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InfoNorth

Life After Death:
The Importance of Salmon Carcasses to British Columbia's Watersheds

By Stephen Watkinson

INTRODUCTION

THE province of British Columbia prides itself on its vast natural resources. Streams, creeks, lakes, and ponds are found throughout the province and provide water and nutrients to both terrestrial and aquatic systems. Adult spawning salmon are a key link between the marine ecosystem and the ecosystems inland.

The Pacific salmon include five species: coho salmon (*Oncorhynchus kisutch*), chum salmon (*O. keta*), chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*). The anadromous life history of Pacific salmon is well known: born in freshwater streams inland, the juvenile salmon migrate downstream to spend the bulk of their adult life at sea. When it is time to reproduce, they perform the heroic feat of swimming upstream to the inland spawning sites, where they lay their eggs and die. The entire life cycle takes 4 to 5 years, except for pink salmon, which has a 2-year life cycle.

As returning adults approach the streams they will enter to spawn, they stop feeding. Their bodies contain only an insignificant amount (<1%) of residual freshwater-derived biomass, accumulated when they were smolts developing in the stream environment (Kline et al., 1997). Thus, the body of an adult salmon is almost entirely constructed from marine sources. These marine-derived nutrients enter the stream ecosystem before, during, and after spawning, through excretion, release of gametes, and carcass decomposition, respectively (Brickell and Goering, 1972). Once released, these marine-derived nutrients become available to enter into the food-web dynamics of both the aquatic and the surrounding terrestrial ecosystems. Bilby et al. (1996) demonstrated that in a headwater stream containing heterotrophic species, up to 40% of the nitrogen in the aquatic food chain is marine derived, released from the carcasses of coho salmon. When fewer salmon return to the spawning grounds, smaller quantities of marine-derived nutrients are supplied to the surrounding ecosystems. Larkin and Slaney (1997) showed that as carcass availability in a stream declined, so did nutrient and carbon sources for developing salmonids. This suggests that salmon parents assist their progeny in the fight for survival long after they are gone themselves.

THE AQUATIC ECOSYSTEM

Johnston et al. (1990) showed that juvenile salmonid biomass increased in streams that had been enriched with nitrogen and phosphorous by whole-river fertilization. To gain mass, an organism must consume calories; but since juvenile fish do not prey upon nutrients directly, how can fertilizers increase their biomass? Organisms at trophic levels below the juvenile fish must respond positively to the increase in nutrients, which increases their biomass, making more food or higher-quality food available for the juvenile fish. The streams in which salmon spawn and juveniles are reared are continuously flowing. Thus the nutrients released from the carcasses must somehow be retained, or a large portion of the nutrients will be flushed out of the system. One retention mechanism suggested by Donaldson (1967) is algal uptake, as he observed extensive growth of periphyton near major spawning areas, which suggests a concentration and retention of nutrients following spawning. Growth of algae and biofilm was also observed to increase as much as 15 times in streams that were supplemented with salmon carcasses (Wipfli et al., 1998; Fisher Wold and Hershey, 1999). Since algae are at the bottom of the trophic pyramid for the aquatic ecosystem, increasing the base of the pyramid may lead to increasing the biomass of the trophic levels above. However, fish that are considered important to humans do not consume algae directly, so increasing algae production does not guarantee an increase in fish biomass.

At the next level up the trophic pyramid, which does connect algae and fish, are the macroinvertebrates. Some of the most abundant macroinvertebrates include Chionomids, mayflies, and stoneflies. Wipfli et al. (1998) found that in a natural stream that had been carcass enriched, biofilm production increased and total macroinvertebrate densities increased 25 times. Increasing the food available to invertebrates allows their biomass to increase. This is meaningful to fish, since the invertebrates are their primary food source while in the stream environment.

