COST IMPLICATIONS FOR FISHERIES

Brian J. Shuter
Ontario Ministry of Natural Resources/University of Toronto, Canada

Charles K. Minns
Department of Fisheries and Oceans, Burlington, Canada

Keywords: Fish, fisheries, sustainable yields, zoogeographic boundaries, adaptation, regional tactics, no-regrets approach

Contents

Summary

Fisheries are founded on populations of animals living in natural, uncontrolled environments. The geographic distribution of these populations, their abundance, and their productivity are all shaped by climate and hence sensitive to climate change: therefore, the fisheries that exploit these populations will also be sensitive to climate change. For marine, estuarine, and freshwater fish and fisheries, the climate-driven environmental changes that will be most influential vary widely. For marine systems, changes in sea level, current patterns, and water temperatures will be of greatest importance. For estuarine systems, shifts in the position of the freshwater/salt water interface and the presence of impediments to inland migration of fish habitat will be of greatest importance. For freshwater lake and river systems, changes in water levels and water temperature will be most important. Such environmental changes will affect the fisheries of a particular geographic region by altering sustainable harvests at both the ecosystem and the population levels, the mixture of species that can be sustainably

harvested, the location of profitable fishing grounds, and the efficiency of some fishing gear. Economic impacts will vary regionally, depending on regional differences in both the kind of aquatic system supporting fisheries, and the kind of fisheries (i.e. commercial, recreational, subsistence) that are supported. In Canada, impacts on total fish harvest will be dominated by changes in the Atlantic marine ecosystems that support major commercial fisheries, while impacts on total dollars invested in fisheries will be dominated by changes in the inland freshwater ecosystems that support major recreational fisheries. Particularly in freshwater systems, indirect impacts of climate change, arising from adaptation in other economic sectors to fresh water shortages, may have a greater influence on fisheries than do direct impacts. This has a positive aspect: such indirect impacts can be managed or mitigated through an adaptation strategy that uses flexible tactics to allow for regional diversity under a set of national principles that ensures overall consistency. Implementation of a regionally diverse, "no-regrets" approach to managing adaptation to climate change should be founded on the principle of applying best available science to forecast changes and to identify effective adaptive actions. This requires ongoing support of programs aimed at measuring the current direction and pace of climate change, and support of new research in climate science and the role of climate in shaping the character of renewable resources.

1. Introduction

Fisheries exist to harvest organisms that spend their entire lives in water. Most of these organisms are poikliotherms—animals whose body temperature is essentially identical to that of the water they live in. Climate change will alter most aquatic ecosystems on the planet: water volumes and seasonal water temperature cycles will change (see *Effects of Global Warming on Water Resources and Supplies*, *Effects of Global Warming on Marine Ecosystems*, and *Effects of Global Warming on Wetlands*). Such changes will significantly affect the communities of fish living in those ecosystems and the fisheries that exploit them. In addition, most major fisheries around the world exploit fish populations at levels that meet or sporadically exceed maximum sustainable levels. These high levels of current use almost certainly increase the inherent sensitivity of these populations to climate change. Stresses imposed by other anthropogenic influences on aquatic ecosystems (e.g. acid rain, toxic waste dumping, destruction of shoreline habitats: see *Effects of Global Warming on Environmental Pollution*) will almost certainly further increase such sensitivities.

To understand and predict how different fisheries will be affected by climate change, it is essential to understand how climate change will affect the biology of exploited fish populations. In order to understand this, it is important to recognize that different ecosystems will respond differently to climate change. Differences in the responses of six major categories of aquatic ecosystems will be discussed in this article: offshore marine systems, arctic marine systems, coastal marine systems, estuarine systems, lake systems, and river systems.

To evaluate the potential costs and benefits of climate change to individual fisheries, it is important to recognize that valuing a fishery is a complex process that differs radically across types of fishery. Problems involved in evaluating three types of fisheries will be discussed in this article: commercial fisheries, recreational fisheries, and subsistence fisheries.

To develop a comprehensive appraisal of the overall costs and benefits of climate change to the fisheries of a nation, it is important to recognize regional disparities in both the kinds of ecosystems that support fisheries and the kinds of fisheries that they support. In this article, the fisheries of Canada are used to illustrate these types of disparities and the complexities they can generate in trying to arrive at a comprehensive national evaluation of costs and benefits.

