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Archaeological Evidence for Resilience of Pacific Northwest Salmon Populations and the Socioecological System Over the Last ~7,500 Years

Sarah K. Campbell
Western Washington University

Virginia L. Butler
Portland State University, virginia@pdx.edu

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

Archaeological Evidence for Resilience of Pacific Northwest Salmon Populations and the Socioecological System over the last ~7,500 years

Sarah K. Campbell [1] *and Virginia L. Butler* [2]

ABSTRACT. Archaeological data on the long history of interaction between indigenous people and salmon have rarely been applied to conservation management. When joined with ethnohistoric records, archaeology provides an alternative conceptual view of the potential for sustainable harvests and can suggest possible social mechanisms for managing human behavior. Review of the ~7,500-year-long fish bone record from two subregions of the Pacific Northwest shows remarkable stability in salmon use. As major changes in the ecological and social system occurred over this lengthy period, persistence in the fishery is not due simply to a lack of perturbation, but rather indicates resilience in the ecological–human system. Of several factors possibly contributing to resilience, low human population size and harvesting pressure, habitat enhancement, and suppression of competing predators do not appear to be of major importance. Flexible resource use, including human use of a range of local resources, many of which are linked in a food web with salmon, likely contributed to resilience. Most important were the beliefs and social institutions (including ownership, regulation, rituals, and monitoring) that placed restraints on salmon use as a common pool resource. In contrast, only a small fraction of our modern society relies economically on or has direct interaction with the fish, which limits our concern and willingness to fundamentally change behaviors that contribute to habitat degradation and loss, the main challenges facing salmon populations today. Salmon recovery efforts may benefit substantially from investing more resources into establishing links between community groups and actual fish populations, which would create a sense of proprietorship, one of the keys to resilience in the indigenous salmon fishery.

Key Words: *indigenous resource management; Pacific Northwest; salmon; sustainable harvests; zooarchaeology*

INTRODUCTION

Declines in the abundance and genetic diversity of native North Pacific salmon (*Oncorhynchus* spp.) stocks, begun over 120 years ago, continue unabated in recent decades despite billions of dollars spent for fish recovery. Alarmed by the failure to halt what appear to be irreversible declines, fisheries scientists and managers are exploring new conceptual models for management, especially ecosystem and resilience-based approaches (e.g., Williams 2005). New sources of information include local or traditional knowledge of fishermen in tribal and other communities and even fish remains from archaeological sites to provide an historic benchmark (e.g., Haggan et al. 2006). Archaeological data on the long history of interaction between indigenous people and salmon in this region have not, however, been sought out or applied. We suggest that a long-term view can contribute to understanding human–salmon interactions, especially within an ecosystem resilience approach that incorporates social-science models for human use of common-pool resources. Despite challenges translating archaeological data into social behavioral models based on contemporary observations, when combined with ethnohistoric records, archaeology provides an alternative conceptual view of the potential for sustainability of harvests and can suggest possible social mechanisms for managing human behavior.

Anthropologists and archaeologists have long assumed that over the last 10,000 years, native

[1]Department of Anthropology, Western Washington University, [2]Department of Anthropology, Portland State University

people in the Pacific Northwest came to rely more and more heavily on salmon over time, supporting the gradual development of a social organization unusually complex among foraging peoples (Matson 1992, Hayden and Schulting 1997). This view focuses on the potential for intensification of salmon production through storage and mass-capture methods, and treats salmon as persistently resilient and immune to overexploitation. Given that these views had never been directly tested with archaeological animal bone records, in a previous study we analyzed faunal records from archaeological sites in the latitudinal center of the salmon region of western North America (Butler and Campbell 2004). We found that salmon were the most ubiquitous fish prey and numerically dominated most of the assemblages, and that overall, the proportion of salmon taken relative to other fish changed little over 7,500 years (all ages hereafter in uncalibrated, radiocarbon years). This indicates sustainable use, rather than overfishing, despite the fact that the region supported extremely high human population densities, and cultures had the technology to greatly reduce salmon populations (Haggan et al. 2006). Studies from other parts of the world have shown overexploitation of preferred animal resources by small-scale foraging and farming societies (Smith and Wishnie 2000, Grayson 2001), thus long-term sustainable use was by no means a foregone conclusion.

This paper's main goal is to examine the factors that could account for persistence of the indigenous fishery, despite numerous environmental and cultural changes over the last several millennia. After first discussing the conceptual basis for sustainability and resilience, we present background to the ecological and social systems, summarizing our previous findings from archaeological fish bone records that show a long-term enduring fishery. Drawing on both ethnohistorical and archaeological records, we then evaluate five factors that might possibly contribute to sustainability: size of the human population and magnitude of harvest pressure, habitat enhancement, suppression of competing predators, resource flexibility, and social institutions and beliefs. We argue that beliefs and social institutions contributed the most to sustainable use, as they place restraints on salmon use as a common-pool resource (see also Trosper 2003, Haggan et al. 2006). Finally, we make suggestions for contemporary management strategies.

RESILIENCE AND SUSTAINABILITY OF COMMON-POOL RESOURCES

Our paper defines "resilience" as the capacity of a system to tolerate disturbance without collapsing into a different state by maintaining the same basic properties and functions. "Sustainability" can be defined as the ability of something, such as a yield, a predator–prey relationship, or an ecosystem, to persist for an extended period and is a concept, like fitness in biology, that can only be determined after the fact (Costanza and Patten 1995). "Persistence" is the primary measure of sustainability whereas an argument for resilience further requires demonstration that there were perturbations to which the system had to respond. Both sustainability and resilience are applicable to a wide variety of scales; thus, one must delineate the size and duration of the system under review (Costanza and Patten 1995, Redman et al. 2002).

Social scientists have expressed a wide range of views on whether open-access resources like fisheries can be used sustainably. Within the fields of economics and political science, the view has evolved significantly from the alarmist message of Hardin (1968) in "The tragedy of the commons" to recognizing and understanding the many ways human groups self-impose restrictions and convert open-access resources to common-pool resources (Ostrom et al. 1999). Many examples of successful common-pool resource management involve small-scale groups or traditional communities. It is not surprising, therefore, that within anthropology, group cooperation in small-scale societies and little, if any, impact on the resource base were common assumptions. Anthropologists emphasizing traditional ecological knowledge (TEK) tend to follow this general premise, and an extensive literature in maritime anthropology documents successful cooperative efforts to create sustainable fisheries (Acheson and McCay 1987).

However, in the last few decades anthropologists and archaeologists applying the principles of behavioral ecology and optimal foraging theory to humans have documented cases of overuse of resources among foragers and other small-scale societies (Grayson 2001). Overuse is interpreted as consistent with the premise, drawn from evolutionary theory in biology, that individuals will maximize their own benefits, the same assumption underlying classical economics theory. Within this framework, true conservation behavior, i.e.,

choosing long-term benefits over immediate returns, is expected to be rare (e.g., Smith and Wishnie 2000, Borgerhoff Mulder and Coppolillo 2005). Strategic interactions among individuals are dominated by the possibility of "cheaters" taking the harvest, a cost that looms large against an unknown future, and cooperative behavior rarely develops. The debate between the TEK and human behavioral ecology paradigms has stimulated considerable empirical research, resulting in cases supporting both positions. Recognizing that social bonds and future values are nontrivial in affecting individual decisions, but that self-interest remains a powerful factor as well, a synthesis of the two positions is both feasible and needed. Such an approach is critical to an evolutionary perspective, accounting for why, as Berkes (2006) has emphasized, common-pool systems go through cycles of crisis and recovery, and should be viewed as resilient, not stable. In this paper, we find ideas and approaches from both paradigms useful for understanding the longevity of salmon harvesting in the Pacific Northwest.