Another pathway by which marine-derived nutrients may be passed from adult carcasses to juvenile fish is through direct consumption of flesh and eggs. Using stable isotope analysis, Bilby et al. (1998) found that placing salmon carcasses in a stream increased the proportion of marine-derived nitrogen ($\delta^{15}N$) in the muscle tissue of juvenile salmonids up to 39%. Analysis of gut content revealed that the juveniles had been feeding primarily (60–90%) on carcass flesh and eggs. Since eggs are highly nutritious, it is advantageous for the fish to eat as many eggs as possible while they are available.

The different spawning times of salmon species serve to spread out the availability of carcasses, making their effect similar to that of a time-release vitamin pill. The system can assimilate more of the nutrients than it could if all were released in one major pulse.

The end result from carcass → nutrients → algae → benthic invertebrates → juvenile salmonids or from carcasses → juvenile salmonids is increased smolt size at the time of out-migration. A larger smolt size has been shown to result in better survival rates in years when ocean survival rates were relatively poor (Blair Holtby et al., 1990). It is evident that adult salmon returning to spawn perpetuate their species not only by sexual reproduction, but also by increasing primary productivity, which gives the last year's progeny increased food resources.

THE TERRESTRIAL ECOSYSTEM

The effects of salmon carcasses are not confined to the aquatic ecosystem, as ecosystem boundaries are merely an anthropocentric way of describing nature. Many bird and mammal species depend on the annual flux of spawning salmon and have incorporated this resource into their own interannual migration patterns. Wilson and Halupka (1995) report that in Alaska, over 40 species of mammals and birds are known to feed on salmon and their carcasses, eggs, and juveniles in freshwater habitats.

Bald eagles (*Haliaeetus leucocephalus*) congregate in areas where salmon are accessible to them. In some areas, the number of bald eagles can rise from a mere few to 1000 after the spawning salmon arrive (Drew, 1996). Stalmaster and Kaiser (1997) studied the winter ecology of bald eagles on the Nisqually River and Muck Creek, Washington, over three years. They found that spawning chum salmon (*O. keta*) constituted their primary food source, predicting that the eagle population of approximately 150 birds would consume 1100 salmon carcasses each winter. Stalmaster and Gessaman (1984) estimated that chum made up 96% of the eagles' diet when the salmon were available. Chum salmon are typically a late-spawning species. The peak of their die-off in the Nisqually River occurs in January, making the chum a vitally important winter food source for these eagles.

Bears are among the many mammals known to depend heavily on the nutritious spawning salmon as a food source. Both black bears (*Ursus americanus*) and grizzly bears (*U. arctos*) can be found congregated along streams feeding on salmon. The season when salmon are available is the one time of the year when the usually solitary bears congregate and tolerate each other's presence. The main reason that bears depend so heavily on salmon is that the bears will be entering hibernation soon after the runs of salmon arrive. During hibernation, the bears do not actively feed and must rely on energy stored within their bodies. In pregnant black bears, the final 6 to 8 weeks of gestation, the birth of the newborn, and the first 10 to 12 weeks of lactation all occur while the mother is dormant in hibernation (Oftedal et al., 1993). The mother has to not only meet her own energy requirements, but also produce high-quality milk for her offspring; thus, well-fed females may be more successful. Rogers (1976) showed that a strong positive correlation exists between the fall mass of female bears and reproductive success.

Bird and mammal species also play an important role in dispersing salmon carcasses and marine-derived nutrients to the surrounding vegetation. For instance, ravens and crows have been observed storing carcass material in trees, in grass, and under rocks (Willson et al., 1998). While most of the consumption of carcass material occurs quite close to the stream, the marine-derived nutrients may reach well into the riparian vegetation through the deposition of fecal matter. Ben-David et al. (1998) looked at five species of plants along transects from the stream to the upland forest. In three of the five plant species sampled, they found that the value of $\delta^{15}N$ from salmon carcasses decreased significantly as distance from the stream increased. This indicates that salmon carcasses contribute to the nitrogen pool available to riparian vegetation, and $\delta^{15}N$ was found in vegetation as much as 500 m away from the stream. The levels of $\delta^{15}N$ in vegetation were generally higher in areas where predator activity was evident than in areas where no predator activity could be found. Bilby et al. (1998) found that nitrogen from coho salmon remains was responsible for 18% of the nitrogen in the foliage of riparian vegetation along a small stream in Washington.

