The Importance of Human Intervention in the Evolution of Puget Sound Ecosystems

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Abstract

Contemporary restoration efforts in Georgia Basin-Puget Sound tend to rely upon baseline data that are no more than 100 years old. Our research indicates that the marine ecosystems observed by European explorers and settlers in the 19th Century were already profoundly shaped by systematic human interventions and cannot be restored without an understanding and renewal of the human practices that created and sustained them. As a first step, we compiled existing archaeological and ethnographic data on marine resources use for 408 locations in the San Juan archipelago and identified six plausible hypotheses that we plan to test using biochemical and genetic studies of faunal remains at 20% of these sites. Our hypotheses focus on the following:

(1) The role of fire in expanding coastal wetlands.
(2) The effect of hunting pinnipeds and small cetaceans on maintaining salmon stocks.
(3) Heavy but localized seasonal human harvesting of sea urchins and the distribution of kelp forest.
(4) Dense patches of forage for salmon at those weirs and reef-nets where salmon were processed in large numbers.
(5) Selective harvesting and salmonid genetic diversity.
(6) Harvesting techniques and the structure of oyster reef communities.

Our hypotheses were critically informed by discussions with knowledgeable elders.

Introduction

Humans have occupied the shores and islands of the Salish Sea for at least the past 8000 years (Stein 2000). Estimates of the aboriginal population vary greatly; estimates based upon the reports of early European explorers are biased by the fact that European diseases reached the Northwest by way of Spanish Mexico at least a generation before Europeans. Adjusting for these factors, Boyd (1990) concluded that 30,000 Coast Salish lived in the Puget Sound-Georgia Strait basin on the eve of European epidemics, or about the number of people living in the San Juan Islands today. If daily consumption of fish and shellfish were 1.5 kg per day, comparable to Northern hunting peoples studied in the 20th Century, an aboriginal population of 30,000 would have required 16,425 metric tonnes of seafood annually—and for reasons of food security and trade, would likely have harvested more.

Even a relatively small population could have influenced the trajectory of post-glacial re-colonization of the region by plants and associated animal communities, moreover, by the alteration of fire regimes, and the intensive harvesting of migratory fish with weirs, traps, and other efficient gears strategically placed in migration corridors and bottlenecks.

The earliest archaeological evidence suggests a human focus on hunting large terrestrial and marine mammals. However, by 3500 BP, the ancestors of Coast Salish peoples were harvesting a wider range of fish, shellfish, and mammals and processing them on a large scale by smoking and drying, leaving a record of their diet in conspicuous shell middens, remnants of which can still be seen on most Salish Sea beaches. Smoked and dried foods supported prestige feasts, and trade with peoples as far distant as the upper Columbia and Fraser Rivers and the Plateau region of eastern Washington, Idaho and Oregon.

At the Weaverling Spit midden in Fidalgo Bay (45SK43), for example, we are finding the remains of deer, elk, seals, beavers, small rodents and a variety of waterfowl, small birds, salmon, smelt, herring, dogfish, rockfish, sculpins, sea urchins, barnacles, and most of the edible mollusks found in the area including *Saxidomus giganteus*, *Protothaca staminea*, *Mytilis edulis*, *Ostrea lurida*, *Clinocardium nuttalli*, *Tresus* spp, *Thais* spp, and the chiton *Katherina tunicata*. (Cartilaginous fishes and crabs, eaten in abundance by Coast Salish in the 19th Century, may also have been processed at Weaverling Spit, but their remains are rarely preserved in shell middens.) This dietary breadth spread the impacts of human predation across diverse habitats and over several trophic levels. At the same time, Coast Salish maintained favored habitats such as camas meadows by active means (e.g. fire) as well as passive ones (restraints on human population levels and harvest effort). Trosper (2002) contends that Coast Salish economies and ecology remained dynamically stable for 1500 years or longer.

