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A Review of the Impacts of Climate Change on BC's Freshwater Fish Resources and Possible Management Responses

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A Review of the Impacts of Climate Change on BC's Freshwater Fish Resources and Possible Management Responses

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DIRECTOR'S FOREWORD

Climate changes have been implicated in major upheavals in the history of human civilization such as the desertification of the middle east, the collapse of the remarkable civilization of the ancient Egyptians, the dark ages after the fall of the Roman Empire. and the raids of the Vikings. So it is not surprising that climate change is a major worry for all of us. But in fact, climates have always been in a state of change, most notably for BC about 10,000 BP at the end of the last ice age. Indices of climate suggest that the last few thousand years have in fact been unusually stable and hence our use of natural resources for food, fun and profit is built upon a profound expectation of stability. How will our modern society cope with a the major changes in climate wrought by a global warming that we ourselves have likely caused?

In this report Peter Tyedmers and Bruce Ward examine one aspect of this issue: the possible impacts on BC's freshwater fish and how management may attempt to deal with this issue. Their conclusions warn of dramatic changes to abundance and distribution with even the most modest of likely global warming scenarios. They discuss how management may attempt to respond to this challenge and its uncertainties, and in this way, the work fits well with the interdisciplinary mandate of the Fisheries Centre at UBC.

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Tony J. Pitcher
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ABSTRACT

We review the potential impacts of anthropogenic climate change on BC's freshwater fish and provide a set of recommended management responses that address these potential impacts. The direct impacts are rising temperatures, altered hydrologic regimes, and changes in aquatic productivity. The indirect impacts include the potential loss of estuarine habitat due to sea-level rise, and reduced habitat availability due to increased impoundment and abstraction of water for other uses. These impacts will reinforce or counteract each other to alter the abundance and diversity of fish resources, and will make it difficult for managers to protect, restore, and enhance either the diversity of native freshwater fish or the quality of aquatic habitats. Moreover, as a large proportion of current freshwater recreational angling in the Province is conducted in areas where existing fisheries resources are most likely to be negatively influenced by global warming (i.e. in south central and southeastern regions) it will be difficult to maintain and improve the quality and quantity of recreational angling. We detail the following recommendations:

1. develop climate change scenarios that are locally specific;
2. monitor biophysical indicators of change within freshwater (i.e., monitor changes in thermo-hydrodynamic characteristics of rivers and lakes, expand stock assessment and inventory efforts in habitats of greatest concern, and identify and monitor biological indicators of climate change);
3. develop models of the distribution of freshwater fish in BC and anticipated changes; and,
4. adopt management strategies now that will reduce the impact of climate change on individual species, ecosystems, and society.

We conclude that climate change will dramatically alter the abundance, distribution and utilization of many, if not all, species of freshwater fish in the Province. It is essential that in fisheries strategic plans, the challenges posed by climate change are explicitly addressed, and management responses incorporated.

INTRODUCTION

The *BC Freshwater Fisheries: Strategic Program Plan 2001-2004* (hereafter the *Strategic Plan*) is a significant document in that it articulates the vision, guiding principles, goals, objectives, and strategies of BC Fisheries for the next four years. An important issue that has only received minimal attention, however, in the current draft of the *Strategic Plan*, dated February 15, 2001, is the profound impact that anthropogenic climate change will likely have on BC fish, fisheries, and fisheries management into the future. This is a serious oversight as anthropogenic climate change presents a clear challenge to the achievement of many of the conservation and sustainable utilisation goals and objectives of the *Strategic Plan*. Specifically, it will become increasingly difficult to:

1. protect, restore, and enhance native fish to conserve the full range of biodiversity values in BC (Strategic Plan - Conservation Objective 2),
2. protect, restore, and enhance habitat and fish populations to maintain the productive capacity of aquatic ecosystems (Strategic Plan - Conservation Objective 3),
3. protect and restore water quality and quantity for fish (Strategic Plan - Conservation Objective 4),
4. meet food, ceremonial, and societal need obligations to First Nations, and
5. maintain and improve the quality and quantity of recreational angling experiences on freshwater species.

The purpose of this paper is two-fold. It begins by briefly reviewing the range of currently predicted potential impacts of anthropogenic climate change on BC's freshwater fish resources. This is followed by a set of recommended possible management responses that address these potential impacts.

