A Conceptual Framework for the Management of Steelhead, *Oncorhynchus mykiss*

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Fisheries Project Report No. RD101
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Province of BritishColumbia
Ministry of Water, Land, and Air Protection
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Abstract

This paper outlines a possible framework for the management of steelhead in British Columbia and provides a rationale for the elements of the framework. The intent of the management framework is to conserve the productive capacity of steelhead stocks (i.e., populations or aggregates of populations with similar dynamics) by maintaining spawner abundance at levels that potentially provide sustainable benefits to society. The framework consists of: (1) abundance-based biological reference points that define management zones, and (2) associated sets of management actions (decision rules) that adjust either mortality rates or stock productivity to move population abundance towards a desired endpoint within a given time. The framework provides an explicit link between habitat management and harvest management for a stock by defining the reference points in terms of a habitat-based maximum smolt production. The key reference point is the "conservation concern threshold" (CCT) below which the stock is regarded as overfished. For a stock whose recruitment dynamics can be described by a deterministic Beverton-Holt type spawner-recruit relationship, this threshold is at $0.25 \cdot B$, where B is the asymptotic maximum adult recruitment. The CCT has the useful property of being largely independent of stock productivity. We further define a limit reference point (LRP) as the spawner abundance from which a stock can recover to the CCT within a defined time (e.g., one generation) in the absence of harvest. Although the LRP varies with stock productivity, simulations show that it can be approximated by a fixed value near $0.15 \cdot B$ over a wide range of stock productivity if management actions progressively reduce mortality below the CCT. At abundance levels below the LRP, the stock is considered to be an "extreme conservation concern" and extraordinary management actions may be required to eliminate controllable mortality and to increase productivity. Because the LRP and CCT jointly determine the rate at which anthropogenic mortality changes with abundance, it is possible to alter the pair of deterministic values slightly with little impact on the performance of the management system, e.g., for steelhead sport fisheries we could set the CCT at $0.3 \cdot B$ to $0.35 \cdot B$ to accommodate parameter uncertainty and set the LRP at $0.1 \cdot B$ to $0.15 \cdot B$. In conjunction with appropriate management regulations, the system of management zones established by the CCT and LRP will generally maintain stocks at levels well above those at which population viability is a concern. The social cost may be foregone harvest opportunities, particularly for other fisheries that take steelhead as a bycatch.

Introduction

Steelhead trout (*Oncorhynchus mykiss*) sustain important fisheries throughout much of coastal British Columbia. Their beauty, power, and relative scarcity have earned steelhead a near-mythic reputation as an exceptional sport fish. Recreational fisheries for steelhead generate about 150,000 angler days of effort per year in British Columbia. Steelhead are also locally important in some First Nations ceremonial, social, and food fisheries. Some steelhead populations are harvested as an incidental catch in mixed-stock commercial fisheries that target Pacific salmon. Never abundant, some southern BC steelhead populations have declined recently to numbers at which their persistence is uncertain (Ward 2000), and extraordinary efforts are now required to maintain them. Declining abundance has caused the curtailment or elimination of long-established steelhead fisheries. In contrast, some North Coast steelhead escapements have increased over the same period, leading to requests for retention fisheries on wild steelhead populations. These events, and the changes in management practices that they have necessitated, have prompted a review of steelhead management policies. This document summarizes proposed approaches to the conservation and management of steelhead populations, and provides a concise discussion of the technical basis for future policies.

Management Principles

The management of steelhead and other fishes within the jurisdiction of BC Fisheries is founded on three principles that were enunciated in the 1996 Strategic Plan (MELP 1996):

- conservation of wild fishes and their habitats,
- sustainability of benefits for British Columbians, and
- a precautionary approach to management.

These three principles jointly require that the priority for steelhead management be the perpetuation of wild steelhead populations into the future at abundance levels that are capable of providing sustainable benefits to society, despite the considerable uncertainties that arise from environmental variability, an incomplete understanding of steelhead population dynamics, imprecise information, and inexact management controls. The principles provide a natural hierarchy for management objectives: the long-term maintenance of a population takes precedence over the provision of other social or economic benefits. The operational goal of management is, however, to maintain the capacity of a natural population to provide sustainable benefits to society as a whole, not merely to preserve a remnant population. Conserving the productive capacity of a population ensures that sustainable benefits are *potentially* available to society, however we chose to use them. A goal of maintaining productive capacity links habitat management to harvest management by requiring that the effects of habitat quality and quantity on productive capacity be considered.

Precautionary approaches to steelhead management consider the effects of uncertainty to ensure that steelhead stocks will persist while sustainable societal benefits are optimized. The abrupt, large, persistent changes in steelhead smolt-to-adult survival seen over the last decade in some populations (Fig. 1) have greatly altered our perceptions of the normal limits to environmental variability. Management policies should accommodate such uncertainties without placing wild steelhead populations at risk of extirpation or impairing their ability to provide benefits in the future. Where practicable, management policies should incorporate mechanisms to reduce uncertainties. There should be broad consultation about management goals and approaches because policies to deal with management uncertainties may require society to forego current benefits to maintain future productive capacity.

