PERSPECTIVE

Toward a definition of conservation principles for fisheries management

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Abstract: Conservation, like beauty is clearly in the eye of the beholder. The lack of a clear definition of what is meant by the term conservation, however, may encourage misconceptions about the degree to which biological objectives can be traded off against pressing economic and social objectives. Our purpose is to promote a dialogue about the meaning and practice of conservation, which might lead toward consensus on essential biological objectives. We present a brief history of the philosophical evolution of the term conservation and offer a definition of conservation based on the argument for an ecological ethic. This ethic requires that human benefits be derived in a sustainable manner and recognizes that human uses need to be reconciled with intrinsic and necessary ecosystemic functions and structures. We then present a preliminary set of operating principles applicable to the management of fish stocks that are consistent with an ecological or ecosystemic view of conservation. By proposing a set of conservation principles for fisheries management we hope to initiate a debate about just what those principles ought to be.

Résumé : La conservation, comme la beauté, est dans l'oeil de celui qui regarde. Toutefois, l'absence d'une définition claire de ce qu'on entend par le terme conservation peut causer des malentendus quant à la possibilité de compromis entre les objectifs biologiques et des objectifs économiques et sociaux pressants. Le but du présent article est de promouvoir un dialogue sur la signification et la pratique de la conservation, ce qui pourrait amener à un consensus sur les objectifs biologiques essentiels. Nous présentons un bref historique de l'évolution philosophique du terme conservation et offrons une définition de la conservation fondée sur la justification d'une éthique écologique; cette éthique exige que les humains adoptent des pratiques durables et reconnaît que les utilisations humaines doivent concorder avec les fonctions et structures intrinsèques et nécessaires des écosystèmes. Nous présentons ensuite une série préliminaire de principes opérationnels qui sont applicables à la gestion des stocks de poissons et concordent avec une perspective écologique ou écosystémique de la conservation. En proposant ces principes de conservation, nous espérons lancer le débat sur ce que devraient être de tels principes.

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Introduction

A dynamic interplay among biological, economic, and social objectives has, and will, determine the fate of Canada's fisheries resources. Conservation and protection are the central features of any definition of biological objectives, while efficiency and allocation issues dominate the definition of economic and social objectives. Parsons (1993) has reviewed the historical conflict among these objectives and the influence of that conflict on the evolution of fisheries management practice in Canada. This evolution has been marked by recent attempts to enshrine biological objectives in law. In 1985, the federal government amended the Fisheries Act by adding a statement of purposes (cf. Parsons 1993). The first purpose is "to provide for the conservation and protection of fish and waters frequented by fish."

The conservation and allocation of fisheries resources in Canada are also subject to the 1990 Supreme Court of Canada decision (*Regina v. Sparrow* 1990). While this decision established the priority of food fishery rights of indigenous peoples over the rights of other users, it also established the primacy of conservation needs over any use (aboriginal or not). Unfortunately, *Regina v. Sparrow* did not specify what conservation means, nor did it provide

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guidance on how to determine when conservation needs are met.

Although the courts have repeatedly reaffirmed the federal government's responsibility for conservation (Parsons 1993), no federal government agency has, to our knowledge, adopted a formal definition of conservation for fisheries resources. Our concern, shared by Parsons (1993), is that the lack of a clear definition of conservation may foster misconceptions about the degree to which biological objectives can be safely traded off against pressing economic and social objectives. Our purpose is to promote a dialogue about the meaning and practice of conservation, in the hope that this will lead toward consensus on essential biological objectives. We begin with a brief exploration of the philosophical evolution of the term conservation. Then we offer a definition of conservation based on the argument for an ecological ethic. Following the definition, we present a preliminary set of operating principles applicable to the management of fish stocks, principles consistent with an ecological, or ecosystemic, view of conservation.

The principles espoused in this paper are intended to apply mainly to areas in which self-sustaining aquatic ecosystems are the norm. This includes, for example, most of Canada except heavily urbanized regions and regions subject to intensive agriculture where aquatic ecosystems may have been severely altered "by one or more of a score of human or anthropogenic practices deleterious to the more preferred species of fish" (Regier 1976).

A brief philosophical history of conservation

Reviews by Pepper (1984), Callicott (1991), and Norton (1991) provide detailed summaries of the environmentalist view of conservation, as it evolved in the West over the last 200 years. North American usage of this term has been shaped by three ethical precepts: the prescientific Romantic–Transcendental Preservation Ethic of Ralph Waldo Emerson, Henry David Thoreau, and John Muir; the Resource Conservation Ethic of Gifford Pinchot; and the Evolutionary–Ecological Land Ethic of Aldo Leopold (Callicott 1991).

The Romantic–Transcendental Preservationists believed that nature was the proper source of religion. This line of thought runs back to Classical Greece (Boas 1973; Pepper 1984) and partly inspired the romantic movement of the 18th and 19th centuries. Its founders included Rousseau, who argued that the inherent goodness of nature and humanity were inseparable, and Carlyle, Coleridge, and Wordsworth, who each promoted pantheistic themes wherein the natural world was the source of true spiritual knowledge (Baumer 1973; Boas 1973; Pepper 1984). In the New World, Emerson and Thoreau wrote about the connection between nature and the psychological health of mankind. They argued for the intrinsic value of wilderness as a place of beauty, quiet contemplation, and spiritual renewal. Building on these ideas, the strong preservationist wing of the environmental movement emerged. The first leader of this movement was John Muir, wilderness writer and first president of the Sierra Club.