We are currently engaged in the systematic sampling of shell middens in the San Juan-Gulf Islands archipelago to test hypotheses about the nature, extent, and sustainability of Coast Salish cultural transformations of marine ecosystems from 3500 BP to the arrival of Europeans in the late 18th Century. Core samples can be recovered from shell middens using a Giddens hydraulic core drill or in shallower deposits, hand driven bucket augurs, except where substantial rocky material is encountered (compare Cannon 2000a, 2000b). Faunal and plant remains recovered from cores will be identified and subjected to stable isotope ratio analyses that can provide information on oceanographic conditions, trophic complexity and nutrient flows in the ecosystems "sampled" by human harvesters (see e.g. Brenner et al 1999; Tripati et al 2001; Overman and Parrish 2001; Neumann et al 2002). Geochemical dating of cultural deposits will enable us to reconstruct changes over time in the distribution of human harvesting effort, and in the response of local ecosystems—such as Fidalgo Bay—to human activities.

Ecosystems as cultural products

Human impacts on ecosystems are always "cultural" in the sense that different cultures treat their environments differently. There is no universal way of catching fish or making baskets—although there are physical limitations on our options. Differences in behavior within the envelope of feasibility arise from differences in history, social organization, values, religious beliefs, empirical knowledge and technology, and in the ways that we transmit our "way of life" to our children. In this respect, Fidalgo Island was a cultural landscape when Captain George Vancouver explored Deception Pass two centuries ago, although it looked entirely natural and undisturbed to English seamen acquainted with the rowdy London waterfront. Some cultures leave more profound or obvious footprints on the landscape than others, however. Coast Salish burning did not remove forests entirely from Fidalgo Island, but apparently created patchier forests with a higher proportion of hardwoods. Altering forest architecture is a profound ecological impact, but it was less obvious to European eyes than architecture of dead bricks and mortar.

Our current knowledge of Coast Salish resource management practices is based on 19th Century observations, such as the journals of Hudson Bay Company employees from the 1820s, the logs of naval officers with the 1841 U.S. Exploring Expedition, and the 1857-1859 field notes of Northwest Boundary Commission naturalist C. B. Kennerly; as well as the field notes of ethnographers such as Ernst Haeberlin, Bernhard Stern, Sally Snyder, and Wayne Suttles, who interviewed Coast Salish elders in the early to mid-20th Century. Most of the data remains unpublished. As a first step, we assembled and analyzed these existing records, and identified three main vectors of Coast Salish cultural modifications of ecosystems:

1. Selective, localized harvesting of animals and plant.
2. The periodic burning of terrestrial vegetation.
3. Waste disposal practices.

(1) Harvesting regimes

Harvesting of particular taxa could be seasonal, localized, and highly selective as to size, age, life stage or sex, and thus would have significant consequences for the structure and genetics of animal populations. Reef-nets, the dominant salmon harvesting gear utilized by Coast Salish peoples in the archipelago, targeted schools of migrating adult sockeye as they moved inshore to feed in island eelgrass meadows. Escapement needs were met by allowing a "first run" of fish to pass through each reef-net site—a matter of days or even weeks—before beginning the summer fishery (Daniels 2001). There were also relatively few active reef-net sites in the archipelago at any time; Figure 1 shows the distribution of Coast Salish reef-net sites recorded by Suttles (1974). Each site supplied scores of Coast Salish households, while sockeye fed safely at other nearshore areas. Joseph Cagey and Dick Edwards, owners of two Samish reef-net gears on Lopez Island, landed from 3,000 to 4,000 sockeye on each outgoing tide (Rathbun 1895): up 28 metric tons per day.

Species-level and population-scale effects may also have included changes in the ratios of predators and prey. Aggressive human hunting of pinnipeds and small cetaceans reduced non-human predation on salmonids, while intensive human harvesting of eulachon, smelt and herring reduced the supply of prey for salmonids. The salmonid population available for human use was therefore a product of the levels of human predation on other fish and marine mammals. If humans harvested too many herring, or too few seals, salmon stocks in the Salish Sea would have dwindled. It is unlikely that there is only one stable ratio of marine mammals, "forage fish" for salmonids, and salmonids. If there are multiple stable ratios in multi-species predation, humans "choose" a preferred ratio by the way in which they distribute their harvest effort across species. Early post-glacial humans preyed most intensively on marine mammals, thereby facilitating the growth of salmonid populations. Humans subsequently shifted some of their attention to fish, but continued to suppress the other mammalian predators of fish.