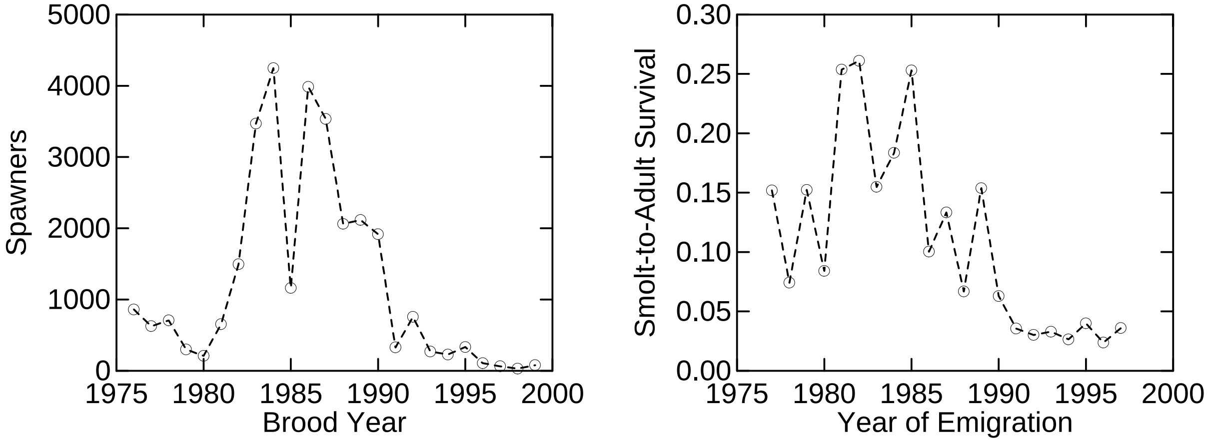

Fig.1. Number of spawners and the smolt-to-adult survival rate for winter-run steelhead in the Keogh River, northern Vancouver Island, between 1976 and 1999. The period of low smolt survival after 1990 is an "ocean regime shift" that caused greatly reduced spawner abundance. Management policies must be capable of responding to such variability in a manner that ensures the persistence of the population while optimizing potential long-term benefits.

The above management principles are not new: they are drawn directly from the United Nation Food and Agricultural Organization's *Code of Conduct for Responsible Fisheries* (FAO 1995). Legislation such as the *Fisheries Act* (RSC), the *Fish Protection Act* (SBC1997), and the *Fisheries Renewal Act* (SBC 1997) provide the mandate and tools to implement these principles.

Methods and Results

Management Approach

A successful management policy must translate principles into viable operational definitions and procedures. For example, what are the operational units to which the policy applies? What are the operational management objectives? What actions are to be considered within the policy?

Management units:

Steelhead in British Columbia have been managed as discrete, reproductively-isolated populations ("stocks") at approximately the scale of third-order or larger watersheds. At this spatial scale, steelhead stocks appear to be sufficiently isolated to have independent population dynamics. Some populations are further subdivided into summer-run and winter-run ecotypes on the basis of migration timing and other life history attributes. Variation in microsatellite DNA allele frequencies and in electrophoretically-distinguishable allozyme frequencies generally support the concept of genetically distinct stocks at the watershed scale (Parkinson 1984, Beacham et al. 1999). The genetic data further suggest regional groupings at the scale of major drainages (e.g., upper Fraser River, Thompson River, Columbia River) and larger geographic groupings that apparently indicate phylogenetic diversity. About 600 putative stocks are recognized in British Columbia, although not all stocks are actively managed. Groups of related, geographically proximate stocks with similar life histories and run timings (e.g., Thompson River stocks) are sometimes managed as stock aggregates, partly because the component stocks are believed to have similar productivity and dynamics, and partly because of the difficulty in managing the stocks separately in mixed stock fisheries.

We propose that watershed-scale "stocks" and stock aggregates continue to be the population units to which this steelhead management policy would apply. Where ecotypes within stocks have characteristics that are of particular interest to the public (e.g., summer runs, exceptional size), the ecotypes may be managed as separate population units to conserve within-population diversity. In practice, geographically proximate, related stocks that have similar life histories, abundance trends, and productivity parameters will likely be subject to common management regulations unless there is a reason (abundance, genetic differentiation, population structure) to apply separate regulations to a particular stock. Note that using stocks as the basic management units does not preclude the prioritization of management resources or level of protection, based, for example, on degree of genetic differentiation or upon the value of a fishery.

The rationale for using watershed-scale populations as the units of conservation policy rather than the larger "evolutionarily significant unit" (ESU) or "conservation unit" (CU) used by other agencies is several-fold. First, it will generally maintain a higher level of genetic diversity within phylogenetically similar groups of populations than ESU or CU policies, which should reduce the likelihood of extinction for the group. Second, populations can be managed according to their individual productivity parameters rather than for the group average, which should help maintain the overall production of fished aggregates of populations and allow greater societal benefits. Third, the available trend data suggest that such stocks are viable populations. The major disadvantage of using watershed-level populations as management units is that it may prove impractical, either because we lack the resources and information to manage individual stocks or because attempting to maintain a stock imposes a social cost that the public deems unacceptable.

