Potential impacts of greenhouse gas accumulations on fish and fisheries

R.J. Beamish

The third assessment report of the Intergovernmental Panel on Climate Change (IPCC 2001a) provides a series of scenarios that indicate the kind of changes that will occur to future climates. The extent of changes depends primarily on the level of emissions of CO_2. For example, if there are no changes in the current rate of increase of CO_2, then the global average surface air temperature is predicted to increase by 3°C by the 2080s compared to the present. The land areas will warm twice as fast as the oceans with more warming occurring in the winter in high latitudes. If CO_2 emissions can be controlled and stabilized at two times the pre-industrial levels i.e. 550ppm or three times the pre-industrial levels i.e. 750ppm, then the impacts will be different. A rise of 2°C above the present day, which is expected by the 2050s, would be delayed by 50 years if CO_2 emissions were stabilized at 750ppm and by over 100 years if stabilization occurred at 550ppm (IPCC 2001b). If current CO_2 emissions were reduced by 60% to 70%, there would still be a 0.7°C increase in global average surface temperatures. This is approximately the magnitude of change observed over the last 150 years. Associated with this general warming in the past 150 years, there has been a gradual decrease in the number of cold days and an increase in the number of warm days. In northern latitudes, winters have been wetter and summers drier. The 1990s were particularly warm, with 1998 being the warmest year since instrumental records began in the mid-1800s.

A standard reference point used to provide a scale of possible change is 2°C by the 2050s if there is no change in the rate of CO_2 production (if CO_2 is stabilized at 550ppm, the 2°C increase would occur about 2230). Sea level rise is associated mainly with the thermal expansion of water and water from melting glaciers and ice caps. This sea level rise is an inevitable consequence of global temperature increase. The projected rise between 1990 and 2100 is between 0.09 and 0.88m. The central value is 0.48m, which corresponds to an average rate of about 2 to 4 times the rate observed during the 20th century. An estimate of a 40cm increase in sea levels by the 2080s would be delayed by about 25 years to 40 years if CO_2 emissions were stabilized at 750ppm or 550ppm, respectively. The variation in the range in sea level rise at the regional level could be substantial. It is likely that precipitation will increase in the northern mid-latitudes in the winter and in the northern high latitudes in the summer and winter. There is an expectation that the increases in precipitation will also result in increases in extreme precipitation events. Relative to the 1961 to 1990 average, the expected increases of 20% to 40% appear modest, but there is not good agreement among models.

The Arctic provides a good example of the uncertainty of prediction, but not the certainty of change. A variety of models and emission scenarios indicate a 2°C to 6°C warming in the Arctic by 2070, with considerable uncertainty around these estimates and large model-to-model differences that range between 1.5°C to 7.6°C in the area between 60°N and 90°N. It is our general poor understanding of processes as well as our inability to predict the future CO_2 emission levels that limit the ability of models to see into the future in the Arctic. Meaningful application of model results in all regions is also difficult as regional models are only beginning to be developed, yet it is the diversity of regional ecosystems that complicates fisheries management. Because of the uncertainties of the climate models and the uncertainties associated with the dynamics of fisheries, it has been very difficult to integrate the knowledge of professionals in these two areas in a way that produces advice that can be developed into policies for future fisheries management.

Pacific Pacific salmon are well-known for their ability to home from feeding areas in the open ocean to the exact areas of their birth in coastal freshwater rivers (Groot and Margolis 1991). Less well-known is their ability to stray. It is this straying rate that can range up to 10% (Groot and Margolis 1991) that provides Pacific salmon with an ability to adapt to large scale climate change such as past periods of glaciation. All 5 species of Pacific salmon have been reported from Canadian Arctic waters (Hunter 1974; Babaluk et al. 2000) with pink salmon being the most frequently observed and chinook salmon the least freqently seen. Recently Babaluk et al. (2000) reported first records of sockeye and pink salmon from Sachs Harbour on Banks Island, in the the Beaufort Sea. Although, pacific salmon had been observed previously, the report of Babaluk et al. (2000) represented extensions of these earlier records. One reprot of a coho caught on Great Bear Lake on September 25, 1987 represented an extension of 1500 km east of an earlier report at Prudhoe Bay Alaska . These reports are noteworthy because they highlight the rare occureence of Pacific salmon in the Arctic, however, they also indicate that straying is occurring.