Gifford Pinchot, Chief of the U.S. Forest Service from 1898 to 1910, was the leader of the utilitarian school of early environmentalists and helped to formulate the policies that became known as the conservation movement. Until the early 1900s, the public had never heard of the term conservation, but through President Theodore Roosevelt, it became the "label of a national issue" (Leopold 1933). The new policy was defined as "the use of the natural resources for the greatest good of the greatest number for the longest time" (Pinchot 1947). This phrase is probably the progenitor of the maxim "conservation through wise use," or simply "wise use," a term that Pinchot himself used (Pinchot 1947). According to Nash (1969), Pinchot and his colleagues appropriated the term conservation for the wise-use movement.[1] Pinchot's secular, utilitarian view of conservation, with its dual principles of equity and efficiency (Callicott 1991), became the basis for the Resource Conservation Ethic.

Pinchot's view of conservation led to conflict with the preservationists, and particularly with John Muir. A disagreement between them in 1897 over the use of forest preserves (later called National Forests), and a long and acrimonious battle some years later over the building of a dam in Yosemite National Park, produced a permanent split in the leadership of the nascent conservation movement. Two distinct and intractable schools of thought were established, each claiming exclusive rights to the meaning of the term conservation, and each accusing the other of being "false standard bearers of the gospel" (Hays 1959).

These conflicting views on the meaning of conservation are also evident in early literature on the subject in Canada. Canadian participation in Roosevelt's North American Conservation Conference led directly to the establishment of the Commission of Conservation of Canada in May 1909 (Sifton 1910). In the public minutes of this group, the meaning of conservation slides back and forth between protection and wise use, with the Dominion entomologist Gordon Hewitt (1918) echoing Pinchot's view ("the real idea of conservation; use without abuse") and the Chairman of the Commission, Clifford Sifton (1910), being very careful to draw a line between "effective conservation" of resources and their "economical use."

Today, the most powerful and influential private conservation organizations represent the interests of preservationists and thus "remain firmly rooted in the prescientific Romantic–Transcendental intellectual complex." In contrast, government resource agencies "are still very much ruled by the 19th century Resource Conservation Ethic" (Callicott 1991). Thus, current events are still influenced by the internecine conflicts of the 1890s.

Aldo Leopold developed an alternative to the strict preservationist and utilitarian viewpoints. His understanding of conservation evolved beyond his early practice of wise use because of his interest in ecology and his seminal activities in the emerging field of wildlife management.

[1] Not to be confused with a loose amalgam of some 250 disparate groups associated under the name Wise Use or Wise Use Movement created in the late 1980s, whose express purpose is to destroy the environmental movement (Krakauer 1991).

Leopold (1939) suggested that economic biology, with its focus on providing a competitive advantage to "useful" species, needed to be replaced by an ecological approach that conceived of the biota as a single system, the land organism, "so complex, so conditioned by interwoven cooperations and competitions, that no man can say where utility begins or ends." The purpose of conservation was to perpetuate the health of this system. Health was simply "the capacity of the land for self-renewal" and conservation "our effort to understand and preserve this capacity" (Leopold 1949).

Leopold based his view of conservation on two complementary principles: first, that humanity is best served by preserving the natural life support systems of the planet; second, that indigenous ecological systems have intrinsic value that must be respected. He built an ecological rationale for his views that avoided the largely untenable sentimentalism of the Romantics and the strictly anthropocentric utilitarianism of the advocates of wise use. His ideas found eloquent advocates in Canada (e.g., Clarke 1963; Coventry 1963).

The evolutionary–ecological land ethic of Leopold is grounded in an intimate appreciation of the interconnected structures and functions of ecosystems and their vulnerability to unguarded tinkering. Since Leopold's time, the land ethic has evolved into the concept of the ecosystem approach (Christie et al. 1986), which aims to balance ecological, economic, and social objectives and recognizes that human uses must be reconciled with intrinsic and necessary ecosystemic functions and structures.

Miller (1986), Regier and Bronson (1992), and others have further attempted to recognize and codify the range of thinking exemplified by the preservationist and utilitarian attitudes. Miller (1986) describes the divergent viewpoints that are generally represented in environmental disputes as technocratic (=utilitarian) and humanistic (=preservationist). These are ideological perspectives that cannot be resolved by scientific validation and rational debate.

Both the preservationist and utilitarian approaches to conservation have weaknesses. Both represent anthropocentric views of ecosystems. The former focuses on meeting the aesthetic and spiritual needs of humans while the latter focuses on meeting their material needs. Extreme preservationist attitudes promote intrinsic valuation of resources and view wild ecosystems as temporally static, rather than naturally dynamic. Extreme utilitarian attitudes promote monetary valuation of resources and view ecosystems as collections of organisms that can be arranged and rearranged at will. Science cannot be used to determine how resources should be valued in either case; however, science can provide objective validation of those assumptions about the real world that underlie any particular valuation procedure. Current ecological science presents a view of ecosystems (e.g., Pimm 1991: systems of interacting biological populations, characterized by temporal variation in abundance and species composition that are constrained by past and present environmental conditions and competitive–predatory linkages) that is quite incompatible with either of the ideological positions outlined above.