Management framework:

The proposed management approach consists of stock-specific biological reference points and pre-defined decision rules. Biological reference points are biologically derived indices of stock status, which are used to initiate management actions to achieve particular objectives. Many fisheries agencies have adopted reference points as a conceptual framework for implementing a precautionary approach to fisheries management. Minimally, the framework consists of a target reference point (TRP) that defines a desired state, a limit reference point (LRP) that defines a highly undesired state, and a set of control rules for the three regions below, between, and above the two reference points which constrains the stock to states near the TRP (Fig. 2). A precautionary threshold (PT) may be inserted between the LRP and the TRP to reduce the risk that the LRP will be reached without corrective action being taken.

The reference points can be expressed as abundance levels or as harvest rates, and are usually intended to avoid severe recruitment overfishing. The desired relationship among abundance reference points is: average system state ≈ TRP > PT >> LRP. TRP is usually chosen to optimize some measure of societal benefits, while LRP is often chosen to ensure the long term persistence of the population while simultaneously ensuring a desired rate of recovery to the TRP. The reference points provide operational objectives for implementing a management policy.

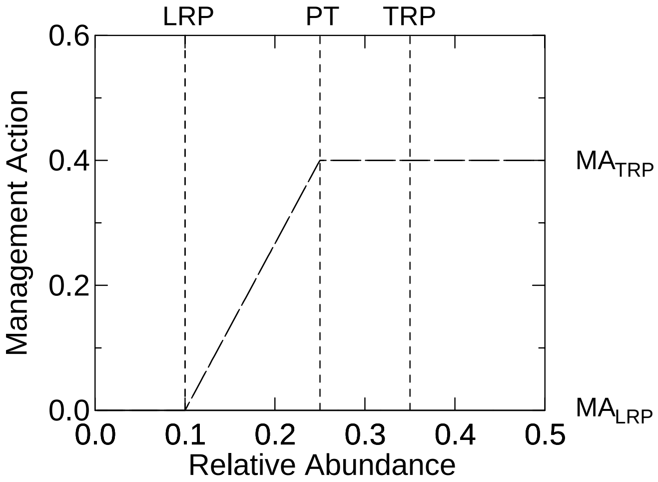

Fig.2. A hypothetical example of biological reference points and decision rules based on spawner abundance. LRP and TRP delineate regions of abundance where different decision rules apply. The decision rules are: If the abundance is less than LRP, then apply the management action MA_{LRP}. If the abundance exceeds TRP, then apply management action MA_{TRP}. If abundance lies between LRP and TRP, then apply a variable management action whose intensity depends on abundance. PT is a precautionary threshold below which the intensity of management actions changes rapidly to move abundance quickly back towards TRP.

Fisheries management systems that use reference points and explicit control rules have several desirable features. The management process is clearly defined so that the technical basis of any particular management action is readily apparent to the public. Management actions can easily be connected to agreed-upon management objectives. Management objectives are stated explicitly so that the performance of the management system can be monitored. Possible disadvantages might be: limited management flexibility if novel situations arise, impractical requirements for management information, and lack of a public consensus on management goals or actions.

Operational objectives:

The minimum management objective for a steelhead stock should be to “maintain or restore stocks at (abundance) levels capable of producing maximum sustainable yield”, as recommended in the FAO *Code of Conduct for Responsible Fisheries*. Computer simulations based on a well-studied coastal winter steelhead stock indicate that managing for this objective will usually result in a viable population, even under conditions of large, autocorrelated environmental variation and realistic uncertainty in information and implementation (Johnston et al. 2000). We propose that the spawner abundance level that produces the maximum long-term average yield be a *minimum* operational abundance target for a stock, below which the stock is considered to be overfished. A population whose abundance exceeds this minimum abundance target can be managed to optimize other societal objectives. For example, the management objective may be to keep abundance near the unfished equilibrium level to maintain important ecosystem processes within the watershed or to provide for a given level of catch success or fishing effort in a catch-and-release fishery.

A management framework that uses target and limit reference points that are defined in terms of fish abundance establishes *three management zones* with different management objectives and actions (Fig. 3). A population whose abundance is above the minimum TRP can be managed to optimize a management objective that is established by public consultation through a fishery management plan, for example, to maintain a particular catch per unit effort or to maximize long-term average yield. Management actions would limit harvest and protect habitat through regulation and enforcement. If fish abundance lies within the conservation concern zone, the population is recognized as overfished, and management actions increasingly reduce harvest or other controllable sources of mortality as abundance declines. Management actions would attempt to promote the recovery of the population to the TRP within some desired time frame. If abundance lies within the extreme conservation zone, the viability of the population or its ability to provide societal benefits in the future is in jeopardy. Management actions would aim to preserve the population and promote its recovery to the TRP. Management actions to achieve these objectives could include extraordinary measures to increase productivity (habitat enhancement, fertilization, hatchery supplementation) or to eliminate all controllable sources of mortality.

