OPERATIONAL GUIDELINES FOR NEW ZEALAND'S HARVEST STRATEGY STANDARD

Revision 1

Ministry of Fisheries
June 2011

Contents

INTRODUCTION

The Operational Guidelines consist of two key parts: (i) Technical Guidelines, which contain guidance on calculations of biological reference points to be used as inputs to setting fishing targets, and the basis for the default limits specified in the Harvest Strategy Standard; and (ii) Implementation Guidelines, which include sections on the transition period for implementing the Harvest Strategy Standard, the roles and responsibilities of science working groups and management working groups in estimating biological reference points and setting management targets, and the implications of implementing the Harvest Strategy Standard. They also include several appendices that provide ancillary information, which will be augmented with an annotated bibliography that gives an overview of the application of various reference points and metrics that have been used to formulate these Guidelines, and/or may be used in their further development.

The Operational Guidelines have been formulated as a companion document to support the implementation of the Harvest Strategy Standard. However, the Guidelines do not have the same status as the Standard and it is intended that they will continually evolve as new data, analyses and insights become available. The Ministry of Fisheries ("the Ministry") is currently developing a process whereby each version of the Operational Guidelines will be evaluated and adopted.

Technical terms are defined in the Glossary (**Appendix I**) and/or the footnotes, both of which provide explanation and elaboration of the statements made in the text.

PART I. TECHNICAL GUIDELINES

Providing for utilisation while ensuring sustainability

Figure 1 illustrates the long-term implications of providing for utilisation while ensuring sustainability (as required in the Purpose statement (section 8) of the Fisheries Act 1996 – "the Act"). Over the long run, utilisation and sustainability act in the same direction for stocks that have been depleted below B_{MSY}. In other words, it is beneficial to maintain stocks near or somewhat above B_{MSY} from both a utilisation and a sustainability perspective. In fact, even from a single-species perspective, maintaining stocks above B_{MSY} can be beneficial. For relatively small sacrifices in yield, average biomass can be maintained relatively far above B_{MSY} (**Appendix II**), resulting in reduced sustainability risks, and higher catch per unit effort and therefore reduced costs of catching fish. The fisheries management problem that most of the world faces is the short-term perspective related to the need to maximise current catches in order to meet immediate financial incentives or obligations.

However, fisheries management is also rapidly evolving towards incorporating ecosystem considerations into harvest strategies. For the most part, this is likely to mean that catch levels should be set more conservatively than those that meet single-species considerations alone.

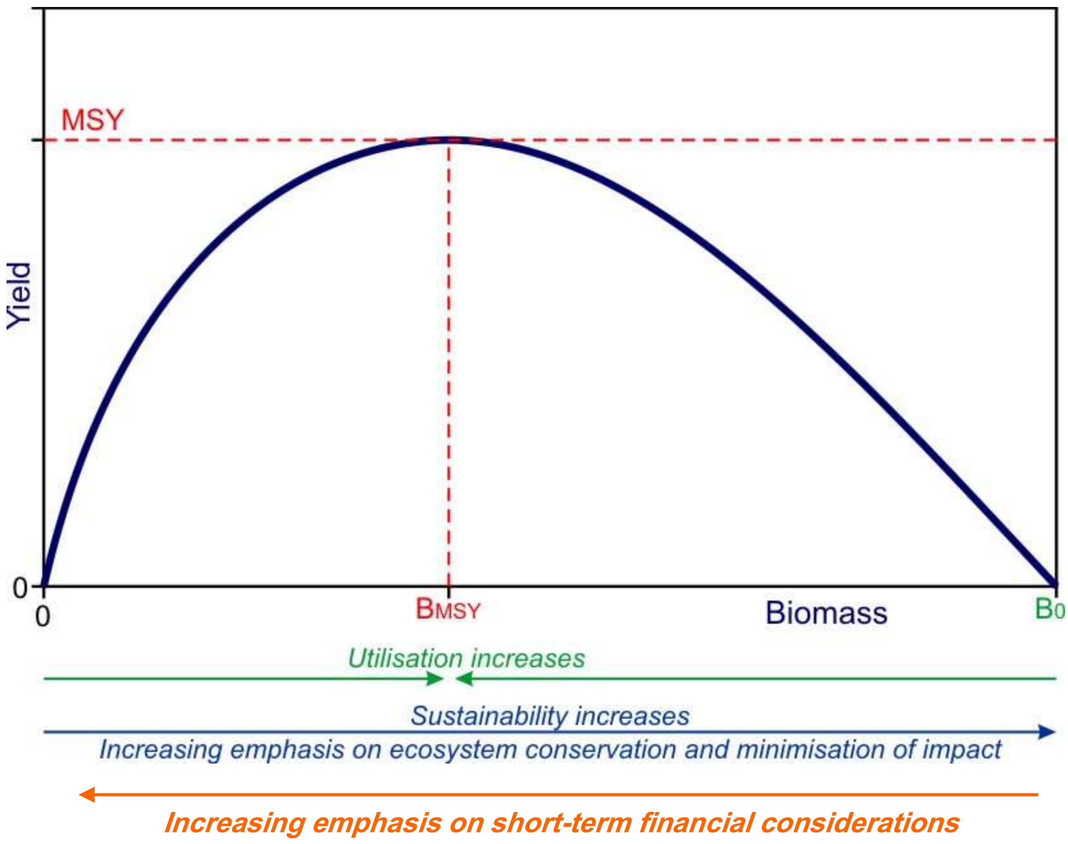


Figure 1. The long-term average (equilibrium) implications of providing for utilisation while ensuring sustainability in an MSY context. Arrows underneath the figure show that utilisation and sustainability considerations act in the same direction when biomass is below B_{MSY}, but in opposite directions when it is above.

Targets

What is a target?

A target is the desired biomass level or fishing mortality rate [1], or a catch, or proxies for each of these. Fish populations fluctuate in size even in the absence of fishing. With any harvest strategy the biomass will continually fluctuate. The average level around which biomass is expected to fluctuate constitutes the target biomass. Fishing mortality may also fluctuate around a target fishing mortality, and catch may fluctuate around an average target catch.

There is no single target level applicable for all species and stocks. The targets chosen for individual stocks will vary depending on the biological characteristics of the stock, the harvest strategy adopted and the type, amount and quality of data available.

The Harvest Strategy Standard specifies that targets should be based on MSY-compatible reference points [2] at the minimum. However, estimates of MSY-compatible points are only one of the inputs into the setting of targets. Other relevant inputs include economic, social,

[1] Throughout this document, the term "fishing mortality" or "fishing mortality rate" can usually be substituted with the term "exploitation rate" or "fishing intensity". The relationship between fishing mortality rates and exploitation rates is outlined in Appendix III.

[2] MSY-compatible reference points include those related to stock biomass (i.e. B_{MSY}), fishing mortality (i.e. F_{MSY}) and catch (i.e. MSY itself), as well as analytical and conceptual proxies for each of these three quantities.

cultural and ecosystem considerations, which will generally result in targets equal to the MSY-compatible reference points, or better.[3] Thus, the MSY-compatible reference points should generally be regarded as a minimum standard for targets. (Part II of this document outlines the responsibilities of science working groups and fisheries managers in estimating MSY-compatible reference points and in the setting of targets.)

Approaches to the section 13 MSY requirement

Every fishery–stock combination is unique in some way. In terms of the Harvest Strategy Standard, the most important differences are the types, amounts and qualities of data available for calculating biological reference points and assessing the status of stocks relative to MSY-compatible reference points [2] or better [3] and related limits. This means that the phrases

> "maintain the stock at or above a level that can produce the maximum sustainable yield" in section 13(2)(a) of the Act, and
>
> "set a total allowable catch … that is not inconsistent with the objective of maintaining the stock at or above, or moving the stock towards or above, a level that can produce the maximum sustainable yield" in section 13(2A) of the Act

need to be applied in different ways for different fisheries depending on the available data. The following four approaches may not be sufficient to cover all fish stocks, and therefore the list may need to be expanded in the future.[4] For simplicity and readability, the term "or better" is not always used in the following sections, but the consequences of moving in the "or better" direction should be readily apparent. [3] The proposed approaches are also applicable for most section 14 stocks.

