A note on the cost of instability in whale management

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ABSTRACT

The history of whaling has been characterised by considerable variation in management 'philosophy'. For example, an early period of overexploitation led eventually to the present period of protectionism and might be followed by a period of excessive catches. Is such instability in long-term management costly? The risk of depletion increases with increasing instability. If the net production function governing whale dynamics is essentially convex, it is demonstrated that long-term catches are necessarily smaller the greater the management instability. A simulation experiment is carried out to quantify the loss in whale catches due to 'stop-go' instability in whale management. To examine possible costs in terms of fisheries for cod and herring, a multi-species simulation model is used, with minke whales managed by a stochastic stop-go procedure and with cod, herring and capelin managed by VPA-type procedures. In the simulations, whale catches are reduced by increased instability in whale management while long-term catches of cod and herring are unaffected, provided mean whale abundance is kept fixed.

KEYWORDS: MANAGEMENT; WHALING-MODERN; MODELLING; FISHERIES

INTRODUCTION

Schweder (1999) argued that the management of whaling by the International Whaling Commission (IWC) was guided more by economic (before 1975) and political interests (from 1982) than science. This led to fluctuations in management 'philosophy', first with excessive catches and then with excessive protectionism. He argued that if protectionism is allowed to prevail, despite the existence of the IWC's Revised Management Procedure (RMP; IWC, 1993) which provides for scientifically defensible whaling, science in the context of whale management will be undermined. However, should the current political support for the ban on commercial whaling fade, it is possible that a new period may begin that places economic interests in whaling at an advantage. Thus the situation may continue that management is based largely on politics rather than science.

Long-term instability in whale management philosophy is a possibility that deserves discussion. Excessive fluctuations in the management regime are undesirable in that they make stock size vary more than necessary, with a consequential risk of stock depletion. Such long-term instability does not comprise a precautionary approach to management (FAO, 1995). This paper argues mathematically that it is also costly with respect to utilisation: the average annual catch of whales is generally a decreasing function of the variability in stock abundance around a stationary level.

The paper also investigates the quantitative relationship between long-term catches of whales and the degree of instability in whale management. A simulation model is used in which whaling is treated as a 'stop-go' process in order to mimic a long-term situation with alternating periods of protectionism and over-utilisation. The model is a relatively simple multi-species model for the Barents Sea using minke whale, cod, herring and capelin. Simulation is also used to examine the potential impact on fisheries of instability in whale management. Theory suggests that long-term catches of whales will be inversely related to the degree of instability in whale management, all else being equal. Long-term catches of cod and herring would not be expected to depend on the degree of instability in whale management given that in the present model, catches of cod and herring are essentially linearly related to whale abundance (Schweder *et al.*, 1998; 1999), despite the complex predation structure with its potential for non-linearity. With such a linear response, the mean catch is unaffected by instability in whale management with consequential variability in whale abundance and whale predation, provided mean whale abundance is kept constant.

Although the multi-species model is relatively simple, the simulation experiment itself is rather complex. Since the results from the experiments are as expected from the theory, the simulation model, the experiment and the results are only presented in general terms.

Theoretical considerations of whaling and its management

The basic concept of management is that of strategy. A management strategy might be a catch limit rule augmented by other controls, or catches might be determined by a system of economic incentives, perhaps in a stochastic manner. A strategy might be explicitly defined, or might follow more implicitly from political or economic circumstances (although whether the word 'strategy' is appropriate here is a moot point).

In this paper, the catch taken in year t, C_t, is regarded as a stochastic variable with distribution dependent on the stock abundance in that year. It may also depend on the previous history of stock size and catches. For simplicity, consider a population (of whales) that is aggregated over age, sex and other characteristics. Let the abundance in year t be P_t. The distribution of P_{t+1} depends on the catch and the abundance in the previous year, and possibly on further aspects of the history of the stock until, and including, year t, H_t.