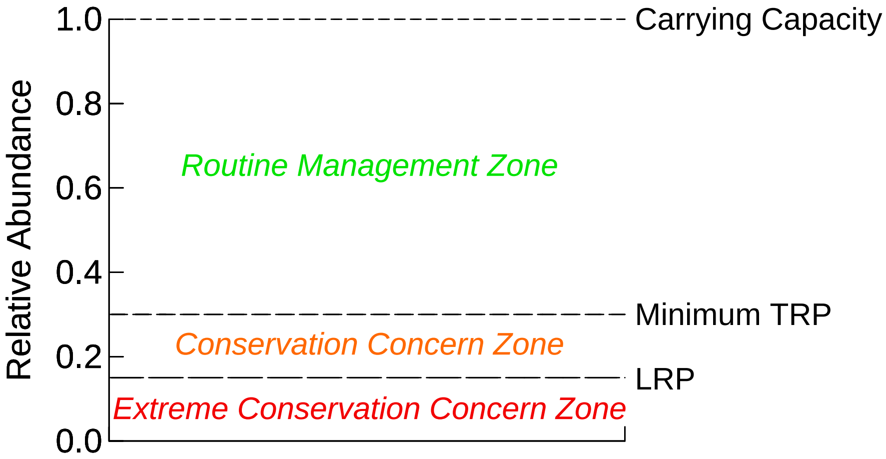

Fig. 3. A management framework that uses reference points defined in terms of steelhead abundance results in three distinct management zones with different management objectives and actions. The carrying capacity is the asymptotic maximum recruitment. TRP and LRP are target and limit reference points. The locations of the minimum TRP and LRP here are for illustrative purposes only.

Establishing biological reference points for steelhead:

In practice, defining reference points for steelhead and other species that exist as numerous small, discrete populations is difficult because normally there is little or no quantitative abundance information available for a given population from which commonly-used reference points can be calculated. In particular, there are few data on stock productivity, which determines the rate of recovery at low abundance. Even where reliable data exist, estimates of the parameters that are needed to establish reference points can be very imprecise. Establishing effective limit reference points is particularly important for steelhead stocks, however, because the small size of many populations increases their vulnerability to extirpation, which has occurred (Slaney et al. 1996). Because of the data limitations, effective reference points that do not require stock productivity information are desirable.

Our approach was to use a simple analytical method (Johnston et al. 2002) to determine stock-specific TRPs and LRPs for steelhead and other territorial, stream-rearing salmonids whose stock-recruit relationship approximates a Beverton-Holt model (Fig. A1). Although there are other alternatives, this model is reasonable, given our information about steelhead population dynamics (Ward 1996, 2000). The method assumes that there is an upper limit to smolt production that is determined by the amount and quality of freshwater spawning and rearing habitat, and that the maximum smolt recruitment is, in principle, predictable from habitat characteristics. We defined a minimum TRP, N_{TRP},, as 25% of the asymptotic maximum recruitment, B, because this value closely approximated the spawner abundance that produces the maximum long-term average yield (N_{MSY}) over a wide range of stock productivity values for the Beverton-Holt model (Fig. 4). We used the concept of a specified recovery trajectory to identify a LRP. The operational LRP, N_{LRP}, was the spawner abundance from which the model population recovered to the minimum TRP within one generation in the absence of harvest (Fig. 4). We then used an age-structured population model that incorporated realistic levels of parameter uncertainty, autocorrelated environmental variation, and implementation error to compare the performance of these and other common biological reference points under different control rules and management goals; the results are presented in detail elsewhere (Johnston et al. 2000).

The analysis gave several general results. First, threshold harvesting policies that reduced the harvest rate when abundance was below a TRP and ceased harvest below a LRP lowered the risk of

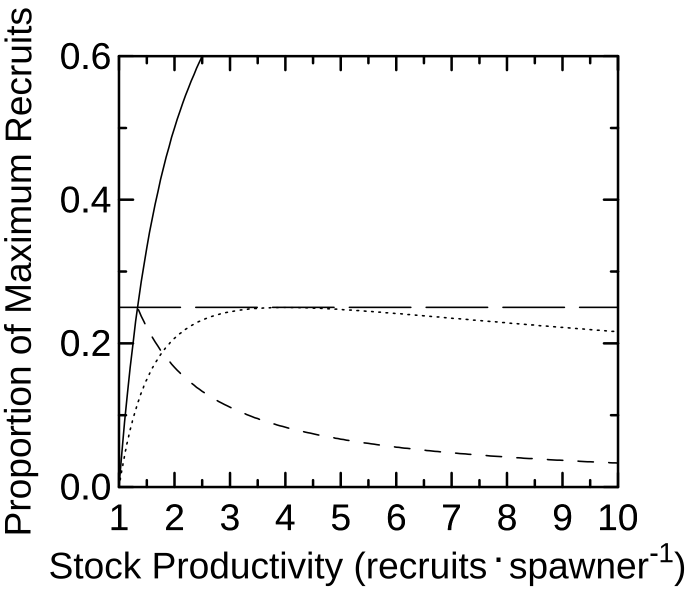

Fig. 4. The spawner abundance at MSY, N_{MSY} (······); the minimum target reference point, N_{TRP} (— — —), defined as 0.25 of the asymptotic maximum adult recruitment; the limit reference point, N_{LRP} (– – –), defined as the spawner abundance from which the population will recover to N_{TRP} in one generation in the absence of harvest; and the unfished equilibrium abundance, N_{equil} (——), as functions of the productivity parameter, *a*, of the Beverton-Holt stock-recruitment relationship, $N_{t+1} = \dfrac{a \cdot N_t}{(1 + a \cdot N_t / B)}$.

extirpation, increased catch, and reduced recovery time for small populations. Second, abundance thresholds that were fixed proportions of the maximum recruitment performed similarly to thresholds that required productivity information: a fixed LRP in the range 10% to 20% of the maximum recruitment will approximate N_{LRP}. Third, the effects of environmental variability and uncertain information in the simulations were to increase slightly the fixed LRP that maximized catch and minimized extirpation risk. Fourth, yield response surfaces were quite flat near the maxima so that several combinations of LRP and minimum TRP often gave equivalent, near maximal average catches. Fifth, small, very unproductive stocks in variable environments had a high risk of extirpation under any policy that permitted harvest.