REVIEW OF POTENTIAL CLIMATE CHANGE INDUCED IMPACTS ON BC FISHERIES RESOURCES

It is now widely recognised that the structure and composition of biotic communities can be profoundly influenced by climatic variability (Ketchen 1956, Bell and Pruter 1958, Beamish and Boulton 1993, Beamish 1993, Beamish 1995, Hare and Francis 1995, Klyashtorin 1998). Not surprisingly, most research to date has focussed on understanding the impact that historical, apparently natural, shifts in climate have had. Since the late 1980's, however, as a result of increasing concern regarding the likely magnitude and rapidity of anthropogenic climate change due to greenhouse gas accumulation in the atmosphere, attention has begun to shift to the following considerations:

- how these changes may affect the biotic systems upon which we depend (Kennedy 1990, Levy 1992, Henderson *et al.* 1992, Northcote, 1992, Eaton and Scheller 1996, Keleher and Rahel 1996, Rahel *et al.* 1996, Wood and MacDonald 1997, Magnuson *et al.* 1997, Mulholland *et al.* 1997, Mortsch 1998, Welch *et al.* 1998, Hartman *et al.* 2000, Ward 2000, Schindler 2001), and
- the steps that can be taken to either mitigate or adapt to these changes (Healey 1990, Levy 1992, Troadec 2000).

GENERAL PATTERN OF REGIONAL CLIMATE CHANGE

As a result of an anticipated doubling of atmospheric CO_2 concentrations over the next century, most current models predict that mean global surface temperatures will rise between 3 and 5°C by 2100. On regional scales, however, model predictions vary more widely (Hengeveld 2000). As a result, there is greater uncertainty with respect to how climate change may play out in BC. With this proviso in mind, the most advanced Canadian model, CGCM1, suggests that by 2030, BC will experience an increase in mean annual temperature of up to 2°C, and by 2100 from between 2 and 4°C (Table 1). The CGCM1 model also indicates that by the end of the century, most of BC will only experience a modest increase in total annual precipitation, on the order of 10 to 20% above the recent historical average. The bulk of this additional precipitation will likely occur in winter (Hengeveld 2000, his Fig. 6 through 9).

Table 1. Projected Changes in Mean Annual Temperature and Precipitation for BC to 2100

Period	Mean annual temperature change relative to 1975-1995 average	Percentage increase in precipitation above 1975-1995 average
2010 to 2030	0-2°C	0-10
2040 to 2060	1-3°C	0-10
2080 to 2100	3-5°C	0-20

From Hengeveld 2000, Figures 6 and 8.

It is important to note that of temperature and precipitation, climate change modellers consider projections of temperature to be most certain. Nevertheless, as temperature drives the hydrological cycle, it is unlikely that precipitation patterns will remain the same, even if the precise direction and magnitude of the change for BC is uncertain.

How these broad regional changes will manifest themselves on a local level is less certain still because:

- the physiography of BC is highly varied, and
- the spatial scale of current global models is very coarse reflecting the extremely high computational demands of the underlying computer models. For example, in most models all of BC is represented by only between 6-10 grid points. As a result, fine-scaled "predictions" of the impact of global warming on specific areas of the province are not yet possible.

The following broad generalisations, however, can be ventured:

- greater relative increases in mean annual air temperatures in northern interior and southeastern BC than in coastal, southern parts of the province, and
- a greater relative increase in winter precipitation in southern BC along with a greater relative increase in summer precipitation in northeastern BC.

HOW BC'S FISHERIES RESOURCES MIGHT BE AFFECTED

Not only is BC physiographically diverse, it possesses a rich freshwater and anadromous fish fauna encompassing approximately 84 native and exotic species. Most work to date regarding the potential impact of anthropogenic climate change on freshwater fish, both in BC and elsewhere, has focussed largely on salmonids due to their economic and cultural importance. As a result, much of the following review is similarly biased. It should also be noted that the following only provides a broad overview of the potential impacts identified to date and should not be considered an exhaustive review of the literature.

For convenience, the following discussion is divided into a consideration of three major direct and two indirect potential impacts. The direct impacts considered are:

- rising temperatures,
- altered hydrologic regimes, and
- changes in aquatic productivity.

The indirect impacts that are briefly considered include:

- the potential loss of estuarine habitat due to sea-level rise, and
- reduced habitat availability due to increased impoundment and abstraction of water for other uses.

In many cases, these impacts may reinforce or counteract each other to alter the abundance and diversity of fish resources in BC. Some of these potential interactions are also addressed in the discussion that follows.

