VALUING FRESHWATER SALMON HABITAT AS A BENEFIT OF PROTECTED AREAS ON THE WEST COAST OF CANADA[1]

D. Knowler[1], B. MacGregot[2], M. Bradford[3] and R. Peterman[1]

[1]School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6
[2]Industry, Economics, and Programs Branch, Canadian Forest Service, Natural Resources Canada, Ottawa, ON
[3]Fisheries and Oceans Canada and Cooperative Resource Management Institute (CRMI), Simon Fraser University, Burnaby, BC, Canada

SUMMARY
This paper presents results from a valuation study of habitat used by salmon for spawning and rearing on Canada's west coast. Coho salmon making use of the Thompson River watershed are examined as a case study. Due to data limitations we concentrate on the historical commercial coho fishery in British Columbia's Strait of Georgia. Initially, optimal values for management of the coho fishery are derived assuming freshwater habitat is undisturbed and then the net benefits (e.g., economic rents) attributable to the fishery are estimated. Applying a bioeconomic modeling approach to valuation, we allow the level of environmental quality to vary and derive new optimal values for management of the fishery. The difference in the net benefits at these two levels of environmental quality reveals the value associated with maintaining pristine habitat. For our analysis, we considered a South Thompson watershed and allowed this to degrade from a pristine state to its current state. In this case, the loss in ecosystem services is $2 to $3 per ha of drainage basin or about $3730 per km of spawning stream length. Along with the other benefits of protected areas, the benefits of protecting habitat should be considered in comparisons of alternative uses of parkland.

Keywords: salmon, valuation, coho, environmental quality, British Columbia

1. INTRODUCTION

Valuation of non-market environmental goods and services is now a well-recognized practice, as demonstrated by the development of legally defensible damage assessment methodologies [1]. However, relatively few valuation studies have considered the impact of changes in the quality of fish habitat on recreational and commercial fisheries. By necessity, much of the empirical research greatly simplifies the ecological and economic characteristics of the systems investigated. For example, in order to estimate the parameters of interest, numerous studies begin with highly aggregated modelling of population dynamics and an assumption of static bioeconomic equilibrium. In addition, the measurement of economic gains or losses often does not adhere to proper welfare measurement as economists conceive of it, and in many instances simple changes in gross revenues are used for this purpose. Finally, the multi-functional nature of ecosystems is rarely accommodated; in some cases, optimisation techniques are applied in models where important ecosystem values have not been included.

We would argue with Freeman [2], that valuing an environmental asset that is a production input should adhere to proper welfare theory and recognise as much biological complexity as possible. One approach is to assume that the downstream production activity (e.g., fishery) is efficiently managed, as this best represents the opportunities foregone when environmental assets are damaged or lost. Accordingly, valuing fish habitat when the fish stock is commercially

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important would involve an assumption of optimal management. The valuation model described in our full-length paper integrates these concerns using a Pacific coho salmon stock and modification of its habitat in the interior of British Columbia (B.C.), Canada, as a case study.

Pacific salmon are anadromous, as they are born in freshwater but migrate to the Pacific Ocean to mature before returning to their natal waters to spawn. Coho spend approximately 18 months in the ocean before returning to their natal watersheds as three-year-old spawners in the fall of their second ocean year [3]. Owing to the length of their freshwater residency, the quality and quantity of freshwater habitat play a large role in the population dynamics of coho salmon. Land-use practices can have significant effects on the dynamics of coho by influencing the environment in which eggs incubate and in which juveniles rear prior to migrating after becoming smolts [4].

In this study we used a bioeconomic modelling approach to value changes in coho salmon habitat in the South Thompson River drainage in the interior of B.C. This coho population contributes to the Strait of Georgia coho fisheries off the southwestern B.C. coast. Use of a bioeconomic model allowed us to estimate habitat values under the assumption the fishery was managed optimally. In conventional bioeconomic models, environmental or habitat conditions are assumed to remain constant. In our study we relaxed this assumption to analyse the more realistic case where habitat conditions are modified by human activities. As a result, we were able to determine the benefits of protecting salmon habitat, as occurs when pristine spawning areas are enclosed within national parks or other protected areas. One of the most important aspects of the analysis was the way in which the habitat support function provided by the environment was incorporated. We developed an indicator measuring habitat quality and then incorporated this into the population dynamics of the coho. Then we valued changes in the supply of the environmental input relatively using standard techniques from production economics and welfare analysis.

In the sections below, we first outline a general theoretical methodology to value salmon habitat. Subsequently, the empirical model specifying the linkage between salmon population dynamics and freshwater habitat quality is developed. Economic aspects of the model are introduced next, and this is followed by the solution values for the model assuming an optimally managed commercial troll fishery is the sole user of the fish stock. Finally, estimates are made of the value of habitat when this is allowed to deteriorate from pristine conditions (e.g., protected area) to the disturbed conditions characterising areas in the watershed that are not protected. The paper closes with a few observations on the limits of the analysis.

