Through discussion and analysis of more than four dozen original maps, the *Atlas of Pacific Salmon* offers the first panoramic perspective on the status of Pacific salmon throughout their entire distributional range. The author and cartographer present new data that demonstrate an international pattern of systemic decline in risk of extinction in salmon populations, which requires immediate attention. So informed, we have a richer understanding of the ecological, economic, and cultural importance of salmon in the waterways and landscapes and among the people of the North Pacific.

"This atlas is no less than a guide to salmon conservation from California to Japan. The maps are works of art and their message is urgent: salmon populations need help everywhere."

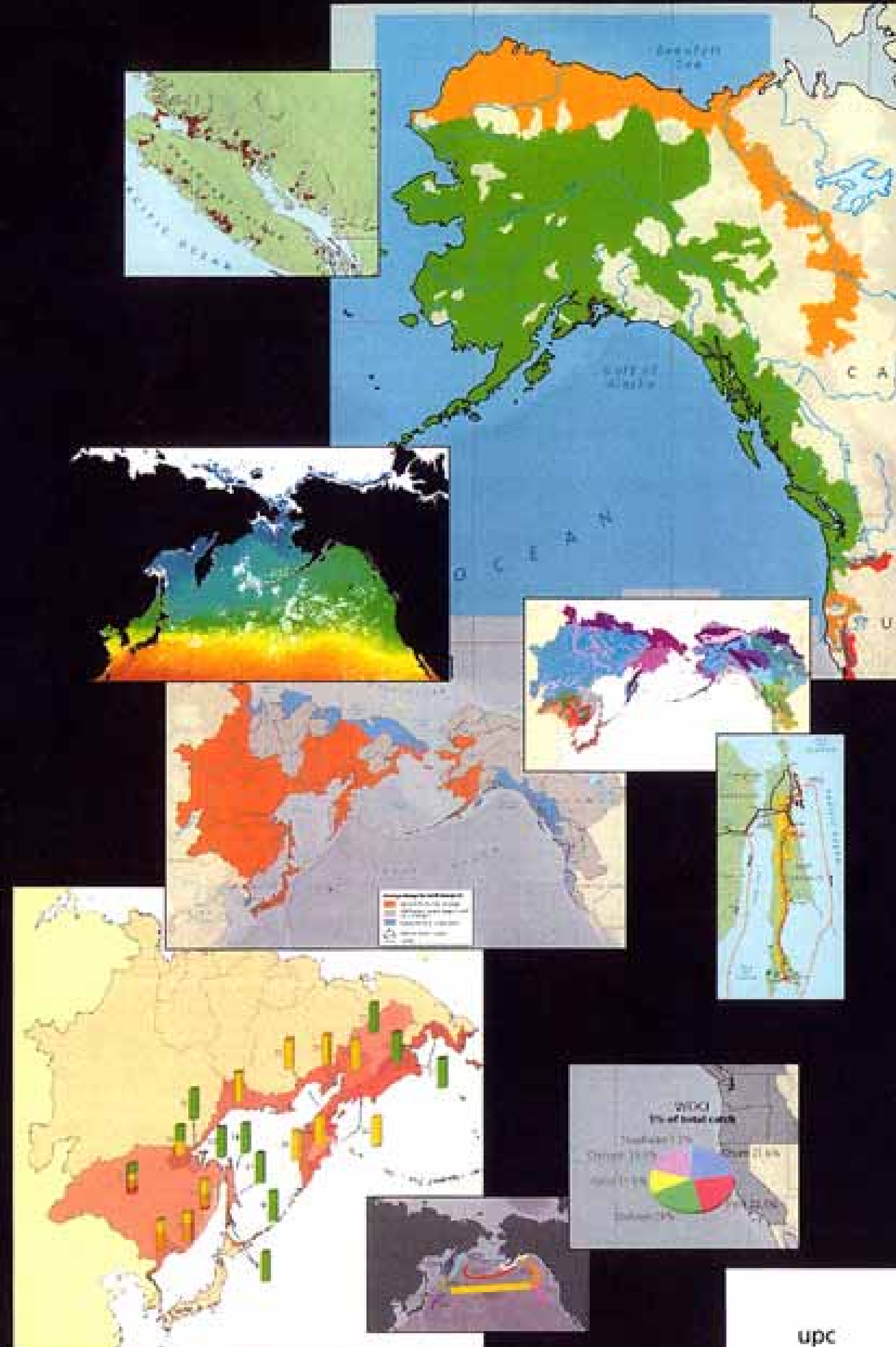
—Peter B. Moyle
author of *Inland Fishes of California*

"Finally, a book that recognizes the true size and scope of the Pacific salmon ecosystem and the biological, cultural, and economic importance of salmon in that vast area. Such a bold and holistic approach has been needed for a long time."