THERMAL IMPACTS

The thermal regime of almost all lakes and rivers is ultimately controlled by atmospheric temperatures. However, the degree to which a waterbody reacts to both short- and long-term changes in atmospheric temperature is influenced by a variety of factors. In general, a waterbody's size affects how quickly it will respond to changes in both average and short-term extremes in atmospheric temperature. Similarly, due to their relatively large surface area to volume ratios, rivers and streams typically respond more quickly to changes in atmospheric temperature than do lakes and reservoirs.

Additional factors that influence how a river or stream may respond to changes in mean annual, and short-term atmospheric temperatures include:

- the degree to which its flow is sustained by groundwater. While shallow groundwater temperatures are partially tied to mean annual air temperatures and will therefore increase gradually over time as a result of climate warming (Meisner *et al.* 1988, Meisner 1990a and 1990b), groundwater fed streams tend to be less responsive to short term atmospheric temperature extremes.
- the timing and magnitude of snowmelt runoff. As spring freshet events will likely occur earlier in the year and may be more intense in many parts of the province (Clair et al. 1998), the summertime buffering of stream temperatures by snowmelt will likely be reduced.
- the extent of shading by riparian vegetation.

In the case of lakes and reservoirs, other changes that can be expected to occur as a result of climate warming include:

- shorter ice free periods. For example, Schindler *et al.* (1990) documented that for lakes in the Experimental Lakes Area in northwestern Ontario, as mean annual air temperatures rose ~2°C over the period from 1969 to 1988, their annual ice-free period was extended by ~20 days. Similarly, Northcote (1992) estimated that for lakes near the geographic centre of BC, an increase in the mean annual air temperature of 4°C would likely extend the average ice free period each year by about two months, while Assel (1991) projected that as a result of a doubling of atmospheric CO_2, the ice cover of both Lakes Erie and Superior would be substantially reduced in most years.
- earlier onset of thermal stratification and longer seasonal duration of stratification resulting in decreased hypolimnetic oxygen concentrations, and in turn increasing the potential of both summer- and winter-kill.
- changes in the depth of the thermocline and hence the relative volume of both the epilimnion and hypolimnion in stratified lakes[1] (Magnuson *et al.* 1997). For example, Schindler *et al.* (1990) found that in experimental Lake 239 in Ontario, the depth at which its thermocline formed each year increased steadily as mean annual air temperatures rose by about 2°C over the period from 1969 to 1988.
- increases in mean surface water temperatures.

As all freshwater fish are cold-blooded, and a great many essential physiological processes are regulated by temperature, fish are sensitive to changes in their thermal environment. However, the preferred as well as the maximum temperature that a species of fish can tolerate varies widely (Table 2).

As a result, any climate-induced change in the average annual, or maximum seasonal, temperature of aquatic habitats in BC will affect various species differently. In general, cold water guild species[2], including all of BC's salmonids, are the most likely to be negatively impacted as temperatures rise. In contrast, cool and warm water species potentially have the most to gain from an increase in atmospheric temperatures in BC.

Table 2. Maximum Tolerable and Preferred Temperature for Selected BC Fish

Species	Max. Tolerable Temp (°C)[a]	Preferred Temp (°C)[b]
Chum salmon (*Oncorhynchus keta*)	19.8	14.1
Pink salmon (*O. gorbuscha*)	21.0	11.7
Brook trout (*Salvelinus fontinalis*)	22.4	
Mountain whitefish (*Prosopium williamsoni*)	23.1	
Cutthroat trout (*O. clarki*)	23.3	
Coho salmon (*O. kisutch*)	23.4	11.4
Chinook salmon (*O. tshawytscha*)	24.0	11.7
Rainbow trout (*O. mykiss*)	24.0	
Brown trout (*Salmo trutta*)	24.1	
Longnose dace (*Rhinichthys cataractae*)	26.5	
White sucker (*Catostomus commersoni*)	27.4	
Northern pike (*Esox lucius*)	28.0	
Walleye (*Stizostedion vitreum*)	29.0	
Pumpkinseed (*Lepomis gibbosus*)	29.1	
Smallmouth bass (*Micropterus dolomieui*)	29.5	
Black crappie (*Pomoxis nigromaculatus*)	30.5	
Common carp (*Cyprinus carpio*)	35.0	
Largemouth bass (*Micropterus salmoides*)	35.5	

Sources: a. Eaton and Scheller 1996
b. Levy 1992

SHORTER TEMPORAL AND SMALLER GEOGRAPHIC SCALE IMPACTS OF INCREASED TEMPERATURE

For populations of cold water guild species whose habitat is restricted to lakes or streams that currently experience summer temperatures near the species' maximum thermal tolerance (this will typically occur in smaller more southerly lakes and streams at lower elevations), as temperatures increase these populations are likely to experience an increased frequency of heat-related mortality (Fagerlund *et al.* 1995). Furthermore, as the solubility of oxygen in water decreases as temperatures increase, oxygen deficiencies that result for the prolonged thermal stratification of lakes may be exacerbated as mean annual, and seasonal maximum temperatures go up.