These simulations suggest the following basic management framework for a harvest fishery:

(1) that 25% of the maximum recruitment, *B*, under the long-term average smolt-to-adult survival be used as a minimum target reference point, which we will call a *conservation concern threshold* (CCT), below which abundance the productive capacity of the stock is impaired (Fig. 5).

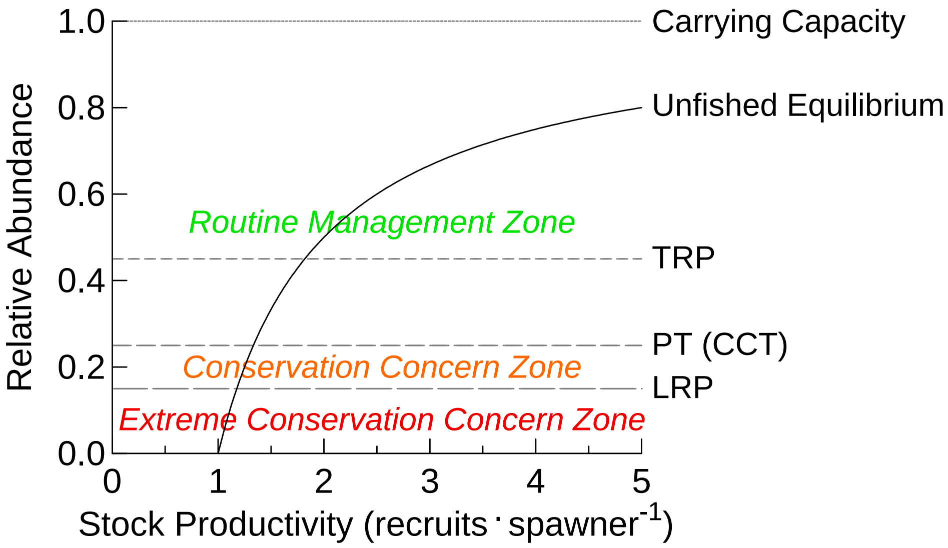

Fig. 5. Proposed basic framework for steelhead management, showing the locations of abundance thresholds and management zones. The conservation concern threshold (CCT) is a minimum target reference point that is used as a precautionary threshold (PT) to initiate management actions to return the population to an operational target reference point (TRP) within the routine management zone. "Carrying capacity" here is the asymptotic maximum recruitment, not the unfished equilibrium abundance.

The CCT functions as a precautionary threshold to force management actions that will increase abundance.

(2) that 15% of the maximum recruitment be used as a *limit reference point*, below which abundance the persistence of a small stock may be at risk. If direct estimates of productivity and maximum recruitment are both available for a stock then the LRP and CCT could be calculated directly rather than using the suggested fixed thresholds. Note that the proposed LRP and CCT may be substantial portions of the unfished equilibrium abundance for an unproductive stock (Fig. 5).

(3) that an operational *target reference point* (TRP) be established above the CCT for a stock whose management goal requires that higher abundance be maintained to optimize societal benefits.

For sport fisheries, or other situations where it is desirable to maintain higher escapements, we propose that the basic threshold levels be altered by raising the precautionary threshold to 30-35% and lowering the limit reference point to 10-15% of maximum recruitment. This modification will generally maintain near-maximal potential production and a low risk of extirpation, but increases the escapement and reduces the frequency of fishery closures. The LRP should not be lowered further, however, because the risk of extirpation may increase and potential yield decrease for unproductive or small populations.

An estimate of the maximum recruitment at average smolt survival (i.e., the average adult asymptotic recruitment, or "carrying capacity") is needed to define the limit reference point and the conservation concern threshold for a stock. There are currently two ways to determine average "carrying capacity". Maximum recruitment can be estimated from standard stock-recruitment analysis for a population where the numbers of spawners and the resultant recruits are monitored over large fluctuations in spawner abundance; these data are available for only a few steelhead stocks. Maximum recruitment can also be estimated from habitat capacity models that use empirical information on habitat conditions at the reach or landscape scale to predict the carrying capacity. If the estimation method is unbiased, even substantial imprecision in the estimate does not alter the average performance of the thresholds.

