NOWHERE TO HIDE

Salmon versus People in the 21st Century

A Report to the B.C. Pacific Salmon Forum
December 4, 2008

Brian Harvey
Victoria, B.C.

FOREWORD

When I was asked by the BC Pacific Salmon Forum to provide an overview of the threats to Pacific salmon, the invitation coincided with reports of record low pink salmon returns in the Broughton Archipelago, and confusing and conflicting assessments of population abundance for all seven anadromous salmon species in British Columbia. So the timing seemed right. The Forum also suggested I take a special look at whether climate change somehow surmounted or altered all the other threats. I decided it did; in fact, I concluded that *all* the threats worked on each other. That might explain the chaos in today's salmon returns; it certainly explains the title of this report.

Anyone who's been around salmon already knows what the threats are, so I looked for something new, something that would keep my report from being just another recitation. I read about a hundred peer-reviewed papers (2004 – 2008) relating to threats to salmon, and the Forum provided me with several kilograms of recent reports by agencies, advisory groups and NGOs. What jumped out was how much the threats complement, reinforce or just confound each other (again, that title); how little we know about the ways salmon can respond even to single threats; and how thinly our resources are spread to do anything about what's essentially a human-created mess.

Another thing I concluded was that the people who want to do something about salmon are going to need a new rallying cry. The days of raising support from governments, foundations, corporations and the public by repeating, "Salmon are an icon of BC!" are numbered. All those threats are just too much, and even if salmon *are* still iconic, it won't be enough to save them. Saving salmon means what combating climate change means: changing our collective lifestyle.

This brings me to the problem of ranking the threats. There are seven threats discussed in this report, and the number could have been different because it all depends on how you lump things. For example, are "dams" a threat on their own, or part of "habitat?" Are escaped Atlantic salmon part of a threat called "salmon farms" or an example of "alien species?" Worse than the lumping problem is the visibility problem: some threats just get more press than others (salmon farming and over-fishing are examples), but that doesn't mean they're the most important. Worst of all, and in my opinion fatal for all attempts to rank threats, is the way they interact, producing additive effects, cascades, and unpredictable results. I provide many examples in this report, most of them having to do with the "meta-threat" of climate change. Here's just one: you may not think that alien species are much of a threat compared, say, to mixed-stock fisheries. But what happens if climate change alters freshwater ecosystems in favour of an invasive species like largemouth bass or yellow perch, which is known to feed on young salmonids?

I think the most practical kind of ranking is in terms of "do-ability" – in other words, how easy is it for us to actually reduce a particular threat? This philosophy ties in nicely with the much-quoted but little-respected “precautionary approach to fisheries,” which says that, in the absence of definitive data, we should reduce harm *where we can*. This is what The Food and Agriculture Organization of the United Nations (FAO), who originally promoted the precautionary approach, describes as “prudent foresight” – the need to take action with incomplete knowledge. Applying the precautionary approach to the threats to Pacific salmon that I describe in this report means worrying less about which threat is worst (because they all interact anyway), and more about which ones we can actually do something about *now*. Happily, there is plenty of evidence of this kind of “fixing what’s fixable” in BC: examples include reductions in mixed stock fisheries and implementation of the Wild Salmon Policy, or the growing recognition that, no matter how large or small the incremental contribution of sea lice by Atlantic salmon farms turns out to be, there are steps that can be taken to reduce it. These are certainly not the only examples.

This report covers a lot of different technical territories, so I asked several experts to help me by reviewing a draft and offering constructive comments. For this invaluable service I would like to thank Blair Holtby, Gordon Hartman, and Craig Orr, who caught outright mistakes and offered new insights.

Brian Harvey
December, 2008

CONTENTS

PART ONE: THE CONTEXT

One of the recurring messages of this report is that the threats to wild Pacific salmon don't occur in isolation. This is hardly a revelatory statement, but it's surprising how often an individual threat is analyzed, argued over, even "dealt with" as though it's the only one that matters. The reality for wild salmon is that shaking one part of the tree will dislodge an apple or two on the other side. Everything is linked, so there has to be context. This section of the report provides some of that context, so that the following discussion of the threats themselves makes more sense.

The elephant in the living room

If you want to see an elephant in British Columbia, Garden Bay is a good place to go. Especially in the summer.

Garden Bay is one of several nooks that make up Pender Harbour, about forty-five nautical miles up the Sunshine Coast from Vancouver. If you anchor there in the summer, you need to arrive by mid-afternoon, because it fills up fast. Inside Garden Bay, you'll be surrounded not only by other boats at anchor, but by several marinas, including the private outstations of the Vancouver Yacht Club and the Seattle Yacht Club, to which there's a constant parade of forty-foot boats whose owners are anxious to plug into the shore power they need to run refrigerators, freezers, TVs. It's crowded.

Residential development in Pender Harbour is intense, especially in Welbourne Cove and around the corner where there's a brand-new timeshare with its own marina. Most of the houses around Garden Bay are sizeable and new.

But if you anchor just off the Seattle Yacht Club outstation and look up, you'll see an old house, almost hidden by the trees, with a path that leads down past a workshop to a small dock where two wooden trollers are tied up. That little house has everything to do with the threats to Pacific salmon.

It was built by John Daly, a fisherman who died in 1978. His widow still lives there. Her book, *Fishing With John*, is a perennial bestseller, and it describes the life of an independent troller in the 1950s to 1970s, when Garden Bay was a very different place (Iglauer 1988). In hindsight, we know that was a good time for salmon fisheries in western Canada: plenty of ups and downs, but before the spike in landings leading up to the mid-1980s, and of course before the great fall that followed (Noakes et al. 2005; Riddell and Tautz 2003). In the time Edith Daly wrote about, the house with a dock and a troller in front was a common sight in Pender Harbour.

What does the history of Garden Bay have to do with threats to Pacific salmon? The yachts that now tie up there are probably on their way to Desolation Sound, an archipelago thirty miles north that's fast becoming over-crowded as a summer destination. Most of the owners are from Victoria, Nanaimo, the lower mainland and the US ports of Anacortes, Seattle and Portland. In Desolation Sound, you can now sit in a summer evening in an anchorage that in John Daly's time would only have held a troller or two, and watch TV through the saloon window of the fifty-foot yacht anchored next door.

The point of this little travelogue is one that is missed by most listings of the threats facing Pacific salmon. In the report that follows, I will describe those threats, even attempt to comment on their relative severity. But the story of Garden Bay needs to come before all that, because it illustrates two extremes: they way it used to be, and the way it is.

John Daly's little house and troller are the way it used to be: lots of room, lots of fish, a simpler world. It's the image most people involved in salmon restoration hold in their minds: *this is what we want back*. The reality, though, is the yacht from Vancouver with the forty-two-inch TV and the diesels that swallow twenty gallons an hour. That yacht represents a growing urban population with disposable income and increasing demands not only for electrical power but also for water and all the other services that support a thriving marine industry (foreshore access, repairs, communication, roads and seaplanes and more). It's not that the yacht does any damage to salmon, rather that the yacht's owner and lifestyle represent an inescapable demographic truth: in much of the Pacific salmon's southerly range, population growth virtually guarantees more electrical needs, more water withdrawal, and more loss of habitat.

Population growth is the elephant in the living room. A few scientists have called attention to it – but not many (Lackey 2003). Lackey et al. (2006) go so far as to suggest that salmon restoration, in the face of such population increase, is a mirage. This view is poorly received by many other scientists, by bureaucrats of all sorts, and especially by local groups struggling to restore streams, but the main point about the importance of sheer population growth is not so easy to argue with. The history of the Fraser Valley alone provides innumerable examples of the decline or destruction of salmon habitat as a result of agriculture, industry and urban development—all those things that indirectly result in yachts replacing trollers in Garden Bay (Pacific Fisheries Resource Conservation Council 2007a).

Salmon need habitat that unfortunately also provides water, power, food and recreation to people. When reading the discussion of individual threats that follows, it's useful to return to this concept, and keep asking: how will such and such a threat increase with population? How much the population increases is of course subject to much debate; Lackey (2003) argues for a total Pacific Northwest expansion from 14 million to 85 million by 2100. Whatever the eventual figure, nobody can argue that there won't be a lot more people expecting a certain lifestyle level, and if one accepts that habitat alteration and loss is one of the biggest threats to wild salmon, more people will only make it worse. Hartman et al. (2000) present evidence for a strong negative correlation between human population density and wild salmon distribution and abundance. Interestingly, some scientists also confirm that the relationship works in the other direction too, namely that fewer people means healthier salmon stocks: the health of some salmon stocks in Alaska may have a lot to do with the low population density near productive watersheds (Adkison and Finney 2003), although the more favourable ocean conditions there may also be very important.

The main argument made by Lackey is not a popular one. It's this: every one of the threats that will be discussed in this report, many of which date back more than a hundred years, were the result of choices that reflected society's priorities. If this is true, maintaining sustainable populations of Pacific salmon over the next hundred years will mean changing some of our core values. If those values don't change, we will continue, as Hartman (2008) eloquently writes, to "sleepwalk into the future". A good place to see what that future looks like, to see the results of unbridled development and the insistence on lifestyle over environment, is Japan, where many wild salmon runs exist only as remnants (see *Hatcheries*, below).

But values and attitudes are hard to change. People will have to care a lot about wild salmon if they're prepared to alter their standard of living to save them. How much do British Columbians really care? On the positive side, there *is* a strong conservation ethic for salmon that doesn't exist for most other species (many of which are in much worse shape than salmon). In a recent study of BC First Nations' views about salmon aquaculture, one respondent said, "a successful fish farm does not farm salmon – sea cucumbers, shellfish and prawns would be successful fish farms" (Gerwing and McDaniels 2006). Time and again, scientists and journalists refer to the "iconic" Pacific salmon – so much so that one might sometimes be forgiven for imagining that being an icon somehow makes something more worth saving.

But, beyond the cedar-boxed smoked salmon in the gift shops, are salmon still iconic in BC? And if so, for whom? For aging baby boomers, or for their children? There's a big difference between growing up in the good times, as I did, when salmon were abundant, and growing up as my children have, when the salmon are struggling. For me, salmon were an icon. For my children, I'm not sure they're more than yet another group of species to fret about.

The problem of governance

Part of the appeal of Pacific salmon is its peripatetic life history: seven species (and many more populations) use habitat that is spread over thousands of kilometers, so that a single salmon hatching in a modest rural stream in the BC Interior can find its way downriver through progressively grander watercourses, through an industrial gauntlet, past freighters at anchor and eventually, after a scenic coastal peregrination, to the middle of the northeast Pacific. And then, years later, all the way back again.

People are impressed by the length of the journey and the number of habitats, but they often forget another hurdle for salmon. This obstacle, worse than the waterfalls the fish so famously leap over, is the man-made but invisible chain of jurisdictional frontiers the salmon have to cross. Every one of those jurisdictions is a fiefdom, and most of them maintain some degree of hostility, ranging from simply not speaking to each other to actually fighting (usually in court, but fists have been used more than once in the BC fishery).

The list of groups that influence Pacific salmon and their habitat is a long one. It includes several countries; in Canada alone it ranges from federal and provincial agencies and First Nations, along past regions and municipalities and into the hands of crown corporations, private companies and their consultants. Even though, in Canada, official control is concentrated in the Federal Fisheries Act (which gives the Minister power to influence all manner of decisions affecting salmon) the number of stakeholders is large enough that there is conflict and confusion. It's not simply a matter of one group feeling it has a "right" to catch fish or create some kind of development, it's the product of a patchwork of enacted *legislation* (which grants powers to government) and *regulations* (how to do what's in the legislation, and usually put in place outside of Parliament). *Policy* (how to interpret law through regulation and enforcement) is a different matter, because there may be a lag between creation and implementation (the Wild Salmon Policy is a good example).

Pacific salmon and their champions can at least be grateful the governance mess isn't worse. In some countries, major rivers cross not only regional and municipal boundaries, but multiple state lines as well. In Brazil, for example, the São Francisco River is 3,000 km long (twice the length of the Fraser) and flows through seven states and several eco-regions. Every drop of its water is bitterly contested at every level of society, with the very real possibility that water extraction dooms fisheries everywhere but in the reservoirs (Harvey 2008). Compared to this situation, even a heavily impacted river like the Fraser is better off.

The governance problems that make it near-impossible to manage Pacific salmon sustainably are the same ones that plague many other species, aquatic and terrestrial; they're one reason that, even if we knew how to do ecosystem-based management, we probably couldn't make it work. Although individual governments can create policy to manage salmon on an ecosystem basis (for example, Fisheries and Oceans Canada 2007; Pacific Fisheries Resource Conservation Council 2007 b,c), the overall governance mechanism just isn't there. A report to the Pacific Salmon Forum on BC statutes and regulations affecting wild salmon pointed this out: there is no formal mechanism for integrating the responsibilities for dealing with watersheds as ecosystems. Walters et al. (2008), in their scientific review of the Skeena fishery, put it more bluntly. After noting "it appears that current authority for making decisions on certain types of land and water uses bypasses input from biologists in the BC Ministry of Environment," they went further and proposed a new governance structure that would include DFO, BC Ministry of Environment, First Nations, representatives of user groups and conservation interests, and independent technical experts. Prominent in their recommendations was a formal structure for data sharing and communication.

Can things change this radically – not just on the Skeena but for the rest of BC? Finding examples where government is not "doing its job" is easy: cuts in monitoring, inadequate enforcement, not enough staff to properly review proposals are all part of a long list of familiar criticisms. Devolution of stream stewardship and habitat restoration to non-governmental groups has been criticized as raising undue expectations of success while furthering internal technical erosion and lack of continuity in the agencies themselves (Pacific Fisheries Resource Conservation Council 2004). All these things should be rectified. But perhaps a better question is: *Can* government do its job, given the fragmentation of responsibilities? If one agency is responsible for gathering and analyzing data on steelhead abundance and another is responsible for managing a fishery that incidentally intercepts those steelhead, how much sense does this make?

The difference between threats and risks

All of the species of Pacific salmon face multiple threats, but none are at risk of extinction. There are many obscure fish species in British Columbia that we know to be in far worse shape (and others where we have nowhere near enough data to do more than hazard a guess). Because there are so many individual populations of Pacific salmon, people concerned about threats have to be very specific about what geographic component of the species is being discussed. Is it a single spawning population in one tributary of the Fraser River that we're talking about, or a group of similar populations that might be considered part of a "conservation unit" under the Wild Salmon Policy, or some politically useful conglomeration such as "Fraser Sockeye"?

For status assessments, such distinctions are critical, and when people don't agree on the lumpings, confusion results. A good example is the recent, and controversial, IUCN Global Status Assessment for sockeye salmon, which assigned the global population a status of "least concern" but identified a number of subpopulations, many of them in the southern part of the species' range in British Columbia, as "threatened" according to standard IUCN criteria (IUCN 2008). Responses to such assessments, for example the one written by the Pacific Salmon Commission to address the Fraser portion of the IUCN report, stress the lack of consistency in defining the population units, and the criteria used to arrive at their status (Pacific Salmon Commission 2008).

The creation and implementation of endangered species legislation in Canada and the US has brought about an important distinction between threats and risk. In pre-legislation days, people concerned about threatened species and populations could use the terms loosely, often interchangeably. Today, however, listing of a species or population carries with it the requirement to create a recovery plan, and more and more these plans contain not only a list of threats but also the amount of risk associated with each. The simplest arrangement is to rank the threats in what is believed to be order of seriousness, but this approach sometimes doesn't deal very well with the real world where the link between the action and the probability of some effect of that action is largely unknown. There is also a strong trend toward the creation of separate risk assessments that often serve the purpose of helping make the decision on whether to list or not. Authors of such documents are urged to use so-called “risk-based language”, which clearly tells the reader how much risk is associated with each threat. It’s a kind of pseudo-quantification that very often founders on the lack of data, especially for little-known species. In such cases, other species and populations are called in as proxies, which can add its own uncertainties.

Risk assessments get especially complicated and unreliable when several threats work together. Put another way, for many species and populations, the various threats don’t act in isolation. Pollution, for example, may reflect or be exacerbated by habitat loss, which may in turn reflect population growth. All are threats, and the sum is greater. Pacific salmon are probably the most susceptible to this kind of triple whammy effect: their range extends from the upper reaches of streams that may be hundreds of kilometers inland, to the middle of the Northeast Pacific. Kappel (2005) observes that more than half of global marine extinctions are caused by exploitation (fishing), while, on land, the most common threat was habitat loss. Salmon are unfortunate enough to bridge both. The potential interactions between threats rapidly become mind-boggling when you consider how climate change could affect species distribution: habitats will shift, competition with new species will occur, new diseases will arise. In general, evaluating the net effect of multiple threats in such large-scale systems is extremely difficult (McClure et al. 2003). Choosing the right actions for promoting recovery of a given population is equally difficult – which may be why habitat restoration has so often seemed the default choice (visible, easy to do, satisfying, even if returning salmon to a stream is only one of several objectives).

