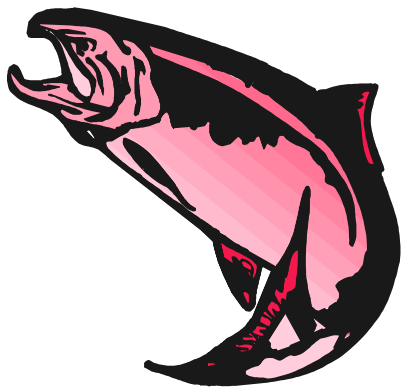
COLUMBIA RIVER SALMON CUMULATIVE IMPACTS EXAMPLE

Several emerging environmental problems around the world illustrate that impacts of development activities can accumulate and create new, unexpected problems. Global warming and worldwide loss of biodiversity through land-use change are large-scale indicators of decades of impacts of human development in many ecosystems. Cumulative impacts can also be found at smaller scales, down to the individual project level. To illustrate some of the challenges in defining, studying and managing any cumulative impacts problem, we will present one example in detail, showing how multiple impacts from several projects combine into a large and multi-jurisdictional cumulative assessment challenge.

We will focus on the Columbia River Basin in the northwestern United States. Many cumulative impact problems revolve around harnessing large rivers for power production, agriculture and industry. Because freshwater systems are linked through the hydrologic cycle, defining sources and consequences of impacts can be easier than in a less-structured system (like atmospheric impacts). However, resolving these impacts is also difficult because of the high value placed on rights to water, and the consequent jurisdictional complexity surrounding water resource management.

The Columbia River example is thought to be relevant to the riparian countries of the Mekong River Basin (MRB). The health of a very significant commercial and cultural fishery has been seriously impacted by the large number of dams constructed along the Columbia River and various tributaries. Salmon are a key component of the ecology and social structure of the Pacific Northwest but have been devastated by the cumulative effects of hydropower development over the last 100 years. Lessons learned in the Columbia River may offer insights to environmental managers in the MRB as they try to avoid similar undesirable impacts of development in the Mekong River.



PROBLEM CONTEXT

All resource-based activities of economic interest, whether primary (e.g., supply of clean water, fish, agricultural products, timber, petroleum), or secondary (e.g., power, transportation, industrial development) are conducted in ecological systems whose interactions are complex. This complexity means that impacts from development are often not linear; linkages between the consequences of a single activity and other related activities are not recognized, and individual effects accumulate in unpredictable ways.

Most ecological processes and their interactions are poorly known. Data are sparse, and critical parameters cannot be measured (e.g., ocean survival of fish). Theory is also limited. Reliable observations are few; the disturbances caused by humans are frequently both large and unprecedented in natural history, so it is unclear what theory to use in generating predictions.

Required time and space scales needed to predict trends are large. For determining effects on salmon, the minimum time scale is five years or more, and the spatial scale is international in scope. Unexpected events are therefore normal. Cumulative effects assessment (CEA) procedures must be designed to seek and respond to surprising or unanticipated events.

The large number of project proponents, regulatory agencies and private interest groups typically involved in a cumulative impacts problem mean that explicit attention needs to be paid to processes of information-sharing, decision-making, and consensus-building.

What is the Problem?

Returns of all species of salmon to the Columbia River have declined from 16 million to 2 million. Stocks began going extinct in the 1920s. Figure 1 shows the decline in the Chinook salmon fishery for a 100-year period. Declines in fish numbers are shown plotted against ‘cumulative’ hydroelectric dam development.

Is this a Cumulative Impact Assessment Problem?

Yes. Many factors have contributed to this loss.

Why is this an Important Problem?

On the Pacific coast of North America, salmon are an extremely important resource because:

- They are an important food source regionally, and worldwide
- Salmon migrate thousands of kilometres through rivers and oceans, making them a good indicator of the environmental conditions in those habitats
- Strong cultural bonds exist between people and salmon
- Salmon management is politically sensitive locally and internationally.

Why Study this Particular Problem?

A great deal is known about the life history of salmon in the Columbia River. Understanding how cumulative impacts affect salmon populations may help us to understand other, less well-known, systems.