—Jim Lichatowich
author of *Salmon Without Rivers*

"Salmon are the world's most complex fishes and no other swimming creatures have so affected peoples' view of themselves and their place in the world. This excellent Atlas is the most illuminating overview ever conceived about these miraculous creatures and their human and biological context."

—Carl Safina
author of *Song for the Blue Ocean* and *Eye of the Albatross*



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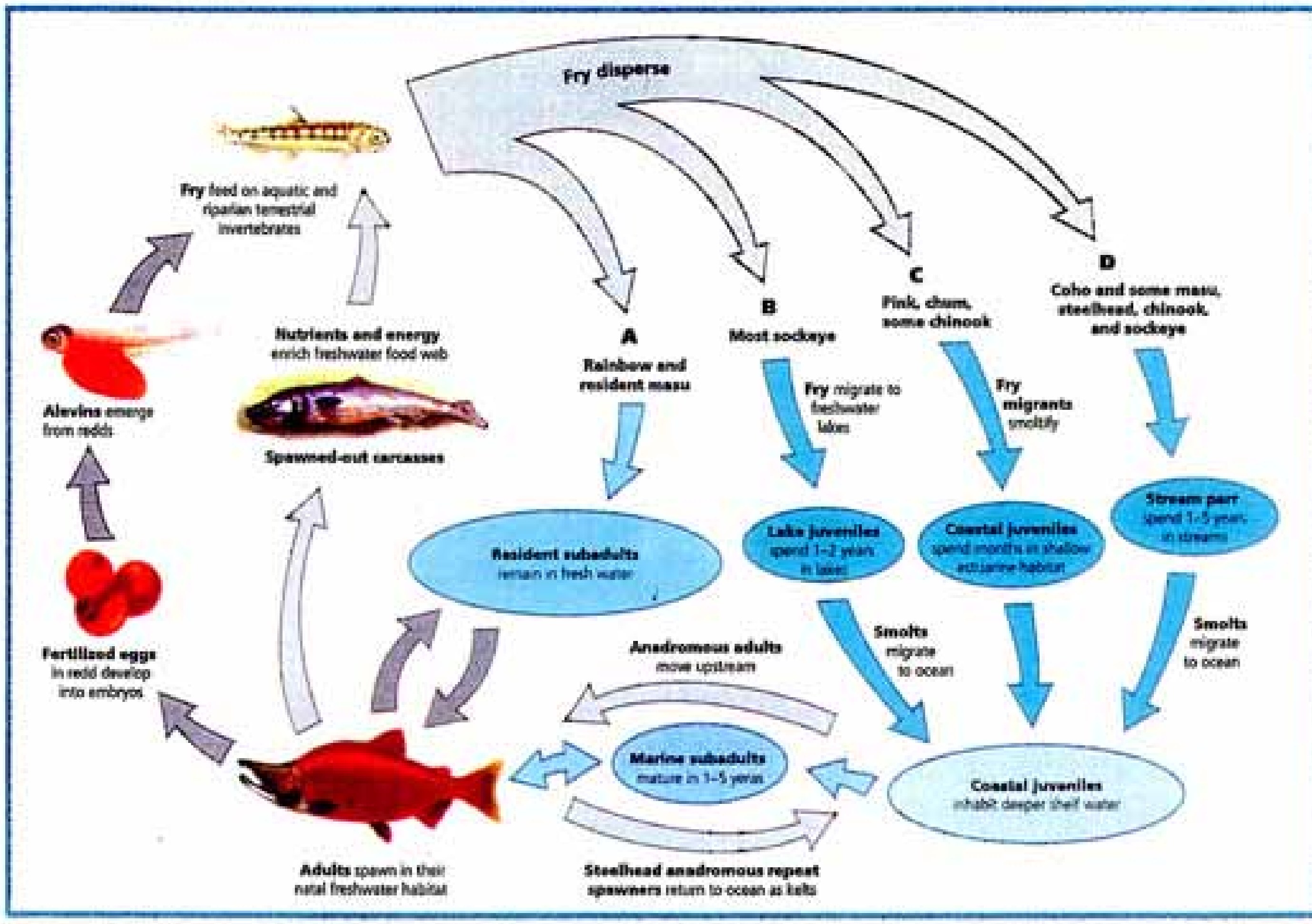
cease feeding and direct all their energy toward migration, courtship, and spawning. The male salmon arrives first to stake out territory, often defending it from rivals; the female arrives soon after to begin the process of digging her redd, which can take up to a week. During this time, the female will lie on her side and flap her caudal fin to excavate a depression in the gravel, from several centimeters to several meters across. Then the female steadies herself in the current, using her open mouth as a rudder to still her body while she lays her eggs. One or many male salmon simultaneously deposit milt on the redd. In her final act of athleticism, once the eggs have been fertilized, the female covers the nest undulating her body and fanning her fin to move the gravel gently onto the top of the redd.