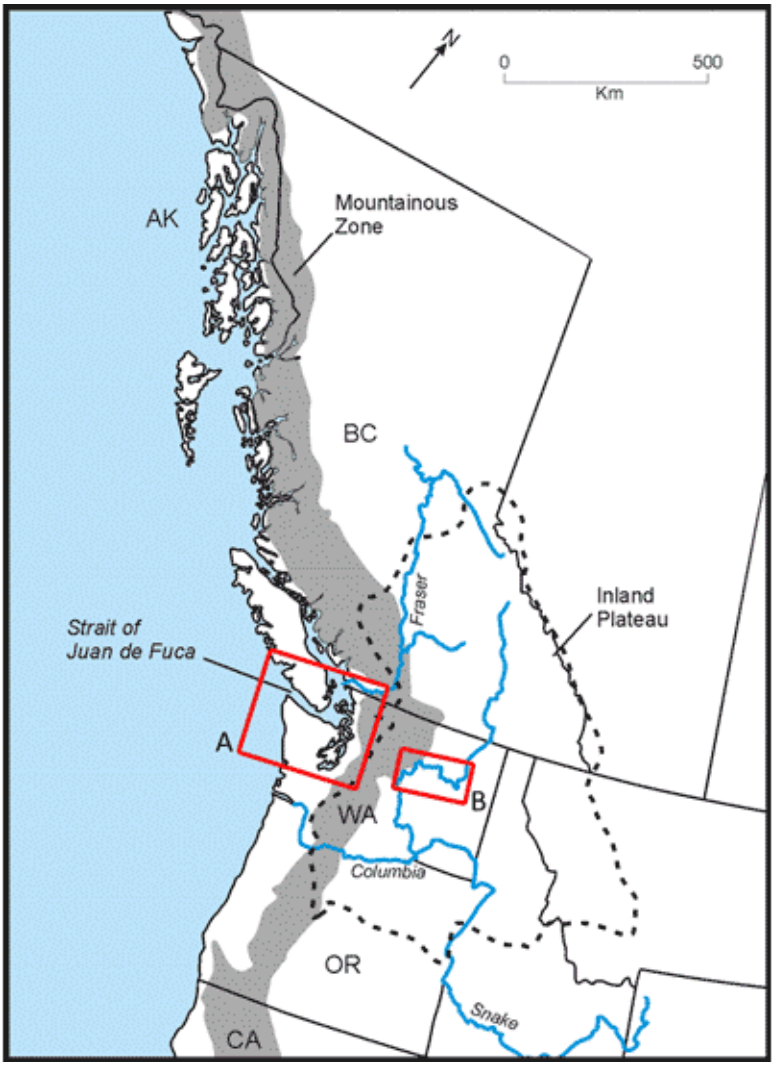
PAST ECOLOGICAL AND SOCIAL SYSTEMS IN THE PACIFIC NORTHWEST

Indigenous peoples of the Pacific Northwest occupy two distinct physiographic provinces, the coastal zone and the arid interior, separated by north-to-south trending mountain ranges (Suttles 1990, Chatters 1998) (Fig. 1). Although the areas vary greatly in resources and climate, they are unified by salmon as the Fraser and Columbia Rivers cut through the mountain ranges and provide migration corridors to large expanses of the dry interior. The earliest anthropologists surveying indigenous cultures in North America highlighted the importance of salmon to peoples living in both regions and defined the "Salmon Area" to reflect this commonality. Later researchers separated the Northwest Coast and Plateau cultural areas based on economic and social–political differences. Northwest Coast cultures are known for their relatively high population density, social organization that included chiefly classes and slaves, ownership of capital, elaborate art style, and semi-sedentary settlement patterns—attributes generally linked to agriculture-based societies (Ames and Maschner 1999). Interior Plateau cultures are characterized by lower population density, egalitarian social organization, and greater mobility, yet include occupation of winter villages (Walker 1998).

Historically known cultures are the endpoints of thousands of years of cultural evolution. Archaeology has established the broad sequence of changes leading to 19th-century cultures, although explanations for the changes are still debated. Earliest peoples between 11,000 and 5,000 years ago were broad-spectrum foragers, residentially mobile bands that moved from place to place, consuming locally or seasonally abundant resources. The limited evidence for house construction suggests frequent residential moves. Similarity in tool kits across sites suggests similar life ways and cultural connections across the whole region. Between 5,000 years ago and until European contact, the archaeological record shows increasing evidence for decreasing mobility, more permanent settlements, reliance on stored foods, growth in human population size (Fig. 2A, D), markers of social ranking, trade networks, and increasing distinctiveness in the artifact and feature records, suggesting life ways comparable to those known in historic times on the coast and interior.

Because of its sheer abundance, salmon is at the heart of most explanations for how wild, rather than domesticated, resources could support large sedentary populations with complex social and political life ways, and also when and how such societies evolved from early mobile foragers. An influential early model (Fladmark 1975) suggested that salmon populations were initially low and only became abundant after sea-level stabilization, about 6000 years ago. Significant salmon populations are now known to have existed much earlier, and the idea of a regional-scale environmental driver is no longer satisfying (Moss et al. 2007). Similarly, the concept of abundance itself has been deconstructed, highlighting the high degree of patchiness and seasonal variation in resource abundance (Schalk 1977). Subsequent models understand salmon to be abundant only during seasonal aggregations as part of reproduction cycles, that the duration of seasonal clumping in spawning cycles varies across this large area, and that fish are easier to capture in certain locations (e.g., rapids and small tributaries). Some have emphasized the development of strategies to overcome the limits of seasonal variations in salmon availability through technology, such as methods for mass harvest, preservation, and storage that allowed more fish to be caught and then saved for use long after the migration period (e.g., Schalk 1977, Matson 1992). This has been referred to as salmon intensification; the concept implicitly assumes both increases in absolute harvest levels and in the degree of specialization.