[1] When lakes become thermally stratified, the warmer lens of water above the thermocline is referred to as the epilimnion while the colder water below is the hypolimnion.

[2] For descriptive simplicity, fish species with similar temperature tolerances are grouped into three temperature "guilds": cold water, cool water, and warm water. Typically, fish that tolerate maximum temperatures up to ~24.5 °C (yet prefer temperatures in the 12 to 15°C range) are assigned to the cold water guild. Species whose maximum thermal tolerance ranges from ~25 to 30°C (but generally prefer temperatures in the 22 to 24°C range) are assigned to the cool water guild. Finally, species that are capable of tolerating temperatures above 30°C (but generally prefer temperatures in the 28 to 30°C range) are considered warm water guild species.

At sub-lethal temperature and oxygen levels, reduced individual rates of growth may occur, particularly in British Columbia's populations of cold water guild fish, as a result of higher metabolic demands, and possibly reduced access to prey (Henderson *et al.* 1992). In contrast, warm water species may grow faster in the same environment due to the relative expansion of their available habitat along with potential increases in overall system productivity. Similarly, in northern parts of the province cold water species that inhabit waters whose current mean summer temperatures are below their preferred thermal range may also experience higher rates of growth due to climate warming.

In some anadromous populations, higher in-stream temperatures may result in greater pre-spawning mortality of upstream migrating adults due to:

- increased metabolic demands as temperatures rise, and
- an increased frequency of disease outbreaks (Roos 1991, Fagerlund *et al.* 1995).

These challenges would be expected to most seriously impact populations that ascend rivers for great distances and whose migration timing coincides with seasonal high instream temperatures. In this regard, Henderson *et al.* (1992) concluded that returning adult Adams River sockeye would *not* likely experience increased rates of pre-spawning mortality due to anthropogenic climate warming. However, this stock ascends the Fraser River in September/October, and is therefore not generally subjected to the highest seasonal instream temperatures and flows. Results of a similar analysis for a mid-summer migrating stock of Fraser River salmon, for example either the Chilko, Stellako or Horsefly stocks, might be very different. Historical temperature-related pre-spawning mortality events amongst these latter three stocks (Roos 1991), together with recent high mortality events amongst the Adams River and Weaver Creek stocks may foreshadow some of the changes that can be expected with increased warming.

Another short-term negative impact that increased temperatures could have on salmonid populations occurs at the beginning of their life history. As Northcote has observed, "Even slight increases in seasonal stream temperatures, especially over the winter, can have major and complex effects on juvenile salmonid emergence, growth, migration and even ocean survival" (1992, p. 45).

Longer Temporal and Larger Geographic Scale Impacts of Increased Temperature

Over time, the shorter duration and smaller scale impacts of higher temperatures will almost certainly result in changes in the current distributions of species, and overall structure of aquatic communities in BC. While research has yet to be conducted to estimate the potential scale of these changes in BC, work from other parts of North America can be used to illustrate the potential degree of change that may be in store. For example:

- On a species-specific basis, Meisner (1990) has estimated that should mean annual air temperatures increase by 3.8°C over the native range of Brook trout in Eastern North America, the lowest elevations at which it is likely to occur in streams in the southern portion of its range will increase by ~700m,
- Within the context of an individual watershed, Rahel *et al.* (1996) predict that as mean summer temperatures increase from 1 to 5°C above current levels in the North Platte River watershed in Wyoming, thermally suitable habitat for cold water guild species will be reduced from ~10 to ~70%, respectively,
- On a regional scale, Keleher and Rahel (1996) estimate that over the entire US Rocky Mountain region (encompassing the states of Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico), climate change induced increases in mean July air temperatures of 1, 2, 3, 4 and 5°C, will reduce suitable salmonid habitat by approximately 17, 36, 50, 62 and 72%, respectively, from its current level, and
- On a national scale, Eaton and Scheller (1996) have estimated that thermally suitable habitat for cold and cool water guild species would be reduced by an average of ~50% across the entire continental USA as a result of climate warming. At the same time, habitat suitable for some warm water species will expand while for others it will decrease.