2. A DYNAMIC BIOECONOMIC MODEL OF COHO SALMON WITH HABITAT INFLUENCE

When modelling the catch from natural populations a dynamic specification is usually preferred. In formulating the Strait of Georgia coho fishery problem in dynamic terms, we took a discrete time approach and focused on harvest (*h*) in the commercial fishery as the choice variable, but it also could be assumed the fishery was recreational.

The expression for net social benefits from the fishery is:

$$W(X_t, h_t) = \int_0^h p(h_t)dz - C(X_t, h_t) \tag{1}$$

where $W(X,h)$ is the net social benefits from the coho stock in period t, including harvest h and other values; X is the aggregate recruitment to the coho stock, measured in numbers of exploitable fish; $p(h)$ is the inverse demand function for coho in either the recreational or commercial fishery; h is the coho harvest in year t, measured in numbers of fish; z is a coefficient of integration; and $C(X,h)$ is a cost function for either the recreational or commercial fishery;

The population dynamics for coho are presented as a transition equation showing the recruitment of young coho to the exploitable stock after a three-year lag between spawning and recruitment. Using a delay recruitment model [5], it is possible to incorporate this lag without resorting to a full age-structured model. To accomplish this, we express coho recruitment in year *t*+1 as the following function of spawner escapement (*X - h*) and habitat quality (*Q*) in year *t-2*:

$$X_{t+1} = R(X_{t-2} - h_{t-2}, Q_{t-2}) \tag{2}$$

where *R(X-h,Q)* is the coho recruitment function governing the entire population aggregate, and *Q* is habitat quality, defined as a measure of average habitat disturbance throughout the entire spawning and rearing area used by the exploitable fish stock. If we substitute *B*(*h*) for the first term on the right in (1), the planner's problem can be expressed as the following constrained dynamic optimisation problem in discrete time:

$$\max \sum_{t=0}^{\infty} \rho^t \{B(h_t) - C(X_t, h_t)\}$$

$$s.t. \quad X_{t+1} = R(X_{t-2} - h_{t-2}, Q_{t-2}) \tag{3}$$

where ρ is the discount term, defined as $1/(1+\delta)^t$, with δ denoting the social discount rate. To solve this problem, we form the appropriate Lagrangean expression, derive the first order conditions and then derive the system of two equations that govern the system at its long run equilibrium or steady state.

To determine the value of habitat at the margin, one can estimate the welfare effect of a small or 'marginal' change in habitat quality under optimal conditions. The partial derivative of the maximised Lagrangean expression with respect to *Q*, the habitat factor, provides the correct welfare measure. Valuing a non-marginal change in salmon habitat at a specific protected area requires a different procedure. First, distinct *Q's* are derived describing habitat quality 'with' and 'without' protected area status (or, equivalently, before and after degradation), where Q^A signifies the former and Q^B the latter, with $Q^A > Q^B$. This approach yields the following expression for the welfare change (▤*W*) from habitat protection:

$$\Delta W(X^*, h^*) = W(X^*, h_A^*; Q^A) \ - \ W(X^*, h_B^*; Q^B) \tag{4}$$

The asterisk (*) indicates that all variables are expressed as optimal values. Expression (4) can be stated more simply as the difference in welfare under the 'with' and 'without' protection situations.

3. SPECIFYING AND SOLVING THE EMPIRICAL BIOECONOMIC MODEL OF THOMSON RIVER COHO SALMON

The full paper also describes the general functional forms used in the empirical model and derives the necessary parameters to accompany these functions (Table 1). Solution of the model provides optimal values for harvest of coho, recruitment of coho and commercial fishing effort. A key aspect was development of a suitable coho stock-recruitment relationship that incorporated habitat quality at the 16 streams in the South Thompson River catchment for which we had data. We estimated an empirical relationship between trends in recruitment at these streams and an index of their habitat quality. Then we estimated the total freshwater capacity (expressed in terms of maximum smolt production) for all Strait of Georgia coho, to scale up the model to the level at which the fishery is managed. As a result, we were able to derive a stock-recruitment relationship for all wild coho in the Georgia Strait fishery for use in our bioeconomic model.

Table 1. Parameter values used in the empirical analysis (1994 $C).

Parameter	Units	Value	Source
Ocean survival rate, *m*	proportion	0.2	[6]
Productivity parameter, *a*	smolts/spawner	40	[7]
Capacity parameter, *b*	smolts	7,257,527	this study
Variable fishing cost, *c*	$/boat-day	109	[8]
Net salmon price, ex-vessel, *p*	$/fish	10.50	[8]
Commercial catchability, *q*	n.a.	0.00003	[3]
Social discount rate, *r*	% per year	5.0	this study

On the economic side, we made the assumption that the Strait of Georgia coho fishery was managed as a commercial troll fishery, selling salmon into an international market where its price was exogenously determined. The economic relationships to be specified included gross harvesting benefits *B(h)* and a cost function *C(X,h).* The key economic parameters in the model were the net price of coho (*p*) and the harvest cost (*c*).