Of course, salmon are not the only marine creatures that face multiple threats that usually occur simultaneously. By concentrating on three of these threats - harvest, habitat fragmentation and warming – Mora et al. (2007) attempted to determine how the threats interacted, and what were their combined effects. This is the kind of study that is extremely hard to conduct in the wild, especially for salmon, but the challenge of predicting cumulative effects is paramount if we are to make decisions about where to put our resources in dealing with them. The experimental system Mora and colleagues used was a planktonic microcosm, a huge simplification of the salmon’s world, but one that provided some food for thought for salmon biologists and managers. They found that experimental populations of rotifers (a planktonic animal) were equally affected by all three threats; more importantly, habitat fragmentation and harvest (removal of rotifers from the system) reduced population resistance to warming, and declines in population size were much faster when all threats acted together. Their results provide the first experimental evidence that threats should be mitigated simultaneously. A recent mathematical model described by Scheuerell et al. (2006) attempts to bring some rationality to the choice by incorporating data on physical restoration changes, hatchery operations and harvest management to show how various combinations of actions would improve abundance, productivity, spatial structure and life-history diversity (in other words, the likelihood of recovery). The results were used to present decision makers (in this case, the Snohomish Basin Recovery Group) with a choice of strategies.

So some context is needed. When we talk about the threats to wild Pacific salmon we're not talking about, say, the speckled dace, a COSEWIC-listed minnow in the Kettle River. For the dace, which occupy well-defined habitat, there are only a few threats; the biggest one, a proposed run of river power station, can be dealt with using good planning and undertakings from the proponent. Having local people rally round the cause will have a good cause-and-effect relationship. Saving the dace is feasible; to compare it to "saving Pacific salmon" is to liken clipping a hangnail to dissecting out a malignant tumour. Too deeply embedded, too fast-growing, too connected, and you need to get it all.

This report looks at the threats to Pacific salmon very broadly, and is not a risk assessment. I do a lot of lumping: after all, Pacific salmon comprises seven species whose lifestyles are quite dissimilar, and within each of those species there are many hundreds of genetically distinct populations (sometimes loosely called stocks). While none of the salmon species are facing extinction, many individual populations have disappeared or seem about to do so. Taking the discussion to the level of the individual population particularizes the threats (and their associated risk) in a way this report does not attempt. Here, the broader brush is used.

For the most part, the threats are the known or historical ones, but potential threats are also noted (as they must be in recovery planning). New threats have a way of cropping up, even if subsequent research eventually allows them to be filed under an existing category. Early upstream migration of late-run sockeye in the Fraser River is a good example: the high resulting mortality was painfully obvious and contributed to risk of extinction for some small populations, but the cause of early migration has yet to be unequivocally nailed down. Infection by a kidney parasite caused the mortality, which would suggest classifying the threat under "parasites and diseases" (Lapointe et al. 2003), but we still don't know why migration was early in the first place. There will be other such examples of threats that are hard to classify.

Reviewers of threats to salmon in the US Pacific Northwest commonly refer to the "four Hs" – habitat degradation, hatcheries, harvest management and hydropower– and, with the understanding that hydropower effects have been lower in Canada, the list generally applies to BC salmon as well. There are newer threats to add to these "usual suspects" (climate change is the biggest one), and there's one that's often unacknowledged, namely the lack of biological understanding and analytical data. It took over a hundred years for the consequences of development and over-fishing to be understood: the "stock concept" so important in management was only described in 1972, and models for applying data generated by tagging technology developed in the 1960s and 1970s were only available in the 1980s (summarized in Riddell and Tautz 2003). Lack of data continues to be a serious limitation on management and conservation of Pacific salmon and is a legitimate threat in its own right, serious enough to trigger application of the "precautionary approach" which is specifically aimed at just this kind of situation. Riddell and Tautz argue that the indirect costs of having poor data actually outweigh the cost of going out and doing the needed sampling. They describe some encouraging advances, including new databases and analytical models and the use of a small, manageable number of indicator stocks for more intensive collection of quantitative data that can be used to predict broader scale effects.

Rankings

When confronted by a list, most people want rankings. Lists of threats seem especially to demand some sort of “severity index”. Unfortunately, the fact that the threats to wild Pacific salmon flow from human actions related to globalization and population growth tends to make them act together. Focusing on one or two may be counter-productive, and raise expectations (Hartman et al. 2000). With this kind of complexity – multiple species, multiple populations, multiple threats – it is impossible to make any but the most general observations about severity. In the end, rankings of threats to salmon are deceptive and self-defeating, because the threats are inter-connected, and work on each other – with the “wild card” of global climate change looming over all of them. We have passed the stage when threats act alone, and tackling them one by one may have little lasting effect.

There are, however, some useful big-picture conclusions that can be drawn from analyzing lists of endangered species. Based on the IUCN Red List and the US Endangered Species list, the most common *listed* threat to marine, estuarine and diadromous species is overexploitation, through direct effects (harvest and bycatch) and indirect effects like prey competition and food-chain cascades (Kappel 2005). The next two most important threats are habitat loss and invasive species, while climate change is moving up in the rankings, probably because it has been underrepresented in earlier listings. For Pacific salmon the severity of threats varies depending on the location. In Alaska, for example, climate fluctuations affecting environmental conditions appear to trump both fishing and habitat loss (Adkison and Finney 2003). The same authors note that when ocean conditions are good for Alaskan sockeye, pink, coho and chum, they tend to be bad for Pacific Northwest chinook and coho. Another useful geographic rule of thumb is that, while northern salmon populations have declined less than southern ones, the problems of the south will move up in the next few decades (Riddell and Tautz 2003). The IUCN status report on sockeye appears to reflect this trend (IUCN 2008).

You can’t go home again

The salmon “community”, which includes First Nations, biologists, engineers, politicians and passionate amateurs, has reached a turning point. For decades, they’ve collectively held onto the image of the lone troller docked in Garden Bay, and believed that, with some changes in management and a lot of elbow grease out on the rivers, they could turn back the clock, the salmon could be brought back. Now, when this has clearly failed to happen, when climate change threatens to knock all the other threats off the board, a narrow perspective on harvest regulation or hatcheries or habitat restoration has been brutally widened to include the realization that the problems of salmon are as far-reaching as the problems of achieving sustainability in a globalized economy.

As Hartman et al. (2000) pointed out nearly a decade ago, salmon are now affected by global processes that also affect millions of people who don't know where their next meal is coming from; these people can be excused for not worrying about our salmon. It logically follows that, for salmon biologists and managers to think – worse, promise – that they can "bring the salmon back" in the face of such formidable opposition is disingenuous. What should they do instead? Confronted by a list of threats like the ones contained in this report, can scientists keep promising, "If you build it, they will come?" Especially when the restored habitat you build may become uninhabitable because of climate change?

The inescapable truth is that salmon are threatened by a complex of human-caused impacts that simply reflect unsustainable development. Indirect impacts of climate change developed slowly and will only slowly be reversed; more direct impacts like those from fishing, forestry or hydroelectric development, can be more quickly tackled. If you were looking for evidence of the interconnectedness of the threats to salmon, you would need go no farther than to consider the culprits identified as responsible for the decline in certain populations. Collapses are variously blamed on such things as overfishing, forestry, sea lice and climate change, and the weight given to each usually reflects an agenda. The reality is worse: they're all to blame, either by simple addition of harm, or by the more worrisome cascade-type effects typical of climate change. The best we can do in the short term is to use the precautionary principle to immediately reduce harm where it's in our power to do so.

Case study: the Skeena

The rest of this report provides an overview of each threat to Pacific salmon, while trying to convey its interconnectedness to all the other threats. How do all these threats interact in a real world fishery? To avoid leaving the reader with a headache or, worse, convinced there is no way out of a morass where every step forward causes something else to cave in behind, we consider the case of the Skeena River salmon fishery. Not because it's a good news story where hard work and good sense saved the day, but because we are fortunate to have a recent, comprehensive scientific review of the fishery that reminds us of some reassuring things: that complexity *can* still be comprehended, that gaps *can* be identified, that options *do* exist. The following overview is taken from the Report of the Skeena Independent Science Review Panel (Walters et al. 2008).

An independent review of Skeena salmon and steelhead was prompted by public debate over management of the fishery in 2006 and 2007, when strong sockeye and weak steelhead runs led to DFO's making controversial decisions that revealed not only a lack of provisions for managing the fishery under the many possible combinations of species and stock abundance, but also a fundamental lack of coordination between federal and provincial ministries. In attempting to optimize the tradeoffs between management principles based on the Wild Salmon Policy and the demands of commercial, recreational and First Nations groups, DFO seemed to have incurred everybody's wrath.

The list of issues that managers had to contend with on the Skeena is a daunting one, and contains all of the threats to be discussed later in this report. The “four Hs” were front and centre. The *harvest* threat was complicated by the conflicting demands of user groups, the attempt to manage for conservation units designated under the Wild Salmon Policy, the need to maintain stock structure (within species) and the added wrinkle of protecting a recreational species that co-migrates with a commercial one. Threats from *hatcheries*, (technically, on the Skeena, enhancement) were represented by the Babine sockeye spawning channels, whose output tends to overpower the non-enhanced stocks. *Habitat* loss, historically a lesser consideration on the Skeena (where human development is nothing like on the scale of more populated regions like the Fraser Valley), was nevertheless poised for a major upward spike with new threats from resource exploration and extraction, including road and pipeline construction and the new threat of groundwater drawdown for coalbed methane. The fourth “H”, *hydro*, was most evident in the surge in interest in run of river power projects. Finally, as the authors of the report pointed out, the impacts of climate change “loom over any attempt to forecast the future for fish and their habitats.”

What prescriptions did the Panel advance in the face of these and other challenges? First, they described options for improving monitoring of both sockeye and steelhead, a critical need because management objectives have grown more complex with the Wild Salmon Policy, and tradeoffs among species and populations are impossible without better information. The monitoring options include documenting habitat characteristics and filling in the almost complete absence of stock trend data for steelhead. Second, the Panel recommended a hard look at the spawning channels that increase sockeye harvest but aggravate the mixed stock fishery problem. Third, they laid out the uncertainties about the sockeye exploitation rates that would cause overfishing of all salmon species including coho, chum, chinook, pink and steelhead, and listed the pros and cons of various kinds of selective fishing to reduce the impact on steelhead. Implicit in these scenarios is the role of the public in saying how much weak stock protection is acceptable.

The final report is long and detailed, and it is not the intention here to include any of those details. It’s the attitude that matters, and the clear positive message: “If you want to fish sustainably on this species or stock while protecting that one, given the likely damage to their habitat and even considering the meta-threat of climate change, then here are your options.” The options may be unpalatable, even painful, and choosing some of them means reforming a dysfunctional governance system in which federal and provincial agencies perpetuate longstanding conflicts that need to be resolved. But the options exist (even though the big unknown of ocean conditions can’t be changed), and together they remind us there can be a better future than the one where groups with different interests squabble and wring their hands and the salmon are collectively written off.

PART TWO: THE THREATS

I describe seven major threats to BC Pacific salmon. I have lumped the effects of dams in with habitat, so the traditional "four Hs" that I discuss first are only three. The fact that climate change is discussed after them reminds us that rankings are not appropriate: all the threats are synergistic, and climate change could just as well have come first. So the list that follows is not in any order of severity. In fact, the only ranking that makes sense to me is according to our ability to actually reduce the threat, which will be the product of our technical know-how and our willingness, as a society, to use it. I don't attempt that here.

THREAT 1: Habitat alteration and loss

While Pacific salmon use both the nearshore and open ocean marine habitats for part of their life cycle, these habitats have not been obviously altered unless one considers pollution effects, which will be dealt with in a later section of this report, and the nearshore effects of development in urban areas. "Unobvious" alteration may, of course, also have occurred, for example the changes in ocean upwelling and stratification that are coming with global warming.

The freshwater portion of their habitat, which is used by adults, embryonic stages and juveniles, is highly vulnerable to human activities – which, as we have already noted, tend to increase with human population. High quality freshwater habitat is a basic requirement for sustainable salmon populations (Levin and Stunz 2005). When it becomes compromised, populations can become reduced in numbers, restricted in range, or extirpated. Listing under endangered species legislation frequently follows habitat loss, and raises the dilemma for recovery planners of what habitat to designate as "critical" to survival. Identifying critical habitat is often the stage at which biology and socio-economics square off, and has been the source of much argument, negotiation and disillusion in experts attempting to draft recovery plans under the Species at Risk Act.

There is another, more subtle effect of habitat degradation on Pacific salmon, although it rarely receives much attention: the evolutionary response of the population. While the worst-case scenario – extinction – may be painstakingly modeled and debated, the question of whether, and how much, the population can actually adapt genetically to, say, elevated temperature is rarely addressed. Of course, if population size is quickly reduced or fragmented, this limits the potential for adaptation to the new conditions. McClure et al. (2008) present arguments for a selective response for certain traits following habitat loss, including run and spawn timing in central Idaho chinook, adoption of a resident (as opposed to anadromous) life history in Central Valley steelhead, and reduction in rearing time in Puget Sound coho. These evolutionary consequences are not trivial, because they demonstrate the kind of adaptability that, so long as it is not too compromised by population restriction, may allow salmon populations to weather future environmental changes. In a climate change scenario, such evolutionary plasticity may be crucial to survival. In the habitat discussion that follows, it would be good to keep in mind that, when choosing between different kinds of habitat management scenarios, conserving genetic diversity needs to be an important criterion (Beechie et al. 2006).

The many kinds of freshwater habitat degradation and their effects on salmonids have been extensively reviewed, and the broad pattern is familiar to people involved in restoration projects. Pacific Fisheries Resource Conservation Council (2007d) summarizes human-caused threats to fish habitat in BC, and notes that the overall habitat condition can often by gauged simply by measuring human activity in a watershed – another way of expressing Lackey's (2003) contention that human population is the main driver of salmon decline. Elevated stream temperature can result from many human activities, from climate change to loss of forest cover or riparian vegetation to extraction of water for irrigation or industry (which reduces flow). None of these effects occur in isolation; loss of riparian vegetation, for example, not only allows temperature to rise, it can also lead to bank erosion, which in turn reduces stream complexity, increases sedimentation, and eliminates cover. Sedimentation can also result from point discharges from land development; either way, it affects salmon by reducing water circulation through egg incubation areas. Actually altering a stream channel, for example by constructing roads and dykes, simplifies the channel and isolates side channels. Removal of gravel for flood control alters stream flow and removes potential spawning habitat. The specific and varied effects of forestry are reviewed by Northcote and Hartman (2004).

Extraction of coalbed methane

The threats to salmon habitat listed above are by no means evenly distributed throughout the province, and they very often work in concert. They are very well known. That is not to say that, in addition to damming rivers, building roads, removing trees and farming intensively, people cannot think of new ways to alter salmon habitat. Extraction of coal bed methane is an example of a new activity whose effects on salmon habitat are hard to predict and potentially serious. It is more land-intensive and with potentially greater effects on water than conventional gas development and has yet to be attempted in a salmon-bearing watershed. Exploration wells for coalbed methane extraction have now been drilled in an area in northwestern BC that provides spawning and rearing habitat for several salmon species (within the current tenure for development, salmon are found in headwaters of the Skeena and Nass Rivers).

Coalbed methane extraction requires that water be pumped from the aquifer that permeates the coalbed (the gas emerges along with the water, which must then be disposed of). Potential effects on salmon streams include not only the familiar things associated with construction in a pristine area (erosion, silting, increased runoff from loss of ground cover), but also the consequence of deliberately pumping water out of the gas-containing aquifer, namely a lower groundwater level. The end result will depend on how closely aquifers are interconnected, but any reduction of stream flow, coupled with increased water temperature, is yet another change for global warming to amplify (Pembina Institute 2008).

Habitat restoration: successes and failures

Habitat problems often occur near places where people live. For this reason, freshwater habitat degradation stands apart from all the other threats to salmon as the one most commonly tackled by people. While other threats, like hatcheries and harvest, even climate change, can arguably be reduced by human actions, habitat damage is unique in being highly visible, close to home, and fixable.

The fixing is called restoration, and is done by a broad spectrum of groups from governments to small communities. Interestingly, the thrust of much of the new research in this area is not in refining our understanding of the damage and how it's caused, but in looking critically at the success of the enormous number of restoration projects that have been, and continue to be, undertaken. The following discussion summarizes some of those findings, with the caveat that much of the research emanates from the US Pacific Northwest.