In the modern parlance of resource management, the terms sustainable development, sustainable use, and conservation are often used interchangeably in ways that are strongly influenced by the wise-use ethic of Pinchot. The original definition of sustainable development, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987), is really wise use with a longer time horizon. A recent redefinition ("improving the quality of human life while living within the carrying capacity of supporting ecosystems" World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991) moves a bit towards Leopold's position by explicitly recognizing the existence of ecological limits on use. Sustainable use ("use of an organism, ecosystem or other renewable resource at a rate within its capacity for renewal" World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991) focuses directly on use, but recognizes that limits on use should be based on resource renewal rates rather than existing inventory levels.

Several recent definitions of conservation also have a strong utilitarian focus. In 1980, the World Conservation Strategy of the International Union for the Conservation of Nature and Natural Resources (1980) defined conservation as "the management of human *use* [our italics] of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations." In 1991, conservation was defined as "the management of human *use* [our italics] of organisms or ecosystems to ensure such use is sustainable. Besides sustainable use, conservation includes protection, maintenance, rehabilitation, restoration, and enhancement of populations and ecosystems" (World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991).

The principal focus of all these definitions is resource use. There are many reasons for rejecting use, or wise use as the main focus for a new definition of conservation: (*i*) It emphasizes the economic aspects of biology and thus it fosters over-valuation of those natural entities that are of direct use to man; (*ii*) It ignores intrinsic values by discounting the complex interrelations between "useful" and "nonuseful" organisms that characterize ecosystem function; as Leopold (1949) noted, "One basic weakness in a conservation system based wholly on economic motives is that most members of the land community have no economic value" but they are "(as far as we know) essential to its healthy functioning"; (*iii*) Wise use is often seen as synonymous with multipurpose use or multiple use that "usually involves an interminable succession of piecemeal additions of new more intensive uses through time and a stepwise ecological shift away from the initial wild state" (Francis et al. 1979); and (*iv*) It signifies continued reliance on an anthropocentric philosophy which holds that "only people possess *intrinsic* value, while nature possesses merely *instrumental* value" (Callicott 1991).

Toward a conservation ethic and a definition

Neither the Romantic Preservation Ethic nor the Resource Conservation Ethic provides a viable foundation for a modern definition of conservation because both represent pre-ecological views of the environment. The first rejects scientific argument entirely, demanding specific, quasireligious commitments that are incompatible with the secular and multifaith societies of today. The second is rooted in a 19th century scientific paradigm that has been superseded by a deeper understanding of environmental realities (Callicott 1991). With its evolutionary and ecological basis, Callicott (1991) argues that Leopold's land ethic "ought to supplant its 19th century antecedents": it is less constrained by the cultural biases that taint the earlier views and it generates management policies that should be acceptable to moderates from both sides of the conservation movement. This ethical position leads to a definition of conservation that recognizes roles for both wise use and preservation but adopts neither as its central premise.

This definition can be developed within the context of current ecological knowledge. Odum (1959) saw conservation in the broadest sense as "probably the most important application of ecology" and he considered the principle of the ecosystem as "the basic and most important principle underlying conservation." Current science views the ecosystem as an integrated collection of abiotic and biotic entities that interact through exchanges of matter and energy (Allen and Hoekstra 1992; Pickett et al. 1992). A major theme is the continuity of ecosystem processes in the face of significant temporal variation in its abiotic components (Pickett et al. 1992). This ability to maintain functional continuity is essential to ecosystem sustainability and has been equated with such desirable qualities as ecosystem integrity and ecosystem health. Another major theme is the role of biodiversity in determining the degree of integration among system components and in supplying the functional redundancy necessary to ensure long-term system sustainability (Allen et al. 1993). In a conservation context, it is important to recognize the distinction between ecosystem function and ecosystem biodiversity. As Allen et al. (1993) pointed out, these two qualities should be treated separately because preservation of ecosystem function is a necessary, but not sufficient, condition to ensure preservation of biodiversity.

From this ecosystem perspective, conservation should mandate the safeguarding of healthy life-support systems that "are the ecological processes that keep the planet fit for life. They shape climate, cleanse air and water, regulate water flow, recycle essential elements, create and regenerate soil, and enable ecosystems to renew themselves" (World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991). In addition, conservation should mandate the control of major stresses (e.g., habitat alteration, exploitation, species introductions) to mitigate negative effects on ecosystem function and biodiversity. The goal of conservation should be healthy ecosystems. This goal is consistent with the land ethic. It can be achieved by ensuring that native biota are sustained in harmony with their natural environments. A conservation ethic based on ecological values requires that humans derive social, economic, recreational, and cultural benefits in a sustainable manner. A definition of conservation consistent with this position follows:

> the protection, maintenance, and rehabilitation of native biota, their habitats, and life-support systems to ensure ecosystem sustainability and biodiversity.