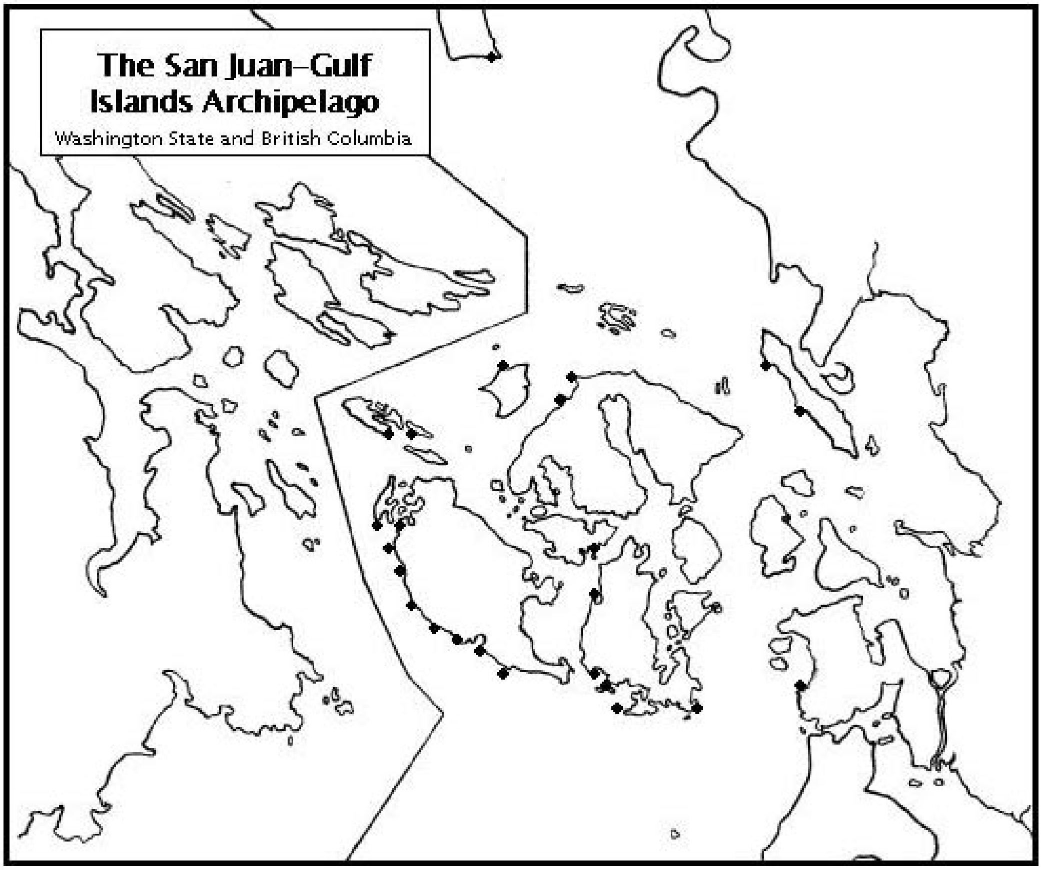

Figure 1. Coast Salish reef-net sites (data from Suttles 1971).

Coast Salish engaged in sea urchin feasts, as evidenced by the occasional substantial lens of sea urchin remains found in shell middens; feasts of raw urchins or "sea eggs" remain popular in northern British Columbia. Periodically cleaning out local urchins could have played an important role in promoting aquatic vegetation in the rocky inter-tidal habitats of the Salish Sea, especially where other predators such as sea otters were not abundant. Humans altered animal communities by addition as well as selective subtraction. Coast Salish bred large flocks of longhaired "wooly" dogs for weaving (Suttles 1974:102-105; Elmendorf 1992:94-99), adding a potentially important terrestrial predator to the native canids of the region.

