the *fish* & the *forest*

By Scott M. Gende and Thomas P. Quinn

Salmon-catching bears fertilize forests with the partially eaten carcasses of their favorite food

Few wildlife spectacles in North America compare to the sight of bears gathered along streams and rivers to scoop up spawning salmon. The hungry bears have long attracted attention, particularly from fishery managers, who in the late 1940s proposed their broadscale culling in Alaska to reduce the "economic damage" the predators might be wreaking on salmon populations. In fact, several sensationalized reports implied that Alaska might fall into "financial and social collapse" unless the bear populations were controlled.

Fortunately, common sense came to the rescue, and the bear cull never came about. Scientific interest in the interaction between bears and salmon died down. Recently, however, researchers have discovered a new facet of this relationship, and the finding has radically changed notions about how the salmon, the streams and the bordering woodlands affect one another—and, naturally, notions about how they should be managed.

SOCKEYE SALMON swims past a foraging brown bear in a small stream in Alaska. The fish turn bright red with a pale green head as they prepare to spawn in freshwater.

JOHN HYDE *Wild Things Photography*

Our own contributions to this work have spanned more than a decade. During this time we have walked hundreds of kilometers along salmon streams, examined tens of thousands of salmon carcasses, and had too many close encounters with agitated bears. Our findings surprised us: bears actually fertilize the forests, nourishing them by discarding partially eaten salmon carcasses. Not intentionally, of course, but the end result is that these large predators bring valuable marine-derived nutrients, in the form of salmon tissue, to the streamside woodlands, where the uneaten fish provide sustenance for an array of animals and plants. The flow of nutrients from ocean to streams to woodlands is an unexpected, even unprecedented, uphill direction for resources to travel. A close look at the life history of the predator and its favorite prey helped us and other scientists piece together how this unusual transfer system operates.

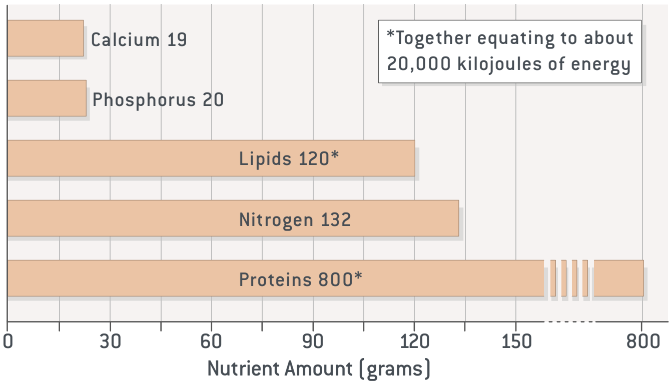
The Nutrient Express

PACIFIC SALMON—including chinook, coho, chum, pink and sockeye—vary in abundance, size and behavior, but all members of this genus (*Oncorhynchus*) share the same general life cycle. Young salmon emerge from the gravel in streams or lakes in spring and then, over various periods of time, migrate to the ocean. After living at sea between one and four years, they return to their natal streams to spawn and die. The young salmon are quite small when they leave freshwater, weighing from less than one gram to about 20 grams, and they are quite big when they return, ranging from two to 10 kilograms or more. Consequently, even though most juveniles die at sea, the return migration and death of adult salmon produce a large net flow of nutrients and energy from the ocean to stream and lake ecosystems.

This influx of energy from the ocean can have an extraordinary effect on freshwater systems because the nutrient composition of the fish and their densities are so great. For example, an adult male chum salmon on the spawning grounds contains an average of 130 grams of nitrogen, 20 grams of phosphorus and more than 20,000 kilojoules of energy in the form of protein and fat. Multiplying the average nutrient composition of salmon by the total number of returning fish, we

NUTRIENTS IN SALMON

Based on adult male chum salmon



BEAR PREDATION

Creek	Average no. of salmon	Average no. killed by bears	Average percent killed
Bear	3,907	1,183	32
Big Whitefish	786	342	48
Eagle	818	399	53
Fenno	5,228	666	12
Hansen	6,229	2,450	49
Hidden Lake	2,010	671	43
Little Whitefish	173	93	58
Pick	5,837	1,949	35

SALMON contain such valuable nutrients (*above*) and their population densities (*below*) are so great that the fish have a huge impact on freshwater systems. The authors calculated that as a result of the foraging bears along several streams in Alaska the total amount of nitrogen and phosphorus provided by salmon carcasses equals or exceeds recommended concentrations of commercial fertilizer for plants in northern forests.