This definition of conservation does not contain the terms use or sustainable use. Conservation can no longer imply just use or advocate use as its central tenet. Conservation must clearly warrant the limitation of use to ensure ecosystem sustainability. In some situations, effective conservation will demand complete prohibition of use. This definition is sufficiently broadly based to include preservation through protection and use through maintenance (e.g., as in maintaining a vehicle that is being used by periodic servicing). We use the term rehabilitation to mean "to return a degraded ecosystem or population to an undegraded condition, which may be different from its original condition" (World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991).

The definition does not include the terms restoration ("to return a degraded ecosystem or population to its original condition") or enhancement ("increasing the capacity of an ecosystem or population to fulfil a particular function or yield a specified product") (World Conservation Union, United Nations Environment Programme, and World Wide Fund for Nature 1991) because (*i*) restoration may be difficult, if not impossible, to achieve in most cases (Francis et al. 1979; Meffe 1995) and (*ii*) attempts at rapid alteration of natural carrying capacities through enhancement activities such as the stocking of desirable exotic species weakens existing ecosystem structure and function (Evans et al. 1987). Community transformations via species invasions and deliberate stocking of exotics (vis à vis enhancement) also make recolonization attempts with native species more difficult (Evans and Olver 1995). Loftus (1976) recommended that rehabilitation should be the approach used in Canadian fisheries science; he rejected enhancement, arguing that it was quite a different approach and perhaps even antagonistic to rehabilitation.

This definition does not preclude the introduction of exotic species, nor does it require blanket acceptance of the consequences of unplanned invasions. However, experience has shown that exotic introductions often have unexpected, negative consequences for native ecosystems that are very difficult to reverse. Thus, we believe such introductions should be carefully evaluated to ensure protection of existing native biodiversity.

Conservation principles for fisheries management

Having offered a definition of conservation, and a rationale to justify it, we now consider how these ideas can be applied in a fisheries management context. Our objective is to develop a set of practical principles that will guide fisheries managers in their role of maintaining the viability of living aquatic resources, and thus ensuring ecosystem sustainability.

Our definition focuses on overall objectives that are ecosystemic. However, typical conservation activities focus on populations of single species without direct reference to ecosystem consequences. This is partly because such populations are usually more obvious and easier to study than communities, landscapes, or genes (Noss 1990). As Magnuson (1976) noted, interactions between populations (e.g., predation and competition) form the heart of the functional aspects of community ecology. Without a reliable methodology that can be applied directly at the ecosystem level, population-based conservation may be the most practical way "to begin to cope with the issue of whole system viability" (Soulé 1987). Significant, but indirect, protection for the entire ecosystem may be provided by actions designed to preserve the viability of populations that fill key functional roles in the system. This approach, founded on such familiar concepts as keystone predators, indicator organisms, and integrator species may be the most effective way currently available to achieve ecosystem sustainability.

A population-level focus is particularly applicable to fisheries management because human exploitation of fish resources has traditionally focused on populations of particular species, which tend to be managed in isolation. What modern conservation ideas demand from management practice is explicit consideration of the ecosystem context that underlies the sustainability of any population (Andrewartha and Birch 1984). Classical practice treated an exploited population as an isolated entity, cut off from its past (i.e., its evolutionary history and consequent genetic heterogeneity), and independent of the abiotic and biotic components of its supporting ecosystem. Modern practice must explicitly recognize the essential roles that all of these components play in determining the sustainability of individual populations, and consequently of entire ecosystems.

The particular importance of genetic heterogeneity to management practice has been the focus of much recent work (Allendorf and Ryman 1987; Ryman and Utter 1987; Hindar et al. 1991). Such considerations, embodied under the rubric of the stock concept, now play a significant role in many fisheries management actions. Stocks are reproductively isolated subunits of populations that may, over time, become genetically differentiated. If the number of stocks involved in a fishery and their relative abundance is not known, the possibility of overfishing will always exist (see Loftus and Regier 1972, for examples drawn from North American Great Lakes fisheries). Even if stock composition is known, allowable harvests must be kept well below values considered as optimal given the history of fisheries exploitation (Larkin 1977; Peterman 1977; Ludwig et al. 1993). In the long term, population sustainability requires stock sustainability and thus stock-specific management. For all of the reasons outlined above, we have made fish stocks the primary focus of the principles espoused in this paper.

Fundamental principle

The primary goal of fisheries management is to ensure the perpetuation of self-sustaining stocks of indigenous aquatic species and, where possible, to allow their sustainable use. A commitment to resource maintenance is essential to preserve the biological base for such use. The principle can be stated as

- aquatic ecosystems should be managed to ensure long-term sustainability of native fish stocks.

Despite efforts to shift the focus of fishery management from species' stocks to multispecies assemblages, most fishery management practice is still stock oriented (Mercer 1982). In an evaluation of New Zealand's approaches to conservation, Towns and Williams (1993) argue that species-, or stock-, oriented approaches must be viewed as complementary to community- or guild-oriented and habitat-oriented approaches. Rich (1939) foresaw that conservation and rehabilitation of salmon (and we would argue other species), if it were to be successful, would have to occur at the stock level.