Summary of the proposed management framework:

To summarize, the proposed management framework (Fig. 5) consists of three management zones that are delineated by abundance thresholds. The key threshold is the conservation concern threshold, CCT, which separates a routine management zone from a conservation concern zone in which a stock is overfished. We approximate CCT by 25% of the asymptotic maximum recruitment. By definition, this CCT is the minimum acceptable target reference point for the stock. In most circumstances, however, the CCT is used as a precautionary threshold to initiate management actions to increase the population to an operational target reference point (TRP) within the routine management zone. The operational TRP is established to optimize some societal benefit, which may vary with management objectives for the stock. Management actions attempt to maintain abundance near the TRP. We define a limit reference point (LRP) to be the spawner abundance from which a population can recover to the CCT in one generation in the absence of harvest. The LRP separates the conservation concern zone from an extreme conservation concern zone in which the ability of the population to provide maximum sustainable benefits is impaired and the probability of extirpation for small unproductive populations increases rapidly with further declines in abundance. The LRP varies with stock productivity, but a fixed threshold near 15% of the asymptotic maximum recruitment provides a reasonable approximation for small, moderately productive stocks. For steelhead sport fisheries, the LRP can be lowered slightly to 10-15% of the asymptotic maximum recruitment if the precautionary threshold is increased to 30-35%; this should increase escapement and reduce the frequency of fishery closures while still maintaining near-maximal potential production and a low risk of extirpation.

Monitoring options:

There are several monitoring options for implementing a reference point based management policy. Managers generally prefer estimates of adult recruits because this information allows active in-season control of harvest and escapement. But both adult abundance and smolt abundance provide information on stock status. Within an "ocean survival regime", steelhead smolt-to-adult survival is independent of smolt density and the subsequent adult recruitment is linearly related to smolt output. Biological reference points derived from adult abundance translate directly into smolt abundance thresholds that can initiate management actions. For example, a smolt output that is less than 25% of the asymptotic maximum predicts an adult return that is, on average, less than 25% of the asymptotic maximum adult recruitment, and implies that harvest is not possible for the smolt cohort if the minimum escapement target (CCT) is to be met. Note that only relative smolt output is needed to assess stock status. Smolt output also gives retrospective information on prior escapement that allows modification of previous management actions, particularly harvest rates. The nonlinear relationship between spawners and smolts alters the direct translation of the relative abundance of spawners into the relative abundance of smolts, however. By definition, an adult escapement at the LRP (i.e., 15%) will result in both the subsequent smolt output and adult recruitment being at the CCT (i.e., 25%). Adult escapement at the CCT (25%) will produce smolt and adult recruitments between 33% and 56% of the maxima for moderately productive stocks (adult productivity between 2 and 5 recruits·spawner^{-1}). Thus, an observed smolt output that is less than 25% of the asymptotic maximum indicates that previous management actions resulted in an adult escapement that was less than the LRP. Such information on past escapement is useful because the overlap in age-at-return from different brood years means that the current escapement can be adjusted to compensate, in part, for past deficiencies.

Management actions:

Management actions attempt to maintain the abundance of a stock (or stock aggregate) at or above the target reference point, with the conservation concern threshold being the minimum TRP. Two types of management actions are available to realize this goal for wild steelhead: mortality rate adjustments and productivity increases (Table 1). Mortality rate changes are usually achieved with regulations that control harvest rates by limiting fishing effort or gear efficiency. Productivity increases are usually accomplished through a combination of habitat protection, restoration, and

Table 1. Management tools that are commonly available to adjust the mortality or productivity of an exploited fish stock.

Regulatory Tools

a. Mortality Reduction

1. Effort limitation:
    a. Total closure
    b. Area / time / species closures (by sector: sport, commercial, First Nations)
    c. Demand management:
        i. Limited entry fisheries
        ii. Reservation systems
    d. Enforcement

2. Efficiency limitation:
    a. Catch-and-release
    b. Catch limits
    c. Gear restrictions:
        i. Bait restrictions
        ii. Bait ban
        iii. Artificial fly only
        iv. Single hook
        v. Single barbless hook
        vi. Specific gear types (e.g., fly fishing only)
        vii. Boating restrictions

Productivity Tools

b. Restoration and Enhancement

1. Habitat protection:
    a. Enforcement
    b. Land use plans
    c. Watershed production planning

        d. Legislation:
            i. Sensitive stream designation
            ii. Threatened or endangered species designation
2. Habitat manipulation:
    a. Physical habitat restoration
        i. In-stream structures
        ii. Riparian restoration
        iii. Flow or temperature control
        iv. Passageways, culverts
    b. Nutrient addition

c. Fish Culture

1. Living gene bank projects:
    a. Experimental supplementation from native wild stock
2. Hatchery supplementation:
    a. Limited supplementation with F1 progeny of native wild stock
3. Stock enhancement (augmentation):
    a. Larger-scale supplementation with F1 progeny of native wild stock

enhancement or, more rarely, through hatchery supplementation. Numerous specific activities may be used to implement these management actions. Table 2 outlines management objectives and some possible management actions within each of the proposed management zones. The set of actions to be undertaken in any specific case would vary with our understanding of the causes of the situation, the effectiveness of the actions, and the perceived risk to the stock. Actions would normally be discussed with co-managers or stakeholders as part of a management plan before being implemented.

Discussion

The proposed management framework will generally meet the policy objectives of wild fish conservation, sustainability of benefits, and a precautionary approach to management. It ensures the persistence of individual populations of steelhead by establishing population-specific abundance thresholds that force management action to restore the population should abundance decline below a threshold. Because the lowermost threshold is defined in terms of an expected rate of recovery to an abundance level that approximates N_{MSY}, the framework will usually maintain abundance levels where sustainable benefits are possible, either as potential harvest or as increased average abundance. Moreover, because the thresholds are established in terms of a habitat-based maximum smolt output, the framework necessarily incorporates habitat management as a key element. The framework requires, however, that managers be able to monitor abundance and to modify density-independent mortality and/or stock productivity as needed to move abundance towards desired levels.

