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Biological Reference Points for New Zealand Fisheries Assessments

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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BIOLOGICAL REFERENCE POINTS FOR NEW ZEALAND FISHERIES ASSESSMENTS

Pamela M. Mace and Michael P. Sissenwine

Preface

This document further develops and refines concepts presented in the "Guide to Biological Reference Points for the 1988 Fisheries Assessment Meetings" in Baird and McKoy (1988). It was initially intended that the material presented here would be used as the basis for the 1989 Fisheries Assessment Meetings (1989 FAM). However, in order to maintain consistency with the previous year, and to allow adequate time for thorough review, the 1989 Plenary Session decided not to adopt a new "Guide" at that time. Except for corrections of obvious errors, the 1988 "Guide" was adopted without change for the 1989 meetings (see "Guide to Biological Reference Points for the 1989 Fisheries Assessment Meetings" in Annala 1989).

A revised version of the "Guide" has been prepared for use during the 1990 FAM. The present document forms an important link between the 1988 "Guide" and the 1990 revision, particularly since the latter incorporates several of the refinements contained herein. Therefore, the present document is being published in the New Zealand Fisheries Assessment Research Document series so that the concepts developed in it can be more widely discussed and debated; developments in the basis for assessments between the 1988 and 1990 FAM can be followed more readily; and the paper can be appropriately acknowledged as a source document for the version of the "Guide" prepared for the 1990 FAM.

Introduction

The management of New Zealand fisheries is based on maximum sustainable yield (MSY) as qualified by relevant factors including regional or global standards. There are two global interpretations of MSY that are pertinent to fisheries management in New Zealand: a static interpretation and a dynamic interpretation. The static interpretation corresponds to a dictionary definition of MSY: the highest attainable constant or continuous catch able to be taken from a fishery. The dynamic interpretation recognises that fish populations are not constant in size (i.e. populations and catches may both vary considerably): fisheries scientists usually interpret MSY as the maximum average yield, MAY, that could be taken from a stock (Ricker 1975; Doubleday 1976; Sissenwine 1978).

The two interpretations have different assessment and management implications. It is now well known that the Maximum Constant Yield (MCY) is less than MAY (see for example Doubleday 1976; Sissenwine 1978; Mace 1988a). To achieve MAY (i.e. to maximise long term average yield) it is necessary to vary annual yield in response to changes in the production of a fish stock. This means that a higher yield can be obtained on average if it is possible to determine current stock production, so that the yield can be varied appropriately.

This suggests two approaches to assessment and management strategy. The first approach is based on a constant catch strategy, while the second is based on a variable catch strategy. The most frequently used variable catch strategy is one that applies a constant fishing mortality rate (F) to the current biomass.[1]

[1] All fishing mortality rates referred to in this document are instantaneous rates. The instantaneous fishing mortality rate is equivalent to the fraction removed from the average fishable biomass present during the fishing year.

The biological reference points associated with each approach can be defined as follows:

First approach:

MCY – Maximum Constant Yield[2]
The maximum constant catch that could have been taken throughout the history of the fishery, and is expected to be sustainable (within an acceptable level of risk) in the future.

CCY – Current Constant Yield[2]
The maximum constant catch that is expected to be sustainable (within an acceptable level of risk) given the condition of the population at initiation of the constant yield. If a population has been depleted (e.g. because MCY has been exceeded), CCY will be less than MCY. Otherwise, CCY will equal MCY.

Second approach:

MAY – Maximum Average Yield
The maximum average catch that can be taken from the fishable (i.e. recruited) biomass by varying annual catch.

CAY – Current Annual Yield
The one–year catch attained by applying a reference fishing mortality to an estimate of the fishable biomass present during the next fishing year.

F_{ref} – Reference Fishing Mortality Rate
The fishing mortality rate that results in the maximum average yield that can be taken by applying a constant fishing mortality rate.[3]

The first approach is the static analog of MSY. TACs should be based on MCY or CCY when it is impractical to vary the TAC from year to year. For example, there may be insufficient information to estimate the fishable biomass that will be present during each fishing year. Estimates of MCY may be improved as new knowledge becomes available, but such changes are likely to be infrequent. Estimates of CCY should change whenever there is new information about stock condition.