The distribution of P_{t+1}, given P_t, C_t and further aspects of H_t, is determined by the population dynamic characteristics of the stock. The main characteristic for the population is the conditional expectation

$$E[P_{t+1}|H_t] = P_t - C_t + r(P_t), \qquad (1)$$

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where r is the net recruitment function (proportional to the sustainable yield curve). It is assumed that r is independent of t. Typically, the recruitment curve is convex,

$$r(\alpha p_1 + (1-\alpha)p_2) \geq \alpha r(p_1) + (1-\alpha)r(p_2), \quad 0 \leq \alpha \leq 1$$

Stationary management leads to the stationary development of the stock and the catch. Assume for a moment that the process is in a stationary state (different from extinction). Stationarity implies $EP_{t+1} = EP_t$. Under this assumption, taking the expectation of both sides of (1) yields

$$EC_t = Er(P_t). \qquad (2)$$

When r is convex, $Er(P)$ is a possible and natural measure of dispersion of the stochastic variable P. The smaller $Er(P)$, the more dispersed is the distribution. Let us say that the stationary distribution of P is more r-dispersed the smaller $Er(P)$ is.

Example
Consider the Pella Tomlinson model with

$$r(p) = Ap(1-(p/K)^z)$$

for given carrying capacity K, productivity parameter $A > 0$ and shape (add the inequality) parameter $z > 0$. This net recruitment curve is convex for the natural range, $p \geq 0$. Let $D = P/K$ denote depletion and let $\delta = ED$ be a given level of mean depletion. Then, $EC = Er(P) = AK(\delta - ED^{z+1})$. For non-negative random variables, D, with mean δ, degree of dispersion is sensibly measured by the moment ED^{z+1}, $z > 0$. Given this we can say that P is more dispersed the smaller $Er(P)$ is. For example, with $z = 1$:

$$Er(P) = AK(\delta - ED^2) = AK(\delta(1-\delta) - \mathrm{var}(D)).$$

In this case P is more r-dispersed th_n P^* whenever $\mathrm{var}(P) > \mathrm{var}(P^*)$.

When the relative depletion has a stationary beta distribution, the expected yearly catch has an analytic form. The beta distribution with parameters α and β has density

$$f(d) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} d^{\alpha-1}(1-d)^{\beta-1}; \qquad 0 < d < 1,$$

and mean $\delta = \alpha/(\alpha+\beta)$. Further,

$$ED^{z+1} = \frac{\Gamma(\alpha+\beta)\Gamma(\alpha+z+1)}{\Gamma(\alpha+\beta+z+1)\Gamma(\alpha)}.$$

Here, Γ denotes the gamma function. The variance is

$$\sigma^2 = \delta(1-\delta)/(\alpha+\beta+1).$$

To get a feel for the effect of instability, Fig. 1 presents the percentage difference, $100(r(\delta) - Er(P))/r(\delta)$, for $z = 2.39$ (making maximum sustainable yield level (MSYL) $= 0.6$) and for various values of σ for expected stationary depletion $\delta = 0.72$. This value was chosen because the IWC set a target depletion level at 0.72 for its RMP when maximum sustainable yield rate (MSYR) $= 1\%$ (IWC, 1999c). A similar picture is obtained for all mean stationary depletion levels. This concludes the example.

From (2), the expected catch is larger the less r-dispersed the stationary abundance distribution is. The opposite is equally true. The provision is that the production curve is convex over the support of the stationary distribution to make the concept of r-dispersion meaningful.

Consider two strategies, s and σ, making the process stationary and leading to the same stationary population mean, $\mu = E_s P = E_\sigma P$. Let p_s and p_σ denote their respective probability densities of stationary abundance levels (both with mean μ). It is helpful to link the concept of r-dispersion to differences between the two densities. The simplest concept of dispersion is that this difference is positive within an interval, and negative outside it. If, in fact, this is the case, σ is more r-dispersed than s, regardless of r as long as it is convex:

Lemma
If π_σ is more density-dispersed than π_s, in that there exist levels $a < b$ with $\pi_\sigma(p) < \pi_s(p)$ for $a < p < b$ and $\pi_\sigma(p) \geq \pi_s(p)$ for $p \notin (a,b)$, then σ is more r-dispersed than s for all convex functions r.

