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A MODEL FOR MANAGING EXPLOITATION OF BROOK TROUT (*Salvelinus fontinalis Mitchill.)* IN INDIAN BAY, NEWFOUNDLAND

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Abstract

We used creel and index fishing data from ponds in Indian Bay Newfoundland to construct a model for managing the exploitation of brook trout (*Salvelinus fontinalis*). Our model describes the expected relationship between angling effort (angler-hr/ha) and brook trout yield (kg/ha). It predicts a maximum yield of approximately 0.4 kg/ha at a fishing effort of 3 angler-hrs/ha and extinction of the fish population at 8 angler-hrs/ha. Maintenance of a high quality fishery calls for regulations that restrict fishing effort or reduce its potential impact. We used a dynamic simulation model (calibrated for Indian Bay brook trout) to compare the effectiveness of various types of management regulations (e.g. creel limits, size-based restrictions on harvest). Our simulation results indicate that creel limits will not prevent over-fishing and that size-based management is needed to offer a sustainable high quality fishery.

Résumé

Des données sur les captures au casier et les pêches indicatrices dans des lacs d'Indian Bay, à Terre-Neuve, ont servi de base à l'élaboration d'un modèle de gestion de l'exploitation de l'omble de fontaine (*Salvelinus fontinalis*). Ce modèle décrit le rapport attendu entre l'effort de la pêche à la ligne (pêcheur-h/ha) et le rendement en ombles (kg/ha). Il prévoit un rendement maximum d'environ 0,4 kg/ha à un effort de pêche de 3 pêcheurs-h/ha, et l'extinction de la population de poissons à 8 pêcheurs-h/ha. Le maintien d'une pêche de haute qualité exige des règlements qui limitent l'effort de pêche ou en réduisent les incidences. Pour comparer l'efficacité de divers règlements sur la gestion (limites de captures et de tailles à la récolte), nous avons eu recours à un modèle de simulation dynamique (étalonné pour l'omble d'Indian Bay). Les résultats de notre simulation indiquent que des limites de captures ne préviendraient pas la surpêche et qu'un régime de gestion reposant sur la taille des prises est nécessaire pour assurer le maintien d'une pêche de qualité.

Introduction

Science-based management of a fishery calls for two types of understanding: 1) a biological model that describes the effect of exploitation on the fish population and 2) a socio-economic model that describes the response of humans to potential changes in the fish population. Equipped with this understanding, the manager can balance the trade-off that exists between the amount of fishing allowed and the yield of fishing quality that results. This report deals only with first type of understanding.

We present a biological model that predicts the effects of angling on the yield and fishing quality of a brook trout fishery in Indian Bay, Newfoundland. The fishery consists of 15 ponds. Recent studies have described the growth and reproductive characteristics of brook trout population in these ponds (van Zyll de Jong, Lester, Korver, Norris and Wicks 1999). We used the combined data from all ponds to develop our model. Although some differences exist among ponds, we do not have sufficient data to argue that these differences are related to inherent properties of the ponds. Given the dynamics of how populations respond to stress, these differences may reflect different stages of response to changes in fishing pressure.

Our model addresses several key questions: What is the maximum potential yield (kg/ha)? How much fishing effort will result in this maximum yield? How much fishing effort can be sustained? In order to answer the preceeding questions we need to define the relationship between fishing effort and yield. This problem can be approached by noting that the yield-effort relation depends on the nature of two relations (Fig. 1). First, we need to understand how yield varies with changes in fishing mortality rate (Fig 1A). Second, we need to understand the relationship between fishing mortality rate (f) and fishing effort (Fig 1B). When these relations have been defined, we can define the yield-effort relation (Fig 1C) by mapping the yield axis in Fig 1A onto the effort axis in Fig 1B, using F as the common variable.

In essence, this model-building is an attempt to define the capacity of an unregulated brook trout fishery. The model supplies key reference points (e.g. effort at maximum yield, effort at extinction) for evaluating whether a fishery is near full capacity. Since we expect demands for fishing will grow and exceed the capacity of an unregulated system, there comes a time when fishing regulations are needed to protect the fish population from overexploitation. The question that arises is: what works best? We use the model to compare the effectiveness of various management actions.