When spawning is complete, the salmon (except for *mykiss* and some *masou*) die, depositing in their home streams an abundance of marine-derived nutrients such as nitrogen, phosphorus, carbon, trace minerals, and vital organic matter. Those carcasses will directly feed many river basin residents, including insects and bacteria, minks and otters, and jays and eagles.

For salmon populations to prosper, the whole sequence of habitats must be intact and functioning. But if several important habitats are threatened, populations may be at risk.



SALMON LIFE CYCLE From snow melt to the high seas, water (salt and fresh) conveys salmon throughout the ecosystem. The odds for salmon survival are slim even if all aspects of the habitat are healthy. Only several of the thousands of eggs fertilized in a redd will grow into adults that return to spawn successfully. The cycle—hatch, migrate, spawn, die—repeats with every generation and has done so for millions of years.

THE ROLE OF BIOLOGICAL DIVERSITY

At the macro level, there is impressive consistency in the 18 million-year history of *Oncorhynchus*, which has maintained an enduring presence in freshwater and estuaries throughout the North Pacific. But at the micro level, salmon life histories are variegated and diverse as they adapt to local conditions. Natural selection rewards resilience: as populations evolve with changing conditions, the suitability of habitat changes across the North Pacific; run timing shifts; spawning locations move; and migration distances and duration adjust so that adversity within one population will not affect the viability of the species. Those qualities that prove hardiest are written into the genetic road map that will be used and amended by generations to come.

Salmon have recolonized streams following ice ages, volcanic eruptions, climatic shifts, and unimaginable ecological challenges. Those selfsame life history strategies, which spread risk over individuals and populations, give fishery managers and biologists cause for optimism; the extraordinary resilience of this genus may be its most effective tool on the road to recovery.

Salmon Ecoregions

In order to present distribution and risk of extinction data at a uniform scale across the North Pacific, we needed to build a geographic framework with a consistent spatial resolution for integrating widely divergent sources of information. Recognizing that water is what matters most to a migratory fish, we crafted a lens through which to view habitats occupied by salmon based primarily on natural hydrological boundaries. We parsed the North Pacific Rim into regions defined not by political boundaries but as parts of a full sequence of catchments and nearshore and ocean ecosystems that salmon use, each with distinct physical characteristics. From this we created our ecoregion template, which, in simple terms, maps at a coarse grain the neighborhoods that salmon populations call home—a set of 66 distinct ecosystems inhabited by salmon around the North Pacific.

The final criteria and boundaries for the ecoregions were developed in 1999 during a workshop in Corvallis, Oregon, attended by Japanese, Russian, Canadian, and U.S. scientists (see Acknowledgments, page 142). Workshop participants endorsed a four-level hierarchical classification that defined salmon ecoregions.

Once the ecoregions were determined, we used the Environmental Systems Research Institute's (ESRI) Digital Chart of the World to provide a digital geographic representation of the North Pacific in order to identify the stream networks and spatial boundaries of each ecoregion and to establish a geographically explicit system for data management. To define ecoregion boundaries, we digitally drew polygons around the stream networks associated with each of the four levels of the hierarchy.