LUCY READING-IKKANDA

found that a 250-meter reach of stream in southeastern Alaska received more than 80 kilograms of nitrogen and 11 kilograms of phosphorus in the form of chum salmon tissue in just over a month.

The behavior of the bears that feast on the salmon—brown bears (*Ursus arctos,* also known as grizzlies at inland locations) and black bears (*U. americanus*)—is the other part of the equation. Salmon are a crucial resource for the bears because the survival and reproductive success of these large mammals depend on the amount of fat they can deposit in the late summer and fall. Once bears enter their dens in the early winter, they neither eat nor drink for up to seven months. Yet bears are not true hibernators—their body temperature stays above ambient levels—so they must produce body heat to maintain metabolic functions throughout the cold months. In addition, females give birth and lactate during this time.

Because the bears' survival and reproductive success are closely tied to their physical condition in the autumn, natural selection favors those that get the most nourishment out of the fish they eat. And bears exhibit two behaviors to this end.

Overview/*Sea to Shore*

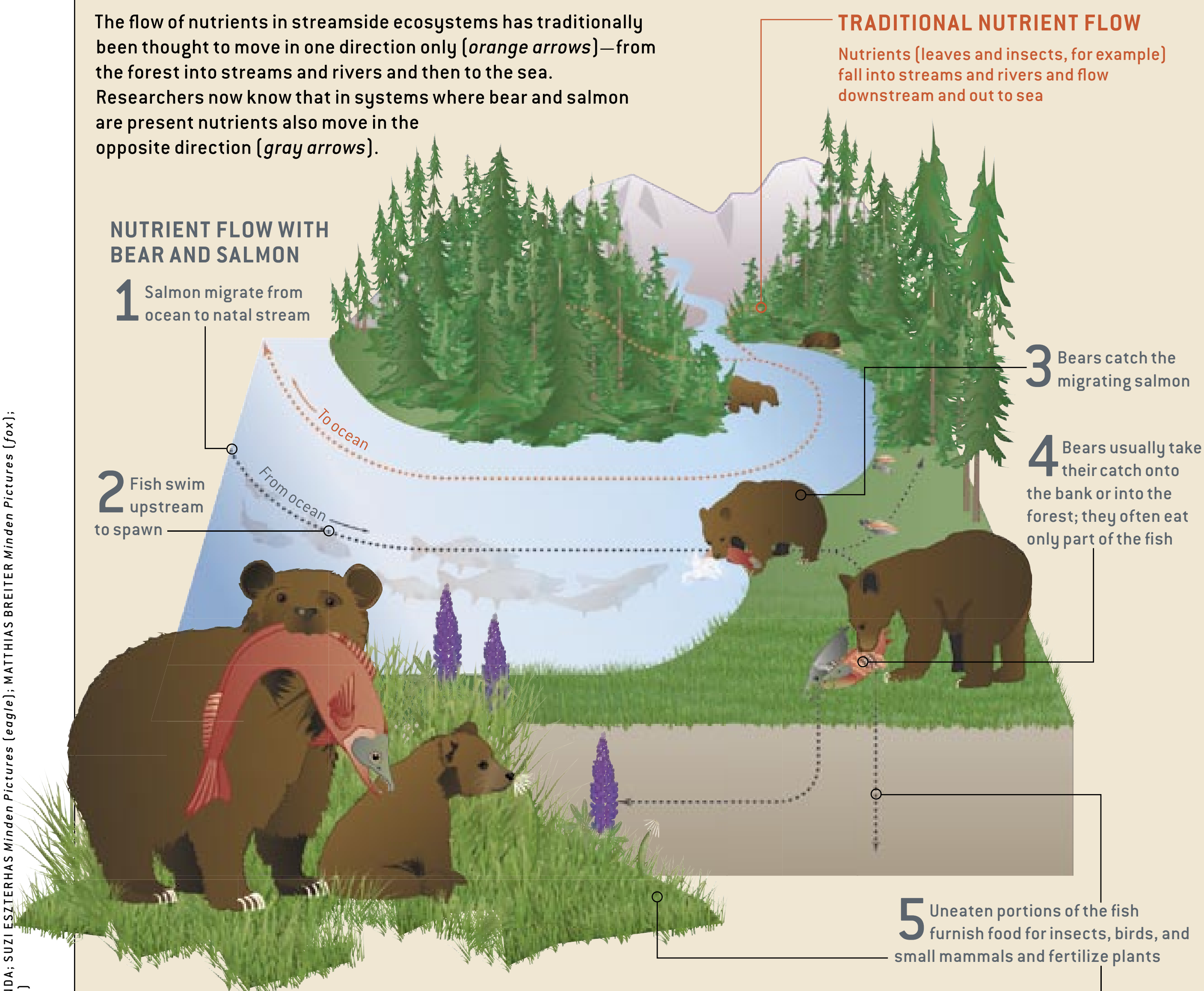
- To avoid confrontations, bears often carry their salmon catch onto the streamside bank or into the forest.
- Once safely alone, they usually eat only the most nutritious part of the fish and discard the rest, which still contains many valuable minerals and calories.
- These rich remains support a hierarchy of animals and plants.
- The dependence of the ecosystem on the salmon carcasses has captured the attention of fishery and forest managers, who now recognize the importance of both bears and salmon to the system.