Yield and fishing mortality rate

We used an age-structured equilibrium model to describe the relationship between yield and fishing mortality rate. This model was derived by combining a generalized stock-recruitment relationship with conventional yield-per-recruit and biomass-per-recruit functions (see Appendix 1 in Shuter et al 1998). The algebraic

$$Yield=f(W_{\infty}, \omega, \tau_m, f_{max}, \alpha_{max}, M; \beta, B_o; t_c, F)$$

solution is fairly complex , but the model can be summarized in the following form:
where the parameters can be grouped as follows:

1) Life history parameters, defining rates of growth, natural mortality and reproduction in the absence of intraspecific competition:

W4 - asymptotic weight of an adult fish (kg);

ω - growth rate (cm per year) early in life;

t_m - age at maturity (knife edge transition assumed)

f_{max} - fecundity, the number of eggs per kilogram for a mature female at low population density;

α_{max} - survival from egg to age 1 at low population density

M - instantaneous natural mortality rate (per year) for fish aged 1 year and over.

2) Habitat quantity parameters, defining the rates at which early survival of fecundity are reduced from their maximal values as the population fills available habitat and approaches its carrying capacity:

β - a parameter that sets the rate of decline in survival or fecundity;

Bo - a scaling parameter (kg per hectare) that reflects the amount of habitat available to the population and hence is directly related to both the carrying capacity of the population and its maximum sustainable yield.

3) Fishery parameters, defining what part of the population is exploited and the intensity of exploitation:

t_c- age at first capture (knife-edged transition to full vulnerability assumed),

F, - instantaneous fishing mortality rate (per year) applied to all fish aged .= tc.

Parameters needed to construct this model for Indian Bay brook trout (Table 1) were taken from van Zyll de Jong et al (1999).

Table 1. Parameter value used in constructing the Yield-Fishing mortality model.

Parameter group	Parameter	Value
Life History	Growth (Von Bertalanffy):	ω = 15.02 cm/yr L4 = 40.6 cm k = 0.37
	Length at Maturation - 50%	L_m = 22.5 cm
	Length at Vulnerability- 50%	L_c = 20.0 cm
	Maximum fecundity:	2540 eggs/kg
	Maximum early survival (egg to age 1)	0.007
	Natural mortality(instantaneous, age >= 1)	M = 0.45 /yr
Habitat quantity	Shape parameter	β =1
	Carrying capacity parameters	B_o = 1.5
Fishery	Length at capture	Lc = 20.0 cm

The model predicts that yield increases while fishing mortality rate remains less than 0.22 and reaches a maximum level of 0.4 kg/ha (Fig. 2A). As mortality rate increases further, yield decreases and extinguishes when mortality equals 0.56. this extinction of the yield is due to the decrease in fish abundance that results from higher fishing mortality (Fig 2B).

Fishing mortality rate and fishing effort

To convert fishing effort into a fishing mortality rate (F) one needs an estimate of the catchability coefficient

$$F=qE$$

of angling :

where E is effort intensity (angler-hr.ha^{-1}) measured on an annual basis. Catchability can be calculated from

$$Catch=F\times Abundance$$

the relationship between CUE and fish abundance. Given that

and F = qE,

then Catch = q x E x Abundance

and CUE = q x Abundance

Thus, catchability is the slope of the relationship between CUE and fish abundance. This interpretation assumes that q is a constant (i.e. independent of abundance) and therefore CUE is linearly related to abundance. A more complex formulation is needed if this is not the case.

Results for the Indian Bay fishery are shown in Fig 3. Angling CUE is plotted against estimated fish density for 8 ponds where mark-recapture studies supplied estimates of abundance (Fig 3a). These abundance estimates refer to fish that are at least 2 years old. Younger fish are excluded because they are not vulnerable to angling. The graph excludes one observation (Skippers Pond, Density = 115 fish/ha, CUE = 0.73 fish/angler-hr) which is clearly an outlier. With the exception of one other pond, most of the points fall near a regression line forced through the origin whose slope implies q = 0.072.