The second approach is the dynamic analog of MSY. TACs should be based on CAY when it is practical to vary them from year to year. Generally, this will require that there be sufficient information to estimate a reference fishing mortality rate (F_{ref}) and to apply it to estimates of fishable biomass. Estimates of CAY should be updated annually. Estimates of F_{ref} may also need to be revised periodically as new information becomes available. TACs would be varied frequently (e.g. annually) so as to achieve MAY. But, with the exception of stocks that are highly dependent on annual recruitment, the changes from one year to the next should not be large.

In the majority of years CAY will be larger than MCY. But when fishable biomass becomes low (through overfishing, poor environmental conditions, or a combination of

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[2] There is always some finite probability that a constant catch is not sustainable.

[3] In fact, the global maximum average yield will be achieved by varying both annual yield and annual fishing mortality. But, in general, determination of the time path of fishing mortality rates is an optimal control problem that is too complex to be solved in assessment meetings.

both), CAY will be less than MCY, and possibly less than CCY. This is true even if the estimates of CAY and MCY are exact. The following diagram shows the relationships between CAY, MCY and MAY.

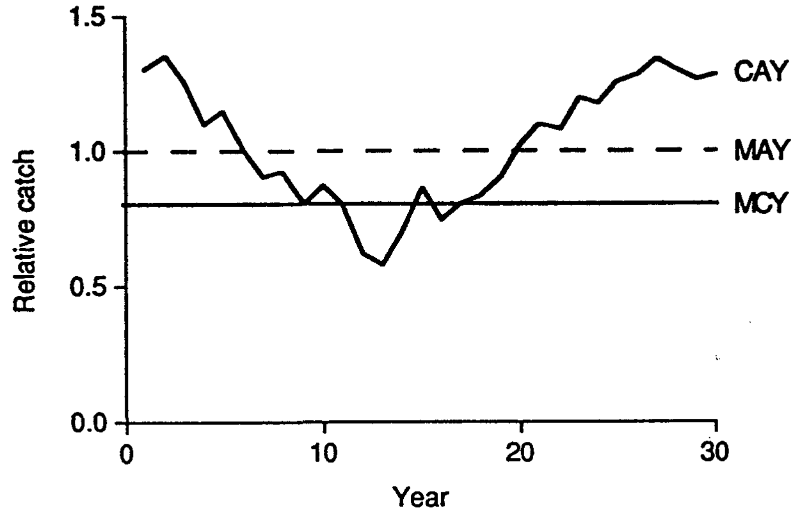

Figure 1. Relationship between CAY, MCY and MAY.

In this example CAY represents a constant fraction of the fishable biomass, and so (if it is estimated and applied exactly) it will track the fish population exactly. MAY is the average over time of CAY. The difference between MAY and MCY can be interpreted as a measure of the potential utility of variable TACs, which require ongoing research to estimate biomass and refine estimates of stock productivity.[4]

The reason MCY is less than MAY is that MCY must be low enough so that the fraction of the population removed does not constitute an unacceptable risk to the future viability of the population. With an MCY strategy, the fraction of a population that is removed by fishing increases with decreasing stock size. With a CAY strategy, the fraction removed remains constant. Thus, the reason that MAY cannot be achieved by taking a constant yield is that the MAY level has a high risk at low stock sizes.

Adoption of these two approaches does not mean that TACs will always equal MCY, CCY, or CAY. This applies particularly to the situations of depleted stocks and virgin fisheries. If the stock has been depleted, the TAC may be set even lower than CCY in order to promote stock recovery. For a virgin fishery it may be appropriate for the TAC to exceed MCY or CAY while some of the accumulated biomass is harvested.

There are also other reasons why the TAC may differ from MCY, CCY, or CAY. These include economic considerations, effects of fishing practices and interdependence between stocks of fish.

