A note on the development of Catch Control Laws for multi-species subsistence whaling

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ABSTRACT

Past work on Aboriginal Whaling Management Procedures (AWMPs) has focused on single-species approaches. This paper considers the issue of multi-species approaches by superimposing multi-species Catch Control Laws (CCLs) on top of underlying single-species models. Multi-species CCLs can fulfill larger 'need' than purely single-species approaches and can optimise the recovery rates of multiple species when need is satisfied. Four examples of multi-species CCLs are described to instigate discussion. The algorithms are based on the principles of species ranking, even catch, even exploitation and even recovery, respectively. These allocation principles are discussed in relation to management objectives for aboriginal subsistence whaling.

KEYWORDS: MANAGEMENT PROCEDURE; WHALING-ABORIGINAL

INTRODUCTION

In the development of management procedures, the International Whaling Commission (IWC) differentiates between commercial and subsistence whaling. A major difference between the two types of whaling is that the Revised Management Procedure (RMP) for commercial whaling is based on the objectives of 'recovery' and 'risk' (Donovan, 1989; IWC, 1994a; b), while the Aboriginal Whaling Management Procedure (AWMP) for subsistence whaling will also be based on the additional objective of 'need' (to 'enable aboriginal people to harvest whales in perpetuity at levels appropriate to their cultural and nutritional requirements'; IWC, 1995). A further difference is that the RMP was developed as a generic management procedure for baleen whales, whereas the AWMP will probably comprise some general aspects common to all fisheries as well as case-specific components (Donovan, 1999).

This note considers the design of the AWMP sub-component known as the Catch Control Law (CCL):

> 'Any potential AWMP will almost certainly include a *Strike Limit Algorithm* (*SLA*) which comprises a CCL, i.e. catch (strike) calculation based on population size and other parameters, and a specification of the data requirements and how those data are used so that the CCL can be applied' (Wade and Givens, 1997).

It is the CCL that calculates the strike limit from the estimated parameter distributions. This paper considers one of many possible frameworks for extending single-species CCLs into multi-species CCLs.

In the development of management procedures the IWC Scientific Committee has dealt almost exclusively with single-species systems. However, during the development of the AWMP it has become apparent that the multi-species case is also important. In particular, when Greenland presented its 'need' request to the IWC it expressed it as a number of tons of whale meat per year, with need not assigned to species (in recent years Greenlanders have hunted minke, fin and humpback whales). The importance and complexity of this issue has been recognised by the IWC (IWC, 1998).

In addition, when a single-species approach fails to fulfill need it may be possible to fulfil the need objectives if catches are taken from several species. Finally, for stocks below the maximum sustainable yield (MSY) level, under the present rules the IWC has requested its Scientific Committee to advise 'on a range of rates of increase towards the MSY level under different catch regimes' (IWC, 2000a). When need is satisfied from multiple species it is possible to optimise the recovery of the different species in a variety of ways, which leaves more room for the development of procedures that can satisfy the diversity of interests associated with subsistence whaling.

An essential question to be addressed in the multi-species case is the level at which the biological system should be modelled. In the ideal case, a multi-species AWMP should be based on the population dynamic interactions among the species in the multi-species system. However, given the complexity of parameter and especially model uncertainty associated with multi-species systems and a lack of appropriate data, adequate modelling of multi-species dynamics is probably beyond present day capabilities. Thus the potential approaches discussed in this paper do not use 'true' multi-species models, but rather a set of independent single-species approaches linked by a multi-species CCL.

This note is intended to stimulate discussion on how the objectives of subsistence whaling can be incorporated into the management of multi-species whaling. The four multi-species CCLs considered here are thus preliminary and presented to illustrate some of the ways to optimise the recovery rates of the different species in a multi-species AWMP. The note also shows how individual single-species approaches can be extended into a multi-species AWMP by superimposing a multi-species CCL on top of the estimated maximum allowable catch limits for individual species. In the simplest case, this framework shows how a multi-species AWMP can be constructed from a set of independent single-species approaches without the need for further parameter estimation. For other more complex cases, additional parameters may need to be estimated and larger simulation frameworks may need to be developed.