The Arcitic is one area that may be exhibiting early impacts of global warming. Model predictions are that a doubling of CO_2 would reduce the extent of sea ice by 60% and the volume by 25 to 45% (Gordon and O'Farrell 1997). There also would be greater freshwater runoff. Over the period 1978 to 1996, there has been a 2.9 – 3.5% per decade decrease in the extent of Arctic sea ice (Cavalieri et al. 1997). If such dramatic chagnes were to continue, conditions favourable to straying and perhaps feeding for Pacific salmon my improve.

The general impacts of global warming that affect fish production are temperature, precipitation, winds, currents, sea level, salinity, upwelling, ice coverage, and UV-B radiation. In the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001a), there is better agreement among models about changes in temperature and sea level than about precipitation, winds, and storminess. Temperature is important, but winds and storminess may be the parameters that most affect ecosystems in the subarctic Pacific. The assessment of the impact of climate change on marine fishes in the third IPCC assessment report emphasized the impacts on the ecosystems that support the particular species of interest (IPCC 2001a). The importance of temperature, salinity, nutrients, sea level, currents, and the amount of sea ice were noted, as all of these abiotic factors will be affected by climate change. However, there was much greater emphasis on the impacts of the carrying capacity of ocean habitats than in the past. The response of individual species to temperature change has been the focus for impacts because we know much more about temperature responses than the factors that affect carrying capacity. There are examples in the third assessment report of how temperature increases will affect abundances and distributions, impact on spawning success, affect larval and juvenile survival, affect growth, and the rate of food production which in turn affects food availability for a species. However, scientists are increasingly recognizing that there are natural long-term fluctuations in fish production that occur over scales of 10 to 60 years. These natural cycles emphasize the importance of considering the ecosystem impacts of climate variations, as well as changes to individual species. The third assessment report emphasizes that the assumptions that marine ecosystems are stable are no longer acceptable. In fact, some scientists are proposing that the success of future fish stock assessments would depend to a large extent, on the ability to predict the impacts of climate change on the dynamics of marine ecosystems.

Regimes are now a generally accepted phenomenon within the fisheries science community (Beamish et al. 1999a; Hare and Mantua 2000). Large-scale climate oscillations have been described for the Arctic (Thompson and Wallace 1998), the Atlantic (Hurrell 1995), and the Pacific (Beamish et al. 2000; Hare and Mantua 2000; McFarlane et al. 2000). General trends in atmospheric circulation patterns that change quickly to new states have also been described for areas over Europe and over the subarctic Pacific (Beamish et al. 1999a, King et al. 1998). The large interdecadal climate fluctuations that occurred in the North Pacific have not yet been reproduced effectively in climate models, however, they are a critical component of the variability. In the Pacific, decadal-scale variability results in abrupt changes in the dynamics of mid-ocean and coastal ecosystems (Deser et al. 1996). Coupled global climate models or atmosphere-ocean general circulation models will have to be able to simulate the regime shifts before it will be possible to predict the changes to the dynamics of the fish populations in these ecosystems. One attempt to assess the decadal-scale changes by Mote (1999) indicated that both the Hadley and Canadian climate models predicted an increase in the intensity of the Aleutian Low pressure area in the winter in the subarctic Pacific. One model indicated a general trend towards stormier winters, while the other model indicated a greater variability followed by the increased trend to stormier winters. Increased storminess has been associated with increased production in the open ocean, but the impacts of a combination of warmer oceans and increased storminess remain to be determined.

Because decadal-scale variability can be large, and the causes are not known, it is possible that one of the most important impacts of global warming will be the change in the nature of decadal-scale variability. More frequent changes and more extreme changes will have profound impacts on the dynamics of fish, fisheries, and fisheries management as judged from the effects observed in the 1990s for species such as coho (Beamish et al. 2000). If global warming impacts the mechanism(s) that cause decadal-scale variations, the magnitude and abruptness of change may become the major factor in the regulation and management of marine fisheries. One expected source of variability is of direct concern to the aquaculture industry. Intense El Ninos reduce the productivity of anchovy off the coast of Peru. The 1997-1998 El Nino was associated with the worst season on record for the production of fish meal. If one of the impacts of global warming is more frequent and intense El Ninos as some have speculated (Timmermann et al. 1999), there will be tremendous pressure on the aquaculture industry to reduce its dependency on fish protein.

Species and ecosystems are regulated by processes that we are only beginning to understand. We know that climate profoundly affects the trophic relationship as well as species-specific productivity. We know that we selectively remove species, sometimes from the top of the food chain, without even trying to understand how these removals affect the dynamics of the ecosystem. We know that we are changing our climate as a consequence of greenhouse gas production. We propose that management must consider the certainty that unknown factors will have surprise impacts that will disrupt even the best management structure. This means that we need to be less deterministic in our management approches at the single species level, and reduce exploitation rates for some species.