Thus, the key to conservation is sustainability of naturally reproducing wild stocks of native fish. These stocks embody thousands of years of evolutionary adaptations to local environments. The unique biological suitability of native stocks to their resident water bodies ensures that they are best able to withstand significant human use without serious deterioration in their long-term sustainability. These small, spatially isolated stocks are important guarantors of the genetic diversity of a species. In particular, stocks that occur in marginal habitats that may be active sites of natural selection may be of adaptive significance to the species as a whole (Scudder 1989; Northcote 1992).

The role of hatcheries and stocking in conservation must be re-evaluated. Hatchery programs intended to supplement existing wild, native stocks may have the opposite effect. The artificial selection process in hatcheries favours domestic, as opposed to wild, traits. Subsequent inbreeding with wild stocks can quickly undo thousands of years of natural selection and lead to loss of local stocks (Nehlsen et al. 1991; Hilborn 1992). Recruitment overfishing of wild stocks, stimulated by the planting of hatchery fish, can have the same effect (Evans and Willox 1991). The stocking of hatchery fish to mitigate stock declines, caused primarily by other factors such as habitat degradation and dam construction, can also accelerate the loss of wild stocks (Nehlsen et al. 1991), while failing to address the primary causes of population decline. The overall effect is a loss of genetic diversity. The reliance on technological solutions such as the stocking of hatchery fish to redress man-made problems has been at the expense of ethical, ecological, and genetic considerations (Scarnecchia 1988; Hilborn 1992; Meffe 1992). Meffe (1992) has called this "techno-arrogance," an attitude that has clearly undermined conservation efforts. Artificial fisheries, which rely wholly on stocking for their continued existence, are not sustainable and thus have no part in a conservation ethic.

Even while the inadequacies of fisheries management strategies based on hatcheries and stocking are becoming evident, investments in intensive aquaculture are growing rapidly. Aquaculture is not based on conservation principles and, when practiced in natural systems, it may enhance the degradation and abandonment of sustainable fisheries. In such systems, aquaculture can contribute to the genetic deterioration and loss of natural stocks, enhance the spread of diseases, accelerate the rates of invasion of exotic species, and promote habitat destruction and degradation (Folke et al. 1994).

Stocks are the repository of the genetic diversity within each species and are the building blocks on which fisheries management is based. Hence, the focus on fish stocks in the development of conservation principles is appropriate. Species and, by extension, stock diversity is a reliable indicator of biodiversity in aquatic systems (Moyle and Leidy 1992). Thus, a focus on preserving fish stock diversity is a practicable strategy for protecting overall biodiversity of aquatic systems. As fish are often primary determinants of ecosystem structure (Brooks and Dodson 1965; McQueen et al. 1986; Carpenter 1988), protecting extant fish assemblages should usually protect extant ecosystem structure. In an individual water body, a population may be composed of one or several stocks. We believe that primary conservation requirements are met when the sustainability of individual fish stocks is secured.

Supporting principles

To ensure ecosystem protection, degradation of the physical environment (e.g., habitat destruction), the chemical environment (e.g., water quality deterioration), and the biological environment (e.g., transfer of non-native stocks, introduction of exotic species) should be prevented. To ensure sustainable use of fish stocks, those populations that can be exploited, and those that cannot, need to be identified. For populations that can be exploited, the amount of harvest must be limited and the manner of harvesting must be controlled. The principles that we believe are necessary to effectively guide such actions are outlined below.

Principles of ecosystem protection

- The sustainability of a fish stock requires protection of the specific physical and chemical habitats utilized by the individual members of that stock.

The existence of clean, undamaged environments is critical to sustainability. The biological processes that underlie sustainability require good substrate, adequate water supply, suitable thermal characteristics, and good water quality. Habitat alterations or modifications that decrease ecological productivity will undermine efforts to conserve stocks. The right to use ecological productivity does not bestow the right to abuse it. Attempts to conserve habitat often depend on simplified assumptions that (*i*) the level of productivity is roughly proportional to the supply of suitable habitat and (*ii*) the loss of habitat units that are noncritical will not noticeably affect sustainable levels of the preferred use, exploitation. Recent research by Pulliam and Danielson (1991) challenges these simple models. Good habitats may facilitate surplus production but other, mediocre or poor, habitats may be necessary to accommodate the accumulated biomass. Hence, the total habitat may be required to support the level of biomass needed to support harvest expectations. Preserving critical spawning habitats may be pointless if there is nowhere for adults to live before becoming vulnerable to exploitation. In related studies, Danielson (1991, 1992) has shown how changes in the relative supplies of different habitat types can shape the outcome of interspecific interactions. Sutherland and Anderson (1993) showed, with simple models, how biased elimination of better or poorer habitat units in a fragmented landscape can determine the shape of the relationship between sustainable population size and overall habitat supply.

Given the temptation to measure the degree of conservation success within fisheries in terms of productivity or potential yield, there is a clear danger that ecosystem modifications that increase production, such as climate warming, eutrophication, or aquaculture, might be viewed as changes that are consistent with conservation objectives. However, if the prior, undegraded condition of an ecosystem provides the direction for rehabilitation efforts and the benchmark for achievement of sustainable conservation success, any action that moves an ecosystem away from that benchmark state may be clearly judged as degradation.