For the simplifying and transparent case where the different components of management procedures are independent units, the differences in the frameworks of the RMP and the potential single- and multi-species AWMPs are illustrated in Fig. 1. Given population parameters, the CCL of the RMP calculates the catch limit as a one-dimensional function of the abundance. The CCL of a potential AWMP will almost certainly calculate the strike limit as a two-dimensional function of abundance and need. It is the

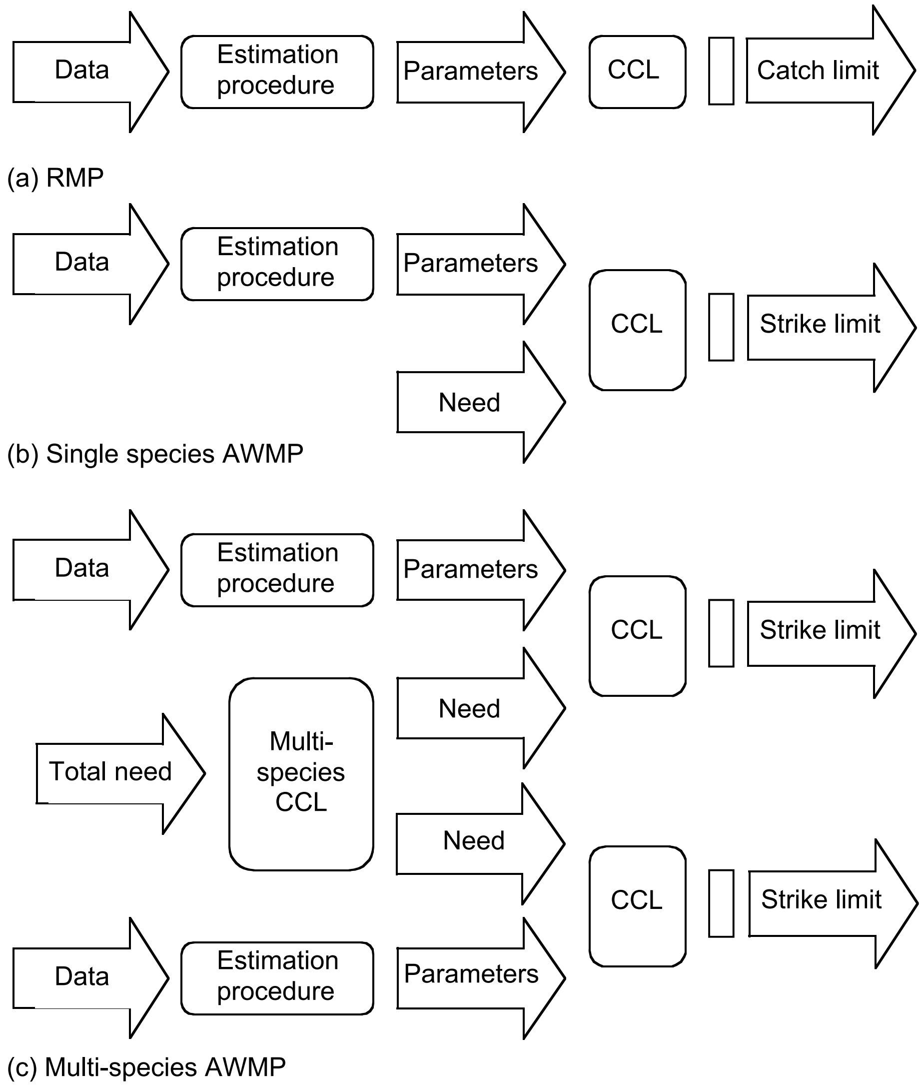

Fig. 1. An illustration of how the data are transformed into a catch or strike limit for (a) the Revised Management Procedure (RMP), (b) a single-species Aboriginal Whaling Management Procedure (AWMP) and (c) a multi-species AWMP (two species), assuming that the single- and multi-species CCLs are independent of one another. For details see the text.

inclusion of need in the CCL of the AWMP that makes the multi-species issue an interesting case for subsistence whaling, just as it is the lack of need that makes the multi-species issue a trivial case for commercial whaling (at least when there is no attempt made to model multi-species population dynamics). For commercial whaling, the multi-species case is simply the sum of the catches estimated for each species individually. This contrasts to subsistence whaling when, for example, 'need' is given in tons of whale meat not assigned to any particular species. Here, the multi-species CCL can be regarded as a method of distributing the total need among the various species such that the catch of a species depends not only on its own abundance but also on the assignment of need to the other species. This interconnection implies that there can be a variety of different patterns of catches that all satisfy total need but each satisfy a different set of interests or weights assigned to the various management objectives.