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[4] To properly determine MCY and the reference fishing mortality rate associated with MAY, comparable amounts of population dynamics (growth, mortality and recruitment) information are required. But once MCY has been estimated it can be applied without annual estimates of biomass, whereas CAY cannot.

Methods of estimating MCY, CCY, and CAY

Having defined MCY, CCY, and CAY and discussed their general properties, it is useful to specify methods for their estimation. It should be possible to estimate MCY or CCY (with varying degrees of confidence) for most fish stocks. Estimates of MCY and/or CCY can be extracted from catch records and other relevant data. CAY can only be estimated when there is a basis to estimate current stock size. The proposed methods of estimation represent professional judgements on the interpretation of available data. If these (or other) methods are adopted they should represent the concensus judgement of the Fisheries Assessment Working Groups, and their statistical properties should be rigorously evaluated.

The following examples define MCY, CCY and CAY in an operational context with respect to the type, quality and quantity of data available. Knowledge about the accuracy or applicability of the data (e.g. reporting anomalies, atypical catches in anticipation of the introduction of the QMS) should play a part in determining which data sets are to be included in the analysis. If the results are not consistent with all available information (including informed judgement), they should be used with caution.

First Approach[5]

1. New fisheries

$$MCY = 0.25\ F_{0.1}\ B_0$$

where $F_{0.1}$ is a reference fishing mortality[6] derived from yield per recruit (YPR) analysis and B_0 is an estimate of virgin recruited biomass. If there are insufficient data to conduct YPR analysis, $F_{0.1}$ should be replaced with an estimate of natural mortality (M).[7] Tables 1–3 in Mace (1988b) show that $F_{0.1}$ is usually similar to (or sometimes slightly greater than) M.

It may appear that the estimate of MCY for new fisheries is overly conservative, particularly when compared to the common approximation to MSY of 0.5 MB_0 (Gulland 1971). However various authors (including Beddington and Cooke 1983; Getz et al. 1987; Mace 1988a) have shown that 0.5 MB_0 often overestimates MSY particularly for a constant catch strategy or when recruitment declines with stock size. Moreover, it has often been observed that the development of new fisheries (or the rapid expansion of existing fisheries) occurs when stock size is unusually large, and that catches plummet as the accumulated biomass is fished up.

New fisheries become developed fisheries once F has approximated or exceeded M for several successive years, depending on the lifespan of the species.

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[5] The risk associated with MCY strategies derived from the methods described in this section is not specified. In general, stochastic simulation techniques will be necessary to assess the risk.

[6] $F_{0.1}$, pronounced "F zero point one", is a reference fishing mortality rate that is used as a basis for fisheries management decisions throughout the world (i.e. globally). It is widely believed to produce a high level of yield on a sustainable basis.

[7] A rough estimate of M can be obtained by dividing $\log_e 100$ by the maximum age observed in the population. This method assumes that the maximum age is the age that about 1% of the population reach in an unexploited or lightly exploited population. When appropriate data are available, more rigorous techniques such as catch curve analysis can be used to estimate M.

2. Developed fisheries with historic estimates of biomass

$$MCY = F_{0.1}\,B_{min}$$

or

$$MCY = 0.5\,F_{0.1}\,B_{av}$$

where B_{min} is an estimate of the minimum historic recruited biomass, B_{av} is the average historic recruited biomass, and the fishery is believed to have been fully exploited (i.e. fishing mortality has been near the level that would produce MAY). The formulations assume that $F_{0.1}$ approximates the average productivity of a stock, and that stock biomass can be expected to vary by a factor of two (half or double) from the average.

If it is believed that the biomass estimates are from a depleted stock (such that MCY is not sustainable), and the population is still depleted, then

$$CCY = F_{0.1}\,B_{min}$$

or

$$CCY = 0.5\,F_{0.1}\,B_{av}$$

As in the previous method, an estimate of M can be substituted for $F_{0.1}$ if estimates of $F_{0.1}$ are not available.