(2) Fire regimes

The most important tool of ecological modification in the Salish Sea, however, was fire. Members of the Northwest Boundary Commission noted the effects of frequent fires on the San Juan Islands, which they attributed to Indian deer-hunting as well as hunting and clearing by recently arrived settlers: there were parkland forests "very easy to traverse," with abundant meadows, and only scattered groves of large trees (Kennery 1859: 52-54, 58-59, 86). They estimated that two-thirds of Lopez Island alone was meadowland. On the most heavily settled island (San Juan) they noted that the coniferous regrowth was "as thick as ferns," however, presumably because Coast Salish were no longer setting fires to clear the understory and open the canopy (ibid 114).

Fire operated at the landscape scale. Clearing fires in the understory of upland forests suppressed conifers, maintained hardwoods, opened the canopy, promoted the growth of berries and of forage for deer and elk, and facilitated human travel (Snyder 1955, SS/n 109/2:21). Well-drained meadows and rocky hillsides were burned to suppress shrubs and trees and promote the growth of camas (*Camassia quamash*) for food; camas beds were also seasonally tilled and re-seeded to help the camas grow better (Suttles 1974:59-61; Turner 1995:42-43). Moist lowlands were burnt to cultivate nettles for making tough twine used in nets, baskets, and blankets (Snyder 1955:90). Wetlands and estuaries were probably burnt to promote the growth of grasses and cattails used in baskets (compare the California Indian practices in Anderson 1996); to facilitate canoe transportation and duck hunting, and perhaps inadvertently to grow fish, as described below. Although the total extent of lands burned annually for camas is unknown, the habitats preferred for growing camas are widespread throughout the San Juan and Gulf Islands, and camas comprised a major article of year-round diet and trade.

From an ecological perspective, frequent burning prevented accumulations of fuel and reduced the risk of cataclysmic wildfires. Frequent burning would also have recycled nutrients from woody material to soils, fresh water run-off, and ultimately the nearshore environment.

(3) Recycling and focusing nutrients

Within landscapes, Coast Salish peoples wittingly or unwittingly redistributed nutrients not only by burning particular patches of vegetation, but also by burning and disposing of food waste in rivers, estuaries, and bay shores. Charcoal and ash, animal and fish bones, calcined shells and other inedible organic materials were concentrated in the habitats that provided most of the Coast Salish diet. All household refuse was biodegradable and non-toxic, unlike a large proportion of household refuse today. Even tools were largely made of sources of nutrients for aquatic animals and plants, such as wood, bone and antler; the stone parts tumbled on beaches and eventually returned to pebbles.

As noted above, salmon were harvested on an industrial scale by gears such as reef-nets, traps, and weirs. When members of the Northwest Boundary Commission landed at the Point Doughty reef-net grounds in 1859, they were repulsed by the "immense quantities of salmon heads that were strewed around" the beach, through which they were forced to wade to higher ground (Kennerly 1859:126). Salmon were processed near reef-net sites by removing heads, tails, and backbones, all of which were returned immediately to the beach and bay; and then by smoking and drying over beach fires fueled with local wood. Butchering refuse, charcoal and ashes went directly back into the eelgrass meadows and "reefs" (shoals) from which the fish had been removed. A reef net operation not only recycled nutrients from the forest and the sea but also *focused* them, drawing upon widely dispersed nutrient sources (wherever sockeye traveled throughout the North Pacific), and concentrating the accumulated nutrients at ca. 40 sites in the San Juan and Gulf Islands.

Nutrient loading of reef-net grounds would have fed the next generation of sockeye on the remains of the parents, analogous to the nutrient dynamics of freshwater spawning areas where juvenile salmon and their prey feed on the carcasses of spawned out adults. Reducing salmon spawning escapement not only reduces the number of eggs deposited in terminal areas, but may also reduce the food stock available to salmon smolts when they emerge from the gravel the following spring. *Increasing* the load of salmon carcasses at certain points along salmon migration paths may have created attractive feeding stations for outbound juveniles, to which they returned as inbound adults. By this means, each reef-net operation sustained its own supplies of sockeye by recycling refuse into salmon prey (i.e. small fish and crustaceans that fed on the carcasses and inhabited "fertilized" eelgrass meadows), attracting the next generation of harvestable fish to the site. If this analysis is correct, reef-net grounds in the San Juan Islands would also have played an important role as feeding stations for outbound salmon and presumably contributed to their survival.