In the second report of the IPCC (IPCC 1996), climate change impcats were viewed as adding additional stress to a fishery that was fullyutilizing world stocks by a fleet that was excessively over capacity. However, in the next 50 to 100 year period, if fisheries management would become more precautionary, climate change could become a more serious management issue than overfishing. The discovery that climate has a major impact on the dynamics of fish populations, and the expectation of greater climate impacts should be seen as a forecast of greater variability in the supply of wild marine fish. Fisheries may even become less stable as distributions change and movements across international boundaries start new rounds of fishing treaty negotiations.

If overfishing could be diminished, then the increased production of greenhouse gas could contribute to increasing total marine fish production. These conclusions were made by the IPCC (1996), and were based on the assumption that natural climate variability and the structure and stength of wind fields and ocean currents would remain about the same. There would be shifts in distributions and abundances as ecosystems were displaced geographically and changed internally. Positive effects on fish production could include longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes. If ecosystems changes rapidly, and wind patterns were also affected as identified by King et al. (1998), the production in the subarctic Pacific could be enhanced according to the scenarios reported by Beamish and Noakes (2002). If these changes occurred, and management became more precautionary, there would be opportunities to rebuild populations of some species.

Expectations for more frequent change and increased uncertainty in fisheries management

Although there is certainty that climate related changes can be as significant as fishing related changes, there is uncertainty about the impacts of greenhouse gas-produced climate changes on the dynamics of marine fish populations. We believe that in the future, climate related impacts on the dynamics of fish populations will be more important than fishing effects. The uncertainties regarding climate trends results from the difficulty of predicting climate changes and from an inability to interpret how these changes will alter the dynamics of marine ecosystems. The uncertainties related to climatic prediction results from the general difficulty of predicting climate, the assumptions about future greenhouse gas production, and the limitations of the current climate models. Even if the modeling difficulties were overcome, there are profound problems relating changes to the dynamics of fish populations. A consideration that is frequently ignored when assessing the potential impacts of climate variability on fisheries is the life history of the various fish species in the particular ecosystem. Species have evolved to survive extremes in climate variability as evidenced by the extensive ranges of species that can extend over a wide range of latitude. Another indicator of the ability of fish to survive climate variability is the variation in the longevities of species. The maximum ages of commercially important fishes off Canada's west coast ranges up to 205 years. Short-lived marine species such as coho salmon and pink salmon will be the most immediate indicators of change and would be expected to have evolved an ability to survive wide fluctuations in their marine habitat at the population level. The longevities of the various species increase from species that live 7 to 20 years such as herring and

Pacific hake, to species that live 20 to 80 years, such as halibut and sablefish, through species that live 100 to 200 years such as spiny dogfish and some rockfish species. It would be expected that the strategies evolved to survive the various kinds of natural climate variability in the ocean habitat would differ among these types of fishes. This means that any assessment of climate impact on fish and fisheries must contain considerations of the particular physiological impacts such as temperature and salinity, on the life history stages of the particular species. If we understood the natural processes that regulated individual species abundances, we would be better equipped to interpret the modeled climate effects at the ecosystem level. If we understood why the Japanese sardine populations fluctuate or why walleye pollock are so abundant or why rougheye rockfish live up to 205 years, we might be able to forecast more accurately how temperature changes or current pattern changes would affect the abundance of these and other species.

Fish have evolved to adapt to the random aspect of climate while maintaining their territory in their preferred habitat. Fish must be able to do this in a competitive environment and must be able to evolve over the long-term to survive the short-term fluctuations. Extinctions occur naturally when the evolutionary history of a species is not adequate to allow a species to adjust to a new environment. Normally this is a natural process, but fishing might reduce the populations ability to adapt to extreme environmental change. If human intervention is at "both ends" of the natural survival process, and our interventions reduce the ability to adapt to extreme climate changes, or enhances the frequency and extent of the climate changes, or both, then we have become a major factor in the ability of existing species to survive. Global warming is a serious concern for fisheries management because it increases the complexity of fisheries management. This is why it is important to be more precautionary in fisheries management. We should expect the unexpected and we should expect increased variability in abundance.