MULTI-SPECIES CATCH CONTROL LAWS

Let us assume that, for given parameter estimates, that the catch of a species is equal to the need allocated to that species provided it is below the estimated maximum allowable catch of that species. Given this, the multi-species algorithms developed here will ensure that only catch limits less than the estimated maximum allowable for any individual species will be set and that total need will be satisfied provided it is less than the sum of the maximum allowable catch limits of all species.

The single-species CCLs will take the following form:

$$l_{s,i} = \begin{cases} l_{n,i} & \text{if } n_i \le l_{u,i} \\ l_{u,i} & \text{if } n_i > l_{u,i} \end{cases} \quad (1)$$

where:

i denotes the ith species;
l_s is the catch limit;
n is the need in numbers of whales;
l_n is the catch limit of need defined as

$$l_n = n \quad (2)$$

and l_u is the estimated maximum allowable catch.

The catch c_i in individuals of the ith species is then set to the catch limit of that species, i.e. $c_i = l_{s,i}$.

To describe the multi-species CCLs let there be p species, $\mathbf{p} = \{1, 2, \ldots i \ldots p\}$. Let n_w be the total need in weight of meat not assigned to any particular species, and let the total catch in weight of whale meat be:

$$c_w = \sum_{i \in \mathbf{p}} c_i w_i \tag{3}$$

where:
c_i is the catch in individuals of species i; and
w_i is the average weight of meat of a caught individual of species i.

As the catch of each species must be below or equal to the maximum allowable catch of that species, the maximum amount of meat that can be caught is:

$$c_{w,max} = \sum_{i \in \mathbf{p}} l_{u,i} w_i \tag{4}$$

If total need is greater than the maximum amount of meat that can be caught, i.e. if $n_w \geq c_{w,max}$ there is only a single solution to the distribution of catches among the p species, assuming that the satisfaction of need shall be as high as possible and that the maximum allowable catches for the individual species cannot be violated, i.e. the catch of each species is set at the maximum allowed for that species ($c_i = l_{u,I}$). If instead total need is below the maximum allowable catch ($n_w < c_{w,max}$), there are a large number of solutions that will ensure total need satisfaction. The best solution will depend on the overall management objectives for the multi-species fishery. Four multi-species CCLs are described below to illustrate how different management objectives can be incorporated into a multi-species AWMP.

Species Ranking Algorithm

A relatively simple algorithm to distribute the catch among the different species is the 'Species Ranking Algorithm', where the need in numbers of individuals of the ith species is defined as:

$$n_i = \begin{cases} 0 & \text{if } n_w \leq c_{w,<i} \\ (n_w - c_{w,<i}) / w_i & \text{if } n_w > c_{w,<i} \end{cases} \tag{5}$$

where $c_{w,<i}$ is the sum of catches in weight of species with species numbers smaller than i, defined as:

$$c_{w,<i} = \begin{cases} 0 & \text{if } i = 1 \\ \sum_{j=1}^{i-1} c_j w_j & \text{if } 2 \leq i \leq p \end{cases} \tag{6}$$

Combined with equation (1), this algorithm distributes the total need into the need of the species with the highest ranking (i.e. lowest species numbers). Thus, the procedure begins with the highest ranked species (species 1) and converts the total need n_w into need for that species. If the total need is below the maximum allowed for species 1 ($n_w < l_{u,1}$), then the total need (and catch limit) will be set in terms of that species ($n_1 = n_w$). If instead n_w exceeds $l_{u,1}$, then the catch limit for species 1 will be set as the maximum allowable and the remaining need transferred to species 2 provided it is below the maximum allowed catch for species 2. If the remaining need exceeds this, the catch limit for species 2 will be the maximum allowed for it and the remaining need transferred to species 3. The CCL continues in this way until the total need is distributed among the different species or, if the total need exceeds $c_{w,max}$, until the catch limits for all species are set to their maximum allowed catch limits. The Species Ranking Algorithm ensures that need is satisfied when $n_w \leq c_{w,max}$.