It is quite clear that spawning salmon and the carcasses they produce play a critical role in maintaining ecosystem health and providing links between ecosystems. The return of anadromous fish to the freshwater ecosystem, including the occurrence of runs in very small streams, has important implications for wildlife biology and conservation of biodiversity (Willson and Halupka, 1995). With so many interactions within an ecosystem involving salmon either directly or indirectly, the term "keystone species" immediately comes to mind. If a keystone species is one that is instrumental in maintaining the integrity and health of the ecosystem in which it interacts, then salmon certainly fill that role. Unfortunately, salmon management in British Columbia is focused on the marine life stage. The optimal number of spawners to replenish the stock is calculated so that estimated surplus of fish can then be commercially harvested. If too many fish enter the spawning grounds, the term “over-escapement” is applied, but I personally have never heard any reports that bears, eagles, or insects had been negatively affected by too many spawning salmon.

RESEARCH PROJECT

I plan to construct an ecosystem model that tracks the flow of marine-derived nitrogen through the stream and adjacent forest ecosystem. The model will focus on converting spawning salmon biomass estimates for a particular stream and using these estimates to calculate the amount of marine-derived nitrogen entering the watershed. The pathways taken by marine-derived nitrogen as it travels throughout and across ecosystems will be compiled into a model, using the Ecopath software.

Study Area

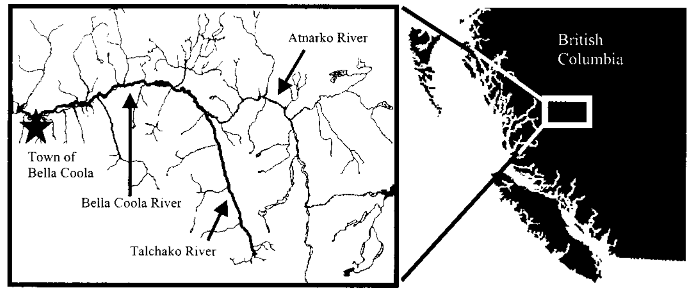
The Atnarko River system has been chosen as the study site. The Atnarko River is located within Tweedsmuir Provincial Park and drains the Interior Plateau flowing west. The Atnarko joins with the Talchako River to form the Bella Coola River. This junction is approximately 61 km from where the Bella Coola River empties into the Pacific Ocean, near the town of Bella Coola. Glaciers feed the rivers as they carve their way through the Coast Mountains before emptying into North Bentinck Arm. The ocean waterways leading into the Bella Coola are deep, steep-walled fjords that were made when the glaciers retreated and are typical of coastal British Columbia.

The Atnarko River receives all five of the salmon species for spawning. The area lies within the traditional territory of the Nuxalk First Nation. Although the Nuxalk do not fish the Atnarko River, food fishing does occur along the Bella Coola River, and many sport anglers visit the Atnarko in the fall to test their luck.

Incorporating Traditional Ecological Knowledge

Studying the Atnarko River system will also give me the opportunity to incorporate the traditional ecological knowledge of the Nuxalk First Nation, which has occupied the Bella Coola region for thousands of years. Western science has a long history of ignoring the knowledge of First Nations people, often dismissing their observations of the land and ocean as mere stories or myths. Recently, however, a trend to incorporate the traditional ecological knowledge (TEK) of First Nations people into western science has established itself.

Presently, scientific studies concern themselves mainly with well-documented quantitative facts and figures. In many cases, however, qualitative local knowledge is needed to compare recent trends with historical conditions. Most notably, it has become obvious that TEK can be an invaluable source of information when trying to piece together historical trends of species abundance and distribution. Thus, a lack of quantitative information should not be seen as a hindrance, but rather as an opportunity to incorporate local TEK into science. Pauly et al. (1998) used this approach to model the Strait of Georgia as it might have been 100 and 500 years ago. This approach allowed them to form a more complete picture of the ecosystem that considered its evolution, rather than just a snapshot in time.