The potential impact of global warming on the important commercial fisheries off Canada's west coast

Approximately 77% of the landed value of all fisheries in British Columbia in 1999 was from 13 species or 8 non-salmon species (Figure 1). These 13 species have a history over the past 20 years of being key to the British Columbia fishing industry. Assessing the impact of climate change on these species provides insight into the possible impacts of greenhouse gas forced climate changes. The following assessments on the non-salmon species are speculations based on published literature and are not meant to be forecasts, but scenarios that put some perspective on what is known, what needs to be known, and what should be done now to begin to adapt.

Sablefish are a longlived species that occupy deeper habitats along the coast. The older ages of about 20 to 60 years in the fishery and the maximum age of 94 years indicate that the species probably reproduces successfully only infrequently despite spawning hundreds of thousands of eggs each year. Thus, it would not be the direct effects of ocean changes on adults that would have the most immediate impact. Rather, it is probable that larval survival would be dependent on the availability, the timing and amount of specialized prey. In the next 50 years, therefore, it may be difficult to distinguish global warming impacts from natural variability. The most immediate adaptive strategy might be to ensure that some areas of sablefish remain unfished so that long-term spawning capability is protected.

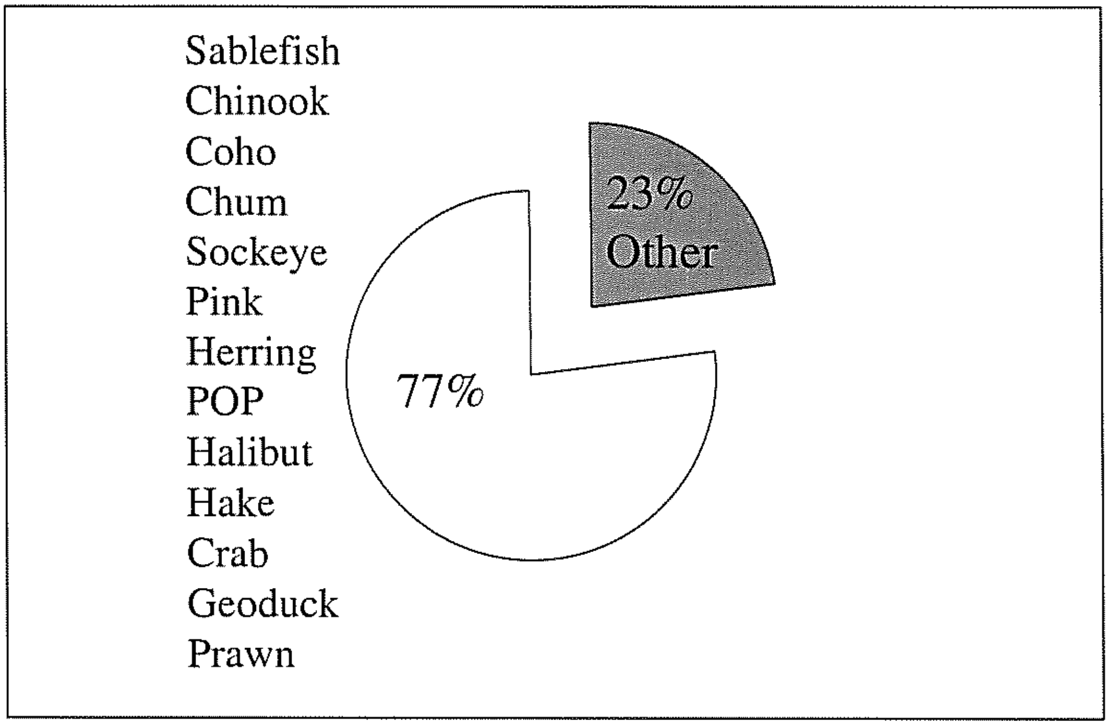

Figure 1. Percentage landed value in 1999 of major and other species.

Pacific herring are relatively short-lived and subject to sudden changes in abundance. The collapse of the herring fishery in the mid-1960s is now recognized as a result of overfishing following a collapse in recruitment related to climate. Pacific herring stocks sustained almost 20 years of high catches from the 1940s through the 1950s. Despite the increasing catches, the abundances in the late 1950s contained to increase. However, there was a change in climate in the 1960s and herring recruitment declined suddenly. After the fishery was closed in 1967, stocks recovered relatively quickly and fishing commenced in the 1970s. The lesson is that climate and ocean conditions can have profound impacts on the recruitment and abundance trends. Herring appear to be more responsive to the shorter-term variability than to variability at the regime scale. Herring also are dependant on near shore habitats for spawning. Thus, sea-level rise and increased storminess would be expected to affect the dynamics of herring populations. The present management strategy of only allowing fishing above minimum spawning abundances should be adequate to adapt to greenhouse gas induced changes.