Some obvious ways to rank the species in the Species Ranking Algorithm are from (1) a nutritional, (2) a conservation and (3) an operational perspective. The nutritional perspective might rank the species according to food quality, with the species with the best quality being ranked highest. Using a conservation perspective, one would give highest ranking to the most abundant species with the rarest species being lowest ranked. The third approach would reflect the operational constraints of the whalers. For example if whaling is conducted from small boats, the lowest ranking would be given to the species most difficult to handle.

Even Catch Algorithm

The merit of the Species Ranking Algorithm is the simplicity by which it distributes the need among the species. Unfortunately, it treats the species very differently: some species might be left unexploited while others are exploited at the rate defined by the maximum allowed catch. This can be avoided by using the 'Even Catch Algorithm' where the need in numbers of individuals of the ith species is defined as:

$$n_i = c \tag{7}$$

with c being the catch of those species that have estimated maximum allowable catches above c, and where the total catch c_w is set to the total need n_w when $n_w < c_{w,max}$. This CCL will ensure that (1) need is satisfied when $n_w \leq c_{w,max}$, (2) the catch is the same for all species that have upper catch limits above or equal to c and (3) that the catch will be the maximum allowed for those species where that value is below c.

From equations (1) and (7), the total catch is:

$$c_w = \sum_{p_i \in \mathbf{p_l}} l_{u,i} w_i + \sum_{p_i \in \mathbf{p_c}} c w_i \tag{8}$$

where $\mathbf{p_l}$ is the species set containing exclusively those species for which the maximum allowable catch is below c, and $\mathbf{p_c}$ is the species set containing exclusively those species for which that value is above or equal to c. Thus, setting equation (8) equal to n_w, the equation can be rearranged to give:

$$c = \frac{n_w - \sum_{p_i \in \mathbf{p_l}} l_{u,i} w_i}{\sum_{p_i \in \mathbf{p_c}} w_i} \tag{9}$$

Note, that the catch limit c determines whether a species belongs to the species set $\mathbf{p_c}$ or $\mathbf{p_l}$ and thus the two species sets $\mathbf{p_c}$ or $\mathbf{p_l}$ are not known *a priori*. Hence, c cannot be calculated directly, but it can be obtained by trial and error. This is done by estimating c by equation (9) for different combinations of species in the two species sets, and then by choosing the estimate where all species in $\mathbf{p_c}$ have upper catch limits above c and all species in $\mathbf{p_l}$ have upper catch limits below c.

Even Exploitation Algorithm

The Even Catch Algorithm has the undesirable property that the same catch for all species will affect the rare species more heavily. The 'Even Exploitation Algorithm' below avoids this:

$$n_i = l_{u,i} \bar{c} / \bar{l}_u \tag{10}$$

where $\bar{c}$ is the average catch and $\bar{l}_u$ the average catch limit for all species $\mathbf{p}$, and the total catch c_w is set to the total need n_w when $n_w < c_{w,max}$. Combined with equation (1) this algorithm ensures that need is satisfied when $n_w \leq c_{w,max}$, and that the ratio between the catch and the maximum allowable catch is the same in all species. This ratio is zero when there is no need and one when $n_w \geq c_{w,max}$. To determine the average catch $\bar{c}$, it is noted (from equations (1) and (10)), that the total catch is:

$$c_w = \sum_{i=1}^{p} l_{u,i} w_i \bar{c} / \bar{l}_u \tag{11}$$

when $n_w < c_{w,max}$. Thus, by setting equation (11) equal to n_w, it can be rearranged to find that:

$$\bar{c} = \frac{\bar{l}_u n_w}{\sum_{i=1}^{p} l_{u,i} w_i} \tag{12}$$

Note that all terms on the right hand side of equation (12) are known and, thus, $\bar{c}$ can be estimated directly. Hence, the Even Exploitation Algorithm is simpler to apply than the Even Catch Algorithm.

