is rigid, with ever fewer young fisher-innovators (declining human capital).

Inferred resilience is greatest for the Russian Far East salmon fishery, which is transitioning from the exploitation to the conservation phase of the fishery (Table 4). The Russian Far East salmon fishery experienced a systemic release after the collapse of the Soviet Union in 1991, resulting in destruction of system structure and connectedness as well as a destruction of constructed capital. The August 1991 coup that toppled the decaying USSR resulted in an unbridled fishing season that year (Augerot 2000). The following 2 yrs, total salmon catches were mediocre.

The Russian Far East salmon fishery is now in a period of exploitation (r), slowly rebuilding the constructed capital and connectedness that was lost in the late 1980s and early 1990s. A new framework fisheries law entered into force in 2005, substantially updating the previous fisheries law dating to 1958. Amendments to the fishery law and new regulations governing the Russian Far East fisheries were issued in 2007 and 2008. The legal framework provides for 20-yr commercial fishing concessions, providing access stability and predictability for commercial operators (constructed capital). Fishermen's associations and provincial authorities have gained authority, with in-season management decisions devolved to newly constituted regional salmon councils in 2008 (Tabunkov et al. 2009).

Alaska is still squarely in the conservation phase of the adaptive cycle, near peak connectedness and capital accumulation (potential) for both constructed and natural forms. The Alaska fishery exhibits resilience and has recently demonstrated its adaptive capacity to contend with global market changes, such as competition from pen-reared Atlantic salmon, through differentiation in the marketplace.

British Columbia is an intermediate case, demonstrating diminishing natural connectedness and moderately high and potentially increasing

Table 4. Tabulated numerical scores for the five regional capital accumulation and connectedness scores (L = 1, M = 2, H = 3). Summary rankings are based on the mean, whereas trend is indicated by the mode.

	Japan	Russia	Alaska	British Columbia	WOCI
Capital					
Natural	111	323	333	232	121
Constructed	3313	1211	2322	3312	3312
Score	m = 1.9, mode = 1	m = 1.9, mode = 1	m = 2.6, mode = 3	m = 2.3, no mode	M = 1.9, mode = 1
Summary Ranking	M↓	M↑	H	M	M↓
Connectedness					
Natural	311	333	333	222	111
Constructed	2113	2222	3233	3233	2323
Score	m = 1.7, mode = 1	m = 2.4, mode = 2	m = 2.9, mode = 3	m = 2.4, mode = 3	M = 1.9, mode = 1
Summary Ranking	M↓	M↑	H	M↑	M↓

constructed connectedness. Federal and provincial treaty negotiations with First Nations include salmon co-management, and federal implementation of Canada's Wild Salmon Policy will likely lead to new or strengthened local fishery-based community organizations. Natural capital in the British Columbia fishery is in significantly better condition than in the WOC fishery, but constructed capital is deteriorating. Resilience is modestly higher in British Columbia than it is in WOC.

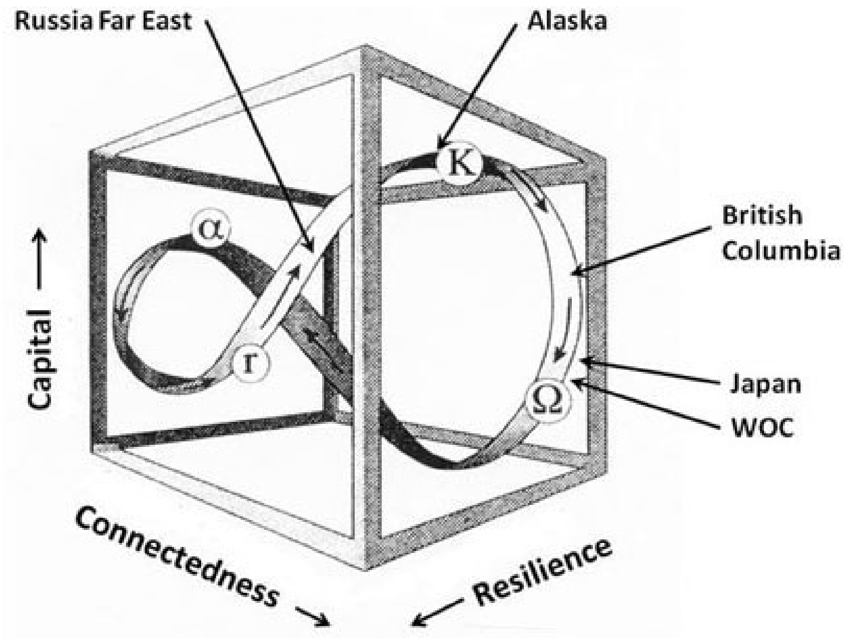
The paucity of natural capital in the WOC fishery and its high constructed connectedness yield less resilience in this system. Run forecasts for coho and northerly Chinook runs for the 2009 season shut down the California and Oregon ocean troll fisheries for the third consecutive season. Althugh salmon are still caught in this regional fishery, most of the catch is bound for the high-end retail or restaurant market and is priced high enough that the fish are no longer accessible to the majority of regional consumers. The provisioning function has become minor.