First, to avoid interference from other bears, they often carry captured salmon to the stream bank or into the riparian (streamside) forest before eating. Bears are relatively solitary for most of their adult lives, save for a few weeks of courtship in spring and summer. When they aggregate in riparian areas to feed on salmon, they become aggressive. These confrontations can be relatively benign, resulting in one bear stealing a fish from another, or violent, ending in serious injury or death to a bear or its offspring. Carrying the carcass into the forest out of sight of other bears is a way to forestall confrontation.

The second important behavior is that the bears often eat only the most nourishing part of the salmon. If the salmon densities are high, it takes a bear less than a minute to capture a fish in a small stream, and under these conditions of plenty,

ENERGY FROM THE SEA

The flow of nutrients in streamside ecosystems has traditionally been thought to move in one direction only (*orange arrows*)—from the forest into streams and rivers and then to the sea. Researchers now know that in systems where bear and salmon are present nutrients also move in the opposite direction (*gray arrows*).



CREATURES that scavenge the discarded salmon include (*left to right*) bald eagles, red foxes and carrion beetles.

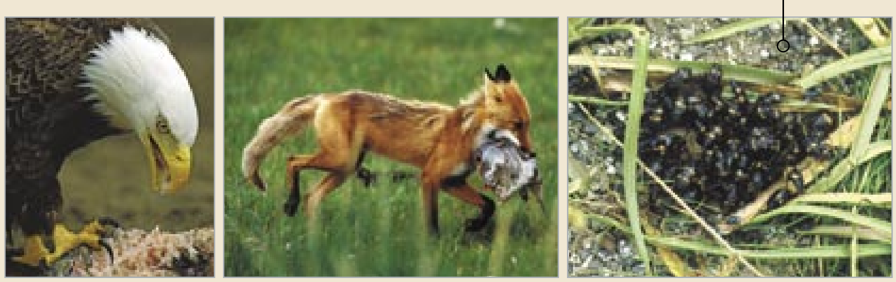


ILLUSTRATION BY LUCY READING-IKKANDA; SUZI ESZTERHAS *Minden Pictures* (*eagle*); MATTHIAS BREITER *Minden Pictures* (*fox*); COURTESY OF SCOTT M. GENDE (*beetles*)