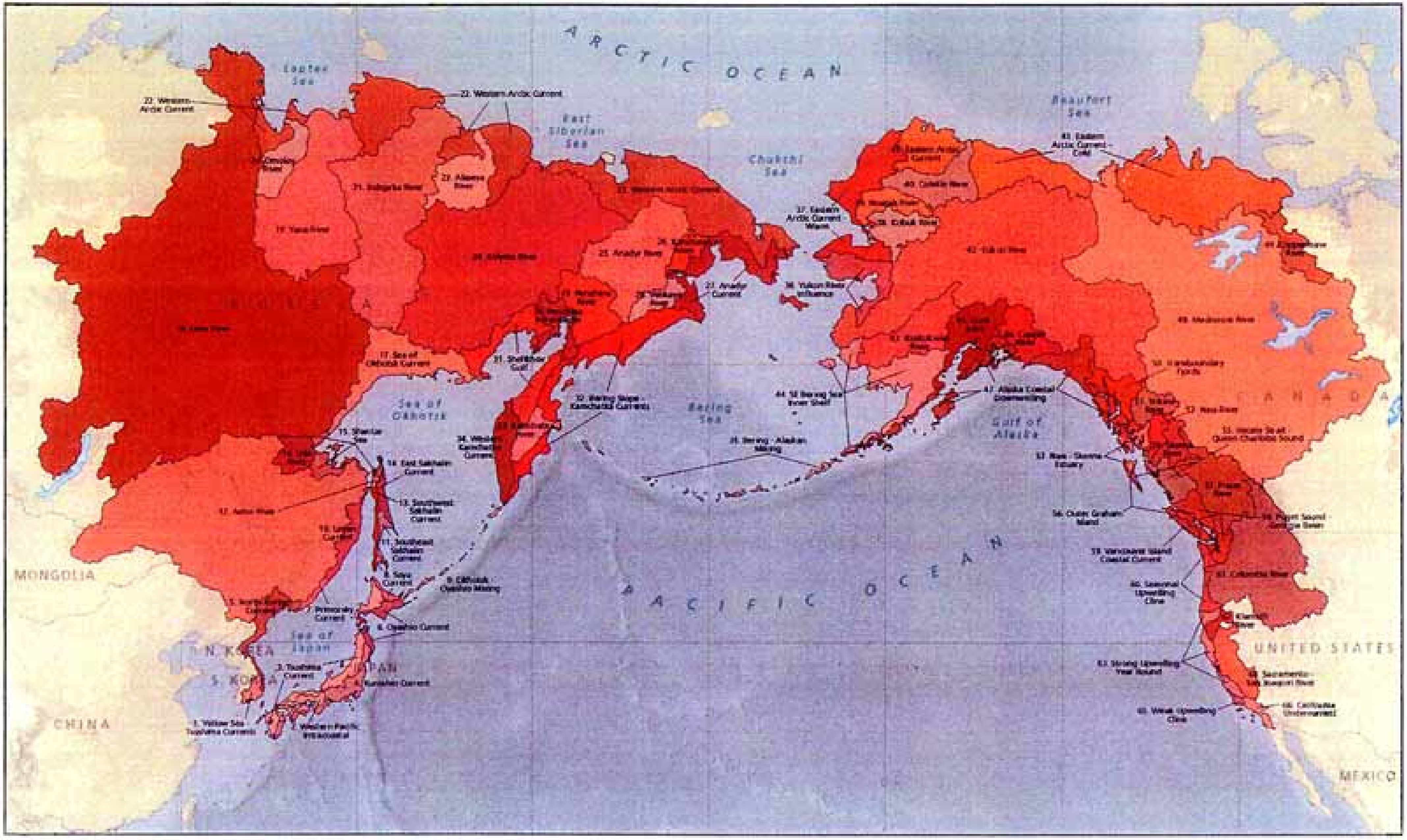
In chapter 4 we present our distribution and risk of extinction data, digitized and mapped at this uniform ecoregional scale. In sum, we can report two overall spatial trends that emerged from our findings: the center of the range of Pacific salmon (with the exception of masu) is generally placed around the Gulf of Alaska, and the risk of extinction for all species increases at the southern edges of the range.

This framework does have its limitations. Data reported on an ecoregional basis run the risk of overrepresenting the geographical extent of salmon habitat. For example, data from a small portion of an ecoregion—such as salmon presence in the Amur River ecoregion (12), which is only along the river and its tributaries—are applied to the entire ecoregion. Nonetheless we found the ecoregional framework useful for data aggregation and interpretation at a North Pacific scale.

Level 1 Ecoregions
Two ecoregions: the Arctic and the Pacific oceans, and associated freshwater drainages.

Level 2 Ecoregions
Eighteen ecoregions, including semi-enclosed seas and primary ocean circulation systems with distinct processes or bathymetric characteristics in the North Pacific and associated freshwater drainages. There are two Arctic Ocean and 16 Pacific Ocean regions defined at this level.

Level 3 Ecoregions
Thirty-nine ecoregions, including finer-scale coastal discontinuities within each semi-enclosed sea or major circulation system, including fjords, straits, and areas with distinct production processes (e.g., upwelling and downwelling areas). There are three Arctic Ocean and 36 Pacific Ocean regions defined at this level.