THE COLUMBIA RIVER BASIN – A BRIEF HISTORY

The Columbia River is the 4th largest river in North America, and flows 1,900 km through two countries (i.e., Canada and the US). Additional tributaries add several thousand more kilometers to that total. Historically, it was the largest single source of salmon on the west coast of North America. Other resources within the watershed were exploited in the past, including wildlife, timber, gold and furs.

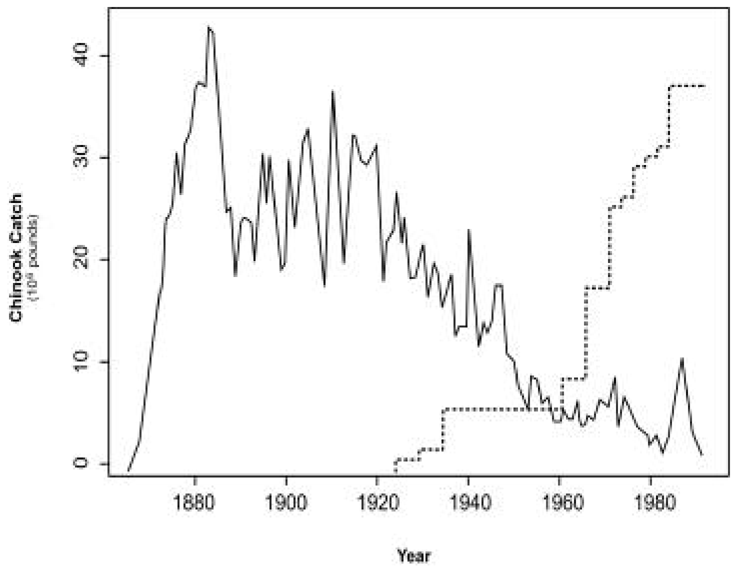


Figure 1 The relationship between declines in the Chinook salmon fishery and increasing hydropower development

As a result of intense industrial development in the last hundred years, the Columbia River now has a total of 19 major power dams, 9 smaller ones, plus more than 60 small-scale hydro projects, making it the world's largest hydroelectric project. The Columbia River Basin has been converted into a vast agricultural plantation of nearly 1.2 million ha through use of irrigation water drawn from the river. As a result of this development, the managed 'Columbia' ecosystem (i.e., estuary, hydroelectric impoundments, riparian lands, forests and irrigated lands) totals an area the size of France.

The Basin now supports a human population of 100 times its original level. The question is whether this development and its consequences can be ecologically (and economically) sustainable.

The governing principle behind developing, or 'taming', the Columbia River has been to maximize the economic rate of return from the resource. Development activities and circumstances contributing to environmental impacts on salmon stocks originating in the Columbia River are highlighted in the following sections.

Power Dams

Many dams were built before environmental impact assessment (EIA) procedures were required. Primary effects of dams on salmon include killing of smolts in turbines or entrapment on debris screens and killing returning adults (i.e., recent estimates suggest 5-11 million adult fish/year are killed). Some stocks must pass as many as eight dams to reach their spawning grounds. Secondary effects include flooding of spawning areas, and slowing salmon migration through altered hydrologic regimes (i.e., exposing young and adults to predators). Tertiary impacts occur through increases in industrial and agricultural development, as well as an increasing human population as a result of cheap power.

Urbanization/Industrialization

Primary impacts are degradation of downstream water quality through pollution (such as pulp mill effluent discharges) and reduced water flow through removal of irrigation water. Secondary impacts are altered temperature and sedimentation regimes due to loss of forest cover and loss of spawning habitat through gold mining.

Agriculture

Primary impacts are losses of migrating young and adults by their diversion into irrigation channels and unsuitable habitat. Secondary impacts are reduced water flows through drawdown at peak migration periods, siltation of spawning habitat and loss of forest cover.

Flood Control

Secondary impacts on salmon occur through elimination of spring and fall flows needed to flush salmon around obstacles, and through introduction of exotic species through cross-drainage flows.

Dredging

Dredging of navigation channels causes secondary impacts on salmon through loss of feeding and spawning beds in the highly productive estuaries of the Basin.

DEVELOPMENT OF THE COLUMBIA RIVER BASIN

1860-1900: Unregulated fishery by Europeans. By 1890 canneries were operating throughout the Columbia River Basin and coastal bay, leading to a million dollar industry.