- The sustainability of a fish stock requires maintenance of its supporting native community.

Degradation of the biological environment, via the transfer of non-native stocks and the introduction of exotic species, must be prevented. Transfers of non-native organisms inevitably result in the loss of locally adapted gene pools. In the Great Lakes basin, the invasion of species like sea lamprey, *Petromyzon marinus*, alewife, *Alosa pseudoharengus*, and rainbow smelt, *Osmerus mordax*, and the introduction of species like common carp, *Cyprinus carpio*, have had considerable, negative impacts on native fish communities (Emery 1985; Crossman 1991).

Hence, deliberately adding species to increase species richness, or more likely to improve exploitation opportunities, cannot be considered a conservation action. The consequent alteration to the productivity of natural ecosystems and the loss of surplus production from native stocks undermines sustainability. In addition, the accompanying degradation of biological habitats represents an irreversible shrinkage in the reservoir of biodiversity that uniquely characterizes each region of Canada.

The rates of deliberate introductions and accidental, but usually man-assisted, invasions are continuing to increase (Crossman 1991; Welcomme 1992; Carlton and Geller 1993). The history of introductions of organisms foreign to native ecosystems is replete with examples demonstrating severe, detrimental effects (Billington and Hebert 1991; Mills et al. 1991). Managing with exotics has been compared to a game of chance (Magnuson 1976), where positive results cannot be guaranteed (Regier 1968). Because changes wrought by such introductions can be extreme and because net results are hard to predict, proposed introductions should be forbidden, unless a situation-specific evaluation confirms that the risk to existing ecosystems is minor. Invasions present a more complex problem, although species transfers by ships' ballast water, the major route in the North American Great Lakes, are now receiving more urgent attention (Carlton and Geller 1993). Carlton and Geller (1993) have characterized these exotic additions as a form of ecological roulette.

Principles of population utilization

• Vulnerable, threatened, and endangered species must be rigidly protected from all anthropogenic stresses.

By definition, the stocks of such species face various degrees of risk of extinction. Removal and (or) prevention of anthropogenic stresses would significantly reduce this risk.

These organisms are irreplaceable segments of the heritage of biodiversity that uniquely characterizes the biota of a region. Any activity that risks their extinction should be proscribed. In Canada, the selection of species at risk and their classification is decided by the Committee on the Status of Endangered Wildlife in Canada, which comprises representatives from federal, provincial, and private agencies. In April, 1993, 35 wild species, subspecies, or separate populations of fish were designated as vulnerable, 11 as threatened, and 3 as endangered (Committee on the Status of Endangered Wildlife in Canada 1993). However, the determinations of the committee have no legal status so that each jurisdiction must provide its own appropriate safeguards to risks imposed on these designated species, subspecies, or separate populations.

• Exploitation of populations or stocks undergoing rehabilitation will delay, and may preclude, full rehabilitation.

For stocks undergoing rehabilitation, any exploitation will delay full rehabilitation and increase the risk of failure. If some harvesting occurs, it should be strictly controlled to ensure that mortality rates do not prevent rehabilitation and are, in fact, low enough to let rehabilitation proceed at a reasonable rate. Allowing higher mortality rates will ensure the perpetuation of put-and-take hatchery-dependent fisheries that may masquerade as rehabilitation projects. If harvest for other species is allowed, fishing practices should minimize the capture of the stock undergoing rehabilitation. This is difficult to achieve in mixed stock fisheries, which should be managed for the protection of the least sustainable individual stock within the mix, or a more selective means of harvesting individual stocks should be found.

• Harvest must not exceed the regeneration rate of a population or its individual stocks.

Exploitation can only be sustained if it is restricted to the annual generation of fish protein that exceeds the maintenance requirements of a population, or its individual stocks. Extinction is inevitable if losses exceed the natural capacity of a population to replenish itself. This is a common characteristic of all renewable resources: sustainable use is equivalent to renewal rate (Daily and Ehrlich 1992). Similar behaviour is well known in economics (Costanza and Daly 1992): exhaustion of capital will occur if annual expenditures exceed interest income. Planned harvest rates should also be sensitive to other uses and stresses imposed on the stock and other ecosystem components. They should acknowledge natural temporal variation in the productivity of the target population and of the ecosystem of which it is a part.

In natural populations, annual regeneration rates vary widely from year to year and cannot be accurately predicted. Given the amplitude of such natural variation, population sustainability can only be guaranteed if fisheries are managed in a cautious manner. Ludwig et al. (1993) offer some sombre reflections on the difficulties of achieving sustainability of exploited fisheries resources. To provide a sufficient margin of safety, total allowable catch should be set well below maximum annual regeneration rates. A variety of formulae have been developed in fisheries science with the aim of establishing defensible limits on exploitation: MSY, OY, $F_{0.1}$, etc. (Parsons 1993). Mostly, these approaches have been developed for single-species stocks, ignoring the ecosystem contexts in which they exist. Some methods developed for multispecies assemblages take account of energy flow dynamics and species interactions. Stock exploitation limits that recognize intrinsic ecosystem dynamics are likely to be more stringent than those obtained by assessing each species in isolation.