Even Recovery Algorithm

In spite of the simplicity of the Even Exploitation Algorithm, the 'Even Recovery Algorithm' below has more biological appeal:

$$n_i = \alpha RY_i \tag{13}$$

where $0 \leq \alpha \leq 1$ is a constant and RY_i is the net production or replacement yield of species i, and the total catch c_w is set to the total need n_w. From this latter constraint, α, which scales the catch so that the total catch is equal to the total need, is

$$\alpha = \frac{n_w - \sum_{p_i \in \mathbf{p_l}} l_{u,i} w_i}{\sum_{p_i \in \mathbf{p_c}} RY_i w_i} \tag{14}$$

where $\mathbf{p_l}$ is the species set containing exclusively those species that have catch limits below αRY_i, and $\mathbf{p_c}$ is the species set containing exclusively those species that have catch limits above or equal to αRY_i. As for the Even Catch Algorithm, the species sets on the right hand side of equation (14) are not known *a priori*. Thus, α cannot be calculated directly but must be estimated by trial and error.

The Even Recovery Algorithm ensures that (1) need is satisfied when $n_w \leq c_{w,max}$, (2) that the ratio between the catch and the replacement yield is the same for all species that have maximum allowable catches above or equal to αRY_i and (3) that the catch is the maximum allowed for all species that have catch limits below αRY_i. In other words, the Even Recovery Algorithm aims to maintain the same relative harvest induced decline in the production of all species. However, as the replacement yield is never known exactly for natural species, at least in the form proposed here, the Even Recovery Algorithm has limited practical importance.

DISCUSSION

The IWC's management objectives for aboriginal subsistence whaling (IWC, 1995) are to:

(1) ensure that the risks of extinction to individual stocks are not seriously increased by subsistence whaling;
(2) enable aboriginal people to harvest whales in perpetuity at levels appropriate to their cultural and nutritional requirements, subject to the other objectives; and
(3) maintain the status of stocks at or above the level giving the highest net recruitment and to ensure that stocks below that level are moved towards it, so far as the environment permits.

These do not specifically refer to multi-species whaling. However, it is reasonable to assume that the maximum allowable catches for any acceptable single-species approach will fulfil these objectives. It should be noted that for objective (3), the rate at which stocks are to move towards the target level is not specified.

In the absence of a specific rate, of the CCLs considered in this paper, the Even Exploitation Algorithm may be the most pragmatic, especially given problems in estimating replacement yield.

The IWC (1995) has assigned the highest priority to objective (1). Given that, an Even Risk of Extinction Algorithm such as that proposed by Givens (IWC, 1999), may perhaps be considered as a more appropriate multi-species CCL. Although extinction risks to individual stocks can be relatively straightforwardly calculated within the population simulation framework being used during the development of the AWMP (IWC, 2000b), the Even Risk of Extinction Algorithm might be difficult to apply since extinction estimates are highly dependent on both model and parameter uncertainty. Both the Even Recovery and the Even Risk of Extinction Algorithms suffer from their dependence on the population dynamic parameters of the different stocks. This contrasts to the Species Ranking, Even Catch and Even Exploitation Algorithms that do not directly incorporate population parameters but only parameters of the single-species CCLs.

All the multi-species CCLs described here should be considered as preliminary suggestions only. Despite their relative simplicity in the form presented, they have the desirable behaviour that they both satisfy total need when total need is below the sum of the upper catch limits of all species, and they optimise the recovery rates of the different species in accordance with some explicitly defined rules. However, this behaviour depends on the assumption that the catch of a species is equal to the need allocated to that species as long as need is below the estimated maximum allowed catch limit of the species. More generally, it is possible that single-species CCLs are developed with a diminishing return where the number of whales given to the quota per unit need is a declining function of need. In this case, there may be situations where the proposed multi-species need-allocation procedures prevent total need being met, although it might have been if need was allocated differently among the different species. For such single-species CCLs, the best approach might be to search over all types of possible need allocations and determine the subset of allocations for which total need is met to the greatest extent. From this subset it will be possible to choose the allocation that comes closest to the desired allocation rule.

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