Figure 2 presents the foregoing hypothesis in schematic form. Solid arrows represent positive feedback; thick solid arrows represent the flow of anthropogenic nutrients; and dashed-line arrows represent negative feedback.

With the advent of canneries in the late 19th Century, most salmon refuse was deposited at cannery sites on the edges of the Salish Sea; today, with the growth of the fresh/frozen marker, most salmon refuse goes to land-fills, and the nutrients are largely removed from the salmonid food chain. Contemporary fishing and agriculture export nutrients from the ecosystems they exploit, without replacing them in kind. Chemical fertilizers and sewage are the principal ways that we "repay" ecosystems, in nutrient terms, for our food stocks. But their chemical constituents differ from the fish and vegetables we remove, and so do their ecological consequences.

(4) Culture and connectivity

Human social organization also played an important role in the pattern of redistribution of nutrients at a regional (Georgia Strait-Puget Sound basin) scale. As Suttles (1987) has persuasively argued, densely interrelated families and villages constituted a Coast Salish "continuum" throughout the Salish Sea. Although there were local cultural and linguistic variations, and fierce, albeit transient, local loyalties, all Coast Salish shared kinship, trade and ceremonial ties. People moved seasonally to fish, hunt, gather plants, trade and feast with distant in-laws, resulting in continuous redeployment of human harvesting effort and redistribution of processed foods. Obligatory exogamy, arranged long-distance marriages between remote high-status lineages, in-law privileges, and prestige feasts ("potlatches"), all served to provide a system of investment and social insurance that was unquestionably critical for the survival of Coast Salish in a relatively unpredictable marine environment. The aim of social life was to have relatives everywhere, and, through generosity, to build up a large fund of reciprocal obligations.