The need for caution in exploiting long-lived species is paramount. Such species typically are slow growing, are late maturing, have a low reproductive potential, and have a low turnover or regeneration rate. They may spawn infrequently. Consequently, they require multiple opportunities to spawn and recruit offspring and long recovery times when populations are depressed. For such species, protection of adults is absolutely critical to long-term population stability. The need to exercise caution may be especially critical for long-lived species that are terminal in the food chain because they exert a dominant role in the integration and maintenance of community structure (Evans et al. 1987; Johnson 1994). Pauly et al. (1989) referred to the decline of fisheries for such key species as ecosystem overfishing.

• Direct exploitation of spawning aggregations increases the risk to sustainability of fish stocks.

Stock sustainability requires that the number of adult fish escaping harvest (i.e., spawner escapement) be sufficient to maintain the reproductive output of the stock. As spawner escapement drops toward zero, the risk to stock sustainability increases rapidly.

The impact of a fixed harvest on spawner escapement is minimized if harvested fish are taken at random from the stock and is maximized if harvested fish are taken directly from aggregations of spawning adults. For example, consider a quota of 10 000 fish applied to a stock containing 40 000 fish big enough to satisfy fishers, of which 10 000 fish are big enough to spawn. If the quota is taken at random from the stock, the number of spawners will be reduced about 25%. If the quota is taken from spawner aggregations, all spawners will be removed and the stock will be threatened with extinction. The risk to sustainability (measured in terms of potential reductions in spawner abundance) imposed by spawner targeting can only be ameliorated by significant reductions in allowable harvest. In our simple example, a 75% reduction in harvest would be required to lower the risk imposed by spawner targeting to that imposed by random selection.

Thus, when spawners are targeted for exploitation, conservation needs demand relatively low harvest levels and strict harvest monitoring to keep the risk to stock sustainability at an acceptable level. This requires information-intensive management (i.e., accurate monitoring of both stock abundance and harvest), which is extremely expensive, and thus justifiable only for those stocks that support large, economically important fisheries. Many oceanic stocks fall into this category (e.g., the cod stocks of the east coast of Canada and the anadromous stocks of the west coast of Canada). However, recent experience (e.g., Finlayson 1994, on the demise of northern stocks of the Atlantic cod (*Gadus morhua*)) suggests that the environments inhabited by such stocks are so vast and complex that it is extremely difficult to get the precise information needed to micromanage spawner-targeted fisheries effectively, even when large amounts of money are set aside to acquire that information. As Hilborn et al. (1993) point out, uncertainty in stock assessment and risk in decision making cannot be eliminated, although both can and must be dealt with.

The west coast anadromous stocks spend much of their life cycle in oceanic habitats so large that efficient harvesting is not possible. Only when they form natural aggregations, just before spawning, are they sufficiently concentrated in space to be effectively harvested. The abundance and economic value of these stocks justify large expenditures for the assessment and enforcement activities necessary to restrict spawner-targeted harvests to levels where the risk to sustainability is acceptable. However, despite large current expenditures on such activities, many stocks are in decline (Nehlsen et al. 1991; Waples 1991; Hilborn and Winton 1993), thus suggesting that effective micromanagement of these stocks may also cost far more than is currently appreciated.

Among freshwater species, only a tiny percentage of the millions of discrete stocks scattered throughout the lakes and rivers of Canada are of sufficient economic importance to support the information-intensive, micromanagement practices demanded by spawner-targeted harvesting. To subject such stocks to spawner-targeted harvesting, without escapement monitoring and absolute abundance estimates, would expose the sustainability of these stocks to risks that are both avoidable and unnecessary. In the vast majority of cases, the efficiency of modern fishing gear is high enough, and dispersal of individuals low enough, to permit cost-effective harvesting of these populations without targeting spawning aggregations.

Harvest theory points to the avoidable damage that spawner targeting can inflict on stock sustainability. In principle, this damage is reversible: a harvest moratorium or harvest refuge (sensu Carr and Reed 1993) may allow regeneration of a depleted stock. However, genetic considerations point to long-term damage that is irreversible (Soulé 1987). When spawners are targeted, exploitation is focused on the only natural measure of stock success, reproduction: only those fish that survive to maturity and are successful in reaching the spawning grounds are killed. By imposing direct selection against successful reproduction, deleterious changes in the population gene pool are likely. Among species that home to specific breeding sites, selection will act against homing and imprinting abilities. Selection will also act against those genetic subgroups that use the exploited spawning sites, leading eventually to elimination of those groups from the population. Among species that have specific spawning periods, selection will act to narrow the range of spawning times, typically favouring spawning times that are later than normal. All such changes reduce the ability of a stock to maintain itself in its natural environment and thus damage stock sustainability.

Additional negative effects that accompany spawner targeting include (*i*) increased risk of inadvertently exceeding allowable harvest; increased risk stems from increased vulnerability of spawning fish to capture: use of killing gear (e.g., gill nets) exacerbates the problem because excess harvest cannot be released alive; and (*ii*) habitat damage and disruption of reproductive behaviour: spawning habitat may be damaged by the placement and use of fishing gear; activity accompanying placement and use of gear may also disrupt the reproductive behaviour of the fish themselves; both effects violate the principle of habitat protection.