2. Impacts of Climate Change on Fish

The body temperature of a fish is essentially equal to the temperature of the water it lives in. Typically, each species exhibits a characteristic preferred temperature—the temperature individuals will choose to live in when given a choice. Rates of food consumption, metabolism, and growth rise slowly as the preferred temperature is approached from below and drop rapidly after it is exceeded (Figure 1), reaching zero at the lethal temperature. The preferred temperature, the temperature tolerance zones for various vital processes, and the lethal temperature are all species-specific characteristics. Tolerance zones vary widely in breadth, with zones for “complex” (i.e. those associated with individual growth and reproduction) processes typically narrower than zones for “simple” (i.e. those associated with basic survival) processes. All tolerance zones include the preferred temperature. In temperate climate regions (e.g. North America), common species of fish can be grouped into thermal guilds according to their preferred temperatures (Figure 2). The thermal guild scheme has provided a convenient framework for comparative studies of the temperature requirements of temperate fishes and has formed the basis for several comparative assessments of the potential effects of climate change on temperate freshwater fishes. For a given species, the daily activities that sustain the lives of individuals (e.g. feeding, predator avoidance, body maintenance, and growth) and the seasonal activities that maintain the existence of populations (e.g. gonad development, reproduction, and parental care) are shaped by both the thermal guild to which the species belongs and the annual water temperature pattern that individual fish experience (Figure 3).

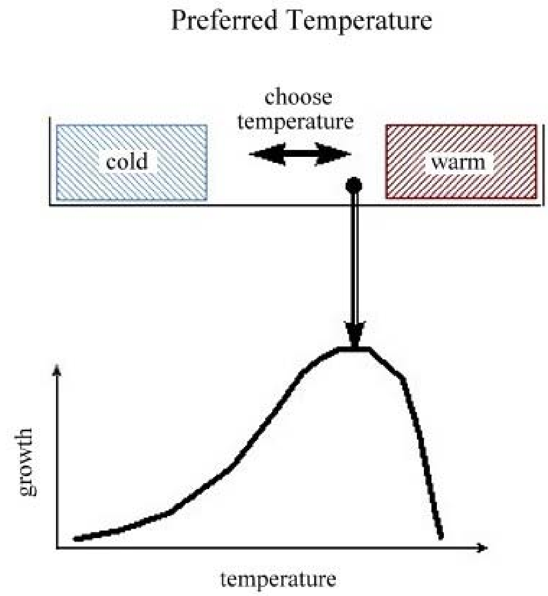

Figure 1. Temperature selection by fish and its consequences. The schematic diagram at the top illustrates a temperature choice experiment in which a fish is placed in a tank that is warm at one end and cool at the other, and is allowed to choose where it will live. The graph at the bottom illustrates how growth rate varies with temperature when food is provided in abundance. Typically, the fish will choose the temperature (its preferred temperature—see arrow) that supports the highest growth rate.