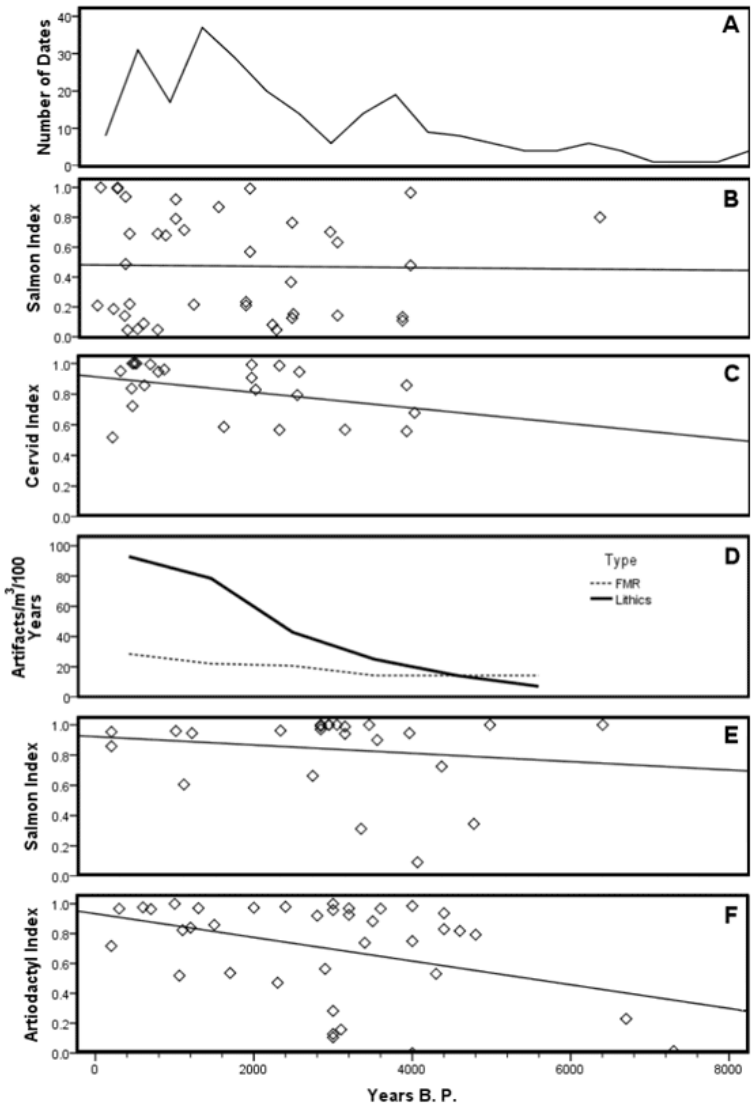
Fig. 1. Map of the Pacific Northwest, showing location of study areas: (A) south–central Northwest Coast; (B) northern Columbia Plateau.



More recent models treat social factors as equally or more important than either environmental or technological ones; these emphasize the development of labor organization to manage tasks involved with harvesting, processing, and stockpiling the resource (Matson 1992, Ames 1994, Prentiss and Chatters 2003). Social ranking is argued to result from social control of resource access (e.g., ownership of weirs or reef net locations) and control of storable commodities exchanged through feasting and trade. Although consideration of social factors has focused primarily on Northwest Coast cultures, Plateau scholars have highlighted the large seasonal aggregations of people near major rapids, and suggested that control of fisheries access and trade led to formation of elites (Hayden and Schulting 1997).

In a previous study (Butler and Campbell 2004), we tested the base assumption for these models, i.e., whether salmon use actually did increase over time. In addition, we challenged another implicit assumption of the models, which was the idea that salmon harvests could be increased indefinitely

Fig. 2. (A) Plot of radiocarbon dates from southern Northwest Coast archaeological sites, used as a proxy for human population size (adapted from Ames and Maschner 1999: Fig. 4a, summing dates by 400-year intervals); (B) Salmon Index, south–central Northwest Coast sites; (C) Cervid Index, south–central Northwest Coast sites; (D) Artifact accumulation, northern Columbia Plateau archaeological sites, used as a proxy for human population size (adapted from Miss 1985: Fig. 9-6, total artifacts/volume/duration of components, averaged for all components; FMR—fire-modified rock; Lithics—stone tools and manufacturing debris); (E) Salmon Index, northern Columbia Plateau; (F) Artiodactyl Index, northern Columbia Plateau. Time scale is radiocarbon years before present. Indices are ratios with values from 1–0 (e.g., frequency of salmonid bones /frequency of all fish bones; frequency of cervid bones/frequency of cervid + small mammal bones, and so forth). For the salmon index, 1 indicates an assemblage composed exclusively of salmon and 0 lacks salmon remains. See Butler and Campbell (2004) for more information.



without having an impact on salmon populations. For this test, we compiled faunal data from archaeological sites in the south–central Northwest Coast and the Northern Columbia Plateau (Fig. 1) to examine temporal trends in animal use. The 46 archaeological sites we included (20 Northwest Coast, 26 Plateau) provided about 250,000 animal bones and teeth from fish, mammals, and birds, as well as 130 kg of shellfish. Because of sampling issues and variable preservation, it is difficult to directly measure absolute exploitation rates, although documenting "relative" change in use is possible using ratios of identified taxa from sites of varying ages. Therefore, we tested a corollary implication of the models, i.e., that salmon would make up increasing proportions of the subsistence base as mass harvest and storage were increasingly used. We calculated simple ratios from each dated site component, comparing the frequency of salmon to other fishes, and evaluated the existence of temporal trends in salmon use. This also allowed us to look for evidence of overharvesting in the form of resource depression.

In developing our test for resource depression of salmon, we drew on optimal foraging precepts that have been used to derive expectations about resource selection and subsistence change under conditions of increased foraging pressure. "Resource depression" refers to a reduction in prey density locally or absolutely due to predation rates. According to the prey choice model, a predator's most efficient strategy, and thus the one favored by natural selection, is to take the highest-ranked prey when encountered, and to shift to lower-ranked resources only when the density of highly ranked prey is reduced. If the predator shifts to another patch or to another resource, the prey population can recover and persist, but if the predator population increases or becomes less mobile, permanent resource depression is predicted (Stephens and Krebs 1986). Previous work has shown that body size is a good proxy measure for prey rank: generally the larger the animal, the higher the return rate (return rate can be expressed in varying currencies; we use energy maximization, or kcal/effort expended). For our test, salmonids are the highest-ranked fish family because species in the family tend to reach much larger size than species in other families (see Butler and Campbell 2004 for additional background).

Overall, our records do not support the view that salmon use actually increased over time relative to other fish nor do they indicate salmon populations were depressed by human exploitation pressure (Fig. 2B, E) (Butler and Campbell 2004). On the south–central Northwest Coast, coastline sites display a range of values for every time period, suggesting salmon was the focus of the fishery in some locations, and only a minor or moderate constituent in others. Riverine sites generally have high ratios for all time periods. The Plateau assemblages also show no trends for increasing or decreasing use of salmon. Our results indicate few trends in use overall, but do confirm that salmon were a persistently important resource throughout time. Salmon remains were present in every dated component, making Salmonidae the most ubiquitous, out of the 24 fish families present.

The generally stable record of salmon use is even more remarkable given environmental changes documented for both the coast and interior regions over the past ~10,000 years. Climate changes affected stream flow and temperatures (Chatters et al. 1995), and more generally ocean–atmosphere circulation and ecosystem dynamics (Finney et al. 2000, 2002). Post-Pleistocene regional sea-level rise extensively altered the lower sections of rivers; lower gradients increased sedimentation, creating deltas and floodplains, and highly productive estuaries and riparian zones (Tveskov and Erlandson 2003, Hutchings and Campbell 2005). Seismic events and volcanism, hallmarks of the Pacific Northwest, would have changed river hydrology (e.g., discharge, river blockage from landslides, position and height of waterfalls). These many stochastic regionwide and local forces would have greatly affected fish abundance and distribution. Waples et al. (2009) argue that the persistence of salmon in the face of continual change in river systems shows their resilience.

Our record is based on the remains of salmon harvested by people over the last 7,500 years and thus is germane to the resilience of the human–salmon interaction, not just the salmonids themselves. When coupled with evidence for a remarkably stable overall mix of resources (Butler and Campbell 2004), such faunal records suggest resilience at the scale of the human–ecosystem interaction. Not only were other important fish taxa (e.g., flatfish [Pleuronectidae], herring [Clupeidae]) used sustainably, but the highest-ranked terrestrial prey, taxa of ungulates in both areas, were also used sustainably, with slightly increasing intensities in late prehistoric times (Fig. 2C, F).