This is seen as follows. Let $L(p)$ be the linear function cutting through the production curve at a and b. Due to the convexity of r, $r(p) > L(p)$ whenever $a < p < b$. Since by linearity $E_s(L) = E_\sigma(L)$,

$$E_s(r) - E_\sigma(r) = E_s(r-L) - E_\sigma(r-L) = \int (r(p) - L(p))(\pi_s(p) - \pi_\sigma(p))dp,$$

which is indeed positive by the assumption of the lemma.

Similar results holds for non-stationary situations. By summing (1) over consecutive years, and taking expectation, we get

$$E\frac{1}{T}\sum_{t=1}^{T} C_t = E\frac{1}{T}\sum_{t=1}^{T} r(P_t) + \frac{1}{T}E(P_{T+1} - P_1) \qquad (3)$$

In the non-stationary case, the concept of r-dispersion must be related to a period. Let us say that $\{P_t\}$ is more r-dispersed over $t = 1,\ldots,T$ than $\{P_t^*\}$ when the expected mean of r has the right ordering,

$$E\frac{1}{T}\sum_{t=1}^{T} r(P_t) < E\frac{1}{T}\sum_{t=1}^{T} r(P_t^*).$$

With this concept, the relation (3) gives us:

Proposition
Consider two strategies s and σ that make the same expected change to the stock over a period of length T, $E_s(P_{T+1} - P_1) = E_\sigma(P_{T+1} - P_1)$. The expected mean catch over the period

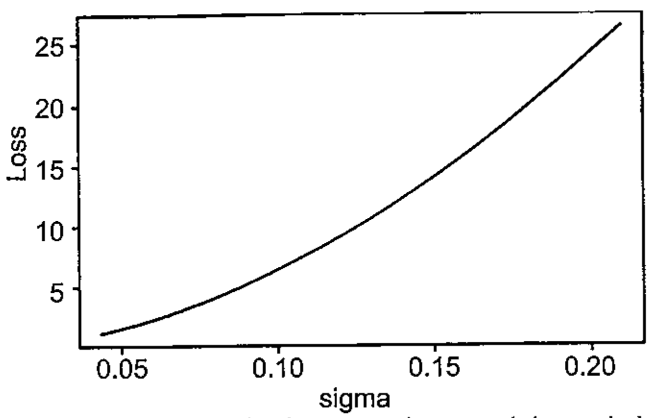

Fig. 1. Percentage reduction in mean stationary catch by standard deviation. Pella Tomlinson production model, $z = 2.39$, stationary beta distribution with mean $\delta = 0.72$.

is larger for s than for σ if the population trajectory is more r-dispersed under σ than s over the period.

This proposition is nothing more than an interpretation of (3). The proposition covers both the stationary and the non-stationary case.

It is obviously preferable to have stable management in order to reduce the risk of depletion of the managed stock. In addition to this benefit of stable strategies, the above results show that on average continuous catches are improved the more stable the management strategy is (assuming equal long-term population mean or equal expected final population size).

SIMULATION EXPERIMENT

The simulation experiment has two aims: (1) to measure the effect of instability in whaling management on the catches of whales; and (2) to investigate whether instability in whaling management affects the catch of cod or herring in a multi-species fisheries model.

The model for whale dynamics represents minke whales in the Greater Barents Sea. As in the implementation trials for the IWC's RMP (IWC, 1993) the age-distributed Leslie model is used with the Pella Tomlinson production model acting on the recruitment. The same model was used by Schweder *et al.* (1998) to investigate the effects of re-tuning the RMP.

Rather than assuming that the RMP is used to regulate whaling, 'stop-go' management is assumed in order to capture the fluctuating management that has occurred in the past (Schweder, 1999). The 'stop-go' strategy is modelled as follows. In 'go' periods 3,000 whales are taken yearly. In 'stop' periods there is no whaling. Transition between stop- and go periods is stochastic. The last year, t, of each five-year cycle of a stop period can mark a transition to a go period. This happens if $P_t > B_+K$ where B_+ is drawn (at the beginning of the stop period) from a beta distribution with mean $0.6 + d$ and with variance v. In the same way, a test is made every fifth year in a go period, and it terminates if $P_t < B_-K$ where B_- is drawn from a beta distribution with mean $0.6 - d$ and with variance v. Numerical values are specified for d and v. For each run, the mean abundance over the 300 year long simulation period is recorded, and the sustainable catch at this level is calculated.