Wu et al. (2003) describe a "salmon recovery culture" that responds to public pressure to do something about salmon declines by using a "study and tinker approach", an example of what Hartman (2008) would call a "problem-solution" trap where each new techno-fix creates its own set of new problems. This is a sensitive subject among researchers, managers, and community groups. The problem is that, over the last few decades, substantial investments have been made in riparian restoration and other conservation measures (based on what some have called the "field of dreams hypothesis"), with little follow-up evaluation beyond some short-term monitoring or qualitative, *ad hoc* observations by local participants. Lack of follow-up has two results: not only do we not know how well something has worked, but we also fail to learn how to do things better. As Bond and Lake (2003) put it, few restoration attempts contribute significantly to our knowledge of the best way to do restoration.

One reason may be that restoration often concentrates on habitat *quality*, such as the condition of substrate, banks, temperature and flow, while habitat *size* and *connectivity* are overlooked. Isaak et al. (2007) concluded that, based on studies with chinook salmon in central Idaho, improving habitat quality is not the whole answer, and that increasing the interactions among existing populations, for example by removing barriers like road crossings, could have equivalent or greater benefits. The choice of which habitats to restore should thus consider habitat geometry, and avoid areas where size and connectivity are low. Bond and Lake (2003) add the importance of restoring habitat on the appropriate scale (for example, to avoid having a small-scale project overwhelmed by catchment-scale problems), as well as the effects of restoration on other species. For example, competition from exotic species that respond rapidly to restoration may negate any beneficial effect on the target salmon population (a good example of how important it is to consider all the threats, not just one). There may also be unintended effects on native species, for example the tradeoff between salmonids and speckled dace: as temperature decreases, salmon abundance increases while dace abundance does the opposite (Wu et al. 2003). There is a broad discussion of restoration in Northcote and Hartman (2004).

If restoration is based simply on improving some on-site factor (a typical one would be water temperature), there should be some expectation that significant improvement can be achieved; in other words, if a lowering of three degrees is necessary and the best that can be achieved with the available resources is one degree, the money could be better spent (Wu et al. 2003). This is a significant concern when large amounts of money are spent on restoration — in the US alone, more than $US 1 billion annually, on projects that remain 90% un-monitored (Bernhardt et al. 2005). Another way of saying it would be that targeting streams that are in the worst shape may provide the least benefit. Given all these complexities, it is little wonder that the study and tinker approach still wins out, and that many projects are begun without understanding the waterway in question (Walter and Merritts 2008).

Dams and fish habitat

Dams cause major alterations to freshwater habitat. A recent bibliography on the environmental effects of dams (Baer 2007) summarizes as follows:

> Dams block or impede fish passage, upstream and down; they inundate spawning habitat and isolate breeding populations; they may change complex and meandering rivers with wide variations in annual flow and extensive and species-rich floodplains (including terrestrial species) into lakes; by homogenizing habitat they alter species composition and reduce biodiversity. Barriers to fish passage and to sediment drift fragment rivers and habitats, disrupt natural nutrient cycles, filter out woody debris that serves as shelter and shade for smaller organisms, and change downstream water temperature regimes and velocities. Turbines and spillway crests increase the levels of dissolved gases in the released water, affecting all multicelled aquatic organisms either through changes in their biochemistry or by floating them to the surface (through the attachment of external bubbles) where they may be picked off by predators. Water released from the hypolimnion, or bottom of the reservoir, may be devoid of oxygen and much colder than the natural river. No method of dam operation returns water to the river in what could be called a natural state. Below the dam the water is generally colder, cleaner (i.e. sediment-poor), and carries a vastly altered gaseous content.

Pacific salmon are among many other species, from the very large (like sturgeon) to the very small (like dace) that are affected by dam construction and operation. A species need not be migratory to be affected by a dam; the minnow-like dace, for example, can lose important riffle habitat simply by its being inundated in the creation of a headpond (Bradford 2008 pers. comm). But migratory species that move upriver to spawn are particularly susceptible to dam effects, which include not only the simple blockage of the spawning adults but also the destruction of offspring in the turbines as the young fish proceed downstream. Globally, many migratory fish species are affected in these and other ways (Harvey 2008; Carolsfeld et al. 2004).

Within the range of Pacific salmon, dams have been constructed for several reasons, including generating electrical power for industrial and residential use, and controlling flooding. The reservoirs created by dams may also be tapped to divert water for agricultural, industrial or municipal use; over longer distances, the removal of water (often by canals, as is the case in the Seton/Bridge River system) becomes a diversion. The net effect, beyond the creation of a barrier to migratory fish, is that the river becomes regulated; in other words, its flow can be manipulated, with sometimes far-reaching effects on temperature, oxygen content and sediment load.

In B.C. as elsewhere, dams range in size from small run-of-river affairs that generate electricity without the creation of a large reservoir (see below for more discussion of run of river power projects), to enormous earth or concrete barriers like the WAC Bennett Dam or the Peace Canyon Dam, capable of providing hundreds or thousands of megawatts. However, much of the literature on the effects of dams on Pacific salmon refers to the US portion of the Columbia River basin, where large-scale damming of the Columbia and Snake Rivers has played a major role in salmon declines. Lorenzo (2005) reviews the biological effects of these large dams (they block adult and juvenile passage, kill young fish in the turbines, create deep pools and reservoirs which alter water velocity and temperature), then goes on to describe the extraordinary volume of litigation over these effects, over subsequent restoration attempts, and over the responsibilities of various parties under the US Environmental Protection Act. Together with the observations of Blumm et al. (2006) on the failure of Columbia basin salmon recovery under the EPA, Lorenzo's review offers a sobering analysis of the difficulties of applying endangered species legislation to cases where there is a strong societal argument for maintaining the status quo. These arguments are relevant to the recovery of listed salmon populations in Canada: once an environmental dispute becomes tied up in court, it can take a very long time to resolve. And maintaining the status quo is exactly what we can't do if we are serious about reducing the threats to salmon.

In B.C., most of the large dams were constructed between the 1950s and 1970s; the most recent large-scale dam (at Revelstoke) was built in the 1980s. In general, what might be called the "Columbia River Syndrome" does not apply in BC. The mainstem Fraser, for example, has not been dammed. A recent scientific paper on the mortality of smolts during their freshwater migration phase compared survival in the Columbia system with that in the Fraser, and concluded that smolt survival during migration was actually higher in the Columbia (Welch et al. 2008). The authors were careful to note that this could also result from unidentified problems in the Fraser system, and the study says nothing about delayed effects and subsequent mortality after fish enter the ocean.

The Pacific Fisheries Resource Conservation Council (2007d) stresses that each dam is a special case, and that there is a cumulative effect of all the small public and private dams built for irrigation, domestic water use and electrical generation. The author especially notes the many small irrigation diversions in smaller streams in the BC interior, which have the effect of increasing water temperature and, compounded with the loss of riparian cover, has had an adverse impact on rivers like the Deadman, Salmon and Nicola. Private dams for irrigation are often constructed without permits.

There are several ways to reduce the impacts of dams on salmon, including fish-friendly turbines, fish ladders, creation of spawning channels and hatchery supplementation. Some or all of these measures are in use at many BC Hydro facilities. Note, however, that hatcheries, once considered a panacea for declining salmon, are also considered a threat to the genetic integrity of wild salmon through competition and interbreeding (see *Hatcheries*). An interesting sidenote shows that the dams themselves can also have genetic effects on wild salmonids (Angilletta et al. 2008). Here, researchers looked for evidence that the changes in river temperature caused by large dams in the Columbia system might stimulate selection for strains with different thermal tolerance. They found that while dams affect water temperature differently depending on the time of year, they generally influence fitness by advancing development and they *do* select strongly for different phenotypes. But, as with the genetic effects of fishing, hard evidence of effects on the genotype (that is, a true evolutionary effect) has not yet been obtained.

Run of river power projects

The relative absence of big dams in BC doesn't mean the threats to salmon from dam construction are static and manageable, they just come from a different direction. As mankind scrambles to avoid the worst consequences of climate change by reducing carbon dioxide emissions, hydropower has demonstrable benefits as a "clean" source of electricity (Scott 2007). The potential for hydropower as a "green" alternative to burning fossil fuels just happens to coincide with a fundamental change in the business model for power generation in BC. The BC Energy Plan of 2002 effectively shifted BC Hydro's mandate for building and managing new electrical generation operations to the private sector (with whom BC Hydro can, however, compete for large projects). Private corporations, municipalities, First Nations and even private citizens can now apply to build and operate dams. Six years after this significant decision, there are 119 licenses for diverting BC rivers to produce electrical power; by 2006, 25 projects had been built. Forty-one more have received approval and were under construction by 2007 (Watershed Watch 2007). More importantly, there are an additional 548 applications for a further 657 such diversions (Private Power Watch 2008).

These diversions create a "run of river" dam in which water is backed up only enough to create pressure that drives it down a penstock and through a turbine. Most run of river projects generate less than 50 megawatts (MW). In such a dam, the penstock and turbine are built beside the river, not in it, and the river continues to flow over the low dam. Apart from short-term construction impacts, effects on fish include loss of riffle habitat in headponds, mortality in penstock intakes and at the dam, and changes to flow, temperature, depth and sediment in the river below the dam that affect the ecosystems fish depend on. These and associated impacts are discussed in Watershed Watch (2007). For most streams, they are not the kind of impacts that affect Pacific salmon directly, because run of river projects are built upstream of salmon spawning areas. The planned development at Sedan Creek in the Skeena watershed may, however, result in a net loss of salmon spawning habitat (Orr 2008 pers. comm.). There may also be cumulative, indirect effects of many such projects on Pacific salmon, through road construction and changes in stream flow and communities. Reduction in flow may be especially significant, as it can reduce the recharging of aquifers. Of course, reduction in flow may also come from another source – the overall predicted decrease in flow rate of glacier-fed streams as a result of global warming (Stahl et al. 2008) that may compromise the sustainability of such projects.

While most of the new construction is for run of river dams, this does not mean that the threat of large-dam construction is completely absent, as the recent revival of the Site C concept illustrates (BC Hydro 2008).This third major dam on the Peace River (the existing ones are the WAC Bennett Dam and the Peace Canyon Dam) would add 900 megawatts to the grid. While there are no salmon implications for the project and it will be years before any decision is made, the current discussion demonstrates that large-dam construction in B.C. may not entirely be a thing of the past.

THREAT 2: Hatcheries and enhancement

Wild salmon are genetically very diverse. The number of distinct populations that comprise the seven species of anadromous salmon in North America has been estimated by many, with widely varying conclusions (Riddell and Tautz 2003). Identification of a population is usually based on its confinement to a natal stream – a criterion that some have argued yields an inflated impression of overall diversity and makes it hard to agree on the overall status of a species. Waples et al. (2001) arrives at a historic figure of 22,300 spawning populations in North America, while Slaney et al. (1996) identify 9,080 populations for BC and Yukon, excluding the Strait of Georgia. In many cases, populations get grouped into meta-populations, based on similarity, geographic closeness and the ability to exchange genes. Meta-populations are increasingly used for describing practical conservation units, and the way they are chosen can often lead to disagreement about the status of salmon (for an example, see Pacific Salmon Commission 2008, which takes issue with the IUCN’s choice of population boundaries for sockeye). For the purposes of this discussion, the “real” number of populations matters less than the fact that genetic variability in Pacific salmon is high.

Salmon hatcheries have long been used to add more fish to the harvest pool and, more recently, to compensate for freshwater habitat loss. Hatchery programs have indeed provided more salmon for harvest, but their cumulative effect on the enormous diversity represented by all the wild populations noted above is now hotly debated. The issue is actually a global one, because the early “success” of salmon hatcheries (not just in North America but in Japan and Russia as well) stimulated similar efforts in other countries. In Brazil, for example, concerns about construction of large dams causing problems for migratory fish species were officially dealt with by massive state-sponsored hatchery programs in the 1970s, which resulted in a large-scale, essentially unmonitored injection of fingerlings into reservoirs and rivers that continues today (Carolsfeld et al. 2004). Nobody really knows if this massive effort, modeled after North American hatcheries, is working. In Japan, where most chum salmon production comes from hatcheries, there is almost no river-specific monitoring, and the concept of managing hatchery and wild fish together is emerging very late in the day (Morita et al. 2006). Despite these warning signs, hatchery-based enhancement is being heavily promoted to "rescue" fisheries in many developing countries. As is so often the case, the North American model may become discredited at home, but it's still exportable.

Kinds of hatchery

It's important not to lump all hatcheries together. There are big differences between traditional large-scale hatcheries, small-scale supplementation or conservation hatcheries, and captive broodstock programs that use second-generation, hatchery-raised breeders when wild breeders are to all intents and purposes unobtainable. Historically, Pacific salmon hatcheries have been used for to mitigate damage (e.g. damage caused by dams or other habitat alteration) and to increase the numbers of fish for harvest. A good broad division can thus be made between hatcheries with fisheries goals, and those aimed at conservation. Naish et al. (2008) suggest the following categories:

- Production hatcheries for fisheries enhancement (includes ocean ranching)
- Mitigation hatcheries (to make up for specific habitat damage)
- Supplementation hatcheries (to improve status of an existing population)
- Captive broodstock programs (when the wild population has collapsed)

Within these broad categories, one has to be careful about the breeding strategy used. A hatchery population can be founded from the local wild population or from a different river (which makes it "non-local"), and it can be perpetuated by spawning hatchery-origin returning breeders or by blending these with the local wild fish (Araki et al. 2008). If most of the adults returning to a hatchery are from hatchery stock themselves, there isn't much room for selecting broodstock. Supplementation or conservation hatcheries try to get around this limitation by using only the original, local stock.

Captive broodstock programs respond to the realities of a collapsed population by producing breeders in-house to eliminate any pressure on wild stocks. In some cases, a captive broodstock programs is the only thing maintaining a run, so the issue of using wild fish for broodstock is academic. The Snake River sockeye in the US is a well-known example; in BC, the captive breeding program for Cultus lake sockeye is another. As things stand now, if there were no captive breeding program for Cultus sockeye, there would be very few returning fish. Cultus sockeye is a case of management pulling out all the technical stops, including gene banking, in a last-ditch attempt to save a population. Cultus lake sockeye is a high profile stock close to population centres; a more remote population would be unlikely to receive such attention. A final irony is the fact that one of the big reasons for the collapse of the Cultus sockeye population was its interception in a mixed stock fishery that relied heavily on sockeye from Weaver Creek, whose numbers were increased by enhancement in a spawning channel.

Criticism of hatcheries

First, we need to remember that the salmon hatchery is a horse that left the barn long ago. There have been hatcheries in B.C. since the 1890s, with a major boost from the Salmonid Enhancement Program (SEP) in the 1970s. Production peaked in 1992 with release of 700 million fish from hatcheries and spawning channels. In contrast, Alaska releases twice as many fish as does B.C. while the world leader, Japan, releases more than 2 billion; most of that country's chum salmon originate in hatcheries (Naish et al. 2008; Morita et al. 2006). This long history means that genetic effects – which are probably the most important and will be reviewed below– have had decades to act, and many hatcheries operated for a long time using egg and sperm donors from non-local stocks.

Criticism of hatchery programs is probably at its most intense in the US Pacific Northwest, where many commentators – on both science and policy — present evidence that hatcheries have *not* contributed to historical increases in salmon. There are many reviews and books to choose from here, for example those of Kleiss (2005) and Lichatowich (1999). The interactions between hatchery-produced and wild salmon have been widely debated for at least two decades, especially in the US Pacific Northwest and British Columbia. Current research strives to quantify effects whose potential was identified many years ago, but for a technology that has been so pervasive and has contributed so much to maintaining harvest rates (a good example is the Robertson Creek chinook hatchery, which supports the Alaska troll fishery) there are unlikely to be any surprises. The real question is what kinds of trade-offs between having wild salmon and having fisheries are acceptable to society.

The federal Salmonid Enhancement Program, which accounts for many of the hatchery programs in BC, has been reviewed in the past (for example, Hilborn and Winton 1993), and continues to be reviewed periodically. Its aims and methods (which are not limited to hatcheries and include other methods of enhancement including spawning channels, lake and stream enrichment and incubation boxes) are described by MacKinlay et al. (2004), who stress the program's strategy of mimicking natural conditions and life history characteristics of each species as much as possible and integrating naturally produced and hatchery-produced portions of target wild stocks. SEP hatcheries follow guidelines that are constantly revised and aim to minimize potential negative effects on adjacent, wild stocks.

What do we now know about hatcheries that justifies their inclusion as a threat to wild salmon? Hatcheries and enhancement programs come in many shapes and sizes, so one needs to be wary of generalizations, especially for the many small-scale operations whose effects are local. It's also important to realize that many of the threats are well recognized in BC and have already been mitigated to some degree, for example by changes in SEP guidelines. The following section summarizes the reported detrimental effects, assigns these to the categories of hatchery already noted above, and notes ways to reduce risk.