Still, a conclusion about resilience depends partly on the scale at which we can measure change and assess what is changing (cultural practices or actual human populations). Most of the models discussed above assume that changes occurred within the trajectory of a continuous population, a view that is challenged by Prentiss and Chatters (2003) in a recent regional synthesis. They emphasize the punctuated character of cultural systems, when examined at finer time scales, and interpret some changes as representing the failure of one social system and replacement by another. Although relevant to questions of resilience, their hypothesis has not been adequately tested or confirmed at this time. Their study highlights, however, the need to examine changes at local scales and over shorter periods of time that may be masked in our long-term regional trend.

The scope of our synthesis precluded review of detailed information on local environmental changes that might affect salmon abundance; however, we tried to assess the degree of local variation subsumed in our overall picture, by examining finer scale trends at single sites that contained multiple dated components. For the nine Northwest Coast sites, two sites show a trend toward increasing salmon use (Glenrose Cannery, West Point 428); others show relative stability (Duwamish), fluctuation (Burton Acres, Decatur Island), or declines (Crescent Beach, West Point 429) (Fig. 3). Only five sites from the Plateau had multiple components in which to study local temporal trends (Fig. 4); except for DO-214, salmon representation is quite stable over time. Detailed site-specific study is needed to account for local variation in resource abundance, which could be due to natural changes in local river systems, or to change in season or purpose of human use rather than systemwide overuse or social system replacement (Prentiss and Chatters 2003).

EXPLAINING SUSTAINABILITY AND RESILIENCE

Salmon biology itself, the genetic variation and phenotypic plasticity in life history and migratory patterns, clearly contributes to long-term species and population survival (e.g., Quinn 2005, Waples et al. 2008) and thus to the resilience of the human–ecological system. The current crisis, however, indicates that the limits of biological resilience are being reached and highlights the need to examine the human side of the relationship.

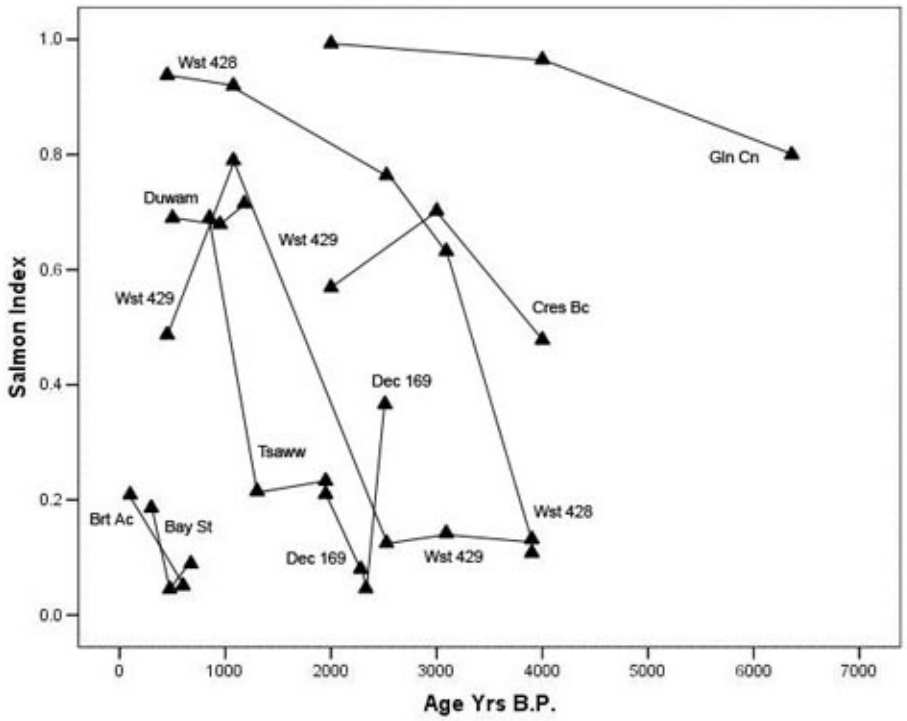
In this section, we consider five aspects of human behavior that may have played a role in sustainability and resilience of the human–salmon interaction: human population size and harvesting pressure, habitat modification, suppression of competing predators, resource flexibility, and social institutions and beliefs. We focus on these factors in particular, either because other researchers proposed they contributed to past sustainable resource use, or because they relate to current management practices. We draw contrasts with contemporary conditions and practices affecting the relationship between people and salmon.

Population Size and Harvesting Pressure

Especially given the great contrast between contemporary population levels and those of past indigenous peoples, the possibility that sustainable harvest is an epiphenomenon of low population size and concomitant low harvesting pressure needs to be considered (Hunn 1982). We argue that prehistoric populations were large enough to have an impact on salmon populations, given the heavy reliance on salmon and the effectiveness of salmon harvesting technologies. The key factor is harvesting pressure, not absolute population size. Because salmon was such an important staple, the harvesting pressure was far higher on a per capita basis than today, and a much smaller population could account for catches approaching the magnitude of historic commercial catches (Hewes 1973, Trosper 2002, Haggan et al. 2006).

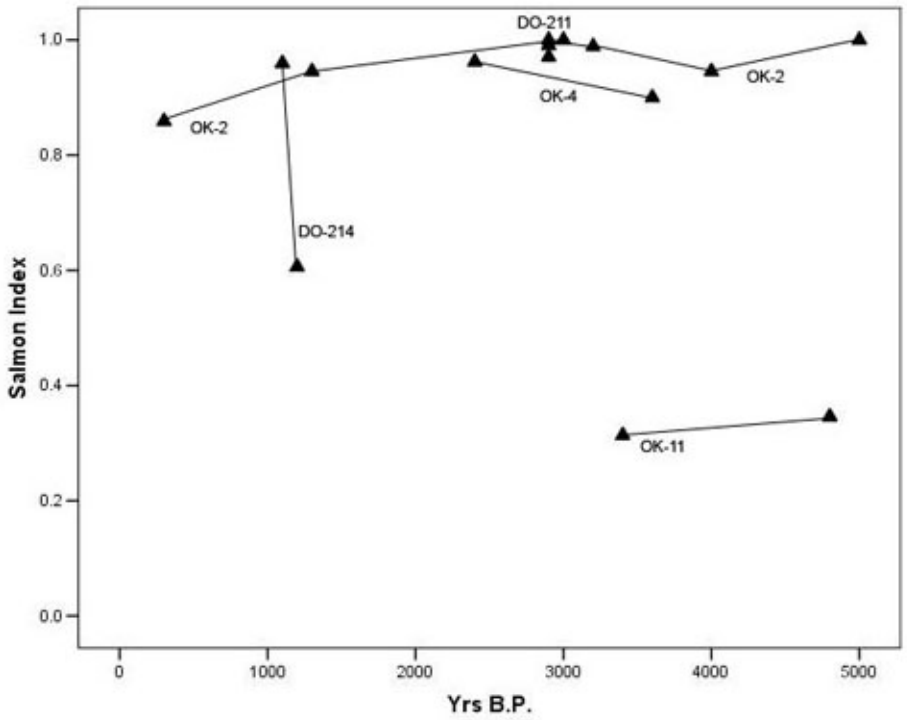
The Northwest Coast was estimated to have the second highest indigenous population density in North America (after California) at European contact, with population estimates ranging from 102,100 to 210,100 (Ubelaker 2006). Haggan et al. (2006) propose an annual average per person consumption rate of 230 kg/yr based on two 19th-century estimates. At this rate, 200,000 people would annually consume 46,000 metric tons (50,706 tons) of salmon, comparable in magnitude to the average yearly commercial catch between 1901 and 2000 (Jones 2002). This quantity does not include the harvest by peoples in the inland Plateau. Population densities were lower in this area, but people took advantage of increasingly restricted migration channels for fish in the upriver stretches.