DISCUSSION

The adaptive cycle is useful for showing the changes that have taken place in the five regional fisheries. Using the adaptive cycle, we describe the pattern of change in each fishery and locate the current status of the fishery. Capital and connectedness help locate the current state for resilience in each of the five regions. This is not to say that resilience is fixed. A major disturbance, such as a sudden decline in marine habitat connectivity associated with climate oscillation or climate change, would challenge the adaptive capacity in these systems.

If marine conditions deteriorated, provoking significant Japanese chum salmon declines, the provisioning function of the regional salmon fishery could collapse and initiate substantive reorganization. The FCAs are locally based and autonomous, although tradition-bound both in their social structure and in their focus on the provisioning function of salmon. If salmon runs were to collapse, the FCAs have a portfolio of other species to depend upon, but may not be able to survive economically

Fig. 3. The stage of the five regional salmon fisheries in the adaptive cycle. Russian Far East fisheries have the highest inferred resilience, followed by Alaska, Japan, British Columbia, and Washington-Oregon-California (WOC).



(Morita et al. 2006*b*). Momentum for change in management intention is coming from fisheries scientists and managers, seeking to increase natural river function, protect native species, and better understand the dynamics of naturally reproducing populations (Fukushima et al. 2007, Morita et al. 2006*b*).

In the Russian Far East regional fishery, adaptive capacity is moderately high. Russian historical experience has resulted in a culture where people expect change and uncertainty and are creative in coping with it. Although not reflected in the Russian fisheries literature, local and experiential knowledge is often incorporated in fisheries forecasts and knowledge systems. However, memory in the Russian system is not systematized at the local or regional levels, and local ecological and historical knowledge is frequently held by unique individuals.

A sudden decline in marine habitat connectivity due to climate oscillation or climate change would likely have varied effects across the Russian Far East. The high rate of unlicensed fishing effort, unreported exports, and underdeveloped catch monitoring and reporting system have led to unbridled growth in the catch capacity of the Russian Far East fishery (Augerot, *unpublished manuscript*). At high fishing rates, escapement levels could become catastrophically low, resulting in a collapse in natural capital across the regional fishery. Indications suggest that this is already occurring in some Kamchatka catchments (Zaporozhets and Zaporozhets 2007).

Alaska’s flexible, locally focused salmon management system would likely cope with dramatic declines in salmon returns fairly well. Constructed capital (processing infrastructure and labor) is eroding, which may limit options for response to systemic shocks. Fishers and fishing communities are vulnerable, due to geographic distance from their markets and the erosion of local value-added processing capacity (Robards and Greenberg 2007). On the other hand, moderate regulatory interconnectedness provides some slack for adaptive salmon management. A dramatic decline in total market value for salmon might sway Alaskans to allow extensive mining, to the detriment of freshwater habitat for Pacific salmon. Mining, oil, and gas interests compete with salmon for access to key habitats, as in the Nushagak River entering Bristol Bay where a large gold and copper mine may soon be developed (Parker et al. 2008).

With the advent of Canada's Wild Salmon Policy, salmon managers in British Columbia expanded the intent of salmon management beyond provisioning to include ecological function (Fisheries and Oceans Canada 2005). The new management approach is data intensive in an era of tight budgets, and the emphasis is on sharing management responsibility more with local groups and First Nations through formal co-management arrangements (McRae and Pearse 2004). This adaptation, although increasing regulatory interconnectedness, is a step downward in scale closer to the fishing itself. This experiment may provide additional adaptive capacity in the British Columbia system, which still has relatively high potential in the form of natural and constructed capital. The provisioning role is clearly changing, with an increased concentration of salmon permit holders living in urban areas rather than in small towns (Scholz et al. 2004) and the provincial emphasis on expanding the pen-reared salmon industry. The concentration of fishing rights in cities may conflict with the policy mandate for co-management.