This interpretation of the data must be treated with some caution. First, we note that the population estimates have wide confidence intervals (see Table 4 in van Zyll de Jong et al, 1999). Second, three of the estimates shown in Fig 3A are based on a single year of mark-recapture work and most of the others are from 2 years of study. Angling CUE is based on mean annual catch and effort; it does not necessarily correspond to the years when mark-recapture studies were done. Third, because mark-recapture studies are expensive they were not done on all lakes, so the number of observations available for examining the CUE-Abundance relationship is smaller than hoped. A larger set of observations is available, however, if we use indices of abundance based on the fyke net index fishing.

Index fishing was done on 13 of the 15 ponds (see Table 5 in Van Zyll de Jong et al 1999). Most ponds were surveyed for 3 or 4 years. We used the mean catch of fish that were at least 2 years old to measure the relative abundance of fish vulnerable to angling. The relationship between angling CUE and this measure of abundance was asymptotic (Fig 3B). When abundance is high, there is no relationship between CUE and abundance. At lower levels of abundance (i.e. < 6), CUE declines roughly in a linear fashion, indicating that catchability is constant.

We conclude that the relationship between CUE and abundance is not linear when one considers the full range of abundance that may exist. A newly exploited pond might offer a CUE in the order of 1 fish/hr and this catch rate might be sustained in spite of changes in abundance due to fishing. Substantial reduction in fish abundance may occur before angling CUE is impacted. Once a critical level is reached, CUE decreases roughly in proportion to abundance. Based on results shown in Fig 3A, we argue that the critical abundance level is approximately 12 fish/ha and that q = 0.072 when density is less than this criterion. This implies

$$F = 0.072 \times E$$

or

$$E = 14.3 \times F$$

In other words, increasing effort by one angler-hr per hectare increases fishing mortality rate by 0.072 units.

Yield and fishing effort

To generate a Yield-Effort relation, we transformed the x-axis of the Yield-F relation (Fig 2) by setting Effort = 14.3 * F. The result implies that the yield peaks when effort equals 3.0 angler-hr/ha and extinguishes at an effort of approximately 8 angler-hr/ha (Fig 4A). CUE decreases as effort increases (Fig 4B). At the effort level that results in maximum yield, CUE equals 0.52 fish per angler-hr.

Observed yield deviates somewhat from the predicted relation (Fig. 4A). These deviations should not be interpreted as an indication that the model is wrong. The model describes an expected equilibrium response, whereas the data describe a transient response. The model addresses the question: if effort was maintained at a specified level for many years, what stable level of yield (and CUE) would eventually result? It may take many years before the system becomes stable. (In the real world, the system may never become stable because environmental factors are never constant.) Thus, differences between predicted and observed yields are expected. On some ponds, the observed yield is much higher than the predicted maximum sustainable level. This difference is expected when exploiting a previously unexploited maximum sustainable level. This difference is expected when exploiting a previously unexploited resource. A time lag (of at least one generation) exists before the effects of exploitation are manifested in terms of future production. Yield measured over a short time interval is not a good indicator of sustainable yield.

Diagnosis of the fishery

Is the Indian Bay Trout fishery overexploited? Using effort at maximum yield (i.e. 3 angler-hr/ha) as a reference point, we see that effort exceeds the criterion on 5 of 13 ponds (Fig. 4A). Thus, one would conclude that some ponds are being overexploited. On the other hand, if one looks at the mean effort for the set of ponds (= 2.6 hrs/ha) one would conclude that the system, as a whole, is operating near full capacity. Although some ponds are overexploited, these excesses are compensated by under-utilization of other ponds. Given open access to all ponds, one expects angler migration between ponds would be driven by differences in CUE and would eventually result in a distribution of fishing effort that equalizes CUE. Thus, over the long term all ponds would be exploited near the optimum level.

Can the Indian Bay fishery sustain an increase in fishing effort? The simple answer is >yes≅. Mean effort is well below the extinction value (i.e. 8 angler-hr/ha) so increases could occur without endangering the fish stocks. The complex answer is Ayes, but at a cost≅. The costs are 1) further degradation of fishing quality and 2) increase likelihood of endangering fish stocks. Fishing regulations that dampen the impact of fishing effort are needed to avoid these costs.