Genetic threats from hatcheries

Hatcheries can reduce the effective population size (which is not the same as census size); the net effect is less genetic diversity and more inbreeding, which eventually causes a loss of fitness. A less-fit population is less able to respond to environmental change.

Hatcheries circumvent many natural processes of selection: spawn timing, competitive mate selection and nest building. In their place, hatcheries substitute another kind of selection, in which the population gradually adapts to hatchery conditions; the effects are larger with captive broodstock rather than broodstock selected from a spawning stream, and get worse with time. Some traits are more likely to be inherited (selected for) than others; in salmon, egg size has frequently been reported to have a strong genetic component (reviewed in Araki et al. 2008).

There is still much discussion about how much adaptation to domestication is phenotypic (a change in appearance that's not inherited) and how much is truly genetic, and whether husbandry practices can minimize selection (Berejikian et al. 2000, 2001). There is much to be learned about the importance of domestication to fisheries management (Naish et al. 2008). Araki et al. (2008) argue for a genetic (heritable) effect of domestication on fitness, and conclude that the loss of fitness is greater when non-local fish are used as broodstock.

If hatchery fish are indeed less fit, hybridization with wild fish can lead to several things, including a reduction in effective population size and a reduction of overall fitness. Hybridization is especially likely to decrease fitness if the hatchery stocks come from a different system; the eventual outcome of hybridization is difficult to predict (McClelland and Naish 2007).

Loss of genetic diversity and domestication selection are the biggest genetic risks for captive broodstock programs. Supplementation hatcheries have the advantage that inbreeding and domestication selection can be reduced by collecting broodstock from the wild, but some change seems inevitable (Waples 1999). Pearsons et al. (2007) showed that conservation or supplementation hatcheries, even using state of the art methods, can produce small domestication effects even after one generation of fish culture; whether the effects are additive in successive years is not known. Production hatcheries have the option not only of obtaining local or outside broodstock, but also of deciding whether or not to keep the hatchery population separate from the wild population (by controlling the breeding of marked individuals). There is much evidence that, if wild and hatchery fish interbreed, the offspring are less fit than wild fish: (Naish et al (2008), provide 34 recent references, and Araki et al. (2008) reach the same conclusion.

In fruit flies, long-term breeding in captivity produces large genetic adaptations (Gilligan and Frankham 2003). While fruit flies are a long way from salmon, the finding is still relevant, and should be in the backs of hatchery managers' minds when captive breeding has become the only way of "saving" a population. Some of the pitfalls of extended captive breeding can be seen from the case of *masu* salmon in Japan, where hatcheries use captive broodstock because of difficulties in collecting from the wild. There has been a clear decline in genetic diversity as well as an increase in abnormal foraging behaviour in these lineages (reviewed in Morita et al. 2006).

In summary, it is clear that hatchery programs affect genetic diversity within hatchery populations, and that the decline in fitness is greater when the hatchery program relies on non-local stocks for its breeders. When hatchery populations are allowed to interact with wild populations (either through the normal course of sharing the same marine environment (which can't be controlled) or through breeding with wild fish (which can), the wild population can suffer. Naish et al (2008), after 26 densely referenced pages reviewing the genetic effects of hatcheries, argue for three "next steps": gather data by means of experimental releases from all hatcheries; develop a monitored, risk-averse approach to hatchery management; and stay tuned to the trade-offs society is prepared to accept, because some genetic change is inevitable.

Behavioural and ecological threats from hatcheries

Hatchery fish compete with wild ones. Having more fish survive the early rearing stages in a hatchery, then adding these huge numbers of fish to the wild, was assumed to be the best way of increasing overall numbers of catchable fish. However, food and space limit the intrinsic smolt production of streams, so competition between juveniles is inevitable. If one cohort has an advantage, the overall population can suffer. For example, if the hatchery-raised fish are larger at release than their wild counterparts, they may be able to out-compete them. This is a murky research area, because few studies distinguish between the effects of competition and those of simple density (Weber and Fausch 2003). At the very least, competition scenarios need to take into account the normal behaviour of the species in question (pink and chum, for example, don't spend much time in rivers).

If competition favours hatchery smolts, through size or sheer numbers, the advantage may be eliminated by their decreased survival and breeding success. The only remedy is to inject more hatchery fish to sustain the population (Kleiss 2005).

Depending again on the species, predation can also happen. Coho smolts especially can eat younger pink, chum, sockeye and chinook fry and smolts. This predation could, of course, go either way, depending on which species was hatchery-produced and which was wild. Recent studies show that vulnerability to predation can increase after as little as one generation of state of the art hatchery culture (Fritts et al. 2007).

Harvest threats from hatcheries

The theory of production hatcheries is simple: increase the number of recruits per spawner by increasing early survival, and you can harvest more fish. Coded wire tagging programs demonstrate that it works very well, and that hatchery stocks can be harvested at very high rates of interception. Here, though, is the problem: wild stocks with lower sustainable exploitation rates are mixed in with the hatchery stocks, and because the stocks are harvested before they have separated out for spawning in their home rivers, the smaller, un-enhanced wild stocks are hit harder. The best-known example is probably the "success" of the Weaver Creek sockeye spawning channel in producing a much healthier run than Cultus sockeye, with which it migrates; disproportionate harvest in this mixed-stock fishery was one of the main reasons for collapse of the Cultus population (Cultus Sockeye Recovery Team 2005). In many cases (for example the chinook troll and sport fishery), hatchery fish come from several different hatcheries. The wild fish mixed in with this collection can be exposed to an unsustainable harvest rate.

Possible solutions include reduced harvest rates; time-area closures for mixed-stock fisheries; selective fishing and hatchery-only retention; and closing down some hatcheries and spawning channels. All of these approaches to reducing the harvest-related impacts of hatcheries and enhancements are either presently being adopted or under discussion in BC.

Disease threats from hatcheries

Most of the pathogens that affect both wild and hatchery salmon originate in the wild. However, their effects are rarely seen in the wild; it's when the disease is amplified in the crowded conditions of culture facilities (higher density, lower water quality) that outbreaks become obvious. McVicar (1997) maintains that there are few well-documented cases where hatchery fish have affected the health of wild stocks. Introduction of exotic pathogens has occasionally occurred, although there have not been any serious effects in B.C. salmon. Amplification of endemic pathogens is more likely, but there is little evidence of this happening in salmon hatcheries in B.C. (Naish et al. 2008). Amplification of sea lice by Atlantic salmon production sites, and subsequent infection of out-migrating wild juvenile salmon will be discussed later (see *Disease*); it is not a hatchery effect. Good fish husbandry can go a long way to reducing disease problems in hatcheries. Paradoxically, hatchery juveniles that have been produced in a hatchery with an effective disease-control program may in fact be more susceptible to disease than wild fish, and suffer an outbreak in the wild that spills over into the wild population – a sort of "amplification in reverse."

THREAT 3: Harvest

Graphs of annual salmon catch show well-known historic peaks and declines and are used to make arguments for a variety of positions. But, as Riddell and Tautz (2003) point out, the story is more complicated, because the number of salmon caught reflects not only salmon production (which is influenced by marine conditions) but also management regulations and the prevailing markets. A decline in catch may indeed mean a decline in status, but it can also mean a shift away from harvest and toward maintaining spawning escapements.

The argument that economic extinction (the point where it's just not worth fishing a species any more) will happen early enough to stave off actual biological extinction has often been advanced as one advantage held by marine species. In other words, fishing will grind to a halt before it's too late. This argument certainly doesn't hold for Pacific salmon *populations*, at least as long as there are mixed-stock fisheries, and the fact that so many of the threats to salmon happen in their freshwater habitat makes it even less relevant.

Although harvest rates have declined from the highs of over 90% to 40-50% (and often lower), most Pacific salmon populations have still experienced many decades of sustained, intensive fishing using a variety of gear types (Hard et al. 2008). Mixed stock fisheries, where weak stocks are harvested disproportionately in comparison to the stronger stocks they happen to be swimming with, have been an undeniable and major source of decline in many populations; the classic case for Fraser sockeye was the small Cultus population. Recently, though, as the Wild Salmon Policy kicks in to limit such mixed stock fisheries (as has now happened for Cultus), the threat posed by commercial fisheries may be less important than, for example, poor ocean conditions (Pacific Salmon Commission 2008).

Whether harvest is a greater or lesser threat than all the others is probably less important than the fact that it may be the easiest to control – easy technically that is, but difficult politically. Rather than join this debate here, it seems more useful to look at some of the effects of fishing beyond the decline in numbers. In other words, what are the less-obvious, but just as important, effects of harvest?

Loss of genetic variability caused by harvest

The vulnerability of salmon is well known, and reflects their use of both ocean and freshwater habitats and their desirability as food; salmon are probably the second most vulnerable anadromous species, after sturgeon (Kenchington 2003). At the population level, much biological diversity can be lost before the species itself becomes extinct, and it is at this level, which provides the "safety net" for adaptation to future environmental changes, where there is most concern.

Over the evolutionary long term, the only way genetic variability can be created is through random mutation, over time scales of thousands of years – but there are several ways it can be eliminated. The commonest is to simply reduce population numbers, which is the best-known effect of harvest. Mixed-stock fisheries that simultaneously harvest genetically distinct stocks of unequal numerical strength are usually the culprit.

The tools to limit this kind of loss have existed for decades (even if they are sometimes excruciatingly difficult to apply). Loss of variability occurs very rapidly, over a few generations, and the smaller the population gets, the more dramatic the change is. The concept of minimum population size continues to change, with the generic values accepted for fish in the 1980s (around 500 successful breeders) being revised upward, toward 1,000-5,000 breeders (Kenchington 2003).

Migrants between populations can reduce the risk of losing genetic variability. In Atlantic salmon, migration between populations can be significant (Hindar et al. 2004); in Pacific salmon, straying varies with the species. Straying is important, as it offers the chance for genetic exchange that may make the difference between survival and extinction; some recent authors prefer the less pejorative term “dispersal” (Schtickzelle and Quinn 2007), and point out that an ability to exchange migrants between populations is part of the definition of a meta-population, a concept that is gaining ground in recovery planning.

DFO’s Wild Salmon Policy (WSP) is a groundbreaking attempt to re-cast the management of Pacific salmon in the light of biodiversity preservation and maintenance of habitat and ecosystem integrity (Government of Canada 2005). Tailoring harvest to preservation of genetic diversity is one major way in which the WSP will be implemented. The WSP acknowledges the importance of genetic diversity for sustainable fisheries in a way that would have been unthinkable even a few decades ago, when the notion of limiting mixed stock fisheries in order to conserve a single weak population would not have arisen. Implementing the policy is not easy, and the participatory process of identifying “conservation units” and then defining harvest regimes sensitive to their health is still a work in progress. A conservation unit (CU) is “a group of wild salmon sufficiently isolated from other groups that, if lost, is very unlikely to re-colonize naturally within an acceptable timeframe;” in many ways, a CU is similar to a meta-population. Even when conservation units have been defined, monitoring them and their habitat status is a big commitment, and maintaining them may be politically unpopular, a reality the WSP acknowledges.

Evolution in response to fishing

There is another, lesser-known way of altering the genetic makeup offish populations, namely by causing selective evolutionary pressure through the act of fishing. Law (2000) concluded that the directional selective pressure of fishing was substantial. Fishing is highly selective (favouring, for example, a particular size, sex, life cycle stage or location), and more researchers are starting to look for evidence that these kinds of selective pressure can actually get reflected in the genotype of a population. Because the salmon phenotype (non-inherited appearance or behaviour) is strongly affected by environmental conditions, there is a big problem separating genetic effects from the effects of the environment: is the effect actually inherited?

For salmon, different gear types have different selection pressure: gillnets, for example, select for size; hook and line fisheries select for size and timing; purse seines are less selective for size but more so for time and location. For some traits, such as the number and size of pink salmon eggs, there is now field evidence of heritability, which in turn means that if fishing selectively targets fish that, say, produce more eggs, the whole population will eventually produce fewer. In other words, fishing will have driven evolution.

A recent review of the scientific evidence for selective evolutionary pressure of fishing was provided by Hard et al. (2008) who cite strong empirical evidence of fisheries-induced *selection*, but still no hard evidence for fisheries-induced *evolution*; in other words, selection is really happening, but it can be overwhelmed by other factors that influence viability. Their review identifies many reports of, for example, declining overall body size in the salmonids fished in BC, but is careful to point out that while all of the reports are consistent with the occurrence of evolution, none of them provide direct evidence. Such evidence is difficult to detect, for reasons pointed out by Riddell (1986), and three major uncertainties remain: which life history traits in salmon are genetically based; how quickly fishery-caused evolution could occur; and whether the effects can be reduced or eliminated through management.

There are nevertheless some examples where an evolutionary effect of fishing seems very clear, including the North Sea plaice and Atlantic cod (Hutchings and Reynolds 2004). Hard et al. (2008) urge a concerted research effort to untangle the genetic effects of fishing from other factors. If the genetic effects of fishing on salmon are as important as many scientists, from Ricker (1981) forward, believe, management tools that could be used to reduce this effect include reducing size selectivity and focus on mature individuals close to spawning areas to avoid selecting for maturation time.

THREAT 4: Climate change

There are two kinds of “climate change” in the North Pacific. One is human-caused global warming caused by increased carbon dioxide and other greenhouse gases in the earth’s atmosphere; the other is called a regime shift. Discussions of the effect of “climate change” on Pacific salmon don’t always make the distinction.

Global warming: one kind of climate change

Global warming is large scale and inexorable. It is the wild card in all our lives, and has turned conservation planning – not just for salmon, but for all plants and animals – on its head. People are just beginning to come to grips with its potential effects, and how to minimize them. There are some predictions about how global warming will affect Pacific salmon, and we will return to them. The important thing to remember is that global warming affects all of the habitats used by Pacific salmon, in the ocean and in freshwater, and all of the life stages.

Climate change may be the ultimate example of humans reaping what they sowed not just yesterday or a few decades ago, but as far back as the last century when economies based on industrialization began to proliferate. Compared to all the other threats described in this report, human-caused global warming is not only the giant among pygmies, it is also the giant that tells the pygmies what to do. Climate change not only acts alone, it also amplifies or transmutes the effects of all the other threats. If stream temperature rises because of groundwater extraction to get at coalbed methane, climate change makes it even worse. If a salmon population's immune system is weakened through chronic exposure to chemical contaminants, a new pathogen brought north by climate change will have that much more of an impact.

Another ricochet effect: the explosion of mountain pine beetle infestation in the Fraser watershed, itself an outcome of global warming, has secondary effects on salmon by altering the way forests hold snow and help regulate flooding, with effects on stream flow and temperature that will be exacerbated by the rush to salvage-log infected trees before they're worthless (Pacific Fisheries Resource Conservation Council 2008). Logging involves road construction and use, falling, yarding and silviculture, and implies a constellation of familiar side-effects on fish habitat that can last for decades. This example perfectly illustrates the folly of considering threats as though they operated in isolation: in this case, climate change has the cascading effect of facilitating an ecosystem change (explosion of beetles; death of trees) that triggers a human response (salvage logging) that harms salmon. The ecological and socioeconomic fallout from this sequence of events in the pine forests are enormously important (Hartman 2008 pers. comm.).

Conservationists and managers can comprehend and reasonably attempt to mitigate things like over-harvest or habitat loss, but it will take a special kind of dedication to do these things in the face of global warming. In a world where the demand for food will increase threefold in the next fifty years, changes in temperature and rainfall become acutely important for *all* kinds of food production, including fisheries and aquaculture, and the importance of preserving salmon biodiversity in southern BC rivers may pale in comparison to things like a fight over water to grow a disease-resistant variety of sorghum. Global conflicts over water alone are likely (McMichael 2001).

In BC, the primary effects of global warming will be seen in the water cycle, through effects on snowpack and by causing more frequent extreme weather events (like flooding). The action in familiar arenas for biological and social conflict, for example competition for water between hydroelectric generation and instream flow, will become more intense (Lemmen et al. 2008).

Regime shifts: another kind of climate change

The other kind of climate change is a dramatic change in marine ecosystem dynamics called a regime shift (Polovina 2005). Regime shifts can occur because large-scale marine ecosystems are highly dynamic – sometimes even chaotic—and able to change quickly (Hsieh et al. 2005). In a regime shift, the abundance of various species at all trophic levels changes over a matter of months, then persists for years to decades. The changes appear to be caused by large-scale shifts in atmospheric or ocean conditions and span entire ocean basins (including the North Pacific). In the Northeast Pacific, the regimes are:

- Cold regimes (also called La Niña-like) with a weak Aleutian low pressure system, a strong California Current, cooler sea surface temperature and high productivity. Cold regimes dominated between around 1900-1925 and 1950-1975.
- Warm regimes (El Niño-like) with a stronger Aleutian low, weaker California Current, higher surface temperatures and lower productivity.