In solving the initial optimal management models, we assumed that freshwater coho habitat throughout the Georgia Basin was fully intact ($Q = 1.0$). Table 2 presents the results.

4. VALUING CHANGES IN FRESHWATER COHO HABITAT

This section derives the value of salmon habitat quality in the South Thompson drainage basin using the results in column 3 of Table 2 as a starting point. As stated earlier, this analysis required that the social returns from optimal harvesting before the change in environmental quality be compared with the social returns after the change. The difference represents the welfare effect of the change. Altering habitat has implications for the optimal harvest rate and stock level in equilibrium, so that these might be expected to differ in the 'with' and 'without' scenarios. For our assessment, we assumed that habitat quality deteriorated at our 16 case study streams in the South Thompson drainage area only (all other areas remain pristine). First, we were required to set Q^A and Q^B, referring to the 'with' and 'without' protected status situations, and then we used these estimates to solve for the optimal system values under each level of environmental quality.

To establish Q^A, we maintained the assumed that the entire Strait of Georgia Basin was pristine, so that the average value of Q for the basin prior to any disturbance was 1.0. For Q^B, measuring habitat quality after the change, we assumed that our 16 case study streams in the South Thompson drainage area were degraded to their current status, with the rest of the Strait of Georgia Basin left undisturbed. Our approach implies that disturbance reduces the habitat quality within the case study streams to 47% of its original productivity. However, as the South Thompson represents only 2.3% of the entire Strait of Georgia catchment, the new value of Q is the weighted average over the entire basin, yielding $Q^B = 0.9878$.

With optimal system values calculated for each of the two habitat quality levels, the welfare losses arising from the degradation of habitat could be estimated as the differences between these values (Table 2). The model indicates that the modification in a portion of the South Thompson drainage area would lead to a loss of $1.87 million in present value terms (and at a 5% discount rate in perpetuity). Since the study portion of the South Thompson contains 503.2 km of spawning stream length, the loss amounts to $3731 per stream km. Our 16 South Thompson streams also constitute a drainage area of about 7130 km^2 (713,000 ha). Distributing the loss from habitat change over this entire area leads to a value of about $2.63 per ha attributable to salmon habitat degradation. These values can be interpreted as the benefits of protecting salmon habitat that is presently pristine, and if that habitat would deteriorate to the current level of disturbance in the absence of this protection.

Table 2. Optimal solution values for the Strait of Georgia coho fishery (1994 $C).

Variable	Historical Average (1953-77)	Optimal Values (Pristine S. Thompson, *Q* = 1.0)	Optimal Values (Degraded S. Thompson, *Q* = 0.9878)	Difference Attributable to Habitat Change
Recruitment (stock), X*	714,000 fish	1,071,001 fish	1,056,482 fish	14,519 fish
Catch, h*	227,000 fish	560,308 fish	548,456 fish	11,852 fish
- Commercial	370,000 fish	-	-	-
- Other	117,000 fish	510,693 fish	508,026 fish	2667 fish
Escapement, X* - h*	25,000 days	24,686 days	24,406 days	280 days
Fishing effort, E*	n.a.	63,849,173	61,971,612	1,877,561
Economic rent	n.a.	-	-	3731.24
- NPV	n.a.	-	-	2.63
- NPV/km				
- NPV/ha				

Note: net present value (*NPV*) is calculated in perpetuity with a 5% discount rate; total stream length is 503.2 km; total watershed area is 713,000 ha

5. CONCLUSION

Our paper takes an approach to valuing habitat that assumes that the production activity dependent on this habitat is efficiently managed. This seems reasonable in light of the opportunities foregone when environmental assets are destroyed and improves on many previous fisheries habitat valuation exercises. Our analysis valued changes in the quality of habitat used by the Strait of Georgia coho salmon stocks. For a non-marginal change in habitat, we considered a hypothetically pristine South Thompson watershed and allowed this to degrade to current ambient conditions. This lead to a loss of welfare in the range of $2 to $3 per ha of drainage basin or about $3700 per km of spawning stream length.

Although the analysis reported in this study relies on numerous assumptions, refinements are unlikely to change the results we obtained very dramatically. This conclusion is fairly robust over a range of sensitivity variations in key parameters, given the description of watershed degradation maintained throughout the study. Along with the other benefits of protected areas, this benefit can be contrasted with the benefits of alternative uses of parkland. Such valuation estimates serve to strengthen the case for protecting valuable ecosystems not only as an end in itself, but as a means of supporting economic activity elsewhere. These direct use benefits are in addition to the inherent values of pristine lands that cannot be so easily quantified or valued.

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