LEVEL 4 ECOREGIONS We have identified 66 distinct ecoregions for the watershed coastal ecosystems used by salmon around the North Pacific. Through this common geographic framework, we are able to depict data at one consistent scale throughout the North Pacific. Although salmon are not ubiquitous within these ecoregions, they rely on the full expanse of habitats from headwaters to coastline and the entire ecosystem that supports them. The size of the ecoregion has no bearing on the extent of salmon presence: for example, the two largest ecoregions, Lena River (18) and Mackenzie River (48), support only limited salmonid distribution.

NOTE: The colors in this map were chosen for contrast to distinguish and separate ecoregions. They do not represent ranges of comparable data or severity of condition, as colors elsewhere in this book do.

Native Americans and Salmon Coevolution

THE PRECEEDING PAGES OFFERED A MACRO view of the relationship between tribal diversity and salmon diversity at a coarse North Pacific scale. Here, to demonstrate the extent to which salmon societies were linked to the salmon resource, we engage in discussion at the micro level, specifically as one group of Native Americans and one population of salmon connected to one particular terrestrial ecoregion straddling Oregon and California.

In the early 20TH century, ethnographers developed the theory of cultural core provinces, footprints of where indigenous people lived and shared material and cultural traits. The first map on the right delineates in lavender the northwestern California core cultural province, ranging from Cape Blanco in the north to Punta Gorda in the south. At the margins of the northern region is the territory of the Cow Creek band of the Umpqua tribe; to the south, the Yuki tribe. However different, these tribes share a core cultural province, having each borrowed aspects of the region's material cultures.

In the second map, we have delineated in red the Southern Oregon-Northern California (SONC) coho evolutionarily significant unit (ESU, see below). This unit—a measure of habitat essential to salmon sharing genetic traits and distinct from their neighbors—was identified by biologists with NOAA Fisheries (National Marine Fisheries Service) who were conducting viability assessments. In the process, these scientists distinguished clusters of localized salmon runs on the basis of genetics (reproductive isolation) and life histories (local adaptations). These yardsticks represent important components of the species' evolutionary legacy.

In the third map, we have outlined in green the approximate boundaries of the Klamath-Siskiyou terrestrial ecoregion, the biotic province that unites this area (see page 54).

When the three maps are overlaid, we see how the boundaries reinforce one another. For thousands of years, the Native Americans who lived in the Klamath-Siskiyou ecoregion and the coho salmon within this ESU developed concurrently. Settlements, economies, and cultures clustered around the fisheries along the coast, estuaries, and rivers.

Researchers have been unable to accurately and decisively define tribal cultural traits and boundaries, which have been blurred through forced removal and genocide. Similarly, natural salmon ESUs may have been blurred through urbanization, hatchery proliferation, and natural resource development, and other threats presented to salmon throughout their range.

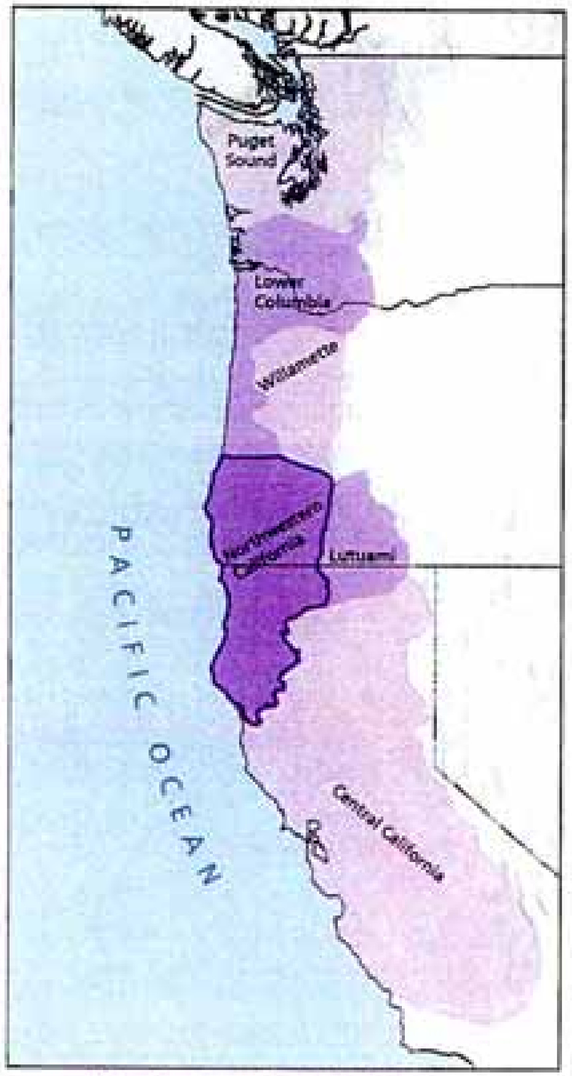
EVOLUTIONARILY SIGNIFICANT UNITS

Biodiversity manifests as variety within species. In the United States, the 1973 Endangered Species Act became the first law to protect species biodiversity, mandating the conservation of species and "distinct population segments" deemed to be at risk of extinction. But scientists soon begged the question, what is a species, and how can we identify distinct population segments that may be at risk?