The potential for undermining population sustainability by targeting adults during their reproductive periods is well recognized in conservation genetics (Lande and Barrowclough 1987; Soulé 1987). Experience in freshwater systems has shown that one of the most cost-effective ways to control nuisance or invading species is to focus intense exploitation on their spawning aggregations. Small, discrete spawning stocks are particularly vulnerable to elimination caused by intense spawner exploitation and genetic deterioration caused by moderate spawner exploitation. Yet, stocks of this sort are important contributors to the genetic diversity of individual populations and to the biodiversity of the species as a whole.

From the arguments presented above, it is clear that, at any level of exploitation, the targeting of spawning fish imposes an additional risk to population sustainability. While the risk may be partly ameliorated by quantitative monitoring of stock abundance and harvest, this is usually practicable only for large populations with known stock compositions. Such populations would have spawner abundances ranging from several thousand to hundreds of thousands of fish, and would include many oceanic, anadromous species where the economic and social value of the fisheries justifies the cost of information-intensive management.

For smaller populations, with unknown stock compositions, such intensive management will rarely be practicable and, where practicable, may not be particularly effective because smaller populations are inherently less predictable than larger populations (Weinberg 1975, p. 20). Such populations would have spawner abundances ranging from less than 100 to several thousand individuals and would include most of the freshwater stocks in Canada's inland lakes and rivers. Generally, spawner-targeted harvesting of such stocks would impose a risk to their sustainability high enough to violate conservation requirements.

The application of conservation principles

At the federal level in Canada, two documents guide the management of fishery resources: the Fisheries Act of 1967 with subsequent revisions, and the Policy for the Management of Fish Habitat issued in 1986 (Department of Fisheries and Oceans 1986). The Act imposes the goal of conservation and protection while the Policy aims for no net loss of productive capacity of fish habitats. In some provinces, relevant policy documents have been developed that are compatible with federal objectives. For example, the policy documents produced by the Ontario Ministry of Natural Resources, Direction '90s (Ontario Ministry of Natural Resources 1991) and the Strategic Plan for Ontario Fisheries, known as SPOF II (Ontario Ministry of Natural Resources 1992), embrace an ecosystem approach to managing fisheries.

At a more prosaic level, the application of conservation principles in the daily work routine of most fisheries biologists relates to determinations they make about resource extraction and development issues. This usually requires them to develop guidelines or regulations to control harvest and protect habitat. The natural tendency to provide oversimplified operational definitions of conservation should be resisted. For example, adequate local control of exploitation cannot be strictly based on species-specific, provincial fecundity and productivity standards. Such standards, while useful first approximations, ignore, of necessity, local circumstances (see Ontario Ministry of Natural Resources 1982 for an example of how a knowledge of local conditions can be used to modify provincial yield guidelines). Without this type of evaluation, the standards sanction harvest levels that approach short-term maximum extraction rates. Such levels are clearly not sustainable because they afford a low margin of safety and take no account of temporal and spatial variation in reproductive success.

The primary literature contains a variety of methods for estimating the optimal sustained yield for individual fish populations in a water body. These studies also discuss why harvests in local waters may vary considerably from predicted values and how yield estimates can be adjusted to provide a closer match to local conditions. Such estimates do provide useful reference points for establishing the lower harvest necessary to provide the margin of safety required to protect stock sustainability. These adjustments require specific knowledge of the water bodies involved and the manner of harvesting. For example, allowable yield should be lower when spawners are targeted for harvest.

Sanctuaries and harvest refuges can be effective tools for applying conservation principles to management issues, particularly those involving immediate threats to stock sustainability. Sanctuaries are water bodies, or parts thereof, where removal of any fish species is prohibited, either for a short period to provide protection to spawning aggregations or for much longer times to allow for rehabilitation of fish stocks. Using examples from coastal marine fisheries and reef fishes in particular, Carr and Reed (1993) define harvest refuges as areas where harvest of target species is restricted, and where the intent of rebuilding stocks of such species is through larval recruitment. It is not clear to us whether the authors include prohibition within the meaning of restriction. Local circumstances, however, will surely dictate a large variety of harvest control regimes including no fishing of target species in some refuges, although fishing for other species may or may not be allowed. Regardless of the type or degree of protection, sanctuary or refuge status should be withdrawn only when special protection is no longer required.

Routine monitoring of ecosystem status is critical to measuring or understanding the status of conservation efforts. For those resources that undergo harvest, stocks must be assessed occasionally, harvest must be determined periodically as a check against sustainable levels, and compliance must be assured. Stock assessment is expensive, but we see no alternative to a judicious and modest program of routine monitoring.

Our intent in presenting this perspective on conservation, vis à vis fish and fisheries, is twofold: to promote an ecological ethic as the foundation for developing a set of conservation principles for the management of fisheries resources in Canada, and to present a set of conservation principles for fisheries management that will evoke a debate about just what those principles ought to be. With respect to the former, we would expect general support from the fisheries community, but we are under no illusion that the fisheries community will endorse this preliminary statement of conservation principles. Any subsequent debate that this article may spark will, however, contribute to a further refinement and elucidation of such principles. This can only benefit the resource, its stewards, and its users.

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