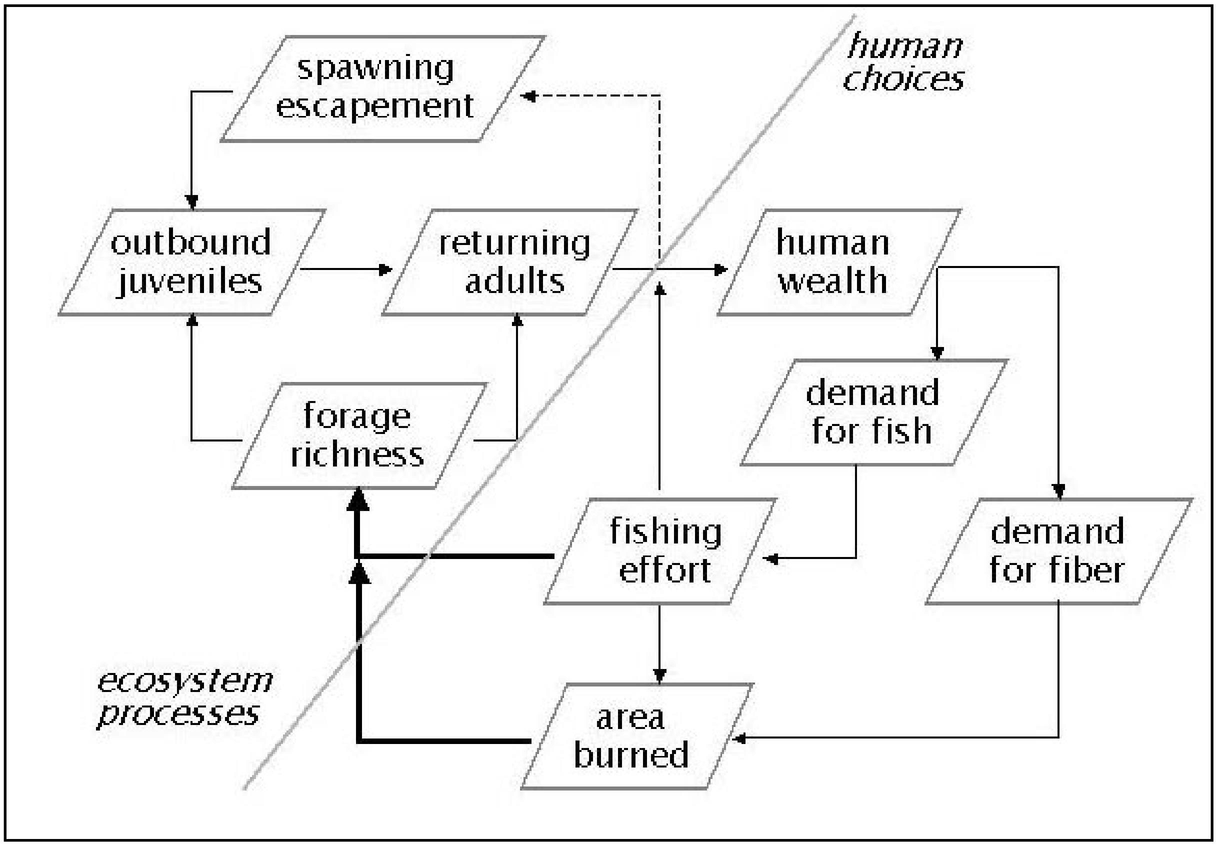

Figure 2. The human ecology of a Coast Salish reef-net fishery.

In human ecological terms, then, Coast Salish social organization (1) broadened access to food resources; (2) deployed harvesting effort to relatively abundant resources regardless of their location in the Salish Sea; and (3) rewarded sound stewardship of harvesting sites by making the local custodians "famous." Custodians of consistently productive reef-net grounds, for example, could afford to be consistently generous in sharing fishing access, and in sponsoring feasts. Families that abused their own local resource sites soon found themselves poor with few "friends," unwelcome as guests, unable to sponsor feasts or to arrange desirable marriages.

In terms now widely used in the discussion of biocomplexity, human social organization provided **connectivity** in the Salish Sea. Coast Salish culture facilitated the movement of people seasonally to habitats where living resources were most abundant and harvesting them would have the least adverse impact. Seasonal human movements counterbalanced the vagaries of climate, currents, predators and parasites affecting local fish and shellfish stocks. Seasonal movements were not repetitive, but responded to ecological signals that changed frequently. At the same time, Coast Salish culture created incentives for leading families to conserve stocks and share them prudently. Just as money creates connectivity in the contemporary global economy, shared beliefs and aspirations regarding standing—a good name—provided connectivity, incentives to "save" assets, and an efficient use of living resources in the aboriginal Salish Sea (compare Trosper 2002).

Coast Salish were not simply eclectic, opportunistic omnivores. They modified habitats to increase their supply of preferred foods, medicines, and plant materials. Fire was used extensively to modify upland and wetland plant communities and burning, harvesting and waste disposal practices had profound impacts on aquatic plant and animal communities. The entire Salish Sea ecosystem, as observed by Europeans in the late 18th and early 19th Centuries, was arguably a cultural artifact.

Fires, forests, and fish

Let us return to what we believe was the key factor in the Salish Sea ecological equation: anthropogenic fire. How much do we know about pre-Columbian uses of fire here in the Pacific Northwest or elsewhere in North America; and to what extent can we recover any reliable biophysical evidence of prehistoric fire regimes and their effects on fish?

Wildfires have occurred, often frequently, for more than 200 million years (Scott 2000). An increase in the frequency and regularity of fires and decrease in their intensity could be evidence of human intervention. Fires produce pulses of particulate carbon in run-off that can leave distinctive “signals” in soils and sediments (Filippi et al 1998; Weiner et al 1998; Lepofsky et al 2003; Hilfinger et al 2001). Inferences about the extent and nature of anthropogenic fire can also be derived from historical changes in plant communities, which are reflected in pollen records recovered from cultural as well as natural deposits. Historical records of changes in fire regimes and their consequences, and experiments in present-day plant communities, form the basis for making inferences from changes in the pollen record.