Based on the general patterns of changes that have been predicted for other jurisdictions, in BC we would expect the following broad changes to occur:

- Amongst cold and possibly cool water guild species, a shift in their distributions to higher latitudes and elevations together with increased population fragmentation in more southerly parts of their ranges. Where range shifts are limited by other factors (for example physical barriers to movement, lack of suitable spawning/rearing habitat, etc.) over the relatively short time scales involved, this would likely result in an overall reduction in the distribution of certain species. In extreme cases, for example where the southern edge of a species' current range extends only a small distance into northern BC, or in the case of a species with relatively limited current distributions in BC (for example the short-nose sucker in the lower Fraser River) this might result in their extirpation from the province.

- Amongst resident warm water guild species, we should expect a general range expansion as their thermally suitable habitat expands to include higher altitudes and more northerly regions. Furthermore, as habitat suitable for warm water species expands, the likelihood of additional successful invasions by exotic species is also increased (see for example Meisner *et al.* 1987, Mandrak 1989, Magnuson *et al.* 1997, Schindler 2001).

ALTERATION OF HYDROLOGIC REGIMES

As previously discussed, current models suggest that over the next 100 years, mean annual precipitation in BC may increase by 10 to 20% over recent historical averages as a result of anthropogenic climate change. Of potentially greater significance, however, is that most of this additional precipitation is expected to fall in the winter (Hengeveld 2000). When coupled with the likely impact that climate *warming* will have on evapotranspiration, and on the extent, depth, and melting rates of snow packs there is further cause for concern regarding BC's aquatic resources.

IMPACTS ON RIVERS AND THEIR FISH

In coastal watersheds in which annual peak flows occur in winter (see Northcote 1992, Fig. 3) , increased precipitation at this time of year may result in reduced egg to fry survival amongst fall spawning species due to increased scouring, etc. Populations of particular concern in this regard include all fall spawning salmonid populations that spawn in insular and smaller coastal watersheds.

Throughout much of the rest of BC, in watersheds where flows typically peak in early summer as a result of snowmelt, recent modelling of the potential impacts of climate change on the extent and timing of seasonal runoff suggests that peak seasonal discharge will likely occur as much as a month earlier than it does now (Clair *et al.* 1998). As the outmigration timing of many salmon smolts is closely tied to current peak seasonal discharge, such a dramatic springward shift in the freshet could seriously affect smolt to adult survival rates in salmon. In addition, amongst spring spawning species, higher spring flows followed by markedly lower summer flows could lead to reduced egg to fry survival due to redd drying.

Relatively unchanged summer precipitation levels together with increased rates of evapotranspiration due to higher temperatures, will generally result in lower mean late summer flows throughout much of the province. As Hartman et al. (2000) have observed, "Small streams will be particularly vulnerable because the shift to warmer, drier conditions in the summer will further reduce streamflow." (p. 42). Clearly, reductions in the absolute volume of seasonally available in-river habitat will have a direct negative impact on a wide range of aquatic species and populations.

IMPACTS ON LAKES AND THEIR FISH

Potential anthropogenic climate change induced alterations in precipitation patterns will also have an impact on the hydrology of lakes and reservoirs in BC. The full nature and extent of these impacts, however, is difficult to predict and will vary with lake depth, altitude, latitude and recharge rate. In general, however, in parts of the province that experience only minor increases in summer precipitation yet a marked increase in mean summer temperatures, both seasonal and mean annual lake volumes will decline. In some instances, this will undoubtedly result in some currently productive shallow lakes drying up in summer. Once again, reductions in the volume of available habitat will have a major impact on the distributions and abundance of resident fish species. In addition, there is also the potential for a net loss of important spawning and rearing habitat from lake margins. Such a loss could either result from increased seasonal fluctuations in water levels, or, in other cases, result from a continuous decline of lake levels (Meisner *et al.* 1987, Mortsch 1998). Productive fish habitat is also likely to be reduced within reservoirs as the magnitude and frequency of water level fluctuations increase with changing seasonal precipitation and electricity generation demands. Finally, in situations in which there is a marked seasonal or mean annual decrease in dissolved organic carbon delivery to lakes and reservoirs, there is the potential that aquatic biota of all types will be exposed to higher, potentially dangerous levels of UV-B radiation (Schindler *et al.* 1996).