1. **Literal (or static) interpretation.** The literal interpretation of section 13(2) (excluding section 13(2A)) is based on estimates of B_{MSY} and other MSY-compatible reference points from static, equilibrium models. Such models do not take account of the natural variation in stock size that occurs even in the absence of fishing. If such reference points are to be used to set constant, or rarely-changing, TACs they must be modified to take account of this deficiency. In other words, *a literal or static interpretation is unlikely to result in fisheries fluctuating around targets based on MSY-compatible reference points, or better,* unless it is appropriately modified.

    - **Adjusting the static interpretation to a dynamic world.** If a static, equilibrium model is used as a basis for setting a constant (or rarely changing) TAC based on MSY-compatible reference points, it is essential to set this TAC at some appropriate fraction (< 1) of the equilibrium estimate of MSY. For example, as recommended in the 2010-11 Guide to Biological Reference Points for the 2010-11 Fishery Assessment Meetings (**Appendix**

[3] "Or better" means being above B_{MSY} or its proxies, and/or below F_{MSY} or its proxies, and/or below MSY or its proxies.

[4] Note that the four approaches do not necessarily represent a descending hierarchy in terms of reliability or robustness; to a large extent the degree of reliability or robustness will depend on the quality of the data and the credibility of the stock assessments.

V), the Maximum Constant Yield (MCY) [5] should be set at ⅔ of the MSY derived from a static, equilibrium model (Method 3). Similarly, the estimate of B_{MSY} from a static, equilibrium model should be treated as an average about which a stock fished at (for example) F_{MSY} will fluctuate, rather than a point estimate of biomass that fisheries management should continually strive to achieve. Estimates of F_{MSY} obtained from static, equilibrium models can generally be considered as either constant or average fishing mortalities that will achieve B_{MSY} on average.

2. **Dynamic (real world) interpretation.** Dynamic interpretations explicitly take account of the fact that fish stocks fluctuate naturally. Some harvest strategies track these fluctuations, while others such as properly-defined constant catch strategies account for the existence of fluctuations even though they do not track them. Those that respond to stock fluctuations by altering TACs to track the fluctuations tend to give high long-term sustainable yields with relatively low risk of stock collapse. The most common type of strategy used in this situation is a constant-F_{MSY} strategy or a modified constant-F_{MSY} strategy where, for example, TACs are appropriately modified frequently, but not necessarily annually. Methods that do not track fluctuations in stock size, but do account for the fact that fish stocks fluctuate naturally, include constant catch strategies such as the MCY concept that has been in use in New Zealand for about two decades, and a constant catch strategy that is modified by reducing the TAC when an appropriate performance measure indicates that stock size may have fallen below a specified level (see Francis and Mace 2005). Harvest strategies that combine consideration of both biomass and fishing mortality [1] reference points (e.g. B_{MSY} and F_{MSY} or proxies) are the most powerful, and are likely to lead to the largest long-term sustainable yields. However, this is generally only possible for relatively high information stocks.

3. **Analytical proxies.** Analytical proxies for B_{MSY}, F_{MSY} and MSY are quantitative surrogates that can be used in the absence of adequate information to estimate the MSY reference points themselves. They are often based on theoretical modelling studies or meta-analyses of estimates from high-information stocks or groups of stocks. In cases where individual estimates of MSY reference points are not considered reliable because, for example, they are based on unsupported assumptions about the steepness of stock-recruitment relationships, analytical proxies may actually be more credible than the stock or species-specific estimates. The literature on fisheries science and management is replete with suggested direct proxies for B_{MSY} and F_{MSY} reference points. There are far fewer proxies for MSY itself.

    - Proxies for B_{MSY}: The most common example of a proxy for B_{MSY} is various percentages of B_0, ranging from about 20% to 65%, depending on the productivity of a species or stock. Guidelines for default $\%B_0$ levels are given in the next section.

    - Proxies for F_{MSY}: Numerous proxies for F_{MSY} have been developed in the past 50 or so years. Initially, F_{max} (a reference point from yield per recruit

---

[5] Although the Guide to Biological Reference Points (which was originally compiled in 1988 and has remained essentially unchanged since 1992) states that MCY is a static interpretation of MSY, this is not actually true because all of the methods suggested for calculating MCY do actually take account of the fact that fish stocks fluctuate naturally. MCY is a constant catch strategy, but it is defined so as to take account of natural fluctuations, by using Methods 1-5 in the Guide. A truly static (and incorrect) interpretation would, for example, use the actual estimate of MSY derived from an equilibrium model as a constant catch to apply over a prolonged period of time. This would inevitably result in the stock becoming progressively depleted once biomass fell to a low level, and would likely not be sustainable.

analysis, **Appendix IV**) was considered to be an appropriate proxy for F_{MSY}. Subsequently, empirical and theoretical studies demonstrated that F_{max} is an inappropriately high target in most cases. As a result, Gulland (1971) developed $F_{0.1}$ as an alternative that is more closely aligned to F_{MSY}. $F_{0.1}$ was widely used as a biological target for many years but has gradually been replaced with other alternatives for most, although not all, fisheries. Nowadays, the most widely-used proxies for F_{MSY} are those derived from spawning biomass per recruit analysis, commonly referred to as levels of $F_{\%SPR}$ (**Appendix IV**). These are generally in the range of about $F_{20\%}$ to $F_{70\%}$, depending on the productivity of the species or stock. In cases where it is possible to estimate realised fishing mortalities (e.g. from stock assessment models or catch curve analysis), these can be compared to an appropriate spawning biomass per recruit reference point to determine stock status. Guidelines for default $F_{\%SPR}$ levels are given in the next section.

- Proxies for MSY: The main ones are those based on maximum constant yield (MCY), which has been in use in New Zealand for about 20 years (**Appendix V**).

4. **Conceptual proxies.** Conceptual proxies for B_{MSY}, F_{MSY} and MSY are qualitative surrogates that can be used in the absence of adequate information to directly estimate these reference points themselves. The conceptual interpretation embraces the spirit and intent of section 13 of the Act. It can be used in cases where there is insufficient information to estimate B_{MSY}, F_{MSY} or MSY explicitly, or where such estimates may be unreliable because, for example, there is little or nothing known about the stock-recruitment relationship.

   - Conceptual B_{MSY}: In cases where the relationship between CPUE and abundance can be assumed to be more or less proportional, or where some other form of relationship has been derived from data, it may be reasonable to select an appropriate historical period when both CPUE and catches were relatively high and to use this CPUE level as a target. The best example in current use in New Zealand is that for rock lobster. Note, however, that "high CPUE" must be treated with caution in cases where it is known or expected that high CPUE can be maintained even for seriously depleted stocks, or where fishing behaviour or gear efficiency has substantially changed over time.

   - Conceptual F_{MSY}: In cases where an estimate of relative biomass exists (e.g. from trawl or trap surveys or models incorporating these), it may be possible to define a catch/relative biomass ratio that reflects an appropriate historical period when both catches and biomass were high, and to use this catch/relative biomass ratio as a fishing mortality target.[6] This method is also referred to as a relative fishing mortality method (NOAA 2002).

   - Conceptual MSY: In cases where the only useable information is the catch history and quantitative or qualitative information on fishing effort or fishing mortality, Method 4 from the 2007-08 Guide to Biological Reference Points should be applied (**Appendix V**). Method 4 sets MCY to be $c*Y_{av}$, where c is a natural variability factor and Y_{av} is the average catch over an appropriate period. The natural variability factor ranges between 0.6 and 1, and is inversely related to the natural mortality rate, M (**Appendix V**). It is

[6] Fishing mortality is the ratio of the annual catch to the *average* or *mid-fishing season* biomass present during the fishing year.

generally not permissible to set MCY to be, for example, the average of a series of landings unless there are valid reasons to believe that this series of landings was well below maximum sustainable levels. Further, the period chosen for calculating the average should generally not include intervals where it is evident that catches were constrained by a catch limit (which will not always be true even if a catch limit was in force).