In the absence of frequent burning, for example, the grasslands of south-central British Columbia succumb to conifers (Turner and Krannitz 2001), a phenomenon easily seen in the meadows and prairies of the San Juan Islands. Other plant communities that require frequent burning include the grasslands of Australia’s Cape York Peninsula (Neldner et al 1997); New England oak-chestnut forests (Foster et al 2002); and oak barrens, oak forests and oak savannas in the American Midwest (Baker et al 1996; Peterson and Reich 2001; Rieske 2002; Guyette et al 2003). Burning is necessary for the survival of some plant species in Wisconsin sedge meadows (Kost and de Steven 2000) and New Zealand peat bogs, which were periodically burned by aboriginal Maori people (Norton and de Lange 2003). Clark and Wilson (2001) found that native wetland graminoids in the Willamette Valley were more fire tolerant than non-native species (but see Patel and Rapport 2001). Native people of northern Mexico still burned wetlands in historic times for the purpose of suppressing woody plants and bulrushes (Davis et al 2002).

Although European management regimes are generally associated with fire suppression, Europeans in New England **increased** the frequency and intensity of fires at first (Parshall and Foster 2002). The same was true in the San Juan Islands, judging from the records of explorers and settlers such as Kennerly (1859) and Keith (1996). Restoration baselines for upland habitats tend to be based on data from the late 19th to early 20th Centuries, after European settlers’ clearing fires, extensive clear-cut logging, and post-logging wildfires had already deflected forest succession trajectories. Burning what is standing today will probably not restore “native” (i.e. pre-settlement) plant communities without gradually re-introducing some important habitat-forming species, such as Garry oak.

Although the use of prescription burning to restore upland vegetation has been gaining a considerable following, surprisingly little attention has been paid thus far to the effects of prescription burning on fish or shellfish. In the small and often steep, rocky islands of the Salish Sea, freshwater run-off quickly transports ash to the marine environment. Burning uplands and wetlands is presumably closely coupled with nearshore nutrient loads.

Studies of forest fires in Quebec found that burning increased key ionic nutrients in lakes and promoted the growth of plankton (Pinel-Alloul et al 2002). Logging also transferred nutrients to lakes, but the promotional effect on plankton was offset by greater turbidity. Related research has not been conducted in marine environments, and most other studies of fire have looked for **adverse** impacts on fish. For example, it was recently found that intense wetland fires can harm fish that are present at the time through the production of cyanide (Barber et al 2003); paleontologists have attributed some catastrophic fish kills to fires (Falcon-Lang 1998).

In Australian forests burned by Aboriginal people for millennia, arthropods appear to be unaffected by all but the most intense fires (Anderson and Muller 2000), suggesting that frequent burning has selected for greater fire tolerance. Fish may also adapt to local fire regimes and their effects on water chemistry and aquatic communities. Salmon rapidly re-colonize Pacific Northwest streams and lakes; for example; perhaps this represents, in part, an evolutionary response to the aboriginal fire regime (Gresswell 1999). Fires may pose a greater threat to fish in arid ecosystems (e.g. Rinne 1996) because of their intrinsic geochemical characteristics, or because prehistoric southwestern farming peoples did *not* burn riparian zones periodically.

Varying the heat flux of anthropogenic fire changes its effects on plant communities and associated wildlife (e.g. Barsh 1997; Pendergrass et al 1998; Davis et al. 2000; Reich et al 2001; Peterson and Reich 2001). Since herbivory affects the results of fire as well (Ford and Grace 1998; Knops et al 2000; Patel and Rapport 2001), intensive human hunting of herbivores could enhance fire effects on the plant biome. For example, Blackfoot people hunted deer and rabbits in Alberta riparian cottonwood forests in spring, before pursuing summer bison herds on more open ground; this practice would have suppressed herbivory on cottonwood shoots and enhanced the regenerative effects of fire-clearance practices in the riparian zone (Knowlton 1997).