An experimental design spanned by factors d, v, K and MSYR governing the whale dynamics and management, and also factors related to fish recruitment, whale predation and fishing management strategies, was determined as an orthogonal array with 27 points, exactly as in Schweder *et al.* (1998). Two independent replicate runs were executed for each of the design points. For each of these 54 runs, a twin simulation was carried out with whale abundance fixed at the observed mean level and all other factors (including stochasticity in fish recruitment) being equal. The details of the experimental scenario are not important for the purpose of this paper but can be obtained in an unpublished note[1]. The maximum sustainable yield level is fixed at MSYL = $0.6K$, which is also the initial population size in all runs with unstable whale management.

A linear regression analysis based on the simulation results was carried out to estimate the loss in whale catches due to instability in management. The factors relevant for the whale catches (MSYR, K, d, v) are numerical, and are used as linear regressors. In addition to the plain experimental factors, an indicator, S, for stability in whale management is included, together with the interactions $S \times K$ and the natural interaction between K and MSYR, MSY = 0.6 × MSYR × K.

The results are presented in Table 1, with non-significant effects excluded. Surprisingly, the fixed effect abundance deviation, d, turned out to be non-significant. Instability in whale management is costly; the main effect of instability (S = 1) is a yearly loss of some 133 whales. The main effect of the standard deviation v of critical abundance limits is also significant, and of expected sign. The regression model fits the simulated data well ($R^2 = 0.98$).

To appreciate the sizes of the estimated regression effects, some information on the productivity of the simulated stock is useful: the 54 cases have MSY values ranging from 126 to 1,094, with a mean of 780, a median of 880 and a standard deviation of 312. The abundance is modelled to vary around MSYL, and it is reasonable to compare the regression effects with MSY.

Whale dynamics are slow in most of the simulation runs. In some cases, there are only a couple of completed stop-go periods, and the pairwise difference in annual catches between the stable and the unstable case is highly dependent on how the last but uncompleted stop-go period is terminated. The mathematical result is that instability is costly in the long run (in the stationary state), and also in the mean over a limited period if the initial stock level is the same within the pair and if the mean pair-wise difference in final abundance is zero. Neither of these conditions apply to cases with slow whale dynamics relative to the 300 year horizon. In about 10% of the simulated 54 pairs, the mean catch was larger with unstable whale management than with a constant catch. These cases were characterised by a long period of catching towards the end of the simulation period, and with consequential low final abundance.

The other purpose of the simulation experiment was to examine whether instability in whale management might influence catches in cod and herring fisheries. The model used is a multi-species model for cod, herring, capelin and minke whales. It has a relatively intricate predation structure, with minke whales preying on all fish species, cod preying on herring, capelin and young cod, and herring preying on capelin fry in years when herring are present in the Barents Sea. Cod and herring fisheries are managed by quotas set by biological reference points based on VPA-type assessments. The details of the model are presented in Schweder *et al.* (1998), and are not repeated here. The main result of the simulation study with respect to fish catches is as expected: they are largely unaffected by instability in the management of whaling.

The simulation experiment was designed with matched pairs. For each of the 54 runs with whaling managed as a stop-go process, a twin run was made with the fish stocks having the same characteristics, including the stochastic effects in fish recruitment. The only difference within pairs

Table 1

Linear regression with yearly mean whale catch as response.

Regressor	Units	Estimate	Standard error
intercept		-321.1	60.2
S	1(0) if (un)stable	132.6	39.1
$\sqrt{v}$	standard deviation	-436.3	162.7
MSY	whales	1.1	0.03
K	1,000 whales	2.4	0.4
$S \times K$	1,000 (0) whales	-1.3	0.4

[1] Unpublished note SAMBA/03/99 available from the Norwegian Computing Center, Box 114 Blindern, 0314 Oslo, Norway.

is that whale abundance varies in one run and is fixed in the other at the realised mean level over the 300 years of simulation in the stop-go case. The only difference for the fish stocks between the twin runs is thus in variability in whale predation.