The shift between the two sets of conditions is called the El Niño Southern Oscillation (ENSO), and it occurs on a fairly short time scale, every 2-7 years (Mote et al. 2003). Another kind of oscillation, the Pacific Decadal Oscillation (PDO), is less well understood than ENSO but affects Pacific salmon more strongly. Its time scale is longer, tending to stay in one phase for 20-30 years at a time. Only two complete oscillations have so far been observed.

The PDO produces an up-and-down effect on salmon productivity in the northeast Pacific that's strong enough to have caused regional differences in abundance about which biologists and managers have had to learn, painfully, over the last two decades. Briefly, salmon in the Pacific Northwest states are more abundant in the cool PDO phase (and less abundant in the warm phase), while Alaska stocks are the reverse. The pattern in BC is mixed.

Regime shifts have political ramifications (Miller and Munro 2994), because they can direct salmon away from one oceanic migration route (for example, through Juan de Fuca Strait) and down another (in this case, Johnstone Strait, where US fishermen have no access). They can also play havoc with international harvest-sharing agreements like the 1985 Pacific Salmon Treaty (Miller and Munro 2004).

The headaches these differences in abundance caused for managers and for Canadian and American negotiators of salmon-sharing agreements have been well reviewed. For example, after the 1977 regime shift, Alaskan catch reached record highs, while stocks in the southern border region plummeted (Noakes et al. 2005). The bottom line is that to fish sustainably under different PDO regimes means adjusting regional harvest rates. It is not possible to sustain constant catches for species that undergo regime shifts (Polovina 2005).

Combined effects of global warming and regime shifts

Managing Pacific salmon is hard enough in the face of what are essentially natural regime shifts. Human-caused climate change (global warming) just makes things worse, adding another level of uncertainty to an already complex situation. Some have argued that the multi-decade time scale of the PDO can give us a taste of what human-caused climate change will be like, but at this point the “threat” of climate change to Pacific salmon can only be stated in the most general of terms. What are they?

First, temperature is critical in all phases of the salmon’s life. Thermal limits define the overall geographic range (which also varies with the species) and mean climate determines productive regions in the ocean. The changes that salmon will face in a warming world are much easier to predict in the freshwater part of its life cycle. A very simplified view of these changes includes:

- Earlier spring snowmelt and freshet (which disrupts smolt out-migration);
- Milder winters with increased fall and winter flooding because of increased rainfall (which disrupts spawning);
- Higher summer stream temperatures and lower stream flows (which disrupts or accelerates migration, spawning and fry development; Casola et al. 2005).

All of the Pacific salmon species and individual populations have adapted over millennia to conditions of temperature, stream flow and the timing of local events; climate change will present them with different conditions. A good example would be smolts arriving at sea earlier than usual because of warmer streams, but finding the ocean and estuary conditions have not caught up (Mote et al. 2003). The Pacific Salmon Commission, in its response to IUCN’s 2008 red listing of certain Fraser sockeye populations, points out that the increased adversity of river conditions is consistent with climate change and may in fact pose the single greatest threat to Fraser sockeye populations (Pacific Salmon Commission 2008).

In the marine environment, effects of warming are much harder to predict because they are probably less direct, being modified by changes in surrounding communities (Mote et al. 2003). They are also harder to study: collecting biological data at sea is more work than measuring stream flow (Mote et al. 2003). Experience with the effects of different levels of ocean productivity that result from the Pacific decadal oscillation suggests that these changes could range from modest to profound. Rising ocean temperatures will increase stratification (layering); changes in wind patterns may affect the amount and timing of up-welling that brings nutrients to the surface; and rising acid levels could change plankton communities, with a ripple effect through the ecosystem (Crozier et al. 2008).

Because there are so many variables – multiple salmon species and populations, multiple life stages and interactions with other species, multiple additional stressors that can interact with climate, ENSO and PDO fluctuations – only the most general predictions can be made about the net effect of global warming on Pacific salmon. And unfortunately, the large scale changes in atmospheric and oceanic circulation patterns that lead to regime shifts are still poorly understood, and unpredictable (Miller and Munro 2004).

Fish can respond to warming in several ways: go extinct from thermal stress; go north; or adapt through rapid natural selection (Reist et al. 2006). Because salmon have diverse life history stages, are locally adapted to different freshwater conditions and have different migration routes at sea, their response to warming will vary. Shifting northward is commonly advanced as the most likely for many species, including salmon, but here again the ecosystem complexity can trip us up, because it's not only salmon that could move.

If salmon respond to global warming they way they do to the warm phase of the PDO, southern BC stocks might be expected to decline, while those in the north, and the Alaskan stocks, increase. Reist et al. (2006) point out that brook trout are very likely to extend their range northward; they may also expand into coastal BC. So too with walleye *Sander vitreus* (Chu et al. 2005). Both of these species can interact with Pacific salmon, by competition or predation (see *Alien species* below); in other words, whole ecosystems will be shuffled.

When there are species shifts in coastal fish communities in general, how much of it is due to climate change, and how much to fishing? By looking at long-term (almost 50 years) trawl surveys in Narragansett Bay, Rhode Island, Collie et al. (2008) tried to determine what had caused the well-known shifts from fish to invertebrates and from a benthic to a pelagic regime. They found the strongest correlation was with the steady increase in sea surface temperature, including replacement of coldwater fish with what used to be seasonal migrants. Fishing was implicated in decline of some of the commercial species, but not with overall species composition. There were thus two long term patterns: a gradual decline in demersal fish, an increase in invertebrates and a decrease in mean size that was driven mainly by temperature, and only secondarily by fishing; and a more rapid shift from benthic to pelagic species that was strongly tied to the North Atlantic Oscillation. In other words, neither climate change nor fishing acted alone.

Genetic adaptation to warming

If salmon adapt, it is still much too early to say how much of that response will be simple toleration ("phenotypic plasticity") that may buffer a population against human-caused threats, and how much will be real genetic adaptation. The problem is, we don't know how to predict which is most likely for any given salmon species, population and threat, and salmon won't have the luxury of adapting to one variable (such as temperature) at a time. Crozier et al. (2008) identify some traits, including upstream migration date and spawning date, where there is good evidence that genetic adaptation will occur; other traits, like emergence timing, smolt migration timing and habitat choice, may be more the result of phenotypic plasticity. It is the mix of these two kinds of adaptation that will determine whether a particular population persists as its surroundings slowly change.

Different species also appear to have different capacity to adapt. Pink and coho seem to be the least flexible, with rigid life histories, while chinook and steelhead have the greatest variety in life history strategies (Waples et al. 2008). Pacific salmon can evolve quite rapidly, both on geologic time scales (for example, areas uncovered by the last glacial retreat show much population diversity). Even within so short a time as 100 years, evolution can occur, as shown by the genetically based trait differences in the descendents of chinook salmon introduced to New Zealand (Waples et al. 2008). As for the amount of adaptation remaining, these authors believe that, if what we have left can be conserved, salmon species can survive and thrive. Further encouraging evidence of the ability to adapt is cited by Gustafson et al. (2006), who describe Pacific salmon spawning and persisting below dams, and in the change of migratory timing and speed in sockeye in the Columbia River in response to decreasing flow and increasing temperature.

The importance of biodiversity

Not surprisingly, different populations of the same species may respond differently to climate change. A recent study of threatened chinook salmon in the Salmon River, Idaho, showed that the 18 populations studied fell into four clusters with different responses to summer temperature and stream flow. This study confirms two important points: there are populations that all respond similarly to climate change, but there are also significant differences in the way such groups respond as a unit. Both findings provide some basis for believing in the latent power of biodiversity (Crozier and Zabel 2006).

Tolimieri and Levin (2004), arguing for including climate change in any look at the risk factors for Pacific salmon, noted that different populations of chinook salmon in Washington and Oregon (some threatened and some not) responded differently to the same regime shift. This research used a mathematical model to predict population response, and highlights the fact that there is very little hard evidence of a true genetic response to climate change. We have already encountered this data gap in the earlier discussion of how salmon may evolve in response to fishing, and the problem is the same: because salmon respond so readily to changes in their environment (what's called "phenotypic plasticity"), it's tempting to say the response is genetic, and will be passed on to future generations. Unfortunately, the research needed to demonstrate genetic effects (which are the evidence of evolutionary change) is complex and difficult.

Yet evolutionary adaptation to climate change has become the strongest argument for preserving as much salmon biodiversity as possible, the reasoning being that the genetic variability contained in the many unique populations of salmon offers the chance that some of that variability will allow a population to tolerate the changed conditions warming will bring. Preserving that biodiversity – what Mote et al. (2003) call the "best hope" for Pacific salmon in a warming climate – of course means preserving habitat, keeping fisheries sustainable, and making sure that hatchery programs do not swamp native biodiversity.

This will be an exquisite balancing act. Climate change complicates the management of threatened or endangered populations. Population viability analysis (PVA), for example, is a tool that is used to predict the ability of a population to persist in the face of different harvest levels. Recent research has, however, shown that factoring climate change into the PVA model can produce quite different scenarios, including very different probabilities of extinction (Zabel et al. 2005).

Factoring climate change into habitat projects

What are the likely impacts of climate change on salmon habitat restoration? Most restoration is currently done without much consideration of climate change, beyond the conviction that “good habitat will be needed.” But in fact salmon inhabit many different kinds of rivers and streams, and the projected climate impacts are greatest for those at higher elevation, where changes in stream flow (the most important) will be greatest in these snowmelt-dominated streams. Paradoxically, preserving this kind of higher-elevation habitat, which is often less damaged, may be a case of spending money where the risk of climate-produced impact is highest (and the chance of success lower). Based on modeling, Battin et al. (2007) conclude that salmon recovery plans that concentrate on lower elevation habitat restoration may have a better chance of success.

Some thought is already going into ways to actually help salmon survive climate change, an approach that acknowledges the species’ intrinsic genetic adaptability and looks for human actions that can provide a better chance of success. Some of these actions, such as better irrigation methods to increase water use efficiency and maintain flow, can stand on their own as good habitat protection. Conserving groundwater by bringing in changes to BC’s outmoded Water Act is a common recommendation that would make sense even in the absence of climate change. But some suggestions are controversial, and in fact appear elsewhere in this report as threats: examples including hatchery breeding to create thermally adapted salmon and construction of new dams and reservoirs to store water needed to offset reductions in stream flow (Nelitz et al. 2007). Contradictions like these only underscore the dilemma salmon find themselves in.

THREAT 5: Salmon farms

For the last decade or so, much of the salmon aquaculture along the BC coast has been for Atlantic salmon, following gradual elimination of the small-scale local operations that introduced salmon aquaculture to the province in the 1980s. Those early efforts concentrated on Pacific salmon, which has declined in favour of the domesticated strains of Atlantic salmon used by the vertically integrated and largely foreign-owned companies that dominate the business today.

The Pacific salmon efforts were seen more as a novelty than a threat, and it was only in the last decade or so, after the rapid expansion of Atlantic salmon net-cage culture, that serious concerns began to be raised about possible environmental effects of salmon farming, including effects on wild salmon. Opposition to salmon farming now mirrors the industry in several ways, including centralized organization (a few large NGOs), better funding (from foundations and public donations) and better technology (a clear, well-crafted and broadly distributed message). Curiously, most of the concerns raised are for the effects of farmed Atlantic salmon, even though, of the 130 sites licensed for marine finfish aquaculture as of December 2007, close to 60% are licensed to produce coho or chinook salmon (Ministry of Agriculture and Lands 2008). The number of active Pacific salmon sites is probably closer to half that number, but there are still significant numbers of Pacific salmon in net cages along the south coast of BC.

Of all the real or perceived threats to wild Pacific salmon, salmon farming is the one in which the general public is most engaged. This does not mean this threat is more serious than, say, habitat loss, fishing or global warming, simply that a lot of time and money are spent trying to find an acceptable middle ground or fill in the knowledge gaps that prevent well-informed decisions. Sea lice is the best example. It and other aquaculture-related threats to wild salmon are discussed below.

Escapes from farms: genetic and ecosystem effects

Farmed fish escape. Some containment systems are better than others (salmon grown in onshore tanks would be less likely to escape than salmon grown in net cages in the ocean), but Murphy's Law has a way of ensuring that none are foolproof. If a truckload of fry traveling between sites goes into a river, fish escape (this has happened in BC). The Food and Agriculture Organization of the United Nations (FAO) recognizes this inevitability by recommending that introducing a new species to aquaculture be considered an introduction to the wild, even for a so-called closed system (FAO 1995).

Atlantic salmon escape from net cages as a result of storms, net failures or the occasional "leakage" of a few fish at a time that Volpe (2001) estimated at 0.5-1% of total annual production. These escapes pose two main threats to wild Pacific salmon. *Genetic* effects could follow if there were successful hybridization between mature Atlantic salmon and Pacific salmon; their offspring, if viable, would contaminate the wild gene pool. *Ecosystem* effects could happen three ways: successful hybrids could compete with wild pacific salmon for food and freshwater habitat; Atlantic salmon attempting to spawn in rivers could compete with wild salmon for space; or, if Atlantic salmon managed to reproduce and become established in a river, they could eliminate the resident Pacific salmon species by competing for spawning and rearing habitat. More subtle ecosystem effects, such as changes in bacterial communities, benthic communities, and fish and bird assemblages can indirectly affect wild salmon, but likely fade away beyond a few kilometers from the culture site.

Cultured fish differ genetically from the same species in the wild. The genetic differences will be greater than those between hatchery and wild fish, because, in addition to domestication selection, farmed fish have been deliberately bred for commercial traits like growth rate, disease resistance and feed conversion (Weir and Grant 2005). Fitness of farmed fish for life in the wild is lower than that of wild fish (Gross 1998), mainly through reduced survival and reproductive success. Gross (1998) goes so far as to describe Atlantic salmon in wild and aquaculture environments as "one species with two biologies," even proposing the species be split into two.

The general tenor of published work on both hatchery-wild interactions and farmed-wild interactions is that, "Yes, the hatchery fish can breed, they just don't do it as well as wild fish." This is a simplification of an extremely complex research field, and you have to remember that, impaired or not, genetically "inferior" fish from hatcheries or farms have managed to effectively replace wild stocks in many rivers in North America and Europe. If left to their own devices and not harvested too aggressively, such stocks would probably evolve and persist on their own, becoming the new "wild" stock.

The spawning requirements of Atlantic salmon are similar to those of Pacific salmon: usually in autumn, in clean, aerated gravel. There is very little evidence of interaction between the two species on the spawning grounds (Bisson 2006). Potential interactions between Atlantic and Pacific salmon juveniles are also hypothetical, but quite plausible, especially in fast water streams such as preferred by steelhead. Volpe et al. (2001) studied the potential interactions in experimental stream channels, and concluded that, because Atlantic salmon spawn earlier than steelhead, their fry would establish feeding territories earlier, and would compete successfully with steelhead, for food and territory. Much more research is needed on potential interspecific interactions.

Do the numbers of escapees justify these concerns? Between 1987 and 2003, more than twice as many chinook escaped as did Atlantics, and the number of reported Atlantic escapees has declined over the years, averaging around 27,000 in the five years between 1997 and 2003 (www.agf.gov.bc.ca/fisheries/escape/escape_reports.htm). However, these numbers represent voluntary reporting, are certainly underestimates (Bisson 2006), and do not go beyond 2003. Recent events like the escape of around 30,000 Atlantic salmon near Campbell River in 2008 are therefore not reflected. The summaries also don't account for small scale losses or "leakage".

In a 2005 review of the effects of farmed Atlantic salmon on wild Atlantic and Pacific salmon, the authors were surprised to find no published studies that directly measured whether wild fish populations had actually changed in size, density or growth rate as a result of salmon farming. In other words, direct demographic effects on wild fish have yet to be demonstrated; in the meantime we continue to rely on indirect evidence and models (Weir and Grant 2005). Direct evidence of competition in the wild is also scarce; which means we rely on laboratory experiments or inferences based on differences in appearance and genetics. An obvious policy recommendation is for more monitoring of demographic effects of escaped farmed fish.

How serious is the threat of escaped Atlantic salmon?