Default $\%B_0$ and $F_{\%SPR}$ reference points

Stock Productivity

It is generally accepted that fish stocks with low productivity (i.e. those with high age of maturity, high longevity, slow growth rates or low fecundity) tend to be less resilient to fishing. In fact, rather than productivity, the demographic variable of greatest relevance to the risk of stock collapse is population resilience, which can be defined as the "ability [of a stock or population] to rebound after perturbation" (Holling 1973). The problem with the concept of resilience is that it is not an operational concept. There is no reliable way of measuring the ability to rebound, except empirically. Due to the lack of operationality of the concept of resilience, population productivity is often used as a measurable proxy for resilience.

More productive species tend to have rapid growth rates, high fecundity and high turnover of generations. Species with high natural mortality must generally be more productive because they must produce higher numbers of offspring to compensate. The question is, "Is species or population productivity positively correlated with resilience?" On average, species with rapid growth, high fecundity, and high turnover of generations will have greater ability to rebound from low numbers because they can quickly take advantage of conditions suitable for re-establishment or re-colonisation. But such species also tend to have higher variability and, therefore, greater risk that population numbers may fluctuate to dangerously low levels, even in the absence of continued exploitation.

In addition, species with high turnover of generations tend to have relatively few mature age classes, which means that recruitment failure is more critical. Conversely, for the same reduction in the percentage of the unexploited level, a long-lived species will have a more seriously truncated age distribution than will a short-lived species and, if egg viability, larval survival and related factors increase with maternal age or size, the ability of such species to rebound or to sustain further exploitation may be seriously compromised. There are also several examples of long-lived marine species with very high recruitment variability (e.g. sporadic exceptionally large year classes with most other year classes being well below the level required for population replacement; Atlantic redfish, Pacific bocaccio and Atlantic ocean quahog are examples).

These considerations must be borne in mind when adopting the hypothesis (assumption) that population productivity is an operational proxy for population resilience. Musick (1999) also made this assumption. In his view, the intrinsic rate of natural increase (r) is the real key to resilience because it incorporates all of the other components of productivity. He further noted that late-maturing, long-lived animals have low intrinsic rates of increase and, therefore, very low resilience to extraordinary mortality.

Another widely-used indicator of the risk of extinction in fisheries is the fishing mortality corresponding to the slope at the origin of a stock-recruitment relationship (i.e. the extinction threshold, called F_τ by Mace 1994 and F_{crash} by ICES 1997). Using a simple age-structure population dynamics model, Mace (1994) showed that F_τ increased with increasing natural mortality and with individual growth rates, both of which are positively related to productivity. F_{MSY} (the fishing mortality rate that results in maximum sustainable yield, MSY) also increased with increasing natural mortality and growth rates. Punt (2000) also showed that both F_τ and F_{MSY} increased with increasing population productivity. In Mace's (1994) studies, F_{MSY} was usually well below F_τ, ranging from about 16% F_τ to 43% F_τ over all tested parameter combinations for Beverton-Holt stock-recruitment relationships, and 38% F_τ to 48% F_τ for Ricker stock-recruitment relationships. Both Mace (1994) and Punt (2000) found that the ratio F_{MSY} / F_τ is a decreasing function of stock productivity (i.e. as productivity increases, F_{MSY} and F_τ become relatively closer together).

Mace (1994) also found that the ratio of B_{MSY} (the average biomass associated with MSY) to B_0 (the unexploited biomass) declined, but only very slightly, over the range of natural mortalities and growth rates considered (M=0.1-0.3 and K=0.1-0.3, respectively). More importantly, F_τ and F_{MSY} both increased substantially with increasing slope at the origin of the stock-recruitment relationship, while $\%B_{MSY}/B_0$ exhibited a pronounced negative relationship with the slope at the origin. This implies that stocks with higher productivity, as indexed by either high natural mortality, high growth rates, or high slope at the origin of a stock-recruitment relationship, can sustain higher harvest rates at lower relative biomass, and that the harvest rate corresponding to stock collapse also increases with productivity.

In the current version of these Guidelines, productivity is considered to be an operational substitute for resilience. (This assumption may be revisited in the future). Two sets of guidelines for categorising species in terms of low, medium and high productivity levels are presented in **Table 1** (from FAO 2001). The unbracketed categorisations were derived by an FAO expert working group and endorsed in a wider FAO technical consultation. For comparison, FAO (2001) also included (bracketed) characterisations from Musick (1999), which were also derived by a large working group of scientists with experience covering a wide diversity of species. The main areas of difference are in the ranges given for the average age of maturity (t_{mat}) and the expected maximum age in the absence of fishing (t_{max}). The FAO working group felt that the age ranges provided by Musick (1999) were generally far lower than those that would be associated with the other life history characteristics; in particular, there are relatively few commercially-exploited aquatic species that have maximum ages of 10 or fewer years, and those with a maximum age of, say, 10-15 years would not generally be classified as "low productivity".

Table 1. Guidelines for categorising productivity levels for exploited fish species. Numbers outside brackets are from FAO (2001); numbers in brackets are from Musick (1999). M is natural mortality; r is the intrinsic rate of natural increase; K is the Brody growth coefficient; t_{mat} is the average age of maturity; t_{max} is the expected maximum age in the absence of fishing, approximated by the formula corresponding to the age at which a cohort drops to 1% of its original number; and G is the average generation time approximated by the formula given. **From** FAO (2001).

Parameter	**Productivity**		
	Low	**Medium**	**High**
M	< 0.2	0.2–0.5	> 0.5
r	< 0.14 (< 0.16)	0.14–0.35 (0.16–0.5)	> 0.35 (> 0.5)
K	< 0.15 (< 0.16)	0.15–0.33 (0.16–0.3)	> 0.33 (> 0.3)
t_{mat} (years)	> 8 (> 4)	3.3–8 (2–4)	< 3.3 (< 1)
t_{max} (years) (t_{max}=4.6/M)	> 25 (> 10)	14–25 (4–10)	< 14 (1–3)
G (years) (G=t_{mat}+1/M)	> 10	5–10	< 5
Examples	orange roughy, many sharks	cod, hake	sardine, anchovy

Both categorisations are based on global considerations of a wide range of commercially-exploited species, including many species with much higher productivity levels than those that are typical for most New Zealand species. In fact, few New Zealand species would fall in the global high productivity category. Four examples that probably do are anchovy, pilchard, red cod and squid. At the other end of the spectrum, there are several low productivity New Zealand examples with life history characteristics that are far away from the bounds given in **Table 1** for low productivity stocks (e.g. orange roughy and oreos). For such stocks (e.g. stocks with $M < 0.1$ and/or $t_{mat} > 15$), an additional "very low productivity" category needs to be created. Note that some species may fall into different categories depending on which life history parameter is considered. When this happens it will be necessary to exercise scientific judgement to determine the most appropriate category overall.

Guidelines for default $\%B_0$ and $F_{\%SPR}$ reference points

Based on a review of the fisheries science and management literature, **Table 2** provides default proxies for B_{MSY} (expressed as $\%B_0$) and F_{MSY} (expressed as $F_{\%SPR}$ levels from spawning biomass per recruit analysis, **Appendix IV**) for four suggested productivity categories. A literature review supporting these ranges is presented in **Appendix VI**. It should be noted that x% B_0 and $F_{x\%}$ (e.g. 40% B_0 and $F_{40\%}$) are not directly comparable, except in situations where recruitment is independent of spawning stock size over the entire range of stock sizes. In other words, the relationship between the two depends on the stock-recruitment relationship. Usually the divergence between x% B_0 and $F_{x\%SPR}$ increases as stock productivity decreases (Mace 1994, Appendix B of that paper).