Pacific ocean perch are a long-lived rockfish that mature at an age of approximately 11 years. They are a schooling species that could be readily overfished. Pacific ocean perch appear to respond to climate variability at the regime scale, however, recruitment success or failure is not evident until long after year-class strength has been determined. The inability to evaluate recruitment in time to make immediate changes to a fishery is an indication that this species (and other rockfish with similar life histories) is likely to be overfished if regime shifts occur more frequently. The most appropriate management adaptation may be to reduce exploitation rates and ensure that some habitat is restricted to either no fishing or to a very reduced, experimental fishery.

Pacific halibut are recognized to live to 55 years, although most fish in the fishery range in age from about 10 to 15 years. Halibut stocks are currently at historic high abundances in part because of the favourable ocean conditions since 1977, and in part because of an error in the stock assessment that resulted in an under estimate of the total biomass. Pacific halibut follow trends in abundance that are related to climate variability at the regime scale. Because halibut are widely distributed as adults, it is probable that the climate-ocean effect is during the larval stage. The existence of older fish in the population may indicate that over evolutionary time, Pacific halibut experienced prolonged periods of poor recruitment. Thus, it is to be expected that recruitment for halibut will become more variable. The fishery is managed by a Commission that allows a percentage of the total biomass to be fished. As declines occur, the catch is reduced. At a minimum population abundance, no fishing would be allowed. If areas need to be closed to protect spawning stocks, there would need to be an agreement between Canada and the United States.

Pacific hake provide the largest fishery on Canada's west coast in recent years. They are a species with a life span of about 21 years and a population structure that is characterized by cyclic strong and weak recruitment. The Canadian fishery is also dependent on a northward migration in the spring and summer. Climate and ocean conditions are associated with year-class strength and migration, but the mechanisms that are linked to climate remain to be determined. Pacific hake are a species that may become more abundant in the Canadian zone as coastal waters warm. There is a joint Canadian and United States process for managing these "offshore" hake stocks which could result in overfishing if adjustments are not made quickly during periods of poor recruitment.

Dungeness crab are fished from California to Alaska and thus can tolerate a wide range of environmental conditions. They are a nearshore species ranging from the intertidal area to about 60m. They release eggs from the fall to early winter and the larval period lasts about 110 days. Juvenile crabs do not survive in depths greater than about 60m. Mating occurs at about age 3 to 4 and total age is for 4 to 7 years. The major factor regulating abundance of crabs appears to be the amount of suitable bottom habitat less than 60m depth. Larval abundance can in the plankton be so dense that crab larvae are a major prey for a variety of species such as coho salmon. Temperature change is unlikely to be a factor affecting crab abundance in the next 50 to 100 years as Dungeness crab in British Columbia are in the middle of their range. There is a possibility that currents and the timing of plankton production affect their survival of crab larvae as crab abundances in British Columbia appeared to increase in the 1990s after the 1989 regime shift. In general, it is possible that fluctuations in abundance will occur, but no major changes would be expected as long as stocks are not overfished during periods of lower abundance.

Spot prawn catches in the 1990s in British Columbia were high indicating that stocks are healthy and management was appropriate. Prawns have the unusual life history termed protandiric hermaphrodism, which means that they change from males to females after an age of about 1 or 2 years. Eggs hatch in the spring and the larvae persist for about 3 months. The prawn is at the centre of its range and thus should be less affected by physical changes than individuals at the extreme limits of the distribution. There may be an impact from changes in currents, however, even these changes may be minor. Perhaps the most serious consequence of climate change might be overfishing during periods of lower marine survival.

Geoduck clams occur subtidally. They are longlived species, reaching ages of 140 years. There is very little known about the recruitment processes of geoducks. Recruitment processes for commercially important bivalves is generally erratic and geoduck recruitment may be exceptionally erratic even episodic. Because geoducks are longlived and at the centre f their distribution in British Columbia, it is unlikely that climate change in the next 50 to 100 years will threaten the elimination of stocks. If plankton becomes more abundant and waters warm, growth rates will increase. A general warming may reduce the occurrence paralytic shellfish poisoning and open more areas to fishing. However, the greatest impact on the abundance of geoducks in the next 100 years could be a combination of fishing and the artificial rearing and seeding of ocean substrate with artificially produced juveniles. As long as the market for geoducks is strong, the developing ability to farm geoducks may eventually remove fishing pressure from many wild stocks and generally increase production.

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