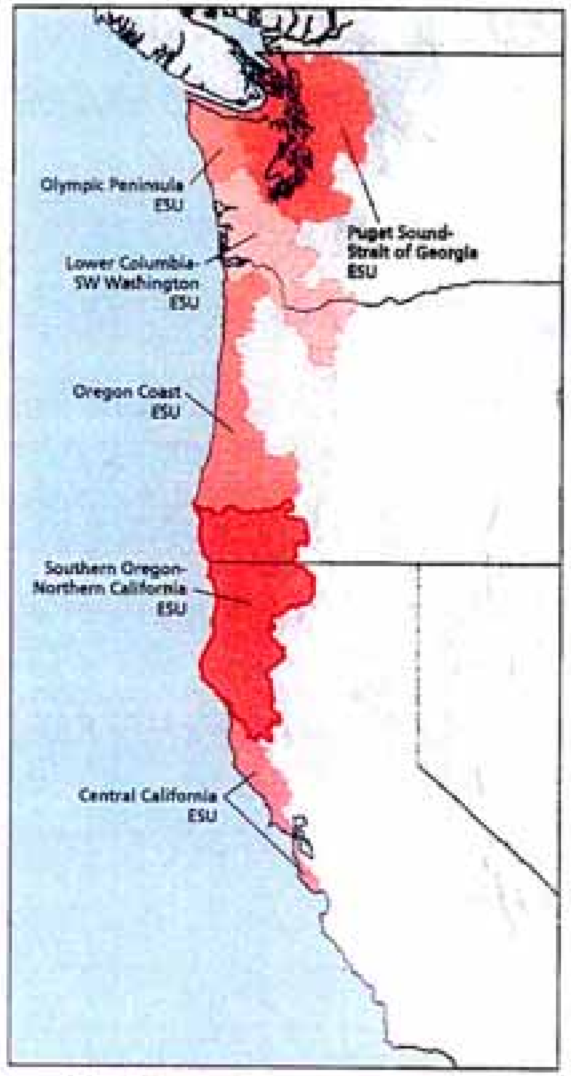
The question was answered only as recently as 1991, when Dr. Robin Waples of the U.S. NOAA Fisheries (National Marine Fisheries Service) Northwest Fisheries Branch in Seattle, Washington, offered a pair of guidelines that, if met, would constitute conservation units meriting protection under the law. If a population was "substantially and reproductively isolated from other conspecific populations" and represented "an important component in the evolutionary legacy of the species," then it would qualify as an "evolutionarily significant unit" (ESU). The two-part test takes into account genetic, ecological, and life-history variability exhibited by individual populations, each with its own unique contribution to the diversity of the species.

Today, although there are seven *Oncorhynchus* species (including cutthroat trout (*O. clarki*)) in Washington, Oregon, California, and Idaho (WOCI), there are more than 50 salmonid ESUs, each with life history strategies and risk factors endemic to their native streams. This relatively fine filter allows managers and conservation strategists to tailor efforts to the needs of locally adapted salmon populations. For example, coho populations in Central California face different challenges from those in Southern Oregon-Northern California and from those in the Lower Columbia River and southern Washington.

Although they may look identical at this stage, eggs and alevin from one population will later exhibit life history strategies markedly different from other populations within the same species. These differences ultimately determine the overall viability of the species.

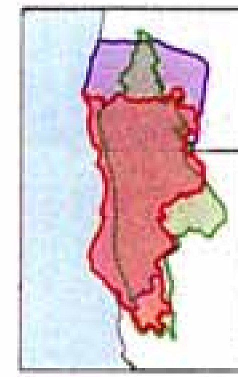


Native American Core Cultural Provinces

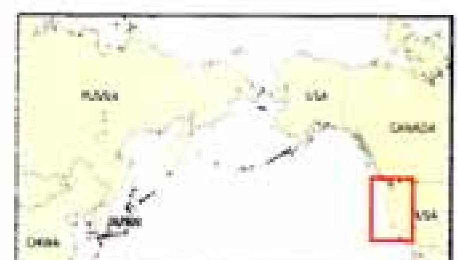


Coho Salmon Evolutionarily Significant Units

Terrestrial Ecoregions (see page 54)