1900-Now: Increasing regulation of the fishery to conserve stocks. New legislation continues to be enacted up to the present, and is international in scope (e.g., 1985 Canada-US salmon treaty).

1902**:** US Reclamation Act assigned agricultural water rights to individuals owning land in the Columbia River Basin.

1902 - 1950s: Large-scale conversion of ranch and forest land to cultivation using irrigation.

1935-1986: Construction of new hydroelectric dams (28 in all). Over 60 additional dams and structures built to control flooding and regulate flows.

1968-1982: Increase generating capacity by 50% by adding turbines to existing dams

1980**:** Pacific Northwest Electric Power and Conservation Act passed to mitigate harmful effects of the hydro development of the Columbia River, and to protect and enhance affected fish and wildlife populations.

1980-Now**:** Mitigation efforts to reduce losses of young and adult fish implemented at a cost of $US100 million annually

1992**:** Snake River chinook become the first salmon species listed under the Endangered Species Act.

Recreation

Primary impacts of recreation are loss of rearing habitat through construction of summer cottages, and fishing of endangered stocks.

Fisheries

Primary impacts of fish harvesting are loss of returning adults (i.e., especially on endangered stocks) through large and efficient commercial fleets. Ocean fishing is difficult to regulate.

CUMULATIVE IMPACTS FROM DEVELOPMENT

Taken together the development activities described above have seriously impacted Columbia River salmon populations. Each new development fosters additional developments, and each development creates more than one type of impact. Many of the impacts are difficult to measure. The major consequences of these impacts are that the upper reaches of the Basin are effectively blocked by dams, while the lower reaches are virtually ruined for spawning by siltation, reduced flows, or high temperatures (as depicted in Figure 2). Mortality to migrating fish is highly variable, depending on climate and cycles of abundance in salmon. Specific impacts and consequences for salmon stocks during the period that they live in freshwater and ocean environments are described in the following sections.

Cumulative Impacts in Freshwater

Impacts to upstream migration (i.e., returning adults – spawning stage) include:

- Capture fisheries in estuary endangers vulnerable stocks
- Pollution degrades viability of spawning/rearing habitat in lower river reaches
- Dredging and industrial facilities eliminate habitat
- Losses due to super-saturated gasses from dam spillways
- Losses due to impassable dams and structures (i.e., depending on water level)
- Losses due to reservoir fisheries in impoundments
- Increased exposure to predators.

Figure 2 Cumulative effects of development on salmon

Impacts to downstream migration (i.e., egg – smolt stage) include:

- Drawdowns of water for irrigation, and power demand expose spawning beds and fry are lost in irrigation channels
- Altered flow of water (e.g., reduced spring flow) causes longer residence time for fry, increasing exposure to predators
- Reduced turbidity increases visibility to predators
- Direct mortality in turbines (i.e., up to 30% of smolts at each dam) and debris traps
- Direct mortality in spillways from supersaturated gasses and temperature shock
- Losses due to industrial pollution.

Cumulative Impacts in the Ocean

Salmon require habitat on a much vaster spatial scale than simply the Columbia River Basin extending far beyond the river into the Northern Pacific as far as Japan and the Bering Sea. Salmon spend much more time in the ocean (i.e., 2-4 years) than they do in the river (i.e., a few months to 1 year). At these large space and time scales, impacts from human activities whether strongly or weakly related to development of the Columbia River Basin interact with other factors (e.g., international fishery management or climate regimes). Some factors may be beyond the ability of governments to control, and the effects of these factors on the resource can take years or decades to understand.

Ocean Harvesting

For much of the 2-4 year period they are in the ocean, Columbia River salmon are subject to a poorly understood and virtually unregulated fisheries (e.g., the drift net fishery) on the open ocean. It is not known what the harvest rates of salmon in this fishery are, as information is politically sensitive and difficult to obtain.

As salmon begin migrating back to the river, they are subject to an intense offshore and near-shore commercial fishery by both Canadian and US fishermen. Much of the harvest of Columbia River salmon is taken off the coast of Alaska and British Columbia. This fishery was regulated by a 1985 International Salmon Treaty, but since 1994, both countries have violated the terms of the treaty.