Fig. 3. Changing salmon ratios within sites with multiple dated components, South–central Northwest Coast sites(salmon index: frequency of salmon bones/number of all fish bones). Site abbreviation key: Gln Cn—Glenrose Cannery; Wst 428—Westpoint KI 428; Wst 429—Westpoint KI 429; Cres Bc—Crescent Beach; Dec 169—Decatur Island; Tsaww—Tsawwassen; Duwam—Duwamish; Bay St—Bay Street; Brt Ac—Burton Acres. See Butler and Campbell (2004) for more site information.



The diversity and ingenuity of the fishing technology developed by Northwest Coast peoples has long been appreciated (Rostlund 1952). Stewart's (1977) graphic illustrations of fishing gear and facilities, based on accounts and specimens from the historic era, consultation with contemporary First Nations fishermen, and to a limited extent, archaeological specimens and excavations, highlight this point. Indigenous technologies certainly were capable of exerting considerable harvesting pressure on salmon. Decades ago, fishery scientists Craig and Hacker (1940) speculated that aboriginal fishing methods such as weirs and traps set across rivers and streams had the potential to severely reduce or eliminate salmon runs migrating to spawning grounds. The impact would be heightened for species such as Chinook (*Oncorhynchus tshawytscha*) and sockeye (*O. nerka*) in which migrating adults show limited amount of straying; it might take many years for new populations to become established if spawning populations were severely depleted by overfishing. The efficiency of aboriginal gear is reflected by the fact that Euroamericans modeled much of their gear after aboriginal designs; indeed, some of the Euroamerican versions were so effective they were banned (Worl 1990, Trosper 2002). One important contrast between Euroamerican and indigenous capture methods is the location: today, the commercial fishery focuses on coastal and estuary settings, whereas the indigenous fishery targeted salmon after they entered freshwater. One exception was the development of "reef net" fishing in the islands of the Gulf of Georgia/northern Puget Sound (Suttles 1951).

Fig. 4. Changing salmon ratios within sites with multiple occupations, northern Columbia Plateau (salmon index: frequency of salmon bones/frequency of all fish bones).



The methods used in historic times for capturing fish represent the culmination of thousands of years of development, during which people continually modified their strategies for catching fish, presumably to increase productivity. For example, developments such as reef nets and specialized types of weirs for different bottom and current conditions would have allowed larger off-take per unit effort, or possibly extended the harvest into additional environments. The preservation and storage of large quantities of fish for storage and for trade, not simply immediate consumption, would have affected the marginal value of salmon by extending the use well outside the season of availability. Models such as that of Kew (1992) suggest plausible lineages and technological adaptations of gear leading up to the historic period diversity although the timing of technological innovations in gear and storage methods is not well understood. Identification and dating of specific gear types in the archaeological record is hampered by preservation biases (i.e., nets, lines, basket traps, weir stakes, and weir lattices are only preserved in waterlogged sites, stone alignments for reef-net anchors are underwater and not readily datable, and composite tools such as harpoons, hooks, and leisters are not found intact, but are represented by nonspecific bone barbs and points). In recent decades, hundreds of intertidal fish weirs represented by rock alignments or the remains of supporting stakes preserved in waterlogged environments have been documented and are dated as much as 4,000 years old in southeast Alaska (Moss and Erlandson 1998). Storage of fish over winter is estimated to have occurred by at least 4,000 years ago (Ames and Maschner 1999) or, alternatively, as far back as 7,000 years ago (Cannon and Yang 2006). Overall, changes in methods of fish capture and processing technologies would have led to increased harvest pressure over time, and thus, cannot be used as an explanation for sustainable use or resilience in the human–ecological system.

Habitat Modification

It is possible that native people deliberately enhanced habitats to increase salmon production, which would have allowed for increased harvest as human populations grew. Pacific Northwest peoples manipulated terrestrial environments to promote desirable plant species (Boyd 1999, Deur and Turner 2005 and references therein): burning to maintain clearings, adding fertilizer, and weeding and transplanting to increase the relative abundance of favored species within their natural habitats.

Similar degrees of ethnobiological knowledge existed for animals and may have been applied in parallel strategies to enhance or manage animal populations (Campbell and Butler 2009). A clear parallel is in the construction of terraced features in the intertidal zone to promote clam growth, a practice that has recently received attention with the identification of over 400 relict rock-walled "clam gardens" on the northeast side of Vancouver Island (Williams 2006). Management strategies for mobile animals with complex life histories might be less common. Maintenance of salmon streams by removing debris, a form of habitat enhancement, is reported for the Heiltsuk of northern British Columbia by Jones (2002). However, references to direct manipulation of organisms to increase the chances for organism survival and fecundity are rare (Campbell and Butler 2009). In a well-documented historic incident in 1913, Indians transported live fish around a landslide on the Fraser River caused by railway construction suggesting that this practice could have been used in the past as well. There is a record from the 1860s of the Nuu-chah-nulth of Vancouver Island transporting salmon eggs between water systems (Sproat 1868), but the extent to which this was practiced is unknown.

Although it seems likely that some enhancement of salmon habitats occurred in prehistoric times, we do not know if it was of sufficient magnitude to contribute to resilience, and it will be difficult to investigate archaeologically. Given the level of engineering, human-caused enhancement would have closely resembled natural processes, that is, log jams break free and salmon colonize new habitats on their own. Human intervention would act to speed up processes that would occur naturally, rather than involving fundamentally different strategies (see Waples et al. 2009 for a comparison of contemporary anthropogenic disturbances to natural habitat disturbance regimes). Overall, we suggest the effects of these processes would have been minor and would not have contributed to long-term sustainability in the fishery.

In contrast to the indigenous case, landscape modification activities associated with modern industrial society have had major, mainly negative, impacts on habitats used by salmon. The scale and extent of such activities, including dam construction and operation, irrigation, logging, agriculture, and mining, are enormous and have greatly contributed to the declines in salmon populations over the past 150 years (e.g., Williams 2005). Moreover, even when habitat enhancement has been the goal, for example, hatcheries and removal of large woody debris, the results have often been counterproductive management (e.g., Lichatowich 1999).

Predator Suppression

Native peoples in the Northwest preyed on carnivores known to pursue salmon, such as phocid and otariid seals and bears (Lyman et al. 2002, Butler and Campbell 2004). Could humans have reduced the population levels of competing predators enough to allow increased harvesting of salmon without causing resource depression? Current salmon recovery efforts involve various programs to reduce the impact of predators that are argued to be contributing to overall declines in fish populations. The predator control program on the Columbia River is the most extensive (Federal Columbia River Power System 2007). It includes a bounty program for native piscivorous fish, northern pikeminnow (*Ptychocheilus oregonensis*), and relocation of Caspian tern (*Sterna caspia*) breeding colonies, both of which prey on out-migrating salmonid smolts; a proposal is currently under review to lethally remove California sea lions (*Zalophus californianus*) preying on upstream migrating adults.