Management scenarios

We used the Fisheries Management Support System (FMSS), developed by R. Korver of the Ontario Ministry of Natural Resources, to simulate the effect of the following regulations:

1. No regulations
2. Limit = 6 fish or 2 lb + 1 fish
3. Minimum size = 22.5 cm
4. Minimum size = 28 cm
5. Minimum size = 35 cm
6. Protected slot = 22.5 - 28 cm

7. Maximum size = 35 cm

The size-based regulations used criteria related to the growth and maturation of Indian Bay brook trout (Fig 5). The first minimum size regulation (#3) implies all fish less than the expected size at maturity (i.e. 22.5 cm) must be released. The next minimum size regulation (#4, 28 cm) implies that the average fish would reproduce once before reaching a size that could be harvested by anglers. The last minimum size regulation (#5, 35 cm) implies the average fish would reproduce trice before reaching a vulnerable size. The protected slot (22.5-28) implies fish could not be harvested during their first year of reproduction. The maximum size regulation (35 cm) implies that large and relatively old fish would be protected. For each scenario, we set effort at a fixed level (7 hr/ha) and simulated a brook trout population for 50 years. We used the response during the last 25 years to compare the effects of each regulation. The response measures included:

Adult abundance - Number fish/ha
CUE - Number fish caught per angler-hr
CUE35 - Number of fish greater than 35 cm caught per angler-hr
HWUE - Kilograms of fish harvested per angler-hr

The fishing quality measures reflect different aspects of the fishing experience. CUE indicates whether the angler is catching fish, CUE35 indicates the chance of catching a large fish, and HWUE indicates whether the angler can expect to bring home dinner.

We chose 7 angler-hr/ha as a basis for comparing these regulations because it represents a level of fishing effort that is barely sustainable when there are no regulations. Thus, we are asking whether we can sustain a high quality fishery at high effort by employing one of these regulations. The other question we addressed is how much effort could be sustained under each regulation. This was determined by running simulations at progressively higher effort levels until we crashed the fish population.

Results indicate that the creel limit was not effective (Fig. 6 and Fig. 7). When fishing effort is high, CUE is low and most anglers do not catch their limit. Consequently, the effect of an creel limit is the same as no regulation at all. Size-based regulations varied in terms of their effectiveness. Protecting small fish (< 22.5 cm, immature) and protecting large fish (> 35 cm) were marginally effective. Protecting fish during the first year of reproduction (22.5 - 28 cm) was more effective, but it does not to compare with the success of the remaining two scenarios. Minimum sizes of 28 cm and 35 cm were by far the most effective regulations. The 28 cm regulation resulted in a higher HWUE, implying a better food fishery, but in all other measures the 35 cm minimum size excelled.

The success of a 35 cm minimum size is hardly surprising. Given the growth and natural mortality rates used in the model, the probability that a fish survives to reach this size is only o.10. Thus, this size regulation will result in mainly a catch-and-release fishery. Although a minimum size of 28 cm results in higher kill rate, the difference in terms of kilograms kept per hour of fishing (HWUE) is marginal (Fig. 6B). For both scenarios, HWUE is in the order of 0.6 kg/hr, implying that approximately 16 angler-hr of fishing would be needed to bring home 1 kg of fish. For other regulations, the take home rate is even smaller. Clearly, none of these regulations will support a food fishery when effort is as high as 7 hrs/ha.

Conclusions

- Our model implies that 1) maximum sustainable yield of brook trout on Indian Bay ponds is approximately 0.4 kg/ha, 2) maximum yield occurs when angling effort is approximately 3 angler-hr/ha, and 3) maximum sustainable effort is approximately 8 angler-hr.ha.

- The model suggests that the Indian Bay fishery is operating near full capacity in terms of the brook trout yield it can supply. Increased fishing effort is expected to result in a decreased yield and further degradation of fishing quality.

- Simulations based on the model indicate that size-based regulations are needed to accommodate increased effort and sustain a high quality fishery. creel limits that allow 6 fish (or 2 pounds plus 1 fish) are not effective when effort is high (i.e. 7 angler-hr/ha) because most anglers will not catch their limit.

- None of the regulations evaluated will provide a good food fishery when effort is high.

- The model has weaknesses due to the uncertainty of several parameters. These uncertainties affect estimates of key reference values (e.g. maximum yield, effort at maximum yield, effort at extinction) and the diagnosis of fishery status. They should not affect conclusions regarding the relative effectiveness of different management actions.

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