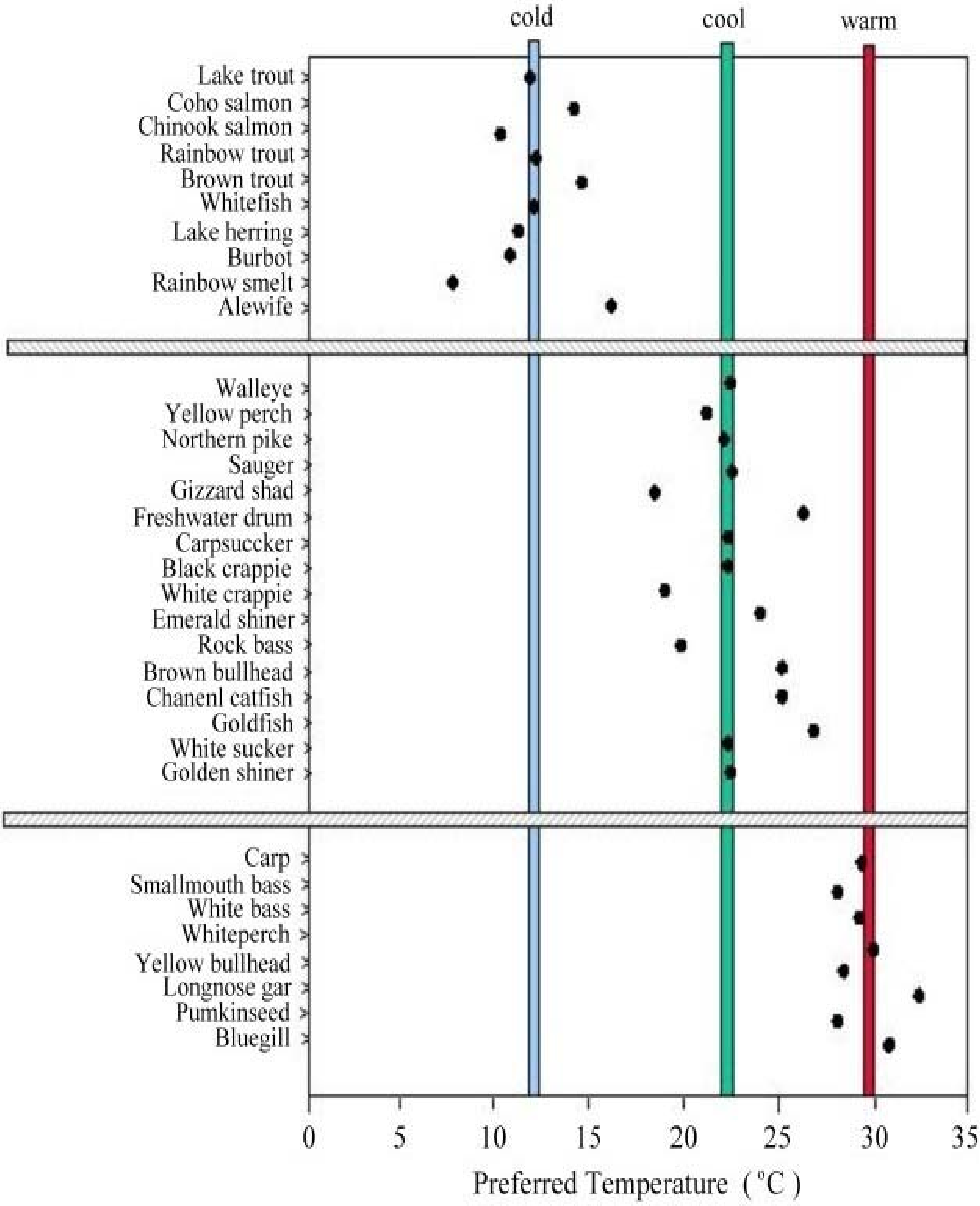

Figure 2. Grouping the common freshwater fish species of the North American Great Lakes Basin into thermal guilds: preferred temperatures for cold water fish center on 13°C, preferred temperatures for cool water fish center on 23°C, and preferred temperatures for warm water fish center on 29°C