Table 2. Recommended default proxies for B_{MSY} (expressed as $\%B_0$) and F_{MSY} (expressed as $F_{\%SPR}$ levels from spawning biomass per recruit analysis).

Productivity level	**$\%B_0$**	**$F_{\%SPR}$**
High productivity	25%	$F_{30\%}$
Medium productivity	35% [7]	$F_{40\%}$ [8]
Low productivity	40%	$F_{45\%}$
Very low productivity	≥ 45% [9]	≤ $F_{50\%}$ [10]

It is becoming increasingly difficult to justify MSY-compatible targets less than 30-40% B_0.

Table 2 is subject to review, and it is anticipated that it will be modified continually as new analyses become available.

Managing at the target level

Fish populations fluctuate in size even in the absence of fishing. Even if an MSY-compatible harvest strategy were to be implemented exactly, biomass would continually fluctuate. B_{MSY} is the average level around which the biomass is expected to fluctuate when a stock is fished

[7] The most commonly recommended and used single species $\%B_0$ target reference point is 40% B_0.
[8] The most commonly recommended and used single species $F_{\%SPR}$ target reference point is $F_{40\%}$.
[9] A target of 60% B_0 is currently used for Cascade Plateau orange roughy in Australia; this is the only Australian orange roughy fishery that is currently open for target fishing.
[10] Maximum yield for U.S. west coast rockfish has been estimated to be as low as $F_{70\%}$ for the least resilience of these species (Dorn 2002). The default proxy for west coast rockfish as a whole is $F_{50\%}$.

at F_{MSY} or on the basis of some other MSY-compatible harvest strategy. One issue is to ascertain the acceptable level of fluctuation.

Harvest strategies should generally constrain fishing so as to maintain stocks near or above B_{MSY}, well within the range of natural fluctuations for a stock managed on the basis of MSY-compatible reference points. A candidate harvest strategy might be that the fishing mortality rate must average F_{MSY} or an appropriate proxy over a defined period of time. The harvest strategy could adopt a retrospective 3-5 year running average. The purpose of using a running average is to avoid overreacting to individual stock assessment estimates by changing TACs every time a stock assessment is conducted. The running average would be calculated on a retrospective basis each time an assessment is conducted to determine whether or not the TAC needs to be adjusted. Where the estimate of F_{MSY} itself changes as a result of an updated assessment, then a TAC change may be required.

The purpose of such a harvest strategy is to reduce the risk of overfishing. A fishing mortality rate greater than F_{MSY} will constitute overfishing. Overfishing can occur at any biomass level and will ultimately lead to a stock declining below B_{MSY} or its proxies.

A harvest strategy based on F_{MSY} or lower should generally be preferred over stipulating an acceptable range of fluctuations. Significant debate could arise as to what constitutes an acceptable level of fluctuation. More importantly, the available information is rarely sufficiently accurate or precise to be able to manage on this basis. A range of plus or minus 10% is well within the margin of error.

For information-limited or information-deficient stocks, a retrospective 3-5 year running average may also be appropriate. For a CPUE proxy, over the 3-5 year period the average CPUE should not fall below the target CPUE level. Similarly, over the preceding 3-5 years, the average reported landings should not exceed the target catch level. This will provide some degree of flexibility for information-limited and information-deficient stocks. A one-off fluctuation should not necessarily result in a change to the TAC. The TAC should be reviewed in the event that the retrospective 3-5 year average is exceeded. Assessment of the available information may indicate that a TAC increase is warranted, although caution may be required so as not to create an incentive to obtain a higher catch level by consistently overcatching the existing TAC. Similarly, some caution is required where the TAC is consistently undercaught. Undercatch of the TAC may not necessarily reflect a decline in abundance.

Limits

<u>What is a limit?</u>

A limit represents a point at which further reductions in stock size (or proxies) are likely to ultimately lead to an unacceptably high risk of stock collapse and/or a point at which current and future utility values are diminished or compromised. Limits (both “soft” and “hard”) should be set well above extinction thresholds – rather, they should act as upper bounds on the zone where depensation[11] may occur, and associated management actions should prevent stocks from falling into such zones.

There are many documented cases where fish populations have recovered from very low biomass levels. However, it is not something that should be repeated on a regular basis, as the circumstances that have led to recovery of stocks are often unclear and, even for highly

[11] Depensation is a situation where depleted populations may start to decline at an accelerated rate due to factors such as an inability to find mates, impaired breeding success, competition and predation. In the ecological literature, these effects are commonly called Allee effects.

productive species (e.g. sardines and herring), recovery has taken as long as 30-40 years, thereby foregoing substantial utilisation opportunities. In some cases, the closure of fisheries or a significant reduction in catch levels has not resulted in the recovery of stocks (e.g. Grand Banks cod, although it is debatable as to whether the actual reduction in fishing mortality rates has been sufficient to enable rebuilding in this case, and in the case of other northwest Atlantic cod stocks). There is also a potential for climate regime changes to occur, or for new species to colonise the area, or for predator/prey relationships to change to such an extent that stocks are unlikely to recover to previous biomass levels. Hence, limits should be set at levels from which the stock is likely to recover in reasonable time.

In the event that a stock falls below a biomass limit, a substantive management response is required. The Harvest Strategy Standard incorporates two types of limits, each triggering a different form of management response:

Soft limit – if this is breached, a formal, time-constrained, rebuilding plan is to be implemented.

Hard limit – if this is breached, fisheries will be considered for closure until the stock has rebuilt at least to at least the level of the soft limit with an acceptable probability (70%).

For both limits, the ultimate goal is to ensure full rebuilding of the stock to the biomass target with an acceptable probability (70%). The reason for requiring a probability level greater than 50% is that a stock that has been severely depleted is likely to have a distorted age structure (an over-reliance on juvenile fish, with relatively few large, highly fecund fish). In such instances it is necessary to rebuild both the biomass and the age composition.

The closure of a fishery should be an act of last resort. However, the risk to sustainability when biomass (or a proxy) is below the level of the hard limit means that the risk to the stock may outweigh any short-term benefits of utilisation. Precedents already exist whereby fisheries have been closed in New Zealand.

The use of “soft” limits that trigger the need for a formal, time-constrained rebuilding plan is common in the United States (**Appendix VI**). In particular, the use of ½ B_{MSY} as a limit that triggers the need for a formal, time-constrained rebuilding plan has been adopted in the United States for up to a decade based on advice from Restrepo *et al* (1998), and has subsequently been embraced by an increasing number of other national and international organisations.

The use of “hard” limits that explicitly trigger the need for fisheries closures is far less prevalent. Four examples of such a requirement are:

(i) the U.S. Pacific Fisheries Management Council (PFMC) routinely uses a “40:10 default harvest rule”, whereby stocks are fished at a constant fishing mortality rate provided they are above 40% B_0 and are closed once they are below 10% B_0 (with fishing mortality decreasing linearly between these levels);

(ii) the U.S. North Pacific Fisheries Management Council (NPFMC) specifies a hard limit of 5% B_0 for all stocks under its jurisdiction;

(iii) the U.S. NPFMC has recently implemented a hard limit of 20% B_0 for Gulf of Alaska walleye pollock; and

(iv) Australia has recently implemented a limit biomass (B_{LIM}) of ½ B_{MSY} (with a default equivalent of 20% B_0) for Commonwealth fisheries. The Commonwealth Fisheries Harvest Strategy Policy was signed off by the Australian Minister for Fisheries and Conservation on 11 September 2007 and it was intended that it would be implemented for all key stocks by 1 January 2008, with target fisheries on stocks identified to be below B_{LIM} to be closed by 1 January 2009 (although the policy and the associated guidelines are somewhat ambiguous about actual closures).

Mixed species fisheries

In a mixed species fishery, the closure of any one stock to fishing could have significant economic implications for fishers targeting other stocks in the fishery. It could either preclude fishing for other healthy stocks or it could result in significant additional economic costs for commercial fishers due to the requirement to pay deemed values. Under this situation, there should be incentives for fishers to take action well in advance of any component of a species assemblage breaching a limit reference point. Setting targets for mixed species above B_{MSY} and well below F_{MSY} (**Appendix II**) would provide an additional buffer that minimises the risk of any one species falling below its biomass limit.