Changes in Productivity

The full nature and extent of potential changes that may occur with respect to the productivity of freshwater bodies as a consequence of climate change is difficult to foresee given the diversity of lakes and rivers in BC, and the range of factors that control productivity. However, in lakes and rivers in which nutrients are not limiting, higher mean temperatures and longer ice free seasons will generally result in increased productivity. This will ultimately translate into higher total fish yields, although the relative abundance of species may change. For example, Meisner *et al.* (1987) predict that with as little as a 2°C rise in mean annual air temperatures, the maximum sustainable yield of some commercially valuable species in the Great Lakes basin could increase by 26%. In the case of BC, the greatest potential increases in climate change induced productivity, and hence fish yields might be expected to occur in the larger more northerly lakes in the province reflecting their relatively low current temperatures, and the likelihood that climate warming effects will be more pronounced as latitude increases (Hengeveld 2000).

Indirect Impacts of Climate Change

Reduction of Available Estuarine Habitat Through Sea-Level Rise

While a range of potential climate change-related impacts on wetlands and estuaries generally have been explored (see for example Kennedy 1990, Kjerfve *et al.* 1994, Jones 1994, Magnuson *et al.* 1997, Mulholland *et al.* 1997, Mortsch 1998, Short and Neckles 1999, Schindler 2001), the effect that the loss of wetland habitat may have on fish has received less attention (see general discussions in Magnuson *et al.* 1997, Mortsch 1998), and almost no work has been done to assess the impact of climate change induced sea-level rise on estuary-dependent freshwater fish resources. Given that: 1) productive estuarine habitat has already been severely reduced in many parts of coastal BC, and in particular throughout much of the Strait of Georgia, and 2) in many instances, any potential landward shift of estuarine habitat is severely limited by dyking and in-filling, there is likely to be a further loss of this important habitat as a result of climate change (for a discussion of this potential process with examples from other jurisdictions see Kjerfve *et al.* 1994). While a further loss of estuarine habitat due to sea level rise would affect most anadromous species to a greater or lesser extent (Thorpe 1994), populations and species of fish that might be most impacted in BC include ocean-type chinook, and coastal cutthroat trout.

Decreased Summer Flows as a Result of Increased Water Abstractions and Impoundments

Neitzel *et al.* (1991), Hartman *et al.* 2000, and Schindler (2001) have all observed that an important yet indirect source of climate change-related impact on freshwater fish will result from the increased impoundment and abstraction of water for other uses. As conditions throughout much of the province become warmer and drier, particularly in the summer, as a result of climate change, there will be tremendous pressure to abstract more water for agriculture and other direct human uses. In addition, because hydroelectric generation is a relatively atmospheric "friendly" form of power generation, increased demand for electricity in the future means that there will be a great deal of pressure to expand BC's hydro-generating capacity to the further potential detriment of freshwater fish resources.

The Challenge

The range of impacts outlined above will make it extremely difficult for BC Fisheries to protect, restore, and enhance either:

1. the full diversity of BC's native freshwater fish (as per Conservation Objective 2 in the *Strategic Plan*), or
2. the quality of aquatic habitats in the province (as per Conservation Objective 3 in the *Strategic Plan*).

Moreover, as a large proportion of current freshwater recreational angling that occurs in the province is conducted in areas where existing fisheries resources are most likely to be negatively impacted by global warming (i.e. in south central and southeastern regions of the province) it will be very difficult to maintain and improve the quality and quantity of recreational angling opportunities, at least as they currently exist.

RECOMMENDATIONS

To improve our understanding of the impact that impending anthropogenic climate change will have on BC's freshwater aquatic resources, and our preparedness for these changes, the following recommendations are made:

1. Refine our understanding of potential sub-regional climate change impacts

As BC encompasses a diverse range of ecotypes and sub-climates, any future work that attempts to improve predictions of climate change impacts on freshwater fish resources, and aquatic ecosystems generally, would benefit from a refined understanding of how anticipated regional changes in temperature and precipitation will affect the various sub-regions of the province. Amongst other things, any improvements in our understanding would assist fisheries scientists and managers in identifying climate change vulnerable populations, and ecosystems for monitoring (see Recommendation 2 below). Moreover, once potentially vulnerable populations are identified proactive management interventions may be possible so as to limit the potential severity of climate change impacts (see Recommendation 4 below).

The challenge, however, is that available climate models do not provide the spatial resolution needed to predict detailed sub-regional potential changes in temperature and precipitation. As a result, in the short-term it may only be possible to engage in a generalised planning exercise that attempts to predict sub-regional implications of a generally “hotter/drier” future.