Climate Cycles and Ocean Productivity

Since 1990, analysis of long-term climate data has begun revealing a 20 year cycle of ocean temperatures (i.e., 8-11 years of warm water; 8-11 years of cool) that impact Columbia River salmon stocks. The effects of this trend are altered productivity (i.e., warmer waters are generally more productive than cooler waters) and altered distribution of predators (e.g., in warmer years mackerel move further north, preying on smaller salmon). These impacts are beyond the ability of humans to anticipate and manage, and their effect on salmon populations are very difficult to measure. Yet they may have a large impact on effectiveness of other mitigation measures (e.g., hatcheries, smolt transport) currently in place for Columbia River salmon.

Summary of Factors Contributing to Salmon Stock Declines

The factors contributing to Columbia River salmon stock declines are diverse (i.e., arising from many sources) and are highly interrelated.

Direct Factors

These include losses of both young and returning adults at dams, habitat degradation, harvesting pressure, and predators whose abundances and distributions also change as a result of human and ecological alterations.

Indirect Factors

These include changes in water flow regimes adversely affecting timing and rates of movement of salmon and their ability to overcome obstacles in the river. Changes in oceanic temperature and current cycles can indirectly affect both productivity and mortality.

In total, these factors interact and exert a cumulative impact on salmon. One cannot remove (i.e., mitigate) one factor and see a direct and corresponding decrease in impact. The number, magnitude and environmental impacts of these interacting factors was not initially apparent to environment and fisheries managers. Only relatively recently was it obvious that the salmon populations could no longer successfully accommodate the environmental changes associated with substantial development activity.

Measuring Impacts on Columbia River Salmon

Many kinds of data are needed to interpret a complex cumulative impact problem. The three main difficulties for monitoring cumulative impacts are: (i) deciding what to measure (i.e., indicators vary in their ability to identify causal factors); (ii) measuring at the right time (i.e., especially adequate pre-development baseline data); and (iii) identifying effects of measurement errors. For the Columbia River salmon problem, abundance of salmon is the main indicator, but no single method or source of data can capture all the trends and factors influencing salmon populations.

The four main types of data used in monitoring Columbia River salmon are:

1. Catch and effort data, including fish boat logbooks, fish processing plant records, subsamples of landings, and creel surveys. Problems with these data include deliberate omissions, fabrication of landings (i.e., usually to avoid taxes), species mis-identification, unreported illegal catches, poorly trained observers, and unknown variance of estimates.
2. Counts at dams, including visual, video or electronic counts of adult fish passing upstream over a dam. One problem with these data is that the counts usually began after a dam was constructed. The technology changes every few years, making it difficult to compare historical data to the present.
3. Spawning escapement estimates, which are usually based on counts of adults made during a portion of the spawning area and period. Problems include: no data exists pre-1950, many spawning areas are not consistently visited, estimates are strongly subject to bias, and unknown variance. Other counts (e.g., egg or smolt counts), which would be a more direct indicator of

future returns, are much more expensive than escapement estimates.

4. Tag returns are usually conducted on hatchery fish. However, hatchery fish may behave differently than wild fish, making extrapolation of returns misleading.

The success or failure of management and mitigation programs is evaluated on the basis of these estimates. Yet these estimates cannot separate out the influences of impacts operating at different stages in a salmon's life history, nor can they separate out factors affecting fish survival in freshwater and marine habitats.

MITIGATING CUMULATIVE IMPACTS ON THE COLUMBIA RIVER

Mitigation measures now total considerably more than $US100 million annually. Mitigation ranges from technological fixes and solutions to broader ecosystem management methods. Current mitigation measures are briefly summarized as follows.

Fish Protection

Earliest efforts to mitigate impacts on salmon were aimed at reducing direct dam-related moralities of salmon smolts. These measures include:

- Capture and transport of smolts around dams and impoundments – estimated now to be 60-80% effective)
- Addition of fingerling bypasses, and protection from spillways through expensive 'renovation' and re-design of dams
- Construction of screens on irrigation channels
- Augmentation of river flows during migration periods – costing US$40 million annually in lost revenues.