The Atnarko River is located east of the town of Bella Coola. The Atnarko watershed has several lakes and magnificent falls that make the area a popular destination for outdoor enthusiasts.

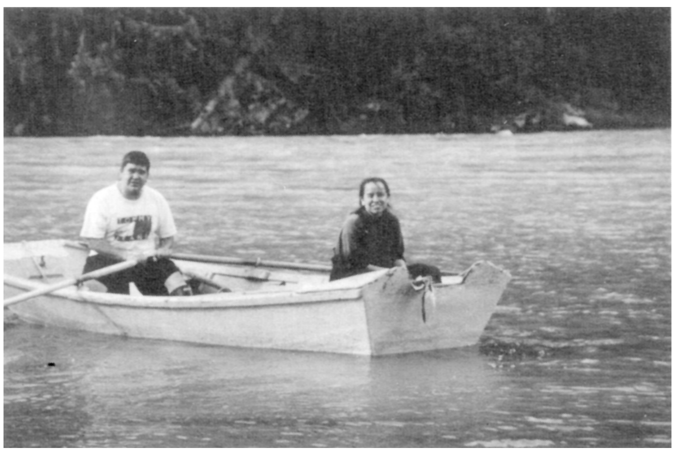
Future Outlook

It is quite clear that salmon management must consider the importance of marine-derived nutrients for all streams that receive spawning salmon, rather than just managing the commercially important runs of salmon. I do not expect this modeling project to alter the way resources are managed throughout British Columbia. But I believe that it will help develop a technique for modeling fishery/forestry interactions related to streams that receive spawning salmon. Like any modeling project, it should help to identify gaps in the data that are used to make management decisions. I do hope that since the project will involve various government agencies and First Nations people in the Bella Coola region, it can serve as a tool to bring them together to start talking to one another about a common resource. Resource managers and users both like to talk about partnership building. Often they share a common goal, despite their different needs. Involving different agencies in the modeling process may help identify gaps in the data and lead to partnership-building projects

Personal Background

I come from the Kitkatla First Nation, although I spent the early years of my life growing up on the northern end of Vancouver Island. The village of Kitkatla is located on an island southwest of Prince Rupert. I have been attending the University of British Columbia since 1994. In the spring of 1998, I graduated from the Faculty of Forestry

Life after death. Salmon carcasses are a key food source for many stream and terrestrial organisms. Photo by Stephen Watkinson.



Nuxalk fishers about to head down the Bella Coola River. The Nuxalk have been fishing the Bella Coola region for thousands of years. Photo by Stephen Watkinson.

with a Bachelor of Science in Natural Resources Conservation. This four-year multidisciplinary program included fish and wildlife management, parks and recreation, and forest management.

I am currently working on a Master of Science degree in the Fisheries Centre at the University of British Columbia. This program enables me to study fisheries science while applying a holistic approach to ecosystem management, which allows for the incorporation of traditional knowledge and values into course work. My courses include biology, policy and planning, population dynamics, and ecosystem modeling.

There are currently few First Nations people with master's or Ph.D. degrees in the field of fisheries management. Since the fisheries resource is so important to First Nations for both food and ceremonial purposes, there is a need for dialogue between government scientists and aboriginal communities. Academic programs are a key step for capacity building so that when the treaties are signed, First

It does not take long for a salmon carcass to be scavenged. The entire carcass is utilized by organisms at various trophic levels in the ecosystem. Photo by Stephen Watkinson.

Nations will have their own scientists in place to manage the surrounding resources. After completing a master's degree, I will be better prepared to help First Nations communities in British Columbia to manage their resources responsibly. I will be able to incorporate the perspectives of First Nations with the knowledge of fisheries science.

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Stephen Watkinson is the recipient of the 1999 Jim Bourque Scholarship. This scholarship is awarded annually to a Canadian aboriginal student who intends to take post-secondary training in education, environmental studies, traditional knowledge, or telecommunications.