THE AUTHORS

SCOTT M. GENDE and *THOMAS P. QUINN* have long shared an interest in the interactions between bears and salmon. Gende is a coastal ecologist with the National Park Service in Juneau, Alaska. He has focused much of his research on the ecological consequences of salmon in aquatic and terrestrial ecosystems. Quinn has been a professor in the School of Aquatic and Fishery Sciences at the University of Washington since 1990. He is author of *Evolution and Behavior of Pacific Salmon and Trout* (University of Washington Press, 2005).

the bears rarely eat the whole fish. An analysis of more than 20,000 carcasses revealed that bears consumed about 25 percent of each captured salmon, selectively eating only the parts highest in fat content, such as the eggs. In fact, it is common for bears to carry a carcass to the stream bank and not eat a bite after finding it is a male salmon or a female that has already spawned her eggs. (Salmon do not feed once they enter freshwater, so their body fat, which is quite high initially, is progressively depleted—by 90 percent or more—as they migrate and spawn.)

After consuming choice morsels, bears abandon the carcass and return to the stream to spear another fish. Thus, bears kill far more salmon than they eat. At a small stream in southeastern Alaska, for instance, we observed a 200-kilogram female brown bear capture more than 40 chum salmon during several foraging bouts over the course of eight hours. She removed over 143 kilograms of salmon (70 percent of her body weight!) from the stream but consumed only a small fraction of this bounty.

Special Delivery

WHY IS THIS UNUSUAL feeding behavior important for the vitality of the ecosystem? After all, in the absence of bears, the salmon would still die following spawning, and their carcasses would be scavenged by birds, fishes and insects in the streams, decomposed by microbes and flushed out to the ocean. By killing many of the fatter salmon, carrying the nutrient-loaded fish to the forest, and abandoning the carcass with most of the biomass remaining, bears make a tremendous amount of food and nutrients available to streamside plants and animals that would not otherwise have access to this resource. The bears are truly ecosystem engineers: they deliver marine-derived nutrients to the riparian system.

The spread occurs because many different animals make use of the protein and fat in the abandoned fish. Flies, beetles, slugs and other invertebrates colonize the carcasses almost immediately and deposit their eggs there. Gulls, ravens, crows, jays, magpies, mink, marten, and other species of birds and mammals readily and often quickly make a meal of the carcasses. (We once observed a bear capture a fish and walk into

Why Some Bears Prefer Berries

Perched on a small wooden platform nearly 30 meters high in a streamside tree, the two of us have spent more than 1,000 hours watching bears spear salmon. We soon noticed that a loose social structure among bears forms at even the smallest streams. In general, larger bears win confrontations or are avoided by smaller bears, regardless of whether the contestants are male or female. Subadults and small females, particularly those accompanied by young cubs, tend to be the most subordinate.

Dominant bears forage more often and for longer periods than other bears; they capture more salmon in each foraging bout; and they carry the carcasses shorter distances from the stream. They also consume less from each captured fish. Subordinate bears kill fewer fish per foraging bout, carry the carcasses much farther from the stream, and eat more tissue from each captured fish.

One ramification of this behavior is that small streams may have an upper limit to the number of bears that will feed there. As the bears become more numerous and aggressive interactions increase, subordinate bears may actually have greater success feeding on lower energy foods, such as berries or grasses, than on salmon. Such pressures may explain why we often see bears in upland or alpine areas far from salmon streams, even when salmon are spawning. *—S.M.G. and T.P.Q.*

CONFRONTATIONS can drive subordinate bears away from salmon-laden streams to feed in more peaceful upland meadows.

STEVEN KAZLOWSKI *Peter Arnold, Inc.*

a high grassy meadow, where it began to feast on its catch. When it was distracted by another bear, a mink darted out of the high grass, grabbed part of the carcass and scampered back into the forest.) In Washington State, researchers have compiled a list of more than 50 species of terrestrial vertebrates nourished by salmon carcasses.

A creature does not have to consume the salmon directly to benefit from the ocean's largesse. The insects that colonize carcasses are devoured in turn by wasps, birds and other insectivores, including small mammals such as voles and mice, that eat not only the insects but the carcasses themselves. We have found that densities of insectivorous songbirds can be higher along salmon streams than along waterways that do not support spawning salmon, suggesting that the bird communities respond to the abundance of insects produced by the harvest of salmon carcasses.