Rebuilding plans

What are rebuilding plans?

If a stock is below B_{MSY}, or is not in conformance with other MSY-compatible reference points, the Act requires that management action should be taken to move it back to or above B_{MSY}. Approaches to rebuilding stocks need to take account of the characteristics of the individual species/stock in determining the way and the rate at which a stock is to be rebuilt. A rebuilding plan consists of the rebuild target, the expected timeframe for rebuilding and a minimum acceptable probability of achieving the rebuild, together with a set of management actions that will achieve the desired rebuild.

The current practice is that a stock assessment must indicate that there is at least a 50% probability that the stock will simply increase in size (potentially by as little as one kilogram) over a specified period of time, usually 3-5 years. This does not represent a “rebuilding plan” in the sense of the usual meaning of the term. In response to this situation, the Harvest Strategy Standard specifies the need for a formal, time-constrained rebuilding plan.

Different management actions will apply depending upon the status of the stock relative to the target and soft limit. When stock size is below the target but above the soft limit, management action needs to be continually applied to ensure that fisheries fluctuate around target levels, particularly when they start to fall below those targets. Management actions need to ensure that stocks do not decline further. When the stock is at or below the soft limit, a formal time-constrained, rebuilding plan with reduced catches needs to be implemented.

Timeframes for rebuilding

The setting of timeframes for rebuilding stocks needs to take into account the interdependence of stocks, the biological characteristics of the stock, any environmental conditions affecting the stock and the economic, social and cultural factors relevant to fisheries on the stock in question. Another relevant issue is the comprehensiveness and reliability of the available information on these factors and on stock status.

The Act requires that relevant economic, social and cultural factors be taken into account in deciding upon the way and rate at which a stock is rebuilt to the target level. In the case of stocks with significant allocations to more than one sector (greater than about 20% of the TAC), there may be considerable disagreement about timeframes for rebuilding. Where a stock is virtually exclusively allocated to one sector, the timeframe selected may be more reflective of the interests of that particular sector.

The Harvest Strategy Standard specifies that where the probability that a stock is at or below the soft limit is greater than 50%, the stock should be rebuilt to the target within a time period between T_{min} and $2*T_{min}$ (where T_{min} is the theoretical number of years required to rebuild a stock to the target with zero fishing mortality).

Mathematical projection models will generally need to be developed to estimate T_{min} and to compare and contrast alternative rebuilding strategies. These will usually be probabilistic models that incorporate uncertainty in the projections. The minimum standard for a rebuilding plan is that 70% of the projected trajectories will result in the achievement of a target based on MSY-compatible reference points or better within the timeframe of T_{min} to $2*T_{min}$. This equates to a probability of 70% that the stock will be above the target level at the end of the timeframe. A stock will not be declared to be rebuilt, and therefore absolved from further rebuilding, until it can be determined that there is at least a 70% probability that the target has been achieved. This means that if the initial rebuilding plan is underachieved/overachieved, it may need to be revised prior to the termination of the timeframe initially set. This may result in a more restrictive, or more lenient, rebuilding plan as time progresses.

T_{min} reflects the extent to which a stock has fallen below the target, the biological characteristics of the stock that limit the rate of rebuild, and the prevailing environmental conditions that also limit the rate of rebuilding. Allowing a rebuilding period up to twice T_{min} allows for some element of socio-economic considerations when complete closure of a fishery could create undue hardships for various fishing sectors and/or when the stock is an unavoidable bycatch of another fishery. The probability of rebuild should be increased where the information is highly uncertain or where multiple sectors have significant interests in the fishery.

Fishing intensity and overfishing reference points

The Harvest Strategy Standard states that (paragraph 28, page 11):

- If the MSY-compatible fishing mortality rate, F_{MSY}, or an appropriate proxy is exceeded on average, [12] ***overfishing*** will be deemed to have been occurring, because stocks fished at rates exceeding F_{MSY} will ultimately be depleted below B_{MSY}.

In this section, the terms "fishing mortality rate" is broadened to "fishing intensity". This was agreed by the Stock Assessment Methods Working Group in order to take account of related metrics that can be used to determine whether or not overfishing has been or is occurring. In line with the broadening of terminology, the terms, F_{targ} or I_{targ} are used to denote the overfishing reference point. In general, estimates of F_{targ} or I_{targ} should relate to fishing intensity levels that correspond to B_{MSY} or proxies thereof.

Calculation of fishing intensity and associated reference points

Fishing intensity and fishing pattern

In a single-fishery model, annual exploitation rates (or fishing mortality rates) can be compared with each other and with a reference rate (e.g., F_{MSY}) to determine when the fishing mortality rate was at its highest level or when it was above or below a reference rate. In a multiple-fishery model, such comparisons cannot easily be made. In this case, each fishery, in each year, has its own exploitation rate (catch divided by selected biomass) but as there is no single selected biomass, there is no obvious method to calculate a single annual exploitation rate which accounts for removals from all fisheries. However, methods have been developed

[12] A 3-5 year running average of the estimated fishing mortality rate or proxy will be deemed to be appropriate for evaluating whether or not "overfishing" has been occurring.

to calculate measures of overall annual "fishing intensity", which can be compared to a reference level in the same metric.

The term "fishing intensity" has its natural meaning – in general terms, higher values correspond to greater fishing effort and a higher fishing mortality rate, lower values to less effort and a lower fishing mortality rate. In a multiple-fishery model, for a given year and a given fishing pattern, the "fishing intensity" in that year is a single number which measures the overall annual fishing mortality rate due to all of the fisheries in the model. There are many valid ways to map the fishing mortality rates of multiple fisheries to a single-dimensional measure of overall annual fishing intensity. Four recommended methods or metrics are presented in this section: two "direct" metrics, which are analogues of instantaneous fishing mortality (F) and exploitation rate (U), and two "indirect" metrics, which measure the theoretical long-term effect of the given fishing intensity on the stock. When the fishing intensity metric is not specified, the generic symbol of "I" is used to refer to fishing intensity.

For a given stock assessment model and parameter vector (e.g., the point estimate from a stock assessment), the "fishing pattern" in each year, is fully defined. The model and point estimate provide the fishing selectivities, the annual timing and duration of the fisheries, and the pattern of exploitation across the fisheries. The direct metrics of fishing intensity can be calculated using the output of the model for the given fishing year (*see* the equivalent-annual measures below). Also, the indirect measures can be calculated by applying the same fishing intensity and fishing pattern indefinitely as the model is run to equilibrium (*see* ESD and SPR below).

However, for multiple-fishery models, the calculation of some fishing-intensity reference points requires an additional element. A set of constraints is needed to specify how the fishing pattern is preserved at different levels of fishing intensity (e.g., how to fish at half or double the existing fishing intensity for a given fishing pattern). This is an essential element for reference points which optimize some quantity as a function of fishing intensity for a given fishing pattern (e.g., F_{MSY}).

For example, in a two-fishery model using the Baranov catch equation, a "natural" constraint, to preserve a given fishing pattern, is to hold the relative proportion of the Fs constant across fisheries (i.e., fishing in the same way forever is achieved by applying the given Fs; an increase or decrease in fishing intensity is achieved by scaling the Fs up or down with the same scalar). Other constraints are possible (e.g., the relative proportions of the exploitation rates held constant).

Defining overfishing reference points

The concept of a target or overfishing reference point, I_{targ}, is applicable to models based on single fisheries and models based on multiple fisheries. In a single-fishery model using the Baranov catch equation (for example), overfishing occurs in a particular year y if $F_y > F_{targ}$. In a multiple-fishery model, the concept of a single fishing mortality rate, with a given selectivity, is generalised to an overall level of fishing intensity (due to all of the fisheries in the model) and a fishing pattern. For a given fishing pattern, overfishing occurs in a particular year when the fishing intensity exceeds a specified target level.