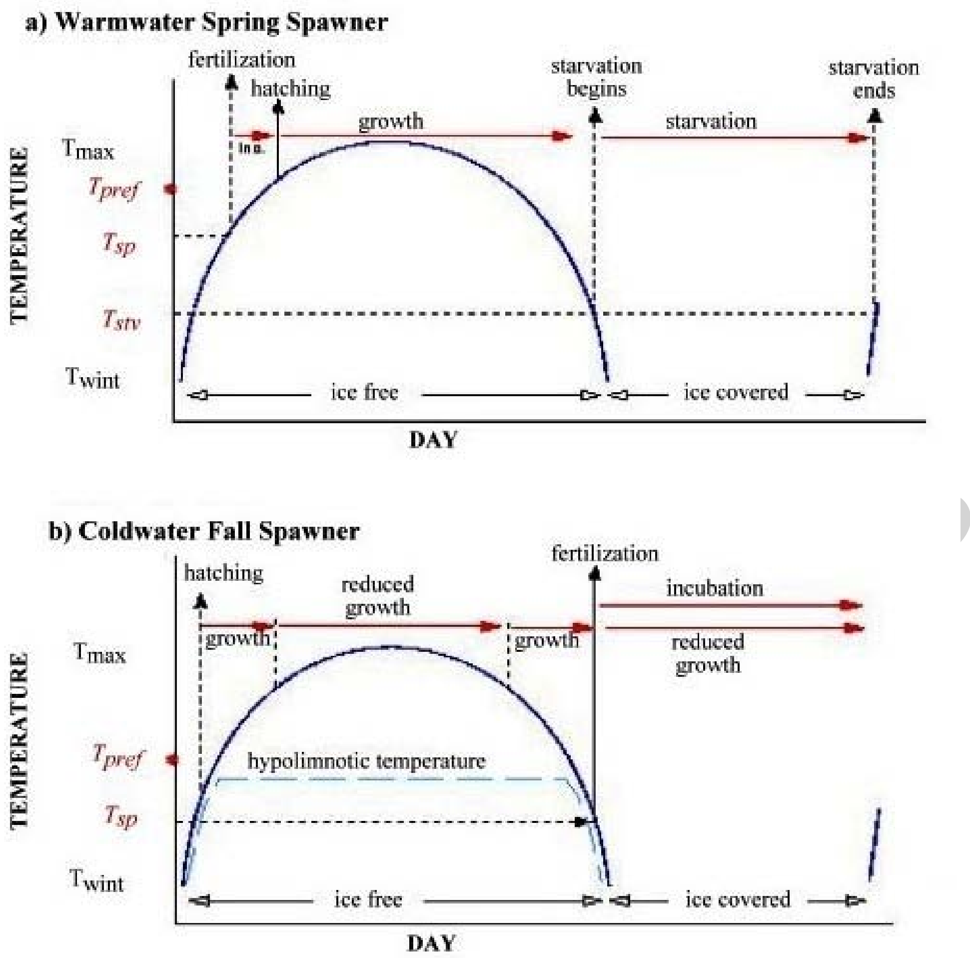

Figure 3. Annual water temperature cycles typical of those experienced by warm and cold water fish living in central North America. Both maximum summer surface-water temperatures (T_{max}) and minimum winter temperatures (T_{wint}) are marked. The graph for the cold water species also gives the annual cycle of cooler temperatures typical of the deep water environments (the hypolimnion) of stratified lakes. Similar cooler summer temperatures are also found near groundwater discharges in rivers and streams. Superimposed on these water temperature cycles are generalized annual growth and reproduction periods typical of warm water and cold water fish. These periods are shaped by the annual temperature cycles through species-specific, critical temperatures (T_{sp}—spawning temperature; T_{pref}—preferred temperature; and T_{stv}—starvation threshold temperature) that initiate significant life cycle events (e.g. fertilization) and initiate/terminate significant life cycle periods (e.g. growth, winter starvation).

Given the importance of temperature in shaping the vital activities of individual fish, fish populations should respond strongly to natural variations in climate that involve systematic changes in water temperature and water volume. Responses to such environmental changes (e.g. changes in sea level, changes in ocean current and upwelling patterns, changes in seasonal temperature cycles in lakes) have been documented for many freshwater and marine populations. These responses fall into two broad categories:

- Changes in fish production in a particular locale
  - Shifts in the overall productivity of entire fish communities
  - Changes in the relative productivity of individual populations within a community
- Changes in fish spatial distributions
  - Shifts in the zoogeographic centers and boundaries of individual species and species groups, as defined on large geographic scales
  - Shifts in the local distributions of individual population members on small geographic scales

These categories of response include most of the projected effects of climate change on wild fish populations. Such responses will produce a variety of impacts on existing fisheries (Table 1). Most of these impacts will stem from two primary mechanisms:

- The overall sustainable harvest of fish will rise and fall with shifts in overall aquatic productivity
- Sustainable harvests from a specific population in a specific location may increase substantially or fall to zero depending on how new climate conditions and species-specific thermal characteristics interact to determine what the population's share of available production will be

Impacts on fish ecology	Consequences for fisheries
Change in overall fish production in most aquatic ecosystems	Change in total sustainable harvest of fish from each ecosystem
Change in relative productivity of individual fish populations in most aquatic ecosystems	Change in the relative levels of exploitation that can be sustainably directed against the fish populations of each ecosystem
Large-scale shifts in the geographic distribution of species	Change in the mixture of species that can be sustainably harvested within a specific geographic area Change in location of profitable fishing grounds
Small-scale shifts in the spatial distribution of members of many populations	Change in sustainable harvest for each population Change in efficiency of fishing gear leading to change in sustainable levels of fishing effort

Table 1. Likely impacts of climate change on fish ecology and consequences for fisheries

Given such impacts, effective human adaptation to the effects of climate change on fisheries would involve reallocation of harvest from those populations that are adversely affected by climate changes to those populations that benefit from such changes. However, there are strong inertial forces in both ecological systems and harvest systems that complicate this simple picture. In ecological systems, concurrent shifts in basic productivity and thermal conditions will cause significant restructuring of the fish community. This period of restructuring can be prolonged and will be characterized by great uncertainty in the sustainable harvests that can be assigned to any community member. Also, in any harvest system there are human preferences for particular species that are difficult to change. The existence of such preferences will tend to prolong exploitation of populations that should be protected. The risk associated with these internal lags is that unsustainable exploitation levels will be maintained on adversely affected populations, leading eventually to both population and fishery collapse. Such risks will increase as the rate of climate change increases.