As an initial test of the hypothesis that indigenous peoples targeted competing predators for adult fish, thus allowing for increasing harvest as human populations increased, we examined the relative frequency of seal remains (Phocidae, Otariidae) in the south–central Northwest Coast assemblages, focusing on the riverine sites where aquatic mammals would be in most direct competition with humans over salmon. Of the nine dated components from riverine sites, seven contained seal remains, but the proportion of aquatic to terrestrial mammal

remains is quite small (between 11% and 3%), except at Hoko River Rockshelter where seals dominate the assemblage, and no temporal trend is shown ($r = 0.38$, $p = 0.458$) (Fig. 5). The frequency of pinniped bones in Columbia River archaeological sites is also quite small and is known only from nine locales on the lower 300-km section of the river below The Dalles. Lyman et al. (2002) report that of 18,000 mammal specimens, only about 100 pinniped bones and teeth (harbor seal [*Phoca vitulina*] and indeterminate species) are present. Overall, the faunal record in this region suggests opportunistic hunting rather than a focus on these marine mammals in river settings. Thus, we reject predator suppression as an explanation for long-term resilience in the salmon fishery.

Resource Flexibility

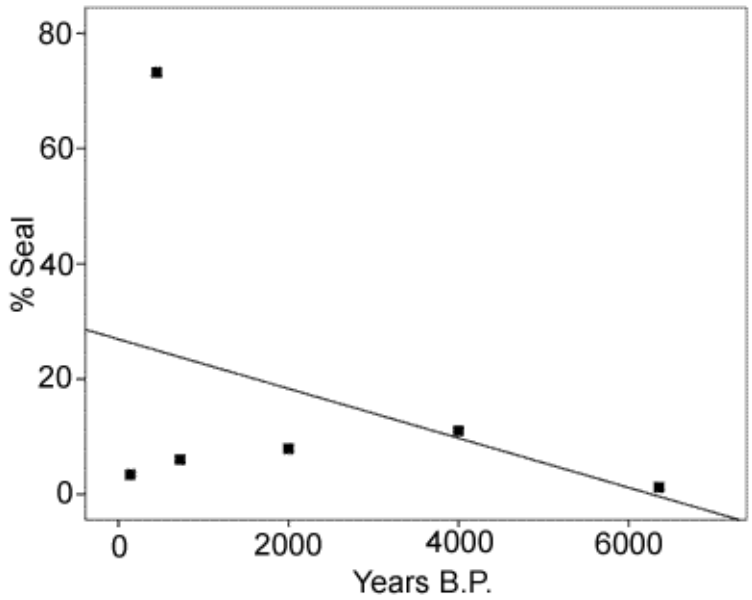
Despite the importance of salmon in the diet of indigenous peoples, salmon harvesting needs to be understood in the context of other resource use, not in isolation. Overall diet breadth and a generalized subsistence strategy afforded past peoples considerable flexibility and the capacity to respond to environmental fluctuations, contributing to resilience in the human populations. Whether generalized resource use helps account for sustainable salmon use is a different issue, as discussed below.

In the historic period, Northwest Coast natives practiced a broad-based fishery (Suttles 1990). This applies to the more distant past as well, as indicated in our archaeological assemblages by measures of ubiquity and relative abundance of fish families exploited. Salmon was the most ubiquitous and the most abundant taxon in about half of the assemblages; in the others, one of the following families, flatfish (Pleuronectidae), sculpin (Cottidae), surfperch (Embiotocidae), herring (Clupeidae), ratfish (Chimaeridae), and greenling (Hexagrammidae), was most numerous. Our archaeo-faunal records from both the coast and interior show procurement of a diverse range of other animals, including 23 families of mammals (e.g., deer, wapiti [Cervidae], beaver [*Castor canadensis*], seals [Phocidae, Otariidae]); 24 families of marine and freshwater invertebrates (e.g., clams [Veneridae, Mactridae], mussels [Mytilidae], freshwater mussels (Margaritiferidae, Unionidae); and 27 families of birds, with aquatic forms (ducks, swans, geese [Anatidae]) the most ubiquitous and dominant form in Northwest Coast sites (Butler and Campbell 2004, Bovy 2005). Assemblages vary regarding which taxa of mammals, birds, or marine invertebrates dominate. Plants also contributed substantially to the diet (Lepofsky 2004). Deur and Turner's (2005) volume shows use of over 75 species of roots and berries on the Northwest Coast.

Foraging adaptations in temperate regions are characterized by regular seasonal switching of prey and of patches exploited; this accounts for much of the diversity we see in the archaeological record. For example, assemblages dominated by non-salmonid fish may represent seasonal fisheries operating when salmon was not available. Other differences between locations and changes in resource use in different occupation periods at single sites (Figs. 3, 4) could represent responses to either short-term (decadal length) fluctuations or long-term declines in salmon runs in a particular drainage. Davis (2007) argues that the development of the winter village pattern on the lower Salmon River of Idaho was delayed relative to other areas of the Columbia system, until hydrologic changes about 2,000 years ago improved salmon spawning habitat and in turn much larger fish runs. Loss or decline of runs in the Fraser River system significantly affected human population density and/or mobility as demonstrated by settlement pattern changes (Hayden and Ryder 1991, 2003, Kuijt 2001, Prentiss et al. 2005). Changes in site function and season of use are mechanisms of cultural resilience, especially for natural resource extraction locations. The short-term use of many of these sites does not indicate abandonment of the area, just of the specific resource extraction locale; in all cases, other sites in the vicinity show ongoing use by people.

Winterhalder and Lu (1997:1354) suggest, on the basis of optimal foraging theory simulation models, that "a prey's vulnerability to local depletion or extinction may depend on the demographic characteristics of the suite of resources harvested along with it." Short-term substitutions of other resources could provide adequate food supplies for people and also allow heavily exploited populations to recover; however, Winterhalder and Lu (1997) showed that the effect of prey-switching can be extremely variable. They examined scenarios in which multiple "fallback" resources are exploited when numbers of preferred prey fall below a certain level. Some simulations led to persistence of

Fig. 5. Relative frequency of seal specimens (Phocidae, Otariidae) in mammal assemblages, south–central Northwest Coast sites located on rivers. Included all assemblages with sample size >30 identified specimens. Sites are Glenrose Cannery (three components) Duwamish, Hoko River Rockshelter, Sbabadid (one component). See Butler and Campbell (2004) for more site information.



preferred prey, sometimes at a reduced absolute population level; others led to its extinction. A contemporary example of prey substitution leading to severe resource depression or extinction is "fishing down the web" (Pauly et al. 1998). This has been well described for the North Atlantic, where substitution of prey in the heavily capitalized modern fishery led to depletion of stock after stock, and shifts to lower trophic-level resources over a 200-year period (Lotze and Milewski 2004). In our case, we do not see evidence of fishing down the web, yet the great diet breadth and resource specificity at different locations suggests that prey-switching occurred regularly at seasonal, annual, and decadal scales.

Substitutions were likely made not only between fish taxa, but also between various marine and terrestrial resources. We did not develop ratios comparing abundance of mammals, fish, birds, and shellfish directly to each other because of sampling and preservation issues; thus, we cannot rule out the possibility that people shifted their reliance over time in response to declining abundances in preferred prey. However, the absence of any evidence for overexploitation of both artiodactyls and salmon (Fig. 2D, F) and mollusks (Butler and Campbell 2004) over the same time period would seem to rule out a scenario in which resource exploitation shifted dramatically from terrestrial to marine (or vice versa) in response to overuse of one or the other.