Given a multiple-fishery stock assessment model, a given population vector (e.g., the point estimate), and definitions of fishing pattern and a fishing intensity metric, it is straightforward to calculate fishing-intensity analogues of standard equilibrium reference points (e.g., I_{MSY}, $I_{40\%}$). The reference points are found in the usual way by constructing a yield curve, or Spawning biomass Per Recruit or Spawning Potential Ratio (SPR) curve, over a range of fishing intensities using the given fishing pattern and constraints (which specify how to fish indefinitely at a given fishing intensity and how to scale fishing intensity up or down).

An overfishing reference point when B_{target} is already defined

In the case where biomass reference points have already been defined, it is recommended that they be used to define corresponding fishing-intensity reference points. For example, if the target biomass is B_{target}, then the overfishing reference point should be taken as the fishing intensity corresponding to an equilibrium biomass of B_{target} (i.e., for the given fishing pattern and population vector, the fishing intensity which, if applied each year, forever, with deterministic recruitment, would cause the model biomass to reach an equilibrium of B_{target}). Similarly, if a biomass target-range is defined, a corresponding range of fishing intensities can be derived (i.e., an I_{low} corresponding to B_{low} and an I_{high} corresponding to B_{high}).

Graphical presentation of historical and current stock status

The recommended template for the "Stock status" sections of FAWG reports requires a graphical presentation that summarises current and historical stock status. For model-based stock assessments, the recommended graphic is a two-dimensional trajectory of spawning stock biomass and fishing intensity (e.g., **Figure 2**). In some cases, separate single-dimensional trajectories of biomass and fishing intensity over time may be preferred. When models have multiple fisheries, fishing intensity should be plotted using one of the four metrics defined in this document. In single-fishery models, the existing U or F from the model should be used (i.e., there is no need to calculate alternative measures of fishing intensity).

Many model-based assessments provide distributional estimates of population parameters and biomass and fishing-intensity trajectories (e.g., Bayesian posterior distributions; bootstrap distributions). Having a distribution available provides a number of different ways to produce two-dimensional and single-dimensional trajectories. However, it also raises some interesting questions about how to compare estimated fishing intensity and biomass with associated target levels. The issue is that target levels will change across the distribution of population parameter estimates and fishing patterns (e.g., F_{MSY} depends on the estimated fishing selectivity – and each population vector potentially has a different fishing selectivity).

For a two-dimensional trajectory (biomass and fishing intensity) the most complete approach is to use each vector in the population-parameter estimates, to calculate, for each year, target levels of biomass and fishing intensity and hence the ratios "I/I_{targ}" and "B/B_{targ}". The medians can then be plotted for each year in the two-dimensional trajectory with horizontal and vertical reference lines at 1. In the final year, it may be desirable to plot the full distributions (at some credibility or confidence level).

The above approach may not be feasible or necessary for some assessments. The primary focus of the graphic is the status in the current year, with the full historical period being a secondary consideration. Therefore, changes in target levels over time are of lesser importance, and targets may only need to be calculated for the current fishing pattern (unless, perhaps, there has been a marked change in fishing pattern over time). A check still needs to be made on how the current targets change across the estimated parameter vectors;- this could necessitate the use of ratios on one or both axes.

In the case of a Bayesian assessment, it may be adequate to calculate annual fishing intensity only for the MPD estimate, and the fishing-intensity target only for the most recent year. However, this would not be recommended unless the MPD estimate is close to the medians of the posterior distributions in terms of biomass and fishing selectivities.

Metrics for fishing intensity

Four alternative metrics are defined for fishing intensity. The first two metrics are measures of "average" exploitation rate (equivalent annual *U*) and "average" instantaneous fishing mortality (equivalent annual *F*). They are "direct" metrics in that they measure "what was happening at the time". However, they require reference levels to be calculated to allow valid interpretation (e.g., it is not possible to tell, without a reference level, whether an equivalent annual *U* of 0.6 is "too high"; it depends on population parameters such as natural mortality and fishing selectivity patterns). The two "indirect" metrics, Equilibrium Stock Depletion (ESD) and SPR, measure fishing intensity in terms of the theoretical long-term effect on the stock (i.e., what happens when "fishing forever" under the given fishing pattern and intensity).

All calculations are done within the model, for a given parameter vector, or use model outputs.

Equivalent annual U

This definition is concerned with tracking the fate of beginning-of-year cohorts within a stock: what proportion of each cohort dies due to fishing?

For each beginning-of-year cohort in a stock (where cohorts are defined by age at the beginning of the year, or age and sex, or length, etc), let:

N_j = the number of fish in the *j*th cohort
C_j = the number of fish from the *j*th cohort that die due to fishing during the year

Note, only three things can happen to the fish that are in any cohort at the beginning of the year, either they die due to fishing, or they die from natural mortality, or they survive.

Let,

$$U_j = \frac{C_j}{N_j}$$

Also, define the equivalent annual *U*:

$$U_{equiv} = \max\left\{U_j : j \in J\right\}$$

and the cohort selectivities as:

$$r_j = \frac{U_j}{U_{equiv}}$$

An interesting result follows from the definition that gives another interpretation of U_{equiv}. The total fishing related deaths in numbers is:

$$C = \sum_j C_j = \sum_j U_j N_j$$

so,

$$C = U_{equiv} \sum_j r_j N_j$$

and

$$U_{equiv} = \frac{C}{\sum_j r_j N_j}$$

Hence, U_{equiv} is the total fishing-death-numbers over selected-numbers.

Note, if new cohorts are created during the year, and they suffer fishing mortality during the year, the above definition is still applicable. Simply create a beginning-of-year cohort which contains the new births and apply zero fishing and natural mortality to them until they are recruited into the vulnerable population.

Equivalent annual F

This approach uses the Baranov equation to ask the question: what *F* would cause the observed reduction in "cell" numbers?

The concept of a "cell" is needed for equivalent annual *F* calculations. A "cell" is a container, within a model, for a group of fish which share common characteristics (e.g., age, sex, stock, length, area, etc) or combinations of characteristics (e.g., a cell could contain the female fish of age 1 in the western stock). The fish within a cell at any point in the model's annual cycle may have come from many beginning-of-year cohorts. Equivalent-annual-*U* calculations track the fishing mortality of beginning-of-year cohorts as they move through cells during the year. Equivalent-annual-*F* calculations accumulate the apparent instantaneous fishing mortality that is applied to cells during the year.

In the case of a single-area model, which uses the Baranov catch equation, the equivalent annual *F* can be calculated directly from the individual *F*s on each cell. However, for multi-area models, even if using the Baranov catch equation, calculations using begin and end of cell numbers are required.

Within a multi-fishery model, during any fishing year, numbers within each cell are modified due to various events: mortality (natural and fishing), recruitment (to the youngest-age/smaller-length classes), ageing/growth, migration (between areas), maturity, etc. In order to obtain an "equivalent annual *F*" it is necessary to consider the change in numbers within cells during mortality events, and to explicitly exclude the changes which occur due to other events.

Consider a single cell containing fish for an individual stock. Consider a single time interval over which a mortality event occurs and let,

N^{begin}	=	number of fish in the cell at the beginning of the interval
N^{end}	=	number of fish in the cell at the end of the interval
M	=	natural mortality applicable to the cell

The instantaneous fishing mortality that would cause the reduction in numbers during the interval is *F*:

$$N^{end} = N^{begin} e^{-(M+F)t}$$

where *t* is the duration of the interval (as a proportion of the year).

The fishing year (in the model) is split into one or more time intervals that incorporate all mortality events; the intervals would, potentially, be separated by ageing or growth events (ageing for age models, growth for length models), and recruitment events. These are nonmortality events that change the number of fish in a cell and so must be excluded from equivalent F calculations. There is an F for each interval and the total F (for the whole fishing year) applicable to a cell is the time-weighted sum of the individual Fs. This can be calculated from the product of the ratios of ending and beginning numbers.