3. Developed fisheries with adequate data to fit a surplus production model, or to conduct a stock reduction analysis.

$$MCY = {}^{2}/_{3}\ MSY$$

where MSY is the deterministic equilibrium yield from a surplus production model. This reference point is slightly more conservative than that adopted by several other stock assessment agencies (e.g. ICES, CAFSAC) that use as a reference point the equilibrium yield corresponding to $^{2}/_{3}$ of the fishing effort (fishing mortality) associated with the deterministic equilibrium MSY. But it is in line with simulation results from Mace (1988a) showing that MCY may be as low as 60% of the deterministic MSY.

A preferred alternative is to estimate MCY from a stochastic simulation model using the mean and variance of yields estimated from the surplus production model. This will result in

$$MCY = cMSY$$

where MSY is the deterministic MSY estimated from the surplus production model, and c is a constant < 1. c may be small (e.g. 0.6 – 0.8) if variability is high, or large (e.g. 0.8 – 0.9) if variability is low (Mace 1988a).

If current biomass is less than the biomass corresponding to the deterministic MSY, MCY may not be sustainable. CCY should then be determined from the equation

$$CCY = cCSP$$

where CSP is the current surplus production estimated from a deterministic surplus production model. The value of c should be determined in the same manner as indicated above.

4. Catch and effort data with insufficient contrast to fit a surplus production model because MSY (MCY) has not been exceeded.

$$MCY = Y_{max}$$

where Y_{max} is the largest historic catch. For a fishery that has not produced yields as high as MCY, increasing trends in catch should be accompanied by a trend in CPUE (or other indices of stock size) that is decreasing more slowly (or not decreasing at all) than catch is increasing.

5. Catch data and information about fishing effort (and/or fishing mortality), either qualitative or quantitative, without a surplus production model.

$$MCY = cY_{av}$$

$$\text{or} \qquad CCY = cY_{av}$$

where c is a constant that depends on the level of variability in stock production and Y_{av} is the average catch over an appropriate period.

If the catch data are from a period when the stock was fully exploited (i.e. fishing mortality near the level that would produce MAY), then the method should provide a good estimate of MCY. In this case, Y_{av} = MAY. If the population was under-exploited, the method gives a conservative estimate of MCY. If the population had been depleted, the method gives an estimate of CCY.

Familiarity with stock demographics and the history of the fishery is necessary to determine an appropriate period on which to base estimates of Y_{av}. The period chosen to perform the averaging will depend on the lifespan of the species (a running average over a period equal to at least one half of the exploited lifespan is desirable), the length of the available time series of catch and effort data, and trends in catch and fishing effort. In general, the averaging should be restricted to periods when there has been no consistent change in fishing effort (and/or fishing mortality). In addition, catches should have:

a) varied without trend,
b) stabilised after a period of increasing or decreasing trend, or
c) exhibited an increasing trend.

Suggested ranges for c are based on stochastic simulation results from Mace (1988a) and other studies. c should be small (0.6 – 0.8) if variability has been high (or the species is short–lived) or large (0.8 – 0.9) if variability has been low (or the species is long–lived). If there is reason to believe that a fishery has not been fully exploited it may be reasonable to set c = 1.

6. Catch data with a decreasing trend up to the present with no consistent change in fishing effort (and/or fishing mortality).

$$CCY \leq Y_{low}$$

where Y_{low} is the lowest catch during the period of decreasing trend (usually the most recent year).

7. Post–ITQ estimation of MCY

   (i) TACs always caught (or exceeded), CPUE not declining:

   MCY is at least as great as the TAC.

   (ii) TACs undercaught or CPUE declining:

   Unless there are extraneous reasons for under–catching quotas (e.g. economic factors, mixed species problems), MCY and/or CCY must be less than the TAC.

Note

It has been suggested that the constant, c, that appears in many of the above examples be chosen from the range 0.6 – 0.9 based on longevity and variability in population size or catches. A preferred approach is to develop stochastic models (e.g. stochastic simulation models, see Mace (1988a) for an example) to estimate c more specifically.