The ability to alter mortality or productivity as a function of abundance in a feedback control loop is essential to the operation of any management framework. Where this ability is lacking, e.g., because mortality is determined by mechanisms that are not amenable to management adjustment or because institutional constraints impede the timely application of predetermined controls (Ludwig et al. 1993), the system of thresholds and management actions may not arrest population decline. Where harvest is a principal source of density-independent mortality, however, and decreases with declining abundance to zero at a LRP, the framework becomes a threshold harvesting system, whose ability to reduce extinction risk and increase average yield is well documented (Quinn et al. 1990, Lande et al. 1997), even in the presence of implementation error (Johnston et al. 2000). Although some important steelhead stocks are subject to high harvest rates as bycatch in commercial salmon fisheries (Cox-Rogers 1994), many steelhead populations are managed as catch-and-release sport fisheries which may impose relatively low mortality. Where there is little scope for reducing fishing mortality (or other anthropogenic sources of density-independent mortality) as abundance declines, costly and uncertain adjustments to productivity through habitat rehabilitation or manipulation (Slaney and Zaldokas 1997) become the principal management tool to increase the abundance of wild stocks. In this circumstance, an effective programme of habitat protection and monitoring to maintain wild stock productivity may be more cost-efficient than after-the-fact rehabilitation of degraded habitat.

The ranges of abundance delineated by the LRP, CCT, and TRP abundance thresholds can be used to assess the conservation status of a steelhead population (Fig. 5). Conservation status is often determined as a quantitative estimate of extinction risk from a population viability analysis (PVA). PVAs have been attempted for some Oregon populations of steelhead (Chilcote 2001), but the calculations require many simplifications (see Chilcote 2001), and have frequently been criticized as misleading (Ludwig 1999, Routledge and Irvine 1999). We lack the data needed to produce credible PVAs for BC populations of steelhead. Many qualitative systems for determining the extinction risk of species or smaller units ("distinct population segments", "evolutionarily significant units") have been established, for fishes (Musick 1999, Wainwright and Kope 1999) and for other organisms (IUCN 2001, COSEWIC 2002), using indices of population size, abundance trends, habitat use, and other information to assess population viability in categories such as: "endangered", "threatened", "vulnerable", "not at risk", etc. The formal assessments of relative extinction risk from these analyses may be precautionary if increases in risk are recognized soon enough to allow effective management responses, but a narrow focus on extinction risk may also promote a minimalist concept of conservation as simply ensuring population persistence. Populations are components of biological communities, and conservation therefore requires that populations be maintained at levels that protect biological integrity and preserve ecological functions (Olver et al. 1995, Callicott et al. 1999). For exploited populations, conservation may also encompass the possibility of sustainable use (Olver et al. 1995). Self-sustaining remnant populations do not fulfill these roles. The status categories of Fig. 5 fit this broader conception of conservation by providing information on the population's ability to return to abundance levels indicative of "proper functioning", as well as conveying relative risk.

Absolute numbers, abundance trends, and habitat use criteria provide useful supplements to conservation status categories defined as proportions of the asymptotic maximum recruitment. As Wainwright and Kope (1999, p. 445) note, "the fact that a population is near its current capacity does not necessarily mean that it is sustainable". For small populations, the LRP and CCT may be very few spawners, whose resilience is uncertain (e.g., because of possible depensatory mechanisms, Liermann and Hilborn 1997). Clearly, extinction risk increases and a population's ability to provide ecological services decreases at low abundance, but these effects vary with productivity and genetic structure. Similarly, high rates of population decline suggest greater risk than lower rates of decline, but the actual risk varies with abundance and productivity, which is unknown for most BC steelhead populations. The widely-used qualitative categorizations of extinction risk (Musick 1999, IUCN 2001) apply general criteria to such situations, some of which could modify the conservation categories demarcated by the LRP and CCT. The IUCN (2001) Red List uses a "population size estimated to number fewer than 50 mature individuals" as one criterion to identify a "critically endangered" taxon, and "population size estimated to number fewer than 250 mature individuals" to identify an "endangered" taxon. Rieman and Allendorf (2001) suggest that a bull trout (*Salvelinus confluentus*) population with an average of 100 spawners per year would have an effective population size between 50 and 150, near the lower limit of the 50/500 rule of thumb thought necessary to maintain genetic variation. For small populations of steelhead, the LRP or CCT may be below these limits. Thus, we suggest as interim minimum criteria that a steelhead population whose estimated spawner abundance is 50 to 100 fish should not be placed above an "extreme conservation concern" category, and that a population estimated at 100 to 250 spawners should not be placed above a "conservation concern" category. Similarly, we suggest that Musick's (1999) rate of decline criterion for a "low productivity" marine fish population (a decline greater than 0.85 over 3 generations) be used to place a steelhead population in the "conservation concern" category in the absence of other information. Changes in habitat use (IUCN 2001) may also guide the assessment of conservation status of a steelhead population.