WOC natural capital has crashed and the commercial fishers are reorganizing their lives. Sport fisheries are also hurting. Beyond the provisioning function, the salmon production (hatcheries) and conservation enterprise is still thriving. As salmon populations have declined, spending for recovery of populations listed under the Endangered Species Act has expanded dramatically, totaling approximately a billion dollars a year in 2009. WOC has been through many small-loop adaptations on the downside of the conservation phase, conserving research and management positions but not the provisioning roles in the fishery. Gear types were eliminated over time to limit effort and eliminate competition, but gillnetting, trolling, and recreational fishing continued in most local fisheries until the past decade. Rather than creating diversity, regulatory and legal adaptations in the WOC fishery handicap themselves by emphasizing access to salmon for everyone, everywhere, which requires restoring ecological functionality to the entire landscape. Given human population and development pressures in the region, abundance and diversity in salmon populations and habitat have declined (Lackey et al. 2006). Calls for a more place- and salmon-population-specific approach (e.g., Rahr et al. 1998, Rahr and Augerot 2007) have gone unheeded.

CONCLUSIONS

We set out to address the provisioning function of salmon social–ecological systems because that is the common intention of salmon management around the North Pacific (Augerot 2000). With respect to provisioning, each of the five regions is currently at a different stage in the renewal cycle. The Russian Far East is moving from the exploitation into the conservation phase. Japan is in the late conservation phase, a cycle ahead of the other areas with its heavy dependence on constructed capital. Alaska is trying to maintain the sweet spot at the top of the conservation phase where capital is accumulating. British Columbia is past the sweet spot, investing constructed capital to reinvent management measures that increase ecological restoration in the system and shift management authority closer to the local fishery scale. WOC is experiencing release and reorganization.

Ultimately, the provisioning role of salmon is dependent on the ecological function, even in Japan, where technology has substituted for natural rivers. Japanese fishers and hatchery operators are acutely aware of the importance of cuing smolt release timing to near-shore ocean conditions to ensure the optimal survival and fitness of the fish as they make their way to sea.

Brittleness, particularly with respect to institutions, has been shown to be detrimental to resilience. Brittleness blocks pathways for institutional novelty that reduce regulations, reconnect local markets to local fisheries, and allow constructed capital accumulations to generate flexibility in the system. The provisioning goal depends on rebuilding natural capital, focusing on normative river function to ensure quality freshwater habitat and reducing catch to allow salmon populations to rebuild. Historical exploration of other regional fishery systems could teach how memory and learning increase adaptive capacity.

The renewal cycle is a useful construct for framing the story of the five salmon regions. Yet, beyond a frame, the renewal cycle is less useful in actually helping to achieve adaptive capacity. Ecological restoration is increasing where release has progressed the farthest. But ecological restoration is still mainly pursued for the purpose of restoring the provisioning potential. So far, the images and intentions of the exploitation and conservation phases still ring true. The renewal cycle warns the next step is reorganization, but when this reorganization occurs and what it needs is unclear.

Because the renewal cycle is most useful for explaining what has happened and much less helpful in elaborating the future, many questions remain to be answered. Will small-loop processes provide a way out as has been the case so far in Alaska? Will a new set of ecological restorations create new options for WOC and Japan? Will regional salmon fisheries systems drop from the consciousness of future generations? The experiences of native populations in the Russian Far East, Alaska, British Columbia, and WOC drive toward one path. The insights of scientific understanding and the role of salmon ecosystems for the ecological health of current social–ecological systems drive in another. The drivers of climate change, globalization, and cross-sectoral conflicts offer different sets of alternative futures. These futures will have to be worked out based on what has been learned and what is known about the salmon ecosystem and its processes. The most critical driver, however, is human intentions and how these are expressed in human (institutional) relationships. For the future, provisioning may be one of the important goals, but it is not likely to be achieved without the maintenance of ecological function and a recognition of the cultural significance of salmon. Cross-sectoral conflicts pit different provisioning approaches against one another and tend to forget the ecological functions and cultural significance needed for social–ecological systems to persist.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss2/art3/responses/

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