Second Approach

1. Estimation of MAY.

   Three alternative methods of estimating MAY are:

   (a) To set it equal to 90–100% of the deterministic MSY. Age–structured simulation models show that MAY is approximately equal to the deterministic MSY (Mace 1988a). However, stochastic production models suggest that it may be somewhat less, by as much as 15% (Sissenwine 1977).

   (b) To calculate it as the product of average recruitment and the yield per recruit produced at an appropriate reference fishing mortality (F_{ref}).

   (c) To equate it with the average yield (Y_{av}) produced over a period when fishing mortality is believed to have been close to F_{ref}.

   Thus, it is not necessary to have estimates of biomass in order to estimate MAY. However, MAY represents the long–term average yield and cannot be used directly to determine annual quotas.

2. Estimation of CAY.

(a) Sufficient data to estimate recent biomass and a reference level of fishing mortality.

   CAY can be estimated from the Baranov catch equation:

$$CAY = \sum_{t=t_r}^{t_{max}} \frac{F_{ref}}{F_{ref} + M} \left(1 - e^{-(F_{ref} + M)}\right) N_t \, W_t$$

where t = age
t_r = age of recruitment
t_{max} = maximum age in the population
F_{ref} = a (constant) reference level of fishing mortality
M = natural mortality
N_t = the estimated number of fish of age t that will be present at the beginning of the next fishing year
W_t = average weight of fish of age t during the next fishing year;

or from the approximation:

$$CAY = F_{ref}\ B_{current}$$

where $B_{current}$ is a projected estimate of the mid–season recruited biomass for the next fishing year. This approximation is reasonable as long as the sum, F_{ref} + M, is less than 0.6 – 0.8.

(b) Status Quo methods

Status quo TACs are TACs which are designed to maintain constant fishing mortality levels. Generally, they are estimated using simple techniques that require only indices of relative biomass, rather than estimates of absolute biomass (e.g. Pope 1983, Shepherd 1984). For example, to maintain a constant fishing mortality the relationship between yield (Y) and catch per unit effort (CPUE) at two points in time, 1 and 2, must be

$$\frac{Y_2}{Y_1} = \frac{CPUE_2}{CPUE_1}$$

Note that it is not necessary to be able to specify the fishing mortality level in order to calculate yields. Numerous status quo methods are currently being developed, particularly by the International Council for the Exploration of the Sea (ICES). These will be considered in the future.

3. Reference fishing mortality rates (F_{ref})

The most common reference fishing mortality will be $F_{0.1}$, as estimated from yield per recruit analysis.[6]

F_{max} is the fishing mortality that produces the maximum yield per recruit. It may be too high as a target fishing mortality because it does not account for recruitment effects, i.e. recruitment declining as stock size is reduced. However, it may be a valid reference point for those fisheries that have histories of sustainable fishing at this level.

F_{msy}, the fishing mortality corresponding to the deterministic MSY, is another appropriate reference fishing mortality. F_{msy} may be estimated from a surplus production model, a stock reduction analysis, or a combination of yield per recruit and stock recruitment models. If F_{msy} can be estimated, it should be used in preference to $F_{0.1}$ or F_{max}.

When economic data are available it may be possible to estimate a reference fishing mortality corresponding to F_{mey} (where MEY is the maximum economic yield) or some other economic optimum. F_{mey} is always less than F_{msy}.

Future developments

1. There is a need to increase the amount and quality of data for assessments. This will improve the quality of MCY estimates, and make CAY estimates possible for more species. A long–term objective is to take progressively more species from the realm of MCY to CAY.

2. Estimating MCY, CCY and CAY is only part of the process of setting and adjusting TACs. There is a need for a more formal framework for optimal decision making, that takes account of economic, social and political factors, and uncertainty.

Further background information on the rationale behind these two approaches and the proposed methods for calculating their associated reference points can be found in Mace (1988a) and other scientific papers listed below.

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