Enhanced Fish Production by Artificial Means

By 1990, over 100 hatcheries and spawning channels were built, mostly in the lower river. New hatcheries are being built upstream. Integration of hatcheries into the cycle of management is a difficult political issue, and important questions about disease propagation, deleterious genetic consequences on wild fish, and those effects on further depression of wild stocks remain.

Habitat Restoration

This includes restoration of natural spawning habitat by re-opening fish passages blocked by earlier human usage and identification of 65,000 stream-kilometers of 'protected areas' where small hydroelectric projects should not be built. Careful management of forests to 'buffer' spawning stream edges and prevent catastrophic debris flows from entering streams is also being practiced.

Removal Of Dams

The removal of four dams along the Snake River, a major tributary of the Columbia, is currently being considered. While it may seem like a radical mitigation strategy, the breaching of dams and restoration of riparian habitat is seen by some environmental managers as the only real hope for long-term viability of salmon populations.

Challenges in the mitigation of complex cumulative impacts include the expense, the coordination of different measures, accounting for unknown variability in the natural system, and dealing with changing societal values and biological understanding. Management of hatchery fish in the Columbia River illustrates this complexity. Hatchery policy is a delicate and controversial issue. Older hatcheries were designed to replace lost stocks, and have now created mixed stock fisheries that are difficult to manage – as well as creating increasing problems with disease and genetic alteration of wild stocks. Newer hatcheries are intended to be 'temporary', designed for assisting stock rebuilding not stock replacement. However, their management requires changes in fishing methods, to which there is stiff social resistance.

INSTITUTIONAL COMPLEXITY

Many government agencies and private interest groups are involved in the management of Columbia River. These include: 11 state and federal agencies, 13 native tribes, 8 hydroelectric power utilities, and numerous interested parties. In the late 1980s and early 1990s, the political climate favored cooperation between government agencies in the Columbia River Basin, such as sharing of data and information and joint development of policy. The current climate does not, making future cooperative efforts much more difficult.

A consensus-building process is essential to managing a cumulative impact problem. Institutions must be able to identify trade-offs and coalitions for joint action, and have the ability to learn from unexpected outcomes. Remedial actions are also very difficult to design and implement because of the obvious question – who should pay? Environmental damages from past actions are a 'sunk cost'; the value of the resource has been taken by the exploiter, who is no longer available to pay for remediation. As well, the ability of the damaged ecosystem to recuperate is often uncertain, such is the case of the Columbia River salmon. A negotiated consensus among government agencies reflecting a mandate for rehabilitation is needed to justify expenditures.

Designing effective strategies for sustainable development under conditions of cumulative impacts requires long-term monitoring and mitigation efforts. In case of salmon, the minimum time scale for measuring any impact is 5 years or more – longer than the mandates of many political initiatives. Some solutions are technological, and costs can be estimated. Others may be more experimental in scope, and require changing societal attitudes and expectations, making cost estimation difficult. Developing the institutional ability to learn from experience, and designing flexible mitigation strategies based on new knowledge, requires a long-term commitment of funding.

SYNOPSIS

In closing, two factors beyond the control of any one government agency have created opportunities and problems in designing appropriate methods for mitigating the cumulative impacts on the Columbia River.

The economic and political climate of the last few decades favored mitigation. In the USA during the late 1970s, assuring a cheap energy supply was a high political priority. However, nuclear power had failed as an alternative in the early 1980s. Utilities had already raised prices by nearly 700% by the early 1980s, largely to pay for nuclear power plants that were never actually built. This revenue was, and still is, being used to pay for the costs of mitigating effects of hydro development on resources like salmon. This raises the important issue of whether the same strategy of building towards sustainable management could have been implemented in a less favorable economic climate.

Current mitigation actions have taken place in the unfavorable portion of the oceanic cycle. Since the late 1970s the ocean temperature cycle has not favored salmon growth and survival. The difficulty of measuring these effects has made expensive mitigation measures vulnerable to political pressure to change or eliminate them. The measures may not be seen as effective, according to the weakly correlated escapement estimates. Under different climatic regimes, however, they may be highly effective. This is a fundamental conflict between short-term political objectives, scientific uncertainty and long-term sustainability.