In the longer term, the foraging of all these animals, together with leaching by rain and microbial activity, breaks down the carcasses, making the nitrogen, phosphorus and other nutrients available to riparian plants. Plant growth in northern forests is often limited by either nitrogen or phosphorus, and thus the bears' foraging activities may influence growth rates of many plant species in these areas. Along several streams in Alaska, we have calculated that the total amount of nitrogen and phosphorus provided by the carcasses equals or exceeds recommended concentrations of commercial fertilizer for similar plants in northern forests. In some cases, up to 70 percent of the nitrogen in the foliage of streamside shrubs and trees is of salmon origin. Not surprisingly, one study found that growth of Sitka spruce, the dominant streamside tree in the area, was three times greater along salmon streams than along nonsalmon streams. In several studies, researchers correlated the amount of salmon-derived nitrogen or carbon directly with the movements of bears, providing further evidence that their foraging behavior is the mechanism that delivers the salmon nutrients to riparian plants.

Managing the Nutrient Express

AS A RESULT of this new understanding, scientists are redefining how these ecosystems function and thus how they could be managed. Traditionally, it was thought that nutrient flow in such systems moved in one direction only, driven by gravity: nutrients, in the form of leaves, invertebrates and other material, fell from the forest into rivers and creeks, flowed downstream and moved out to the ocean. We know now that they also move in the opposite direction: nutrients, in the form of migrating salmon, travel from the ocean to freshwater and then, carried by foraging bears, to land. Any management action that reduces the number of salmon or bears will affect the nutrient flow and the many creatures that depend on it.

Commercial fishing rates, for example, are generally based on the maximum number of salmon that can be captured without threatening the viability of the population; the "excess" individuals are captured in the fishery. Salmon managers have begun to reconsider these rates to incorporate the needs of other species in the ecosystem. In areas where salmon runs are seriously reduced or wiped out, state agencies are now transporting salmon carcasses—dropping them from helicopters or dispersing them from trucks—to riparian systems as a restoration effort intended to mimic natural processes until salmon runs return to their historical levels. The new knowledge has even sparked entrepreneurial enterprises: one company in Alaska, recognizing the fertilization qualities of the marine-derived nitrogen and phosphorus, is exporting compost soil made of wood chips and salmon carcasses.

MATT WALLIS *Skagit Valley Herald*

SALMON CARCASSES are being dispersed by helicopter into areas where populations of bears and salmon have been severely reduced or eliminated, such as this drop over the Baker River in Washington State.

We have come a long way since the 1940s in teasing out the ecological ramifications of the fishing bears, and undoubtedly we will learn much more as research continues. What is clear now, however, is that bears and salmon are key components in these ecosystems and that both have been severely depleted or exterminated in many of their historical areas. It remains to be seen whether the greatest challenge lies in understanding the full extent of this relationship or in restoring it where it once flourished. SA

MORE TO EXPLORE

Balancing Natural and Sexual Selection in Sockeye Salmon: Interactions between Body Size, Reproductive Opportunity and Vulnerability to Predation by Bears. T. P. Quinn, A. P. Hendry and G. B. Buck in *Evolutionary Ecology Research,* Vol. 3, pages 917–937; 2001.

Pacific Salmon in Aquatic and Terrestrial Ecosystems. S. M. Gende, R. T. Edwards, M. F. Willson and M. S. Wipfli in *BioScience,* Vol. 52, No. 10, pages 917–928; October 2002.

Nutrients in Salmonid Ecosystems: Sustaining Production and Biodiversity. Edited by John G. Stockner. American Fisheries Society, 2003.

Magnitude and Fate of Salmon-Derived Nutrients and Energy in a Coastal Stream Ecosystem. S. M. Gende, T. P. Quinn, M. F. Willson, R. Heintz and T. M. Scott in *Journal of Freshwater Ecology,* Vol. 19, No. 1, pages 149–160; March 2004.