Will escaped Atlantic salmon become established in BC streams – that is, can they spawn with each other and produce viable offspring that go to sea, mature, return and spawn? What is the actual evidence? People who believe they *can* point to the published report of Volpe et al. (2000) on Atlantic salmon fry in the Tsitika River on Vancouver Island. Analysis of growth rings on the scales of these fish indicated stream rearing, and the authors concluded they were the offspring of escaped farm fish. Atlantic salmon fry have been identified in other BC streams; Bisson (2006), reviewing the evidence for the US Forest Service, concluded that their origin was equivocal. There have been no further reports on these potentially feral populations, or of others, in the intervening years.

People who believe Atlantic salmon *won't* become established in BC point to the many failed attempts to plant the species outside their native range – including the more than seven million juveniles deliberately released in BC between 1905 and 1934 (reviewed in Bisson 2006).

If this is all the hard evidence we have to go on, how does one interpret the threat of establishment of Atlantic salmon? First, the small number of fry found in BC rivers doesn't mean there aren't more: surveying streams for invasive salmon fry (usually by snorkeling) is extremely time consuming; as Volpe (2001) notes, less than 1% of potential streams had been surveyed, a coverage that is statistically meaningless. Second, just because a species is slow to become established doesn't mean it won't eventually. Atlantic salmon will continue to escape, they spawn in conditions similar to Pacific salmon and their juveniles prefer swiftly flowing streams, as do steelhead and some trout.

Continued recruitment from salmon farms remains a long term threat, as it could lead to local adaptation, repeating the pattern often seen with other invasive aquatic organisms, namely a long period of early colonization followed by rapid expansion. Failure of deliberate introductions doesn't mean that steady seeding, year after year, won't eventually result in establishment. There are no *a priori* biological reasons compelling enough to preclude this. Society, or its self-appointed advocates, has to decide how much this matters – and different societies feel differently about these things. In Japan, several non-native Pacific salmon species were introduced in Hokkaido, in attempts dating back to the 1950s; none became established. Few Japanese would have known about these attempts; even if they had, criticism would have been extremely unlikely. This is, after all, a country where sockeye persist only through continued hatchery propagation (Morita et al. 2006).

Another way of making this point is that societies differ vastly in the degree of risk they will accept, and for all the threats to Pacific salmon, the crucial issue is risk tolerance (Naylor et al. 2005). Risk tolerance of aquatic invasions in BC is inconsistent, especially concerning the objection to Atlantic salmon populations becoming established in BC rivers. Few people seem prepared to demand "wild" oysters or clams on the menu; most are probably unaware that Japanese oyster and "Manila" clams long ago marginalized the native species, a spectacularly successful introduction from a time when such practices were fully sanctioned by government. Many people who are deeply concerned about escaped Atlantic salmon are likely unaware of the larger consequences of climate change on overall salmon distribution.

Finally and most interestingly, the objection to salmon farms in BC seems to concentrate on Atlantic salmon – but the risk of genetic contamination from escaped Pacific salmon is much higher, because there are no barriers to spawning between wild and farmed stocks.

In this sense, the millions of Pacific salmon smolts released from BC hatcheries over the last hundred years are nothing more than "deliberate escapes." Around 20% per cent of the salmon farmed in BC are Pacific species, and the genetic and ecosystem effects they could cause by escaping are, on a per-fish basis, probably much greater than those from Atlantics. Ford and Myers (2008), in their global statistical analysis of aquaculture impacts on wild salmon, said as much in noting greater effects on wild Atlantic salmon populations than in Pacific ones, because Atlantics can interbreed.

Diseases and parasites transmitted from fish farms

A recent review found disease transmission between wild and farmed fish – in either direction – to be poorly documented, mainly because it is so hard to get experimental data on the origin of a pathogen (Weir and Grant 2005). This does not mean that diseases cannot pass from farmed to wild fish; for example, Diamant et al. (2000) matched a bacterial strain found on rabbitfish to those on farmed sea bass in the Red Sea.

As a general rule, the risk of wild population declines from diseases and parasites becomes greater as host genetic diversity declines; put another way, genetic diversity acts as a crucial buffer against epidemics, in organisms as different as frogs, Hawaiian forest birds and Serengeti lions (Altizer et al. 2003). This principle is important for salmon conservation strategies: depending on too small a genetic base may ultimately weaken the host population's disease resistance. Captive breeding programs are a good example.

Weir and Grant (2005) considered the strongest case for pathogen transfer from farmed to wild fish to be sea lice, which represent the second, and much more immediate, threat posed by Atlantic salmon farming (the genetic threat is more slowly expressed, and has already been discussed). The implication of farmed Atlantic salmon in outbreaks of sea lice on wild Pacific salmon has much in common with some of the other threats discussed in this report: a hypothesis that few could argue with, but that's hard to test in the field. A second hypothesis – that sea lice from Atlantic salmon are actually causing the decline of wild salmon populations in BC – still relies on mathematical models. Models can be very powerful tools for visualizing competing scenarios, but they are human creations, responsive to the data fed into them, and malleable. Research on better mathematical models for sea louse dispersion, infection and transport is currently a high priority for the Pacific Salmon Forum.

A recent review of over 100 scientific papers on the effects of sea lice from farmed Atlantic salmon in BC concluded that it was still not possible to conclude that farm-origin sea lice were causing the demise of wild salmon in the study area (the Broughton Archipelago). Reasons included gaps in our knowledge of transmission dynamics in the areas where salmon are farmed and wild salmon occur; still-evolving mathematical models for transmission, infection and ocean currents; and lack of industry data (Harvey 2008). The report concluded that salmon farms in the Broughton produce large numbers of sea louse larvae; that encounters between those farm-produced larvae and juvenile pink and chum salmon cannot yet be observed but are completely plausible biologically and in all current mathematical models; that the percentage of sea lice on wild salmon that come from salmon farms can't be quantified; and that the role of alternate, "natural" sources of sea lice needs to be understood and quantified. Drawing a direct link between sea lice produced on salmon farms and the status of wild salmon populations is the next step; like so many of the other threats discussed in this report, finding unequivocal evidence for this hypothesis means going beyond supposition and mathematical models to confront some very complicated questions of field biology, a research process that is currently taking place in B.C.

While the results of that research accumulate (an updated review is currently under way), society's best response to the threat of sea lice is to recognize that lice from Atlantic salmon farms do represent an un-quantified incremental source of harm to wild Pacific salmon, then apply the precautionary principle by reducing that harm as much as possible.

THREAT 6: Contaminants

The North Pacific Ocean receives many contaminants from industrial and domestic sources. New analytical techniques developed in the last ten years or so have made it possible to detect more contaminants, and at lower levels, and the translation of all these new data into effects on aquatic animals is well behind our ability to measure things (Macdonald et al. 2003). There can be no better example of the power of the global commons to affect Pacific salmon than the finding that many of the contaminants that affect "our" Pacific salmon originate far away, in Asia, and arrive at the other side of the Pacific thanks to ocean winds and currents. Exposure is thus long-term and intergenerational, and includes a complex mix of chemicals whose effects will often be sub-lethal (which makers them very hard to measure) and delayed. Immune suppression, for example, may not matter until a new pathogen comes along. Some contaminants have both acute and chronic effects: oil spills cause immediate ecological disaster, but their effects also persist, and the likelihood of more spills (the last major one in the north Pacific was in 1989) will depend directly on the determination of Canada, the US, Korea and Japan to search for oil in the seabed and to ferry it past coasts.

Organochlorine compounds like PCBs, pesticides and dioxins (these are just a few) arrive in BC waters from Asian and local sources. They are magnified in food chains and very persistent, so bans on the use of some of them have had little effect on their availability to aquatic animals (and the bans have not been universal). Some point sources, such as pulp mills, are well known; some facilities have eliminated the use of many chemicals that nevertheless continue to be used elsewhere around the Pacific Rim.

Heavy metal pollution of the continental shelves of western North America is much lower than in Asia, where much of the marine life in marginal seas and bays is metal-contaminated (McDonald et al. 2003). Metal contamination remains closer to the source, mainly industrial waste and untreated sewage, and includes mercury (the cause of Minamata Disease in Japan) and tributyl tin (TBT), a component of antifouling. The effects of TBT linger, notably imposex (development of a penis by a female whelk). TBT provides a good illustration of how hard it is to regulate a known pollutant when it is globally distributed. Despite its prohibition on Canadian boat bottoms, TBT-containing antifouling paint continued to be used on oceangoing vessels from other nations until 2008; when these big boats congregated, as they did in Vancouver harbour, they released TBT. Ratification of legislation for a ban on the use of TBT antifoulants was only complete in 2007, and they finally became illegal anywhere in the world on September 17, 2008. The twenty-year international process for eliminating this one contaminant is a good example of the challenge of regulating marine pollutants.

Increasing population and industrialization – not only in BC but throughout the Pacific rim – will increase the threat from contaminants. Reducing or eliminating them will be a slow and painful process, particularly because so many contaminants are already loaded into global reservoirs of water, soils and vegetation. New chemicals will also emerge, bringing new problems.

Effects of contaminants on salmon

There are few references in the scientific literature to the effects of contaminants on Pacific salmon, although their presence in the tissues of various life stages has been demonstrated (in other words, we know salmon contain these contaminants, but we don’t yet know what damage they cause).

While salmon can be exposed to contaminants in fresh as well as salt water (agricultural pesticides are a good example), most of the literature concentrates on exposure in estuaries. Juveniles may be especially susceptible, as they are developing rapidly. A recent study of contaminant levels in out-migrating chinook and coho smolts in streams in Washington and Oregon found chemical contaminants (primarily PCBs, DDT and PAHs) in the tissues and prey of both species. Levels were highest in chinook, which spends more time in estuaries than does coho. For some contaminants, especially PBCs, tissue levels were within the range where health or survival could be affected (Johnson et al. 2007).

Possible estuarine effects on returning adult salmon were the subject of a comprehensive sampling study in the lower Fraser River that attempted to answer the question whether chemical contamination could be causing the phenomenon of early migration. Johannessen and Ross (2002) identified several major classes of compound where there was a need for research on exposure levels and effects:

- polybrominated diphenylethers (PBDEs) and phthalate esters (both persistent organic pollutants);
- organic surfactants including alkylphenol ethoxylates (APEs) and their degradation products;
- agricultural and household pesticides including metam sodium, formaldehyde, and chlorothalonil;

- wood preservatives including creosote, copper arsenate and ammoniacal copper zinc arsenate.

There were also contaminants for which there was almost no information but which were likely to be increasing in the environment, including pharmaceutical and personal care products entering waterways with sewage.

THREAT 7: Alien species

Atlantic salmon escaped from net cages are an example of an introduced alien species whose major impact is in the freshwater portion of the Pacific salmon life cycle. As we have seen above, the extent to which Atlantic salmon affect Pacific salmon depends on whether, or how well, they can become established along the coast, and it will be years, if not decades, before those questions are answered. There are, however, a number of other fish species introduced into lakes and rivers whose effects are much better known. The impacts of introducing a number of these species to BC waters have recently been reviewed, including their known effects on salmonids. The following short summaries are based on draft reviews prepared for DFO for northern pike, largemouth bass, pumpkinseed, smallmouth bass, walleye and yellow perch; the reviews are still in manuscript form.

Predation on salmonids by introduced species may be an insignificant contributor to the large declines observed in west coast populations when compared to the effects of habitat modification, fishing, and climate change. Predation could, however, make it harder for salmonids to recover. Alien fish such as largemouth bass are introduced into water-bodies already altered by human activities; once the introduced fish establish thriving populations it is difficult for damaged populations of salmon or trout to become re-established (Lackey 1999). The combination of formidable competition and altered habitat is no longer favourable to salmonids.

Introduced aquatic organisms can have five general kinds of impact: habitat alteration, trophic alteration, spatial alteration, gene pool deterioration and disease introduction (Kohler and Courtenay 1986). Taylor (2004) points also to the more general ‘homogenization’ where regional faunas become more similar to each other (this is also called ‘faunal similarity’).

Northern pike

In British Columbia, the native range of northern pike *Esox lucius* is confined to the northeastern corner of the province contiguous with the Yukon. This includes the Peace, Liard, Yukon, Alsek, Taku and Mackenzie River systems. The first known case of its introduction outside its native range in B.C. was in the Kootenay region in 2005, where several presumably illegally introduced northern pike were captured in Ha Ha Lake (S. Pollard, B.C. Ministry of Environment, pers. comm.). Northern pike have also recently been angled from the extreme northern end of the Koocanusa Reservoir, a large transboundary water body that connects with the mainstem Kootenay River (T. Brown, DFO, pers. comm.).

Most research on the interaction between northern pike and other species concentrates on its effect on prey fish communities. There are numerous reports of the detrimental effects of introduced northern pike on salmonids. Effects on sport fisheries for trout have been reported for a variety of systems in North America (McMahon and Bennett 1996) and Europe (Broughton 2001). Aguilar *et al*. (2005) cites predation on stocked trout in Lake Davis, California, where illegal introduction of northern pike has been well studied and where there is also a threat to the native chinook salmon (*Oncorhynchus tshawytscha*) in nearby watersheds. Northern pike may also be involved in the decline of native cutthroat trout (*O. clarki lewisi*) and bull trout (*Salvelinus confluentus*) in Montana (McMahon and Bennett 1986).

Perhaps the most exhaustive assessment of the potential impact of pike introductions on salmonids is in Alaska. The Southcentral Alaska Northern Pike Control Committee (2006) has reviewed the issue. The chief concern is predation on natural and supplemented populations of Pacific salmon (*Oncorhynchus spp*.), which could have both economic and ecological consequences given the salmon's position as a keystone species. In Alaska, the main problem is introductions outside the pike's native range (the species occurs naturally throughout much of the state), and the authors of the Alaskan report cite anecdotal reports of pike appearing in freshwater salmonid rearing habitat and lakes. A good example is the Kenai River system, where illegal introductions in tributaries have resulted in infiltration of many small lakes and streams; pike are now believed to use the mainstem river as a migratory corridor. There are even reports of their being caught by commercial fishermen in Cook Inlet, suggesting more widespread dispersal.

Largemouth bass

Largemouth bass *Micropterus salmoides* is native to North America. It is a capable invader, a strong competitor, and a known predator on native fish species. Largemouth bass is now one of the most widely distributed fishes in the world, mainly because of its popularity as a sports fish. Its North American expansion started in the late 1800s, aided by extensive stocking and the species' adaptable nature. Its range in Canada has expanded west to British Columbia. Invasive largemouth bass is a potential threat to freshwater biodiversity not only through its ability to alter native minnow communities but also for the potential to complicate recovery of already-depressed salmonid populations.

The most common route in B.C. is through illegal introductions into new water bodies, from which they can move through interconnected waterways to invade adjoining streams and lakes. Bass have dispersed within the Columbia, Kootenay and Okanagan regions through natural movements and illegal introductions. In the Fraser Valley, largemouth bass were introduced into the Sumas River and have spread into numerous water bodies including Hatzic and Silvermere Lakes and the Pitt and Salmon Rivers (McPhail 2007). Slaney and Roberts (2005) noted that invasive fish including largemouth bass have been illegally introduced into several urban Lower Mainland lakes and rivers. They felt these invasive fish have the potential to harm juvenile cutthroat trout through competition and predation.

Largemouth bass compete with a number of other fish species for food and space. Largemouth bass consume salmonids, especially when juveniles are migrating. Pflug (1981) found salmonids were an important diet item for largemouth bass in Lake Sammamish, although consumption of hatchery salmonids may have contributed to this finding. Tabor et al. (2004) examined largemouth diet in Lake Washington from February through June. Salmonid occurrence in largemouth bass varied by season, and was highest in June. Migrating young coho, chinook, and sockeye salmon were all eaten; the major salmonid prey item was coho. Bonar et al (2005) examined predation on coho fry and smolts by piscivorous fish in three shallow Pacific Northwest Lakes. Most predation occurred in spring, when coho smolts were migrating through the lakes or coho fry were moving from creeks into lakes.

In Oregon, interactions between largemouth bass and salmonids occur in coastal lakes with tributaries used by coho salmon, steelhead, and cutthroat trout. Coho are the native species most susceptible to predation because of their small size as fry and their migratory behavior into the lake. The juvenile coho that enter Oregon coastal lakes in autumn and winter are less susceptible to bass predation because they are larger and more pelagic. Summer rearing of coho fry no longer occurs in some lakes. Sea-run cutthroat trout and steelhead smolts migrate to the sea at a larger size, spend less time in the lakes, and are less susceptible to predation.

Smallmouth bass

The original Canadian distribution of smallmouth bass was restricted to the Great Lakes - St Lawrence system (Scott and Crossman 1973). In British Columbia, smallmouth bass now occur in most of the lowland Okanagan lakes, many lakes on Vancouver Island (including the Gulf Islands) and in the Kootenays (McPhail 2007). No transfers of smallmouth bass have been authorized since 1987.