Given that climate change is likely to dramatically affect a wide range of resource users throughout the province, such an evaluation would ideally be undertaken in cooperation with other government agencies, First Nations and industrial interests. To this end, it is recommended that a BC Climate Change Working Group be formed with representation from appropriate provincial and federal ministries and agencies, First Nations, and interested resource stakeholder groups. An example of a major output that the Working Group could strive to produce is provided by the "Impacts of Climate Variability and Change" document prepared by the JISAO Climate Impacts Group at the University of Washington for US Pacific Northwest states (Mote 1999).

2. Monitor biophysical indicators of change within the freshwater environment

A. Monitor changes in thermo-hydrodynamic characteristics of rivers and lakes.

Most of the anticipated impacts of climate change on aquatic organisms are expected to result from alterations in the thermal and hydrologic regime of lakes and rivers. However, as the onset and scale of those changes is uncertain, it is important that data are collected that documents these changes as they occur. Fortunately, an extensive network of ongoing river flow monitoring already exists in the province. Systematic monitoring of in-stream temperatures and the thermodynamic conditions of lakes is less well developed. As a result, it is recommended that:

- Existing freshwater temperature datasets are assembled into a central repository.

  Aquatic temperature data are being collected throughout the province for a variety of purposes. Placing historic and ongoing datasets in a central repository would provide a foundation for monitoring future changes in the aquatic temperature regime in different parts of the province.

- Establish a temperature monitoring program for representative waterbodies from around the province.

  Once existing temperature datasets have been assembled, it will be possible to identify regional and waterbody-type gaps in coverage. Ongoing temperature monitoring should then be initiated to fill these gaps. Where possible, these new temperature monitoring activities should be linked to existing flow monitoring stations.

- Select and monitor a range of representative type-lakes from around the province for changes in their seasonal hydrodynamics and productivity. This work could potentially be incorporated into both the ongoing *Ecosystem Restoration and Bioengineering Research* into the reduced fish productivity of some of BC's large lakes, as well as the *Small Lakes Management and Population Dynamics Research* program.

B. Expand/accelerate stock assessment/ inventory efforts in habitats of greatest concern.

As part of the inventory, assessment and research work that is undertaken in accordance with the *Strategic Plan*'s Conservation Objective #1, specific attention should be paid to stocks and habitats that are most likely to be impacted by climate change.

C. Identify and monitor biological indicators of climate change.

Based on the currently anticipated patterns of change within aquatic ecosystems, it is possible to identify and initiate monitoring of specific populations, species and ecosystems of concern. As the geographic and biological scope of these potential changes is immense, it will be prudent to focus monitoring efforts, at least initially, on higher risk/priority species and ecosystems. Ideally, however, a biological monitoring program would encompass the following:

- populations of cold water species whose habitat currently experiences seasonal temperatures at or near their maximum thermal tolerance,
- changes in the relative rates of growth and population productivity of cold, cool, and warm water species inhabiting the same bodies of water,
- populations of warm water species whose range would be expected to expand with increasing temperatures, and
- the potential invasion of new warm water species should be expected and monitored.

3. Develop models of how the distribution of freshwater fish in BC will be impacted by anticipated changes

As climate change scenarios are developed for different parts of the province and existing temperature and flow data are assembled it will be possible to refine predictions of impacts on BC fish.

Potential approaches that could be pursued include:

- species-specific assessments of potential range alterations (see Meisner 1990),
- watershed specific assessments of changes in guild distributions (see Rahel *et al.* 1996), and
- province wide assessments of potential changes in habitat availability and guild distributions in streams (see Eaton and Scheller 1996, and Keleher and Rahel 1996) and lakes (see Stefan *et al.* 1995, and Minns and Moore 1992).

Analyses on any of these scales would be well suited to take advantage of the GIS accessible data sets of provincial fish and fish habitat that BC Fisheries and DFO have nearly completed.

4. Adopt management strategies now that will reduce the impact of climate change on individual species, ecosystems, and society

While it may be tempting to delay management responses either because of the degree of uncertainty associated with some climate change-related impacts, or because many impacts are only likely to be fully expressed decades into the future, such an approach would be foolhardy. This is because decisions and management actions taken now will have profound repercussions for BC's aquatic resources as they face the challenges posed by climate change.

Although some level of anthropogenic climate change is inevitable given past increases in atmospheric greenhouse gas emissions, opportunities exist to:

- partially mitigate some of its impacts on freshwater fish resources,
- enhance the ability of those resources to adapt to their changing environment, and
- reduce the contribution that BC Fisheries' activities make to global climate change.