For many marine and freshwater systems, current ecological knowledge is sufficient to provide a rough classification of fisheries according to whether they are likely to be positively or negatively affected by specific climatic changes. Tools that can provide more quantitative assessments of impact and define better management responses have yet to be developed.

-
-
-

Bibliography

Beamish R.J., ed. (1995). *Climate Change and Northern Fish Populations* (Proceedings of Symposium, Victoria, B.C., October 1992) (Canadian Special Publication of Fisheries and Aquatic Sciences 121), 739 pp. Ottawa: National Research Council of Canada. [This volume is a collection of research papers focusing on the past and present impacts of climate variation on marine and freshwater fish populations; most of the papers present individual case studies of specific populations; marine populations of the North Pacific Ocean are emphasized.]

Everett J.T. (1996). Fisheries. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific–Technical Analyses* (ed. R.T. Watson, M.C. Zinyowera and R.H. Moss), pp. 511–538. Cambridge, U.K.: Cambridge University Press. [This chapter is a global overview of potential effects of climate change on fisheries, as suggested by the climate change scenarios developed in the Second Assessment of the International Panel on Climate Change.]

Mann K.H. and Lazier J.R.N. (1996). *Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans*, 2nd ed., 394 pp. London: Blackwell Science. [This book provides a very clear synoptic account of the role climate plays in shaping the environments that support marine fisheries.]

Markham A., Dudley N. and Stolton S. (1993). *Some Like It Hot: Climate Change, Biodiversity, and the Survival of Species*, 144 pp. Gland, Switzerland: WWF International. [This book provides a good, non-technical overview of the impacts that climate change may have on both aquatic and terrestrial biota.]

Newell D. and Ommer R.E., eds. (1999). *Fishing Places, Fishing People*, 374 pp. Toronto: University of Toronto Press. [This book presents a series of case studies illustrating the impacts of environmental and social change on small, traditional fishing communities.]

Regier H.A., Magnuson J.J. and Coutant C.C., eds. (1990). Introduction to proceedings: symposium on effects of climate change on fish. *Transactions. American Fisheries Society* **119**(2), 173–175. [This volume is a collection of research papers focusing on possible effects of climate change on both freshwater and marine fish and fisheries; there is a strong emphasis on North American freshwater populations.]

Shuter B.J. et al. (1998). Canada country study: climate impacts and adaptation—fisheries sector. *The Canada Country Study: Climate Impacts and Adaptation* (National Sectoral Volume), Vol. 7 (ed. G. Koshida and W. Avis), pp. 257–318. Ottawa: Environment Canada. [This chapter provides a comprehensive assessment of the possible effects of climate change on the freshwater and marine fisheries of Canada.]

Wood C.M. and McDonald D.G., eds. (1997). *Global Warming: Implications for Freshwater and Marine Fish*, 425 pp. Cambridge, U.K.: Cambridge University Press. [This book provides an authoritative and comprehensive collection of reviews of the current state of scientific knowledge regarding the biochemical, physiological, and ecological responses of fish to climate variation.]

Biographical Sketches

Brian J. Shuter was born in Toronto, Canada, in 1947. He completed his undergraduate and graduate education (M.Sc. and Ph.D.) at the University of Toronto. His graduate research focused on the population dynamics and phenotypic plasticity of aquatic organisms. His postdoctoral work involved detailed assessments of the impacts of thermal effluents on fish population dynamics. Since 1977 he has been a research scientist with the Ontario Ministry of Natural Resources and an adjunct professor in the Department of Zoology, University of Toronto. His recent research has focused on the role of climate in determining natural patterns of variability in the dynamics of fish populations. He has co-authored over 50 papers in the primary scientific literature and has recently co-authored, with Ken Minns and Henry Regier, a comprehensive survey of the likely impacts of climate change on fisheries in Canada.

Charles K. Minns (Ken) was born in London, England, in 1947. He completed his university education in the U.K. and Canada, studying zoology and systems ecology. He has worked since 1974 in fields of freshwater ecology, limnology, and fisheries, with emphasis on systems analysis and modeling, for Canada's Department of Fisheries and Oceans (DFO). He has been active in the regional freshwater impacts assessment arena of climate change, contributing in 1999 with the Canada Country Study on impacts and adaptation, and leading in 2000 a DFO review of research needs for assessing impacts of climate change and variability on Canada's fishery resources. He is currently section leader for Fish Habitat Studies in DFO's Great Lakes Laboratory for Fisheries and Aquatic Sciences and an adjunct professor at both McMaster University and the University of Toronto.