Let i index the time intervals to generalise the above notation (still considering a single cell containing fish from an individual stock). Then,

$$N_i^{end} = N_i^{begin} e^{-(M+F_i)t_i}$$

and

$$\prod_i \frac{N_i^{end}}{N_i^{begin}} = \prod_i e^{-(M+F_i)t_i} = e^{-\left(M+\sum_i F_i t_i\right)}$$

since the t_i sum to 1.

Now consider all of the cells in a convenient aggregated form of the model (e.g., fish classified by age only rather than age, maturity, and area) and further generalise the notation. Let $j \in J$ index the cells (in the aggregate model, for a given single stock) and let,

$$F_j = \sum_i F_{ji} t_i$$

Then,

$$e^{-\left(M_j+F_j\right)} = \prod_i \frac{N_{ji}^{end}}{N_{ji}^{begin}}$$

and

$$F_j = \sum_i \log\left[\frac{N_{ji}^{begin}}{N_{ji}^{end}}\right] - M_j$$

The "equivalent annual F", F_{equiv}, is the maximum F_j and the associated selectivity is the vector/matrix of F_js divided by the equivalent annual F:

$$F_{equiv} = \max\left\{F_j : j \in J\right\}$$

and the cell selectivities are:

$$s_j = \frac{F_j}{F_{equiv}}$$

Equilibrium Stock Depletion (ESD)

Fishing intensity can be measured by its theoretical long-term effect on the model fish-stock. In this approach each fishing intensity is simply labeled with its associated equilibrium spawning stock biomass.

Under any given fishing pattern, the fishing intensity which, under *deterministic* recruitment, will result in an equilibrium spawning stock biomass of $x\%B_0$ is denoted as $F_{x\%B0}$ (i.e., the ESD of the fishing intensity is $x\%B_0$).

Note, “deterministic recruitment” is the recruitment that comes from the stock-recruitment relationship without any recruitment variability.

Spawning Potential Ratio (SPR)

For a given fishing pattern, SPR(*I*) is the ratio of spawning stock biomass per recruit, when fishing at an intensity of *I*, divided by the spawning stock biomass per recruit with no fishing. In the usual notation, if a fishing intensity *I* has an SPR of *x*% then the intensity is denoted as $F_{x\%}$.

From the definition of SPR, it follows that for a given fishing pattern, the fishing intensity $F_{x\%}$, under *constant virgin* recruitment, will result in an equilibrium spawning stock biomass of $x\%B_0$. Hence, for a Beverton-Holt stock recruitment relationship, ESD and SPR are equivalent when steepness is equal to 1.

Examples plots and text for the different fishing intensity metrics

The following text and plots are given as examples of how to use and describe each fishing intensity metric. The first sections provide example text for describing the metric. The plots are for the same example stock assessment and are identical except for the fishing intensity metric used. Each plot is followed by a brief section describing the key features of the plot, with regard to fishing intensity, using terminology appropriate to the fishing intensity metric.

Equivalent annual U

Fishing intensity in each year is measured using a multi-fisheries analogue of exploitation rate called “equivalent annual *U*” and denoted as U_{equiv}.

The fishing mortality across the multiple fisheries, in each fishing year, combine to produce a composite or nett fishing selectivity [*Insert appropriate description*; e.g., “across age classes”]. In each year, U_{equiv} is the catch in numbers (from all fisheries) divided by the beginning-of-year selected numbers (as defined by the composite selectivity).

The fishing intensity reference point, $U_{equiv,targ}$, is [*insert description, e.g.,* $F_{40\%}$] expressed as an equivalent annual *U*. It was determined under the constraint that [*insert description of the constraint; e.g., relative exploitation rates were constant across fisheries*].

Equivalent annual F

Fishing intensity in each year is measured using a multi-fisheries analogue of instantaneous fishing mortality called “equivalent annual *F*” and denoted as F_{equiv}. Associated with F_{equiv} is a composite or nett selectivity that is defined at the “cell” level, which in this case is [*Insert appropriate cell description*; e.g., “across age classes”.]

For each fishing event in the model’s annual cycle, there is an instantaneous fishing mortality F_a, which, if applied in the Baranov catch equation for the duration of the fishing event, would cause the beginning-of-event numbers (in cell *a*) to be reduced to the end-of-event numbers (in cell *a*). F_{equiv} is the maximum, across cells, of the duration-weighted sum of such *F*s across fishing events.

The fishing intensity reference point, $F_{equiv,targ}$, is [*insert description, e.g.,* $F_{40\%}$] expressed as an equivalent annual *F*. It was determined under the constraint that [*insert description of the constraint; e.g., relative fishing mortality rates were constant across fisheries*].

Equilibrium Stock Depletion (ESD)

Fishing intensity is measured by its theoretical long-term effect on the model fish-stock. In this metric (ESD) each fishing intensity is simply labeled with its associated equilibrium spawning stock biomass.

Under any given fishing pattern, the fishing intensity that, under *deterministic* recruitment, will result in an equilibrium spawning stock biomass of $x\%B_0$ is denoted as $F_{x\%B0}$. Note, "deterministic recruitment" is the recruitment that comes from the stock-recruitment relationship without any recruitment variability.

As fishing intensity increases, ESD decreases. Therefore, in a graphical presentation, the fishing intensity axis is plotted upside-down when using the ESD metric (i.e., plot "100 – ESD").

Spawning Potential Ratio (SPR)

Fishing intensity is measured by its theoretical long-term effect on the spawning stock biomass per recruit (SSBperR). For a given fishing pattern, SPR(I) is the ratio of SSBperR, when fishing at an intensity of I, divided by the SSBperR with no fishing. In the usual notation, if a fishing intensity I has an SPR of x% then the intensity is denoted as $F_{x\%}$.

An example stock with results shown as two-dimensional trajectories

The stock in the example-model is assumed to be at virgin equilibrium in 1977-1978 (the first point in the trajectory). The assessment is for the 2007-2008 fishing year (the last point in the trajectory). It is assumed that the target biomass is 35% B_0 and that the fishing-intensity target is derived from the biomass target (i.e., the fishing intensity corresponding to an equilibrium biomass of 35% B_0 for the stock-assessment model). Steepness in the Beverton-Holt stock recruitment relationship is fixed at 0.75.

The trajectories are for an MCMC assessment, where the annual median biomass is plotted on the x-axis and the annual median fishing intensity, or fishing intensity ratio is plotted on the y-axis. In the case of ESD and SPR the y-axis has absolute units (in percentage terms).

For equivalent annual U and F, ratios are used on the y-axis because the fishing-intensity targets change across time (as composite selectivities change) and across the MCMC samples (as fishing selectivities and other parameters change). The ratio for each MCMC sample in each year is the annual fishing intensity divided by the fishing-intensity target (calculated in the same units). The median ratio is plotted each year and the fishing-intensity-ratio target is at 1.