NATIVE AMERICANS AND SALMON COEVOLUTION In this trio of maps, we examine one region through three lenses: people (the Northwestern California core cultural province, including the Karuk and Yurok tribes); fish (the Southern Oregon-Northern California coho evolutionarily significant unit, including discrete salmon populations within it); and place (the Klamath-Siskiyou terrestrial ecoregion). By overlaying these data layers, we can envision how Native Americans, salmon, and landscape influence and reinforce one another, as humans and fish adapt to the unique setting of their catchment. The Klamath Range to the north, the Sierra Nevada to the east, and the Sacramento-San Joaquin estuary to the south served to isolate biological units of both people and fish, which adapted uniquely to the basin. The Eel, Klamath, and Rogue rivers formed the heart of this catchment and bonded living creatures within it.



Logging in Frontier Forests

EIGHT THOUSAND YEARS AGO FORESTS covered half the world's landmass. Today only 20 percent remain standing in their original condition, according to the World Resources Institute (WRI). The WRI calls these regions "frontier" forests, which may be defined as "large, ecologically intact, and relatively undisturbed" self-sustaining ecosystems.

The rest has been logged, often repeatedly, and the pace of deforestation increased exponentially with the advent of industrial-scale logging in the 19TH century. Two major long-term studies, in Carnation Creek in British Columbia and the Alsea watershed in Oregon, explore the complexities of logging in forested salmon streams. Within a coastal stream habitat, salmon depend on an assortment of, and interactions among, natural factors: clean gravel, a variety of pools, side channels, and alcoves, and natural riparian vegetation that regulate the movement of sediments, provide organic matter and insects, and moderate water temperatures through shade. Without these natural buffers, habitat values diminish, resulting in, for example, erosion, siltation, desiccation, debris, disease, and pest infestation. Logging roads bisecting habitat also contribute to the degradation of freshwater resources, increasing siltation and runoff.

Second-growth forests, which suffer greatly for lack of regulatory protection, can offer some of the benefits of old-growth forests. But clearcuts can devastate salmon habitat, as they have in northern California's Eel River and its tributaries, which caused severe erosion, heavy siltation, and landslides in following heavy storms.

Pockets of remaining frontier forests dot the landscape throughout the Pacific Rim, but these fragmented parcels may not function adequately ecologically. On the western side of the Pacific Rim, frontier forest logging occurs primarily in the extensive larch and spruce-fir forests of the southern Far East, which remain largely unprotected. A 2002 United Nations Environment Programme study of closed canopy forests (virgin, old-growth, naturally regenerated woodlands) found that Russia's protections were the weakest in the world.

In the United States and Canada, virtually all frontier forests remaining in salmon spawning grounds are moderately or highly threatened. Alaska's virgin forests are targeted by logging interests, from the Chugach to the Tongass, as are vast swaths of frontier forest in Canada's Northern Interior and Coast forest regions. In WOCI, stretches of pristine forests are threatened at the headwaters of chinook, coho, sockeye, and steelhead distribution.