Partial Mitigation of Impacts

Just as BC Hydro is currently engaged in a process to develop Water Use Plans for all of their facilities that better account for the flow timing needs of downstream users, including fish, downstream "fish friendly" thermal regime targets should also be developed. Moreover, as Hydro facilities and other impoundment structures are refurbished, changes in how they release water could be made so as to allow for cold water releases from the base of these structures in the future.

More generally, when new water license applications are being reviewed and existing permits are up for renewal, explicit consideration should be given to the potential for reduced summer flows in many rivers and streams due to climate change, and the resulting pressures that will be placed on fish populations.

There is also the need to explicitly incorporate the challenges posed by climate change into ongoing species at risk research and management decision-making that is already occurring within BC Fisheries.

ADOPT ADAPTIVE STRATEGIES

As Healey (1990), Levy (1992), and Hartman *et al.* (2000) have all noted, the adoption of adaptive strategies may ultimately be the most prudent approach to take in the face of the persistent and widespread changes that are likely to result from climate change. For example, instead of relying on mitigative techniques that attempt to maintain the current distributions of species, and aquatic ecosystems, experimental options should be pursued that attempt to accommodate likely shifts in ranges and abundance. In this regard, the role of fish culture should be reviewed specifically with respect to possibly shifting its focus from its current emphasis on maintaining consumptive opportunities, to the conservation of threatened species, and the possible experimental out-planting of fish into environments outside their current range.

Similarly, given the tremendous social, cultural, and economic impacts that climate change-related alterations in fish distribution and abundance will likely entail, BC Fisheries should initiate programs that sensitise aboriginal, and recreational fishing interests; and the public at large to the challenges associated with climate change. To this end, a public awareness campaign should be initiated that presents some of the anticipated impacts that climate change will have on BC's freshwater fish resources. Ideally, such a campaign would be a co-operative undertaking on the part of both the Provincial Ministries of Agriculture, Food and Fisheries; and Environment, Lands and Parks in conjunction with Fisheries and Oceans Canada. Media that could be used to deliver such a campaign include: the BC Fisheries' web-site, the annual synopsis of angling regulations, news releases and background papers.

As climate change will often affect the productivity of co-mingling stocks differently, minimising non-target species mortality will become increasingly important if commercial, aboriginal and recreational fishing opportunities are to be maintained in the presence of weakening stocks. To this end, research should be intensified to improve both the selectivity of fishing technologies, and techniques in freshwater; and the post-release survival of non-target species. In addition, as many existing recreational fisheries are going to be profoundly altered as the relative and absolute abundance of supporting stocks change, BC Fisheries should undertake proactive efforts to diversity angling activities both geographically, and in terms of the species that are targeted.

ADDRESSING BC FISHERIES' CONTRIBUTIONS TO CLIMATE CHANGE

Virtually all activities undertaken within a modern industrial society, including those of BC Fisheries, result in greenhouse gas emissions. And although the activities of BC Fisheries make only a tiny contribution to greenhouse gas emissions globally, it is arguably inappropriate to lament the impact of climate change without attempting to address the problem directly. To do so effectively, however, requires data regarding the greenhouse gas emissions associated with the range of program and management options open to BC Fisheries. For example, an analysis of two federal Salmon Enhancement Program hatcheries in BC suggests that for every kilogram of juvenile chinook and coho salmon released into the wild, greenhouse gas emissions equivalent to approximately 4.4 and 7.6 kg of CO_2, respectively are produced (Tyedmers 2000). In order to incorporate greenhouse gas emission contributions into decision-making within BC Fisheries, similar data would have to be generated for a range of management options.

CONCLUSIONS

The current draft of the *BC Freshwater Fisheries Strategic Program Plan 2001-2004* largely overlooks the issue of anthropogenic climate change. This is a significant oversight as climate change has the potential to dramatically alter the abundance, distribution and utilisation of many, if not all, species of freshwater fish in the province. It is therefore essential that in revising the *Strategic Plan*, the challenges posed by climate change are explicitly addressed, and potential management responses incorporated. Specifically, it is recommended that:

- both regionally- and locally-specific scenarios of climate change be developed;
- monitoring of changes in fish populations, and the thermo-physical characteristics of their environment be intensified;
- models of potential changes in the distribution and abundance of key species of concern are refined; and
- proactive management solutions that include species- and watershed-specific management plans be developed.

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