Social Institutions and Beliefs

Although it is likely that the broad-based diet contributed to the resilience of the human–ecological system, we suggest that social institutions and behaviors related to regulating the harvest and associated activities were especially important (see also Trosper 2003). We base this view on two points. First, most of the factors we considered appear to have contributed little to the resilience. Second, and even more compelling, the ethnographic and oral tradition literature from both the Northwest Coast and the Plateau is rich with examples of harvest regulations, beliefs, and rituals,

practices argued to contribute to resource conservation in other small-scale societies (Turney-High 1941 as cited in Trosper 2002, Richardson 1982, Haggan et al. 2006). Examples of ownership of salmon capture locations are ubiquitous and typically linked with constructed facilities (traps, weirs, reef nets) that target locations where fish are concentrated and accessible. Social regulations at such sites not only involved who had the right to fish there but also timing of access and allowing for escapement. In many cases, chiefly managers gave permission for use of capture locations or gear and expected a share of the harvests in return for use (Swezey and Heizer 1977, Johnsen 2001, Trosper 2002, Haggan et al. 2006).

Timing of salmon harvest was socially regulated as well, most notably by the extremely widespread "first salmon ceremony" (e.g., Gunther 1926, Swezey and Heizer 1977). This series of rituals marked the return of the spawning salmon; rules specified who would catch and process the first fish and often included suspension of all fishing until ceremonies were completed. Trosper (2003) emphasizes, as does Haggan et al. (2006), that traditions and facilities that regulated the fishery were not isolated traits, but woven into the social fabric of life. Thus, cooperative behavior was supported in the broader cultural context. This included potlatches, structured ceremonial rituals where corporate household heads gave away surplus to other households.

Swezey and Heizer (1977) provide a particularly detailed record of communal, ritualized fishing activities, specifically among the Karok, Yurok, and Hupa people of northwest California. The fishery for Chinook salmon was highly structured and organized, with lengthy periods of ritual preceding any fishing activity. The first rituals of the year were part of the more inclusive "first salmon ceremony," which entailed a series of ceremonial events and periods of story telling related to the origins of salmon. After 7 d of preparation, ritual specialists (or shamans) thought to have supernatural power would recount narratives in proper sequence; some of the ritual sequences, which were intended to renew salmon abundance, would last 10 d. A salmon would be captured, followed by more ceremony and ritual. Then fishing would be allowed in the river. Later in the year, usually in June–July at the peak of the summer run, another period of ritual and communal activities occurred, focusing on construction of large fish weirs on the Klamath and Trinity Rivers. Ritual specialists directed the building of the weirs, which spanned the entire width of the rivers. Construction of the weir at Kepel on the Klamath River by Yurok people, involved an elaborate 10-d ritual of weir building. Several hundred men from multiple villages were directed to cut wood and construct the elaborate structure. The Kepel weir had nine openings that led to pens in which salmon were held, then removed and dried mainly for later use. After 10 d of fishing, the entire weir was dismantled.

We assert that the institutions, beliefs, and rituals known for the indigenous peoples of the Pacific Northwest had the effect of managing human behavior so that salmon harvest timing and intensity were moderated by some group or central decision-making process. These constraints on salmon harvests converted an open-access resource into a common-pool resource and contributed to the sustainability and resilience of the Native American salmon fishery in historic times. This interpretation of the social institutions is admittedly post hoc; the original descriptions were made for other reasons and are not paired with numerical catch data. We do not uncritically accept such practices as prima facie evidence that they actually worked to conserve the resource. Rather, three lines of evidence convince us that at least some of the complex of behaviors and beliefs did contribute to sustainable use. First is the archaeological record for sustainability, which we have argued is in need of an explanation. Second, the fact that these practices were so widespread across different cultural and language groups within the Pacific Northwest, from northern California to southeast Alaska, suggests they were not simply arbitrary historical traditions. Rather, we propose they evolved in multiple places in response to similar environmental and social pressures and were reinforced in the cultural repertoire at least in part because they actually functioned to regulate and maintain the fishery (see Swezey and Heizer 1977). Third, the Pacific Northwest illustrates many conditions that are thought to promote development of common-pool resource management in small-scale societies (Smith and Wishnie 2000): (a) access to the resource or prey can be controlled; (b) resources are resilient or rapidly renewing and likely to respond to management controls; (c) discount rates are low; and (d) human group size is small with stable membership allowing effective monitoring.

How does the Pacific Northwest traditional salmon fishery satisfy these conditions? First, salmon are constrained temporally and spatially. Their run times are seasonally restricted, and physical constraints exist along their migration route (e.g., shallows in coastal areas, rapids on rivers). Both create opportunities for one social group to control access to and limit the harvest. The size and relative durability of social units would have allowed for monitoring of human behavior and possible cheaters. Households have been the dominant form of social–political organization in the Pacific Northwest for at least 2,000 years; villages composed of closely spaced large plank houses (or pithouses on the Plateau) holding multiple families were occupied for up to several hundred years (Hayden et al. 1996, Ames 2006). Other characteristics of social institutions that contribute to successful common-property systems include harvest rules that assign benefits and costs to users and sanctions to those who violate rules, presence of monitors that audit the resource and behavior of users, and users that have long-term tenure rights (Borgerhoff Mulder and Coppolillo 2005, drawing on Ostrom [1990]). As noted above, there are numerous ethnographic examples of such systems in the Pacific Northwest for both salmon and other resources, and their existence is potentially identifiable in the archaeological record. Wessen (2005) links social control of resources by households to sustainable harvesting of shellfish at the late prehistoric Ozette village site. Interhousehold variation in shellfish taxa represented suggests that households controlled access to specific collection areas, which Wessen argues would reduce harvest pressure by limiting the number of collectors. This would explain the observation that mean valve size of preferred bivalves did not decrease over several hundred years of occupation, contrary to the impact that would be expected from a community of several hundred on a nearby, non-mobile resource.

Understanding how such systems of regulation evolved, and over what time frame, is of great interest. Scholars have emphasized that the evolution of cooperative behavior would be limited by the extent to which people were aware of their impacts—regarding both causing resource declines and the efficacy of human actions to restore a resource. Put simply, how can self-interest be overcome when knowledge of the payoffs (and costs) is imperfect? What sequence of events might trigger social awareness and induce behavioral modification that would in turn be seen as efficacious? Berkes and Turner (2006) suggest that cultural practices and restraints in harvest can develop if a group exceeds the limits of its resource base and becomes aware it caused depletion. We extend this idea by suggesting that awareness is important, but that the link between practices and effects need not be perfect. Any event or sequence of events that cause declines in resource abundance could lead a human group to develop practices or rituals that would attempt to bring the resource back to its earlier abundance. This is illustrated in Oceania, where groups on islands especially affected by hurricanes and droughts have developed more taboos regarding resource use than those on islands where such calamities are uncommon (Chapman 1986, cited in Borgerhoff Mulder and Coppolillo [2005]).

Salmon abundance is highly variable from year to year, apart from fisheries impacts; it is conceivable that people modified their behavior in attempts to reverse declines caused by other factors (e.g., poor ocean conditions, logjams). Subsequent increases in fish abundance would reinforce the belief that the practice was efficacious, and its continued practice could, in fact, be. This interpretation is supported by the variation in degrees of social control over resource ownership and use noted in historic period cultures. Cultures of the northern Northwest Coast culture area (northern British Columbia and southeastern Alaska), where resource availability was subject to greater fluctuation, practiced a greater degree of social control than groups to the south (Schalk 1981). We speculate that the complex array of fishing technology and practices documented historically were not necessarily the endpoint of a slow cumulative trajectory, but may have evolved episodically, in response to extended periods of poor environmental conditions, or to resource depression caused by the development of new technology.