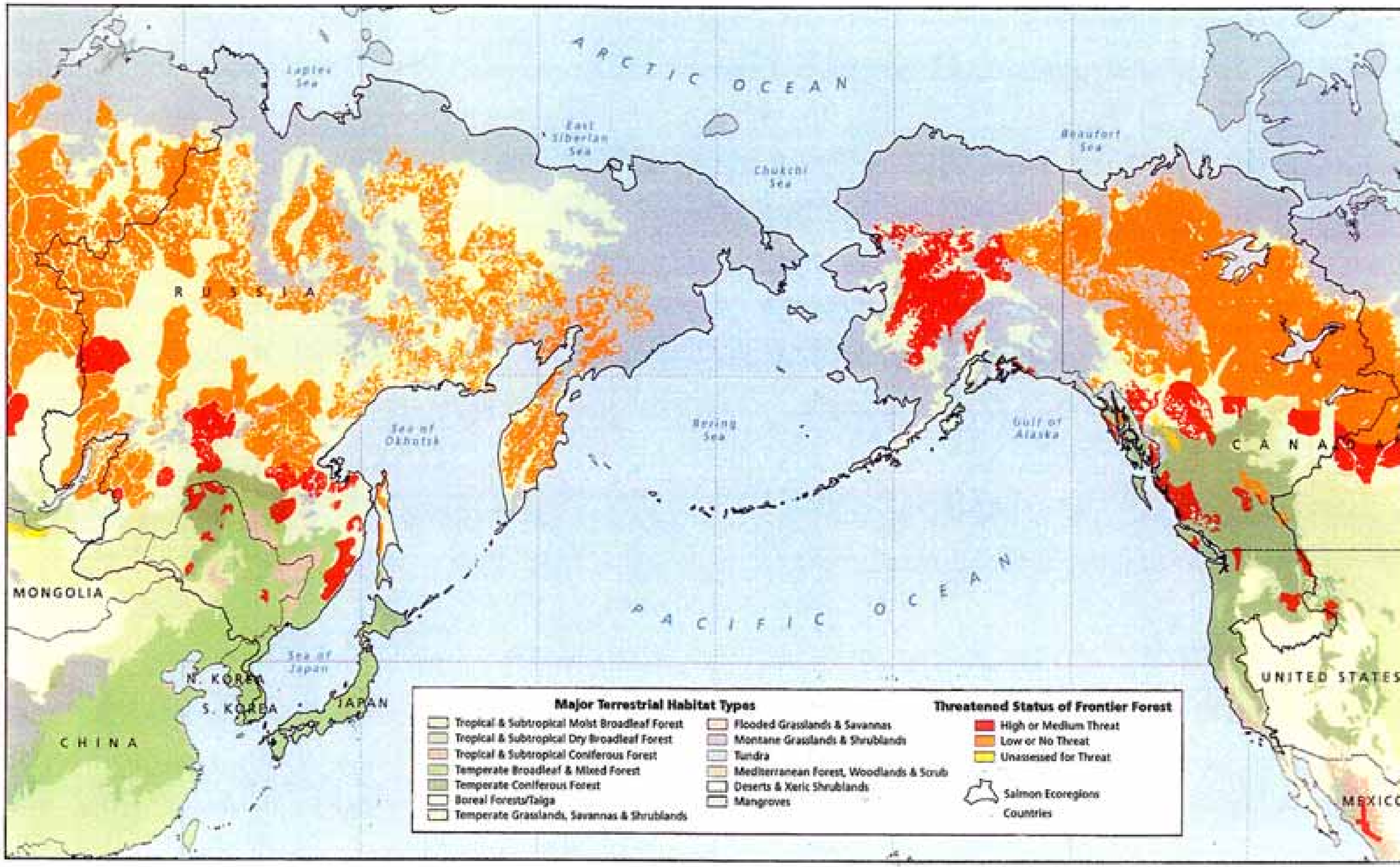
THE EFFECTS OF CLIMATE CHANGE ON INLAND FOREST HABITAT

Global climate change represents an imminent and as-yet-immeasurable threat to forests and stream habitat. A working group of the Intergovernmental Panel on Climate Change predicted that with a doubling of CO_2, Asia boreal forests would be reduced by 50 percent, largely in the Russian Far East; in North America forest cover would shift, increasing in some areas and decreasing in others, altering habitat and modifying biodiversity altogether.

In temperate and alpine zones rising temperatures would hasten glacial melt, thereby changing the hydrological pattern, increasing water flow downriver, and affecting the productivity of salmon redds and juvenile development. Early thaw on temperate lakes would prompt changes in salmon run seasonality, which can disrupt development; higher lake temperatures would affect levels of dissolved oxygen and may boost productivity of invasive and exotic species. Nutrient productivity within streams would be modified; disease and bacteria may proliferate.

Abbreviated winters in boreal forests can alter groundwater discharge, which can compromise water quality and temperature. Rates of evapotranspiration would increase, further reducing water levels and exposing salmon to predators. Increased precipitation would further modify stream flow regimes, rendering some uninhabitable for salmon, which prefer colder temperatures. (Chinook and steelhead have a higher threshold, around 24°C; chum have the lowest, at around 19.8°C.) Rising air temperatures would modify general circulation patterns in and around streams, prompting changes in water flow and water column. In altered landscapes, species may vie for more suitable habitats.

Draining into Russia's Sea of Okhotsk, the Inya River watershed is fed by a series of glacial lakes, including the 15-meter deep Etergen Lake. In temperate forests, climate change can result in increased evapotranspiration and precipitation, affecting salmon productivity.



LOGGING IN FRONTIER FORESTS Frontier forests (above, in yellow and red) are virgin parcels large enough to be ecologically self-sustaining. Scant few remain in the southerm half of the North Pacific; those that do are fragmented, relatively small, and at heightened risk for logging. Salmon in these regions are exposed to increased risk of extinction, as threats of urbanization and edge-of-range effects render populations most vulnerable. Canada hosts a comparatively high number of forests at elevated risk, as does southern Russia. Western Alaska contains the largest swath of at-risk frontier forest, where many salmon rivers have their headwaters.