Improved and expanded monitoring programmes will be necessary to improve upon the approaches to establishing conservation status for steelhead that we have used here. The lack of reliable information on stock productivity precluded quantitative assessments of population viability for particular steelhead stocks, and forced us to status definitions based on maximum recruitment, estimated from habitat characteristics. Monitoring to obtain stock productivity data for a range of populations will be difficult and costly, but the current depressed abundance of many populations provides an opportunity to gain information that is particularly informative about productivity and the nature of the stock-recruit relationship.

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Table 2. Possible management goals and actions within steelhead abundance zones.

Management Zone	**Abundance Thresholds**	**Management Goals**	**Possible Management Actions**			
			(1) Regulations (mortality reduction)		**(2) Productivity increases**	
			(i) Effort limitations	**(ii) Efficiency limitations**	**(i) Restoration / enhancement**	**(ii) Hatchery augmentation / LGB**
Extreme conservation concern zone		***Crisis Plan:*** 1. Active rebuilding to CCZ within a defined time (1-2 generations) or 2. Preserve genetically-viable stock remnant	1. Total fisheries closures 2. Directed sport fisheries closures (area and time closures) to avoid steelhead 3. Entry limitations 4. Bycatch elimination	1. Gear and bait restrictions - no kill 2. Selective fisheries 3. Area and time closures to limit catchability	1. Maximize habitat protection (both habitat and harvest enforcement) 2. Instream habitat restoration 3. Stream fertilization (as a temporary measure)	1."Living gene bank" projects as last resort 2. Changes to existing supplementation projects (fry/smolt; native stock)
----------------	***LRP*** (0.15 $B_{asymptotic}$)	--	--	--	--	--
Conservation concern zone		***Recovery Plan:*** 1. Rebuild to RMZ - fast (within 1-2 generations) or 2. Rebuild to RMZ - slow (> 2 generations) or 3. Manage for other fisheries (First Nations, commercial fisheries)	1. Recovery plan with overall mortality rate negotiated with stakeholders: (i) sport fishery: catch and release temporary closures (area & time) monitoring (ii) commercial fisheries: selective gears / live release area and time closures to reduce bycatch harvest (iii) First Nations fisheries: ceremonial only grading to full Section 35 food fishery	1. Gear and bait restrictions 2. Area and time closures to limit catchability 3. Steelhead catch and release	1. Physical habitat protection 2. Enforcement (harvest and habitat) 3. Increase oportunities for physical habitat restoration; partnerships 4. Watershed level production planning	1. Suspend/reduce hatchery programs
----------------	***CCT*** (0.25 $B_{asymptotic}$)	--	--	--	--	--
Routine management zone		***Management Plan:*** 1. Sustainable fisheries implemented through: (a) Watershed level production plan (b) Negotiated management plans: (i) First Nations fishery (ii) Non-consumptive fishery (iii) Bycatch fisheries (iv) Ecosystem functioning 2. Social benefits	Sport fishery: (1) spawning closures (2) user-defined special fisheries Other fisheries: (1) time and area closures to reduce steelhead harvest	Sport fishery: (1) catch and release on wild stocks (2) negotiated gear and bait restrictions (3) spawning closures (4) catch limits on hatchery stocks Commercial fishery: (1) selective gears / live release First nations fishery: (1) no directed commercial fishery on steelhead	1. Habitat restoration (to historical productivity?) 2. Ongoing habitat protection	1. Limited supplementation for high-use fisheries if abundant wild stock
----------------	***TRP***$_{operational}$	--	--	--	--	--
----------------	***Unfished Equilibrium***	--	--	--	--	--

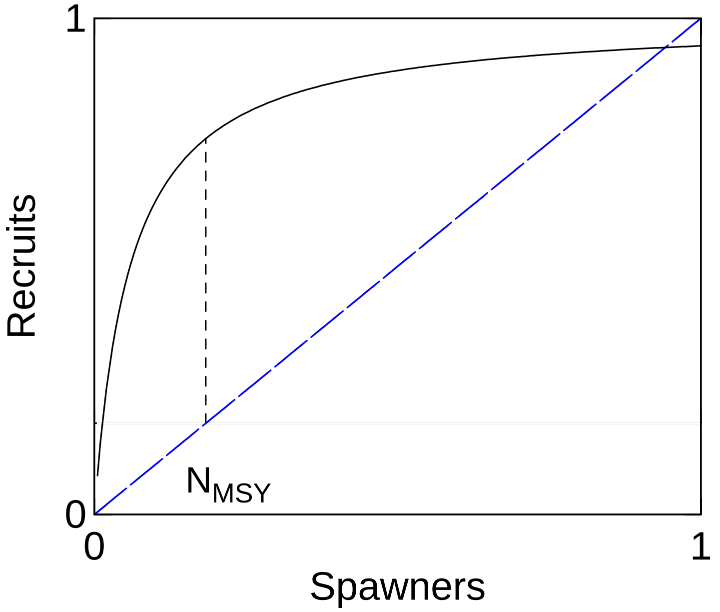

Fig. A1. Beverton-Holt stock-recruitment relationship, $Recruits = \dfrac{a \cdot Spawners}{(1 + a \cdot Spawners / B)}$, where a is the productivity and B is the asymptotic maximum recruitment. N_{MSY}, the spawner abundance at maximum sustainable yield, is the location of the maximum difference (– – –) between spawners (—— ——) and the recruits (——) that they produce.