Smallmouth bass prey on salmonids (Fritts and Pearsons 2006). Reports of such interactions are mostly from the US Pacific Northwest, and, the degree to which they actually affect salmonid abundance is not clear. In the Yakima River, Washington, smallmouth bass have replaced northern pikeminnow as the major piscivore on salmonids (Fritts and Pearsons 2006). In the Columbia River, the dominant fish prey species for smallmouth bass in spring were migrating salmon juveniles. However, no salmonids were observed in bass diet during the summer and autumn.

The timing of juvenile salmon runs as well as spatial habitat overlap are important in establishing the rate of salmonid consumption by bass. For bass and salmonids in Lake

Washington, overlap was minimal because sockeye and coho salmon juveniles had passed through Lake Washington prior to warming of the littoral zone (Fayram 1996; Fayram and Sibley 2000). Bass remain inactive until temperature rises in spring. Studies by Tabor et al. (1993) also indicated seasonal consumption of migrating salmonids. Bennett et al. (1991) concluded that predation on sub-yearling chinook salmon is known to be significant in the Columbia River and the size of juvenile salmonid may influence predation. He suggested that predation on Snake River fall chinook was potentially deleterious. Rieman et al. (1997) felt that sub-yearling chinook salmon may be more susceptible to predation because of their small size and later out-migration.

Walleye

In B.C., walleye occur naturally only in the north-eastern corner of the province. Native distribution includes the lower Peace, Liard, and Hay River drainages. In south-central B.C., however, walleye ascended through the Columbia system through planting, invasion, and illegal transport following the 1960 introduction in Roosevelt Reservoir. McPhail (2007) describes walleye as “seasonally abundant” in the Columbia main stem from Keenleyside dam south to the U.S. border. Walleye are reported from a location between Upper and Lower Arrow lakes, which suggests that the species is still spreading in the upper Columbia system. A barrier on the Kettle River, about 0.5 km upstream from the confluence with the outlet creek from Christina Lake, blocks upstream invasion farther into B.C.; however, further movement into the Arrow lakes is possible.

While the heaviest predator on salmonids in the lower Columbia is pikeminnow (Beamesderfer et al. 1996), losses from walleye are large. The highest losses of salmonids to piscivores occur in the lower Columbia; highest densities of walleye occur in the reservoir above the Dalles dam. In the mid-1980s, salmonids made up 14%, by weight, of the diet of walleye in the lower Columbia River (Temple et al. 1998). These authors estimated that loss of salmonids in the three lowermost reservoirs could be up to two million.

Yellow perch

Yellow perch are not native to the Yukon Territory, British Columbia, Prince Edward Island, Newfoundland or Labrador (Scott and Crossman 1973). The species has been introduced into many regions in North America from which they were historically absent, including most of the western United States (Moyle 2002). In Canada, the largest increase in non-native distribution has been in British Columbia, where yellow perch have been introduced to a number of lakes in the Peace River drainage. The species is now also found in a number of areas in southern B.C. after its introduction into eastern Washington State in the late 1800s; most of the B.C. populations (in the Kettle, Kootenay, Pend d’Oreille, and Okanagan river systems) arrived from downstream sources (McPhail 2007).

In the Columbia River system, yellow perch are abundant but not considered to be a major predator on juvenile salmonids (Zimmerman 1999). Yellow perch have smaller mouths than many piscivores (Keast 1985). In Lake Sammamish, WA, yellow perch had not been considered a major predator on salmonid smolts because of their size in relation to the out-migrating fish. However, following sampling in 2001, 40% of yellow perch contained chinook smolts in spring. Yellow perch may have had the ability to affect chinook migration because of their large population. In May, chinook smolts represented over 50% of yellow perch diet by weight (Footen 2003).

REFERENCES

Achord, S., Levin, P. S. and Zabel, R. W. 2003. Density-dependent mortality in Pacific salmon: the ghost of impacts past? Ecol.Lett. 6(4): 335-342.

Adkison, M. D., Finney, B. P. 2003.The Long-Term Outlook for Salmon Returns to Alaska. Alaska Fish.Res.Bull. 10(2): 83-94.

Aguilar, A. Banks, J. D., Levine, K. F. and Wayne, R. K. 2005. Population genetics of northern pike (*Esox lucius*) introduced into Lake Davis, California. Can. J. Fish. Aquat. Sci. 62: 1589–1599.

Altizer, S., Harvell, D. and Friedle, E. 2003. Rapid evolutionary dynamics and disease threats to biodiversity. Trends in Ecology & Evolution 18(11): 589-596.

Angilletta, M. J., Ashley Steel, E., Bartz, K. K., et al. 2008. Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences. Evolutionary Applications 1(2): 286-299.

Araki, H., Berejikian, B. A., Ford, M. J. and Blouin, M. S. 2008. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 1(2): 342-355.

BC Hydro 2008). www.bchydro.com/policies/sitec/sitec53692.html.

Baer,A. 2007. Dams and the environment: a bibliographic database. FAO Fisheries Circular. Rome, FAO. 2007. 47p.

Battin, J., Wiley, M. W., Ruckelshaus, M. H. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences 104(16): 6720.

Beamesderfer, R.C., D.L. Ward, and A.A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish (*Ptychocheilus oregonensis*) in the Columbia and Snake rivers. Can. J. Fish. Aquat. Sci. 53: 2898 – 2908.

Beechie, T., Buhle, E., Ruckelshaus, M., Fullerton, A. and Holsinger, L. 2006. Hydrologic regime and the conservation of salmon life history diversity. Biol.Conserv. 130 (4): 560-572.

Berejikian, B. A., Tezak, E. P., Flagg, T. A., LaRae, A. L., Kummerow, E. and Mahnken, C. V. W. 2000. Social dominance, growth, and habitat use of age-0 steelhead (*Oncorhynchus mykiss*) grown in enriched and conventional hatchery rearing environments. Can. J. Fish. Aquat. Sci. 57, 628–636.

Berejikian, B. A., Tezak, E. P., Park, L., LaHood, E., Schroder, S. L. and Beall, E. 2001a.

Male competition and breeding success in captively reared and wild coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 58, 804–810.

Berejikian, B. A., Tezak, E. P., Riley, S. C. and LaRae, A. L. 2001b. Competitive ability and social behaviour of juvenile steelhead reared in enriched and conventional hatchery tanks and a stream environment. J. Fish Biol. 59, 1600–1613.

Berejikian, B., Nash, C. 2004. Research on Captive Broodstock Programs for Pacific Salmon: Annual Report 2000-2001. Aqua KE Aquaculture Documents Library 2004: 915.

Bernhardt, E. S., Palmer, M.A., Allan, J. D., Alexander, G, Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, B. Powell, E. Sudduth. 2005. Synthesizing U.S. River Restoration Efforts. Science 308 (5722): 636 – 637.

Bisson, P. A. Assessment of the risk of invasion of national forest streams in the Pacific Northwest by farmed Atlantic salmon. 2006. UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE GENERAL TECHNICAL REPORT PNW 697, US DEPARTMENT OF AGRICULTURE.

Blumm, M. C., Thorson, E. J. and Smith, J. D. 2006. Practiced at the Art of Deception: The Failure of Columbia Basin Salmon Recovery Under the Endangered Species Act. Environmental Law 36.

Bonar, S.A., Bolding B.D., M. Divens, and W. Meyer. 2005. Effects of introduced fishes on wild juvenile coho salmon in three shallow Pacific Northwest lakes. Trans. Am. Fish. Soc. 134: 641-652.

Bond, NR, and Lake, PS. 2003. Local habitat restoration in streams: Constraints on the effectiveness of restoration for stream biota. Ecological Management & Restoration 4(3): 193-198.

Broughton, B. 2001. A Review of the Scientific Basis for Pike Culls. www.pacgb.co.uk/about pike/cullsbb.html

Brown, J. A. 2005. Commercially Harvesting Endangered Salmon-Rethinking the Interaction of Salmon Hatcheries and the Endangered Species Act after Alsea Valley Alliance v. Evans. Ga.L.Rev. 40: 253.

Carolsfeld, J, Harvey, B., Baer, A., and Ross, C. Eds. 2004. Migratory Fish Species of South America: Biology, Fisheries and Conservation. World Bank, Washington. 371 pp.

Casola, J. H., Kay, J. E., Snover, A. K., Norheim, R. A. and Binder, L. C. W. 2005. Climate Impacts on Washington's Hydropower, Water Supply, Forests, Fish, and Agriculture. Centre for Science and the Earth System, University of Washington, Seattle.

Chu, C., Mandrak, N. E. and Minns, C. K. 2005. Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. Diversity & Distributions11 (4): 299-310.

Crozier, L. G., and Zabel, R. W. 2006. Climate impacts at multiple scales: evidence for differential population responses in juvenile Chinook salmon. J.Anim.Ecol. 75 (5):1100-1109.

Crozier, L. G., Zabel, R. W. and Hamlet, A. F. 2008. Predicting differential effects of climate change at the population level with life-cycle models of spring Chinook salmon. Global Change Biol. 14 (2): 236-249.

Crozier, LG; Hendry, AP, Lawson, PW, Quinn, TP, Mantua, NJ, Battin, J.; Shaw, RG; Huey, RB. 2008. Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. Evolutionary Applications 1 (2): 252-270.

Cultus Sockeye Recover Team. 2005. National conservation strategy for sockeye salmon *Oncorhynchus nerka*, Cultus Lake population, in British Columbia. Ottawa, Ontario. 48 pp.

David Suzuki Foundation. 2008. Returning Salmon – Integrated Planning and the Wild Salmon Policy in BC.
http://www.davidsuzuki.org/files/reports/Returning_Salmon.pdf

Diamant, A., A. Banet, M. Ucko, A. Colorni, W. Knibb and H. Kvitt. 2000. Mycobacteriosis in wild rabbitfish associated with cage farming in the Gulf of Eliat, Red Sea. Dis. Aquat. Org. 39: 211-219.

Dulvy, N. K., Sadovy, Y. and Reynolds, J. D. 2003. Extinction vulnerability in marine populations. Fish Fish. 4 (1): 25-64.

Fayram, A. H., Hansen, M. J., and Nate, N. A. 2005. Determining optimal stocking rates using a stock-recruitment model: An example using walleye in northern Wisconsin. N. Am. J. Fish. Mgmt. 25:1215-1225.

Fayram, A.H. and Sibley, T.H. 2000. Impact of predation by smallmouth bass on sockeye salmon in Lake Washington, Washington. N. Am. J. of Fish. Man. 20: 81-89.

Food and Agriculture Organization of the United Nations (FAO). 1995. Precautionary Approach to Capture Fisheries and Species Introductions. FAO Technical Guidelines for Responsible Fisheries, No.2.

Fisheries and Oceans Canada. 2007. A New Ecosystem Science Framework in Support of Integrated Management.. http://www.dfo-mpo.gc.ca/Science/Publications/Ecosystem/ecosystem_index_e.htm

Footen B. 2003. Piscivorous impacts on chinook (*Oncorhynchus tshawytscha*) in the Salmon Bay Estuary, the Lake Washington Ship Canal and Lake Sammamish. Summary Paper, Greater Lake Washington Chinook Workshop. Muckeshoot Indian Tribe Fisheries Division.

Fraser Basin Council. 2007. Harmonizing Salmon Habitat Monitoring. October.

Fritts A.L. and Pearsons, T.N. 2006. Effects of predation by nonnative smallmouth bass on native salmonid prey: the role of predator and prey size. Trans Amer. Fish. Soc. 135: 853-860.

Fritts, A. L., Scott, J. L. and Pearsons, T. N. 2007. The effects of domestication on the relative vulnerability of hatchery and wild origin spring chinook salmon (*Oncorhynchus tshawytscha*) to predation. Can.J.Fish.Aquat.Sci. 64 (5): 813-818.

Gerwing, K., McDaniels, T. 2006. Listening to the Salmon People: Coastal First Nations' Objectives Regarding Salmon Aquaculture in British Columbia. Society & Natural Resources 19 (3): 259-273.

Gilligan, D. M., Frankham, R. 2003. Dynamics of genetic adaptation to captivity. Conserv.Genet. 4 (2): 189-197.

Government of Canada. 2007. From impacts to Adaptation: Canada in a Changing Climate. http://adaptation.nrcan.gc.ca/assess/2007/index_e.php

Government of Canada. 2005. Canada's Policy for Conservation of Wild Pacific Salmon. Fisheries and Oceans Canada, Vancouver. 49 pp.

Gross, L. 2008. Can Farmed and Wild Salmon Coexist? PLoS Biol 6 (2): e46, February 12, 2008.

Gross. M.R. 1998. One species with two biologies: Atlantic salmon in the wild and in aquaculture. Can. J. Fish. Aquat. Sci. 55 (Supp 1): 131-144.

Gustafson,R.G.; Waples,R.S.; Myers,J.M.; Weitkamp,L.A.; Hard,J.J. 2007. Pacific salmon extinctions: quantifying lost and remaining diversity. Conserv.Biol. 21 (4): 1009-1020.

Hard, J.J.; Gross, M.R.; Kope, R.G.; Law, R.; Reynolds, J.D. 2008. Evolutionary consequences of fishing and their implications for salmon. Evolutionary Applications 1(2): 388-408.

Hartman, G. 2008. Converging ecological crises and the need to escape the box of conventional response. Dialogue 22(1): 13-17.

Hartman, G., Groot, K. and Northcote, T. 2000. Science and management in sustainable salmonid fisheries: the ball is not in our court. In: Knudsen, E. Eric, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser, Editors. *Sustainable Fisheries Management: Pacific Salmon.* Lewis Publishers, Boca Raton, Florida, pp. 31-50.

Harvey, B. 2008. The End of the River. ECW Press, Toronto. 376 pp.

Hey, J., Brannon, E. L., Campton, D. E., et al. 2005. Considering Life History, Behavioral, and Ecological Complexity in Defining Conservation Units for Pacific Salmon. Independent panel report for NOAA Fisheries.

Hilborn, R., and Winton, J. 1993. Learning to enhance salmon production : lessons from the salmonid enhancement program. Can. J. Fish Aquat. Sci. 50:2043-2056

Hilderbrand, R. H. 2003.The roles of carrying capacity, immigration, and population synchrony on persistence of stream-resident cutthroat trout. Biol.Conserv. 110 (2):257-266.

Hindar, K., Tufto, J., Saettem, L. M. and Balstad, T. 2004. Conservation of genetic variation in harvested salmon populations. ICES Journal of Marine Science: 61 (8): 1389.

Hsieh, C. H., Glaser, S. M., Lucas, A. J. and Sugihara, G. 2005. Distinguishing random environmental fluctuations from ecological catastrophes for the North Pacific Ocean. Nature 435 (7040): 336-340.

Hutchings, J. A., and Reynolds, J. D. 2004. Marine Fish Population Collapses: Consequences for Recovery and Extinction Risk. Bioscience 54 (4): 297-309.

IUCN. 2008. Global status assessment for sockeye salmon *Oncorhynchus nerka*. IUCN, Gland, Switzerland.

Iglauer, E. 1988. Fishing with John. Harbour Publishing, Madeira Park, BC. 305 pp.

International Maritime Organization. 2002. Focus on IMO: Antifouling systems. www.imo.org. London. 31 pp.

Irvine, J. R., Gross, M. R., Wood, C. C., Holtby, L. B., Schubert, N.D .and Amiro, P.G. 2005. Canada's Species at Risk Act: An Opportunity to Protect" Endangered" Salmon. Fisheries 30 (12): 11-19.

Isaak, D. J., Thurow, R. F., Rieman, B. E. and Dunham, J. B. 2007. CHINOOK SALMON USE OF SPAWNING PATCHES: RELATIVE ROLES OF HABITAT QUALITY, SIZE, AND CONNECTIVITY. Ecol.Appl. 17 (2): 352-364.

Johannessen, D.I. and P.S. Ross. 2002. Late-run Sockeye at Risk: An Overview of Environmental Contaminants in Fraser River Salmon Habitat. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2429. 120 pp.

Johnson, L.L.; Ylitalo, G.M.; Arkoosh, M.R.; Kagley, A.N.; Stafford, C.; Bolton, J.L.; Buzitis, J.; Anulacion, B.F.; Collier, T.K. 2007. Contaminant exposure in outmigrant juvenile salmon from Pacific Northwest estuaries of the United States. Environ.Monit.Assess. 124 (1): 167-194.

Kappel, C. V. 2005. Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species. Frontiers in Ecology and the Environment 3 (5): 275-282.

Keast, A. 1985. The piscivore feeding guild of fishes in small freshwater ecosystems. Env. Bio. Fishes 12(2):119-129.

Kenchington, E. 2003. The effects of fishing on species and genetic diversity: Responsible fisheries in the marine ecosystem. Edited by M.Sinclair and G.Valdimarsson.FAO, Rome, Italy.