As a cautionary note, however, function is not always a guide to ultimate causation in an evolutionary sense. The historically documented human behaviors that have the effect of limiting harvests may have evolved for various reasons, in addition to resource conservation per se. Ownership of facilities such as weirs or fishing places would have contributed to wealth differential and in turn social–political hierarchy seen at European contact (Ames and Maschner 1999). Linking social inequality with game theory, Borgerhoff Mulder and Coppolillo (2005) suggest that some segments

of society may be more predisposed to regulate access because it contributed to their wealth. Contemporary examples show that some common-property institutions that promote resource sustainability also carry social inequalities.

Developing testable models for the evolution of Northwest Coast social institutions related to salmon harvesting is a challenge because of the difficulty of operationalizing relevant variables. Links must be made between abstract concepts like ownership and social regulation of resource use and physical artifacts and facilities. There are no simple archaeological signatures waiting to be uncovered that unambiguously equate to the kinds of social behaviors described above. The presence of weirs in the archaeological record shows the "potential" for regulating access, and we can use their size and complexity of their construction as a proxy measure of the degree of investment and size of the cooperating group. However, weirs themselves do not provide evidence of restraint in harvest; one constructed 4,000 years ago was not necessarily linked to the full panoply of social regulations documented for the historic period.

We note these difficulties to highlight that more work is needed to better understand the evolution in social practices, not to challenge our main argument that social institutions and beliefs contributed to resilience in the system. We find the ethnohistoric evidence compelling; both the salmon resource and the social context meet conditions that are thought to promote development of common-pool resource management in small-scale societies; and other factors (e.g., low harvesting pressure) do not seem to account for the resilience.

CONCLUSIONS AND IMPLICATIONS FOR CONTEMPORARY MANAGEMENT

Our ~7,500-year record of bones from prey species harvested by people shows sustainability in human use of salmon, despite evidence for changes in the social and ecological system, which we take as evidence for resilience. Our study suggests this resilience is best explained by generalized resource use and social institutions regulating fishing. A broad-based diet was characteristic of the entire time period; social institutions, on the other hand, likely developed over time in pace with human population growth, which helps explain how increased exploitation to support higher human population densities could occur without depressing animal populations. Implications for modern fisheries management are that salmon cannot be considered in isolation from the overall ecosystem, and that influencing social behavior is critical to salmon recovery efforts.

Our synthesis of long-term records (Butler and Campbell 2004) emphasizes that salmon were one of dozens of vertebrate and invertebrate taxa (as well as plants) that were part of Pacific Northwest people's subsistence base across this 7,500-year time period. Archaeologists working in the Pacific Northwest have highlighted the central importance of salmon to indigenous peoples, largely because of its presumed relationship to supporting complex social systems unusual for human populations relying on wild resources. Only recently, with help from analyzed faunal records like those presented here, have archaeologists begun to realize they have been suffering from "salmonopia", a kind of tunnel vision focused on salmon alone that has biased and limited interpretation (Monks 1987, Moss 1993). Characterization of Native American cultures as "salmon based" is an oversimplification that led researchers to explanations for cultural change and process that do not encompass the broader socioecological system in which people lived. We suggest a similar "salmonopia" in contemporary fishery management has led managers in unproductive directions. Fish management policy of the industrial economy has tended to focus on isolated technological fixes to address severe declines in salmon rather than address the broader social and ecological context of the problem. Extensive reliance on hatchery programs, despite their lack of success (Lichatowich 1999), is the most extreme example; barging smolts around dams to avoid turbines is another. Contemporary monitoring and management of fish and shellfish focuses on a few commercially important species, whereas indigenous people had a vested interest in a far greater number of species. Our work suggests that recovery efforts would more likely succeed if they addressed the broader issues related to the ecological and social context in which salmon and people live.

Our study highlights the need for greater investment in activities that foster direct connections among people, fish, and other natural resources. Salmon are a charismatic fauna, with high media visibility. Although they are a strong cultural symbol of the Pacific Northwest (Lang 2003), only a small

fraction of our modern society has direct interaction with the fish. This limits our concern and willingness to fundamentally change behaviors that contribute to habitat degradation and loss, the main challenges facing salmon populations today. Nonprofit organizations up and down the Pacific Coast already are working to engage the public about salmon and other resources (e.g., Think Salmon, http//:www.thinksalmon.com; Nooksack Salmon Enhancement, http//:www.n-sea.org; Columbia River Inter-Tribal Fish Commission, http://www.critfc.org; People for Puget Sound, http//:www.pugetsound.org; Ecotrust, http//:www.ecotrust.org ; Salmon Nation, http//:www.salmonnation.com; South Yuba River Citizens League, http//:www.yubariver.net/content/save-yuba-salmon). These groups host community celebrations, develop educational curricula, and organize volunteers for diverse tasks such as replanting stream sides, removing barriers to migration, decorating buses with educational and inspirational messages, and painting signs on storm sewer openings. We urge that salmon recovery funds be devoted to establishing more links between neighborhood and community groups and actual fish populations, allowing for informal monitoring and even proprietorship, important to the resilience of the socioecological system in the past.

As a corollary, salmon recovery in urban landscapes needs to be given a higher priority than it has in the past. Urban areas encompass a relatively small proportion of the migratory routes and spawning habitats of salmon populations, but the vast majority of the human population in the Pacific Northwest region. By re-establishing spawning populations in habitats overlapping urban centers—close to where most people live and work—fish could become part of everyday experience rather than icons on headlines and billboards, for much larger numbers of people. Many municipalities (e.g., Portland, Seattle, San Francisco) are already working to re-establish salmon habitat as part of parks and wetland restoration projects; programs that explicitly extend to community involvement, such as the Salmon Watch program of King County, Washington, should be encouraged.

Would effort focused on relatively small urban streams be misplaced when so many problems need attention? There are three reasons to say no. First, no one knows the true magnitude of salmon populations formerly using such streams for spawning; these are the streams that lost their runs first, and for which there are few historic records. The total magnitude of runs these streams could support might be much greater than is currently understood. Secondly, one of the goals and perhaps one of the requirements of salmon recovery is to maintain genetic diversity. Establishing habitat for additional salmon spawning, even in short, small streams will do much to promote genetic diversity through the natural mechanisms by which salmon colonize newly available waterways. The third reason, alluded to in the preceding paragraph, is the opportunity to reach large numbers of people who will potentially develop greater concern for regional fish recovery efforts.

As historic and contemporary records illustrate, indigenous peoples of the Pacific Northwest engaged in complex rituals that reflected and contributed to core beliefs related to native animals and plants, and the landscape in which people lived. Traditions and institutions of First Nations peoples and Native Americans incorporated explicit monitoring of resource use and proprietorship, which helped convert open-access resources into common-pool ones. In our modern world, the newly formed rituals and beliefs and local community monitoring efforts that emerge from the much greater public engagement we advocate may not be sufficient to restore salmon populations in themselves, but the past tells us social connections are necessary. We need to continue to support scientific studies, and find ways to improve habitats overall, but in the meantime, also put more resources into activities that promote development of social beliefs and traditions about the value of salmon and their ecosystems to our everyday lives.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss1/art17/responses/

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