The case of Pacific herring

Faunal sampling of Salish Sea shell middens indicates that herring were as important as salmon in the prehistoric diet. There is evidence that herring harvests remained relatively stable until c.500 BP, moreover, whereas salmon harvests declined c.3500 BP (Cannon 2000a; Kopperl 2001). Herring may have been more tolerant of the shift in the regional climate regime that occurred c.3500 BP, to which archaeologists attribute the emergence of a more "maritime" culture. Alternatively, human activities may have maintained the habitats preferred by herring, just as humans' use of upland fires maintained hardwoods and meadows against the advance of conifers.

Ocean warming does appear to depress herring recruitment (Tanaka 2002). Archaeology can be used to ascertain whether there has been a longer-term relationship between **ocean temperatures**, as determined from the stable oxygen isotope ratios of herring bones found in shell middens, and **herring abundance,** as inferred from changes over time in the ratio of herring remains to other faunal remains in shell middens (compare Finney et al 2000). We hypothesize that a negative relationship will be found over the Salish Sea as a whole; however, we hypothesize that climate will **not** explain the disappearance of herring from particular bays (compare Wallace and Dalsgaard 1998).

After the influx of European settlers and fishermen c.150 BP, herring have disappeared from many heavily exploited areas, such as Deepwater Bay on Cypress Island, Mackaye Harbor on Lopez Island, and Fishery Point on Waldron Island. Two observations suggest that these disappearances reflect local conditions, such as nutrient loads and aquatic plant communities: (1) archaeological and historical data indicate that herring disappearances have been widely separated in time, i.e. from decades to centuries; and (2) herring persist in some heavily exploited areas, whereas they fail to recover in other areas after cessation of fishing.

Field studies confirm that herring are opportunistic and respond very sensitively to local biophysical conditions (Mackinson 1999; McFarlane et al 2001; Hoshikawa et al 2002). Herring tend to travel together (Hay and McKinnell 2002), but display relatively weak geographical fidelity with respect to spawning areas (Hay et al 2001). Consistent with flexibility and opportunism in spawning selection, there is significant genetic variation within herring spawning aggregations (Olsen et al. 2002), although broad regional-scale genetic aggregations exist (O'Connell et al. 1998) as well as genetic distinctions between migratory and non-migratory stocks (Gao et al 2001).

If herring are opportunistic spawners, relative to salmon, it is plausible that Coast Salish could have successfully and sustainably attracted herring to particular bays by using fire to boost nutrient loads and produce richer aquatic foliage and forage—and that the same nutrient loading mechanisms would have attracted salmon to feed but not to spawn. As a corollary of this hypothesis, the cessation of frequent wetland burning in historical times should have reduced the number of Salish Sea bays that could attract and sustain herring reproduction. Archaeological investigations of shell middens and nearshore sediments in a cross-section of Salish Sea bays can be used to compare signals of anthropogenic fires, anthropogenic and natural nutrient flows to the nearshore, and the relative size of herring harvests over time to test these linked hypotheses.

Conclusions

In summary, the activities of Coast Salish peoples affected the structure and diversity of terrestrial habitats; species richness and the composition of terrestrial and aquatic animal and plant communities; and the structure and genetic diversity of animal populations. We believe the result was a landscape of patchier and more complex mosaic vegetation, with more hardwoods, more prairies and meadows, and more ungulates. We hypothesize that Coast Salish practices also produced coastal areas (or seascapes) with more seagrass and more fish—especially herring, and secondarily sockeye. This is what we mean when we refer to "cultural landscapes."

Localized abundance of salmon and herring may have been artifacts of long established human interventions that concentrated and redistributed nutrients to particular nearshore habitats. If this is correct, restricting harvesting and decontaminating sediments will not restore fish to their former abundance, even after adjusting for warming. Only prescribed burning of wetlands and uplands can restore Coast Salish traditional fisheries fully.

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