Kleiss, M. E. 2004. Salmon Hatchery Myth: When Bad Policy Happens to Good Science. Minn.J. Sci.Tech. 6: 431.

Kohler, C. C., and W. R. Courtenay, Jr. 1986. American Fisheries Society Position on Introductions of Aquatic Species. Fisheries 11(2): 39-42.

Lackey, R. T. 2003. Pacific Northwest Salmon: Forecasting Their Status in 2100. Rev.Fish.Sci 11 (1): 35-88.

Lackey, R. T., Lach, D. H. and Duncan, S. L. 2006. Policy Options to Reverse the Decline of Wild Pacific Salmon. Fisheries31: 344-351.

Lapointe, MF; Cooke, S.J.; Hinch, S.G.; Farrell, A.P.; Jones, S.; Macdonald, S.; Patterson, D.; Healey, M.C.; Van Der Kraak, G. 2004. Late-run sockeye salmon in the Fraser River, British Columbia are experiencing early upstream migration and unusually high rates of mortality: what is going on. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference 31: 1–14.

Law, R. 2000. Fishing, selection and phenotypic evolution. ICES Journal of Marine Science 57: 659-668.

Lemmen, D.S., Warren, F.J., Lacroix, J. and Bush. E. (Eds.). 2008. From impacts to adaptation: Canada in a changing climate 2007. Government of Canada, Ottawa. 448 pp.

Lepofsky, D., Lertzman, K., Hallett, D. and Mathewes, R. 2005. Climate Change and Culture Change on the Southern Coast of British Columbia 2400-1200 CAL. BP: An Hypothesis. American Antiquity 70 (2): 267-294.

Letters, E. 2003. Density-dependent mortality in Pacific salmon: the ghost of impacts past? Ecol.Lett. 6: 335-342.

Levin, P. S.,and Stunz, G. W. 2005. Habitat triage for exploited fishes: Can we identify essential Fish Habitat? Estuar.Coast.Shelf Sci. 64 (1): 70-78.

Lichatowich, J. 1999. Salmon Without Rivers: A History of the Pacific Salmon Crisis. Island Press, 219 pp.

Lorenzo, E. A. 2005. Salmon, Steelhead, and Dams in the Pacific Northwest and the Endangered Species Act . J.Land Resources & Env. 25: 341.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. University of Alberta Press. 620pp.

Macdonald, R. W., Morton, B. and Johannessen, S. C. 2003. A review of marine environmental contaminant issues in the North Pacific: The dangers and how to identify them. Env.Rev. 11 (2): 103-139.

McClelland, E. K. and Naish, K. A. 2007. What is the fitness outcome of crossing unrelated fish populations? A meta-analysis and an evaluation of future research directions. Conserv. Genet. 8, 397–416.

McClure, M.M.; Carlson, S.M.; Beechie, T.J.; Pess, G.R.; Jorgensen, J.C.; Sogard, S.M.; Sultan, S.E.; Holzer, D.M.; Travis, J.; Sanderson, B.L. 2008. Evolutionary consequences of habitat loss for Pacific anadromous salmonids. Evolutionary Applications 1 (2): 300-318.

McClure, M. M., Holmes, E. E., Sanderson, B. L. and Jordan, C. E. 2003. A LARGE-SCALE, MULTISPECIES STATUS ASSESSMENT: ANADROMOUS SALMONIDS IN THE COLUMBIA RIVER BASIN. Ecol.Appl. 13 (4): 964-989.

McMahon, T.E., and David H. Bennett, D.H. 1996. Walleye and northern pike: boost or bane to northwest fisheries? Fisheries 21 (8): 6-13.

McMichael, A. J. 2001. Impact of climatic and other environmental changes on food production and population health in the coming decades. Proc.Nutr.Soc. 60 (2): 195-201.

Miller, K. A. 2003. North American Pacific Salmon: A Case of Fragile Cooperation. FAO Fisheries Report 7-10, FAO Rome (Italy).

Miller, K. A., Munro, G. R. 2004. CLIMATE AND COOPERATION: A NEW PERSPECTIVE ON THE MANAGEMENT OF SHARED FISH STOCKS. Mar.Resour.Econ. 19.

Ministry of Agriculture and Lands 2008. Marine Water Farm Sites December 31, 2007. www.agf.gov.bc.ca/fisheries/licences/MFF_Sites_Current.htm

Mora, C., Metzger, R., Rollo, A. and Myers, R. A. 2007. Experimental simulations about the effects of overexploitation and habitat fragmentation on populations facing environmental warming. Proceedings of the Royal Society B: Biological Sciences274 (1613): 1023-1028.

Morita, K., Saito, T., Miyakoshi, Y., Fukuwaka, M., Nagasawa, T. and Kaeriyama, M. A 2006. Review of Pacific salmon hatchery programmes on Hokkaido Island, Japan. ICES Journal of Marine Science: Journal du Conseil 63 (7): 1353.

Mote, P.W.; Parson, E.A.; Hamlet, A.F.; Keeton, W.S.; Lettenmaier, D.; Mantua, N.; Miles, E.L.; Peterson, D.W.; Peterson, D.L.; and Slaughter, R. 2003. Preparing for Climatic Change: The Water, Salmon, and Forests of the Pacific Northwest. Clim.Change 61 (1): 45-88.

Moyle, P.B. 2002. Inland Fishes of California. Univ. Calif. Press, Los Angeles, Calif. 502pp.

Naylor, R.; Hindar, K.; Fleming, I.A.N.A.; Goldburg, R.; Williams, S.; Volpe, J.; Whoriskey, F.; Eagle, J; Kelso, D.; MangelL, M. 2005. Fugitive Salmon: Assessing the Risks of Escaped Fish from Net-Pen Aquaculture.Bioscience 55 (5): 427-437.

Nickelson, T. 2003. The influence of hatchery coho salmon (*Oncorhynchus kisutch*) on the productivity of wild coho salmon populations in Oregon coastal basins. Can.J.Fish.Aquat.Sci. 60 (9): 1050-1056.

Noakes, D. J., Fang, L., Hipel, K. W. and Kilgour, D. M. 2005. The Pacific Salmon Treaty: A Century of Debate and an Uncertain Future. Group Decis.Negotiation 14 (6): 501-522.

Northcote, T. and G.F. Hartman (Eds). 2004. Fishes and Forestry. Blackwell Publishing. 800 pp.

Ormerod, SJ. 2003. Current issues with fish and fisheries: editor's overview and introduction. J.Appl.Ecol. 40 (2): 204-213.

Pacific Fisheries Resource Conservation Council. 2008. Mountain Pine Beetle: salmon are suffering too. Brochure. 8 pp.

Pacific Fisheries Resource Conservation Council. 2007a. Saving the Heart of the Fraser: Addressing the Human Impacts to the Aquatic Ecosystem of the Fraser River, Hope to Mission, British Columbia http://www.fish.bc.ca/save-heart-fraser-river-damaging-development-fisheries-council-urges-governments-0

Pacific Fisheries Resource Conservation Council. 2007b. Managing Pacific Salmon for Ecosystem Values: Ecosystem Indicators and the Wild Salmon Policy http://www.fish.bc.ca/managing-pacific-salmon-ecosystem-values-ecosystem-indicators-and-wild-salmon-policy

Pacific Fisheries Resource Conservation Council. 2007c. Advisory: Implementing the Habitat and Ecosystem Component's of DFO's Wild Salmon Policy http://www.sehab.org/pdf/R-42%20Advisory-DFOWildSalmonPolicy_2006_0_Complete.pdf

Pacific Fisheries Resource Conservation Council. 2007d. Report on habitat threats: Major impacts on British Columbia fish and fish habitat and human activities that cause those impacts. Prepared by Otto Langer. 10 pp.

Pacific Fisheries Resource Conservation Council. 2004. Reality Stewardship: Survival of the Fittest for Community Salmon Groups. http://www.fish.bc.ca/reality-stewardship-survival-fittest-community-salmon-groups

Pacific Salmon Commission. 2008. Response to IUCN's status assessment of Fraser sockeye. November 13, 2008. 9 pp.

Paragamian, V. L., Beamesderfer, R. C. P. 2004. Dilemma on the Kootenai River- The Risk of Extinction or When Does the Hatchery Become the Best Option? Am.Fish.Soc.Symp. 44: 377-385.

Password, F. 2007a. Metapopulation perspective for salmon and other anadromous fish. Conserv.Biol. 21 (4): 1009-1020.

Password, F. 2007b. Pacific Salmon Extinctions: Quantifying Lost and Remaining Diversity. Fish Fish. 8 (4): 297-314.

Pearsons, T. N., Fritts, A. L. and Scott, J. L. 2007. The effects of hatchery domestication on competitive dominance of juvenile spring chinook salmon (*Oncorhynchus tshawytscha*). Can.J.Fish.Aquat.Sci. 64 (5): 803-812.

Pembina Institute - Coalbed Methane & Salmon: Assessing the Risks. 2008. http://www.pembina.org/pub/1634

Pflug, D.E. 1981. Smallmouth bass (*Micropterus dolomieui*) of Lake Sammamish: a study of their age and growth, food and feeding habitats, population size, movement and homing tendencies, and comparative interactions with largemouth bass. MSc. Thesis, University of Washington, Seattle. 80pp.

Polovina, J. J. 2005. Climate Variation, Regime Shifts, and Implications for Sustainable Fisheries. Bull.Mar.Sci. 76 (2): 233-244.

Private Power Watch. 2008. www.ippwatch.info/w/

Quinn, P., Winton, J. R., Huppert, D. and Hilborn, R. 2007. AN EVALUATION OF THE EFFECTS OF CONSERVATION AND FISHERY ENHANCEMENT HATCHERIES ON WILD POPULATIONS OF SALMON. Advances in Marine Biology, Volume 53. Academic Press.

RL and L Environmental Services. 2000. Resident fish entrainment information review. Draft Report for the Canadian Columbia River Inter-tribal Fisheries Commission. 59 pp.

Reist,J.D.; Wrona,F.J.; Prowse,T.D.; Power,M.; Dempson,J.B.; King,J.R.; Beamish,R.J. 2006. An overview of effects of climate change on selected arctic freshwater and anadromous fishes. Ambio, 35 (7):381-387.

Richter, A., Kolmes, S. A. 2005. Maximum Temperature Limits for chinook, coho, and chum salmon, and Steelhead Trout in the Pacific Northwest. Rev.Fish.Sci. 13 (1): 23-49.

Riddell, B. E. 1986. Assessment of selective fishing on the age at maturity in Atlantic salmon (*Salmo salar*): a genetic perspective. In D. J. Meerburg, ed. Salmonid Age at Maturity, pp. 102–109. Canadian Special Publication in Fisheries and Aquatic Sciences 89, Ottawa, ON.
Riddell, B. E., Tautz, A. F. 2003. State of Pacific salmon and their habitats: Canada and the United States. World Summit on Salmon, Vancouver. 10-13.

Rieman, B.E., Lee, D.C., and Thurow, R.F. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River Basins. North Am. J. Fish. Mgmt.. 17: 1111-1125.

Scheuerell, M.D.; Hilborn, R.; Ruckelshaus, M.H.; Bartz, K.K.; Lagueux, K.M.; Haas, A.D.; Rawson, K. 2006. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Can.J.Fish.Aquat.Sci. 63 (7): 1596-1607.

Schtickzelle, N., Quinn, T. P. 2007. A metapopulation perspective for salmon and other anadromous fish. Fish Fish. 8 (4): 297-314.

Scott, D.S. 2007. Smelling Land: The hydrogen defense against climate catastrophe. Canadian Hydrogen Association. 485 pp.

Scott, W.B. and Crossman, E.J. 1973. Freshwater Fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 p.

Slaney, T.L., K.D. Hyatt, T.G. Northcote, and R.J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21(10): 10 – 35.

Slaney, P. and J. Roberts. 2005. Coastal Cutthroat Trout as Sentinels of Lower Mainland Watershed Health Strategies for Coastal Cutthroat Trout Conservation, Restoration and Recovery. http://www.shim.bc.ca/cutthroat/ct.pdf

South-central Alaska Northern Pike Control Committee. 2006. Management Plan for Invasive Northern Pike in Alaska.

Stahl, K., R. D. Moore, J. M. Shea, D. Hutchinson, and A. J. Cannon. 2008. Coupled modelling of glacier and streamflow response to future climate scenarios. Water Resources Research 44: 13 pp.

Tabor, R.A., B.A. Footen, K.L. Fresh, M.T. Celedonia, F. Mejia, and D.L. Low. 2007. Smallmouth bass and largemouth bass predation on juvenile chinook salmon and other salmonids in the Lake Washington Basin. North American Journal of Fisheries Management 27:1174-1188.

Taylor, E.B. 2004. An analysis of homogenization and differentiation of Canadian freshwater fish faunas with an emphasis on British Columbia. Can. J. Fish. Aquat. Sci. 61: 68–79.

Temple, R., K. Daily, T. Schroder, and B. Hooton. 1998. Predation issues: introduced fishes. Oregon Dept. of Fish and Wildlife.

Tolimieri, N., Levin, P. 2004. Differences in Responses of Chinook Salmon to Climate Shifts: Implications for Conservation. Environ.Biol.Fishes 70 (2): 155-167.

Volpe, J. P. 2000. Evidence of natural reproduction of aquaculture escaped Atlantic salmon (*Salmo salar*) in a coastal British Columbia river. Conservation Biology 14(3): 899-903,

Volpe, J.P.; Anholt, B.R.; and Glickman, B.W. 2001. Competition among juvenile Atlantic salmon (*Salmo salar*) and steelhead (*Oncorhynchus mykiss*): relevance to invasion potential in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. 58:197–207.

Walters, C.J., Lichatowich, J.A., Peterman, R.M., and Reynolds, J.D. 2008. Report of the Skeena Independent Science Review Panel. A report to the Canadian Department of Fisheries and oceans and the British Columbia Ministry of the Environment. 144 pp. Report of the Skeena Independent Science Review Panel. May 2008.

Wandesforde-Smith, G. 2003. Sacrificing the Salmon: A Legal and Policy History of the Decline of the Columbia Basin Salmon. Environmental Law 33 (2): 483-500.

Waples, R. S. 1999. Dispelling some myths about hatcheries. Fisheries 24, 12–21.

Waples, R. S., Adams, P. B., Bohnsack, J. and Taylor, B. L. 2007. A Biological Framework for Evaluating Whether a Species Is Threatened or Endangered in a Significant Portion of Its Range. Conserv.Biol. 21 (4): 964-974.

Waples, R. S., Pess, G. R. and Beechie, T. 2008. Evolutionary history of Pacific salmon in dynamic environments. Evolutionary Applications 1 (2): 189-206.

Waples, R.S., Gustafson, R.G., Weitkamp, L.A., Myers, J.M., O.W. Johnson, P.J. Busby, J.J. Hard, G.J. Bryant, F.W. Waknitz, K. Neely, D. Teel, W.S. Grant, G.A. Winans, S. Phelps, A. Marshall, and B.M. Baker. 2001. Characterizing diversity in salmon from the Pacific Northwest. J. Fish Biol. 59 (Supplement A): 1 – 41.

Watershed Watch. 2007. www.watershed-watch.org

Weber, E. D., Fausch, K. D. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Can.J.Fish.Aquat.Sci.60(8): 1018-1036.

Welch, D.W., E. Rechisky, M. C. Melnychuk, A. D. Porter, C. J. Walters, S. Clements, B. J. Clemens, R. S. McKinley, and C. Schreck. 2008. Survival of migrating salmon smolts in large rivers with and without dams. Plos Biology 6(10): 2101- 2108.

Weir, L. K., Grant, J. W. A. 2005. Effects of aquaculture on wild fish populations: a synthesis of data. Env.Rev. 13(4):145-168.

Wood, C. C., Gross, M. R. 2008. Elemental conservation units: communicating extinction risk without dictating targets for protection. Conserv.Biol. 22 (1): 36-47.

Wu, J., Skelton-Groth, K., Boggess, W. G. and Adams, R. M. 2003. PACIFIC SALMON RESTORATION: TRADE-OFFS BETWEEN ECONOMIC EFFICIENCY AND POLITICAL ACCEPTANCE. Contemporary Economic Policy 21 (1): 78-89.

Zabel, R. W., Scheuerell, M. D., McClure, M. M. and Williams, J. G. 2006. The interplay between climate variability and density dependence in the population viability of chinook salmon. Conserv.Biol. 20 (1): 190-200.

Zimmerman M.P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the Lower Columbia River Basin during outmigration of juvenile anadromous salmonids. Trans. Am. Fish. Soc. 128-1036-1054.