This simulation experiment and its results illustrate what is clear from the theory: (1) increased instability in whale management leads to increased loss in long-term catches of whales, provided the production function is convex; and (2) it has no effect on long-term catches of cod and herring when the mean whale abundance is kept constant. Since the simulation experiment serves only as an illustration, it has only been presented in outline terms. Details are available from the authors.

DISCUSSION

In a realistic situation with management based on stochastic (abundance) data, the catches and the population trajectory become stochastic despite the population dynamics being deterministic. The theory presented here therefore applies to the models considered by the IWC when developing, selecting and implementing the RMP. Take for example the comparison scenarios where competing draft procedures were tuned to make EP_{T+1} equal to a given target, and where the initial abundance, P_1, was given (IWC, 1992). Since by our proposition a decrease in mean catches is equivalent to an increased r-dispersion, the inferior performance of the procedure developed by de la Mare relative to the Punt-Butterworth procedure and the Cooke procedure with respect to mean catch, can be ascribed to its inferior stability properties. Over the 100 year simulation period, stock abundance must, in fact, have been more r-dispersed under the de la Mare procedure than under the two other procedures for the Pella Tomlinson production function used in the scenarios. Another, and perhaps a more intuitive way to put this is that for the Cooke procedure and the Punt-Butterworth procedure, the stock was on average kept closer to MSYL than by the de la Mare procedure.

What characterises stable strategies? If the stationary mean is given, the strategy is more stable the more it is able to drive the population up to its stationary level (if it has fallen below), and down if the level is exceeded. When the data driving the management are unbiased absolute abundance estimates with little noise, a strategy of the 'bang-bang' type (with no catches when the stock estimates are below the target and high catches when it is above) will achieve high stability. Stability can therefore not be measured by interannual variability in catch limits. It is more the medium to long-term auto-correlation structure in the catch limits that determines the stability properties. When there is noise in the data and stochasticity in the process, an optimal strategy will usually be difficult to calculate. In this case, completely stable strategies defined by a target stock level, such as those considered in the simulation experiment, are not achievable. The comparison between the 'stop-go' strategies and their stable twins are therefore mainly of theoretical interest.

There are other types of costs resulting from instability in whale management than the loss in catches of whales demonstrated in this paper. Increased instability in whale management leads to increased variability in whale abundance, and also in catches of fish. This incurs added capital cost and may also lead to reduced mean market value.

However, the most important cost generated by long-term instability in management is the increased risk of stock depletion. The majority of the governments in the IWC are currently in support of a *de facto* continuation of the moratorium on commercial whaling, with a possible exception for Norwegian minke whaling under the RMP (IWC, 1999a, p.22). If this is achieved in the long run, the management is stable and none of the costs discussed here apply. However, it is not necessarily the case that the moratorium will continue in the long term. Circumstances may result in a lack of public support for unconditional protectionism and the moratorium might collapse. This would lead to a new period of whaling. Although the successful development of the RMP has shown that whaling can be managed with sufficient scientific caution, the IWC has, however, not yet implemented the RMP; it is not obvious that it will ever be implemented, even if a new period of exploitation begins. In the opinion of the authors, instead of basing its management on science as envisaged in the 1946 Convention (IWC, 1999b), the IWC initially based it on short-term economics and more recently has based it on protectionist politics. Holt (1992, p.46) expressed, perhaps, the majority view within the IWC:

> 'We have, as it were, gained time through talking about science and conservation. At the same time, scientific research that is relevant has been supportive and political lobbying through the IWC delegations, primarily, and through their superiors in Government, has been intense and continuous... I think we are all agreed that we should aim at keeping the moratorium in place, at least until the year 2000. ...If we can do that and if we can hold the dam, as it were, for a few more years, that will give us time to assemble the ethical arguments against whaling'.

The question is, however, whether 'the dam' can be held forever. If it breaks, perhaps after a long time, this will, in effect, give long-term instability. If whale management is based on politics rather than science it may not only be unstable in the long-term, but the next period of utilisation may turn out to be one of over-exploitation, insufficiently checked by science.

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