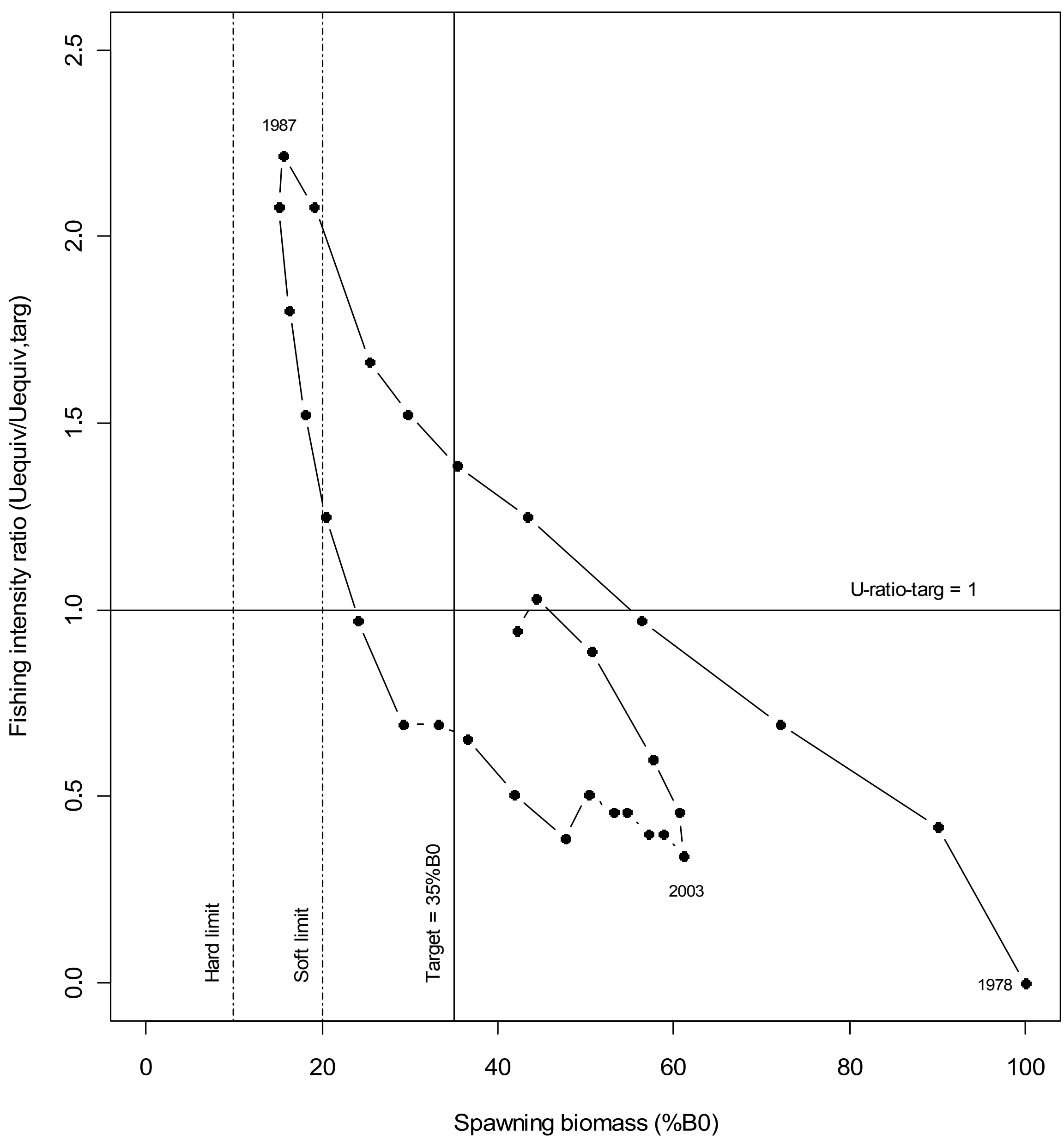


Figure 2: Estimated annual fishing-intensity ratio (Uequiv/Uequiv,targ) and spawning biomass from 1977-78 to 2007-08. The median MCMC estimates are plotted for each year. The biomass target and the fishing intensity ratio of 1 are plotted as solid lines.

Spawning biomass and fishing intensity are currently estimated to be above the target biomass and below the fishing intensity target (**Figure 2**). There has been a small reduction in estimated fishing intensity from 2006-07 when the fishing intensity target was slightly exceeded (**Figure 2**). Fishing intensity is now estimated to be slightly below the target level. It reached a peak in 1987 when the fishing intensity was more than twice the target level.

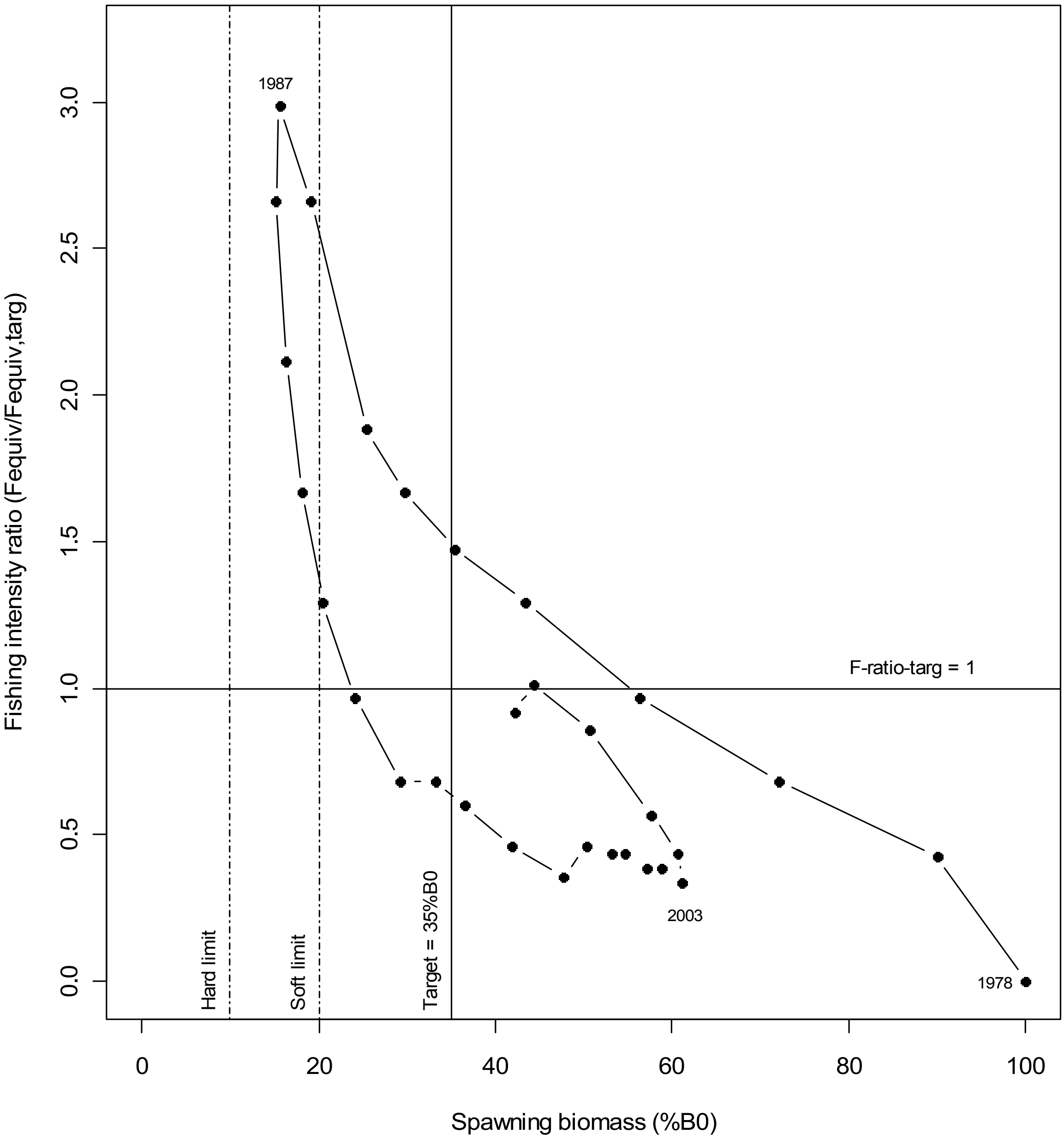


Figure 3: Estimated annual fishing-intensity ratio (Fequiv/Fequiv,targ) and spawning biomass from 1977-78 to 2007-08. The median MCMC estimates are plotted for each year. The biomass target and the fishing intensity ratio of 1 are plotted as solid lines.

Spawning biomass and fishing intensity are currently estimated to be above the target biomass and below the fishing intensity target (**Figure 3**). There has been a small reduction in estimated fishing intensity from 2006-07 when the fishing intensity target was slightly exceeded (**Figure 3**). Fishing intensity is now estimated to be slightly below the target level. It reached a peak in 1987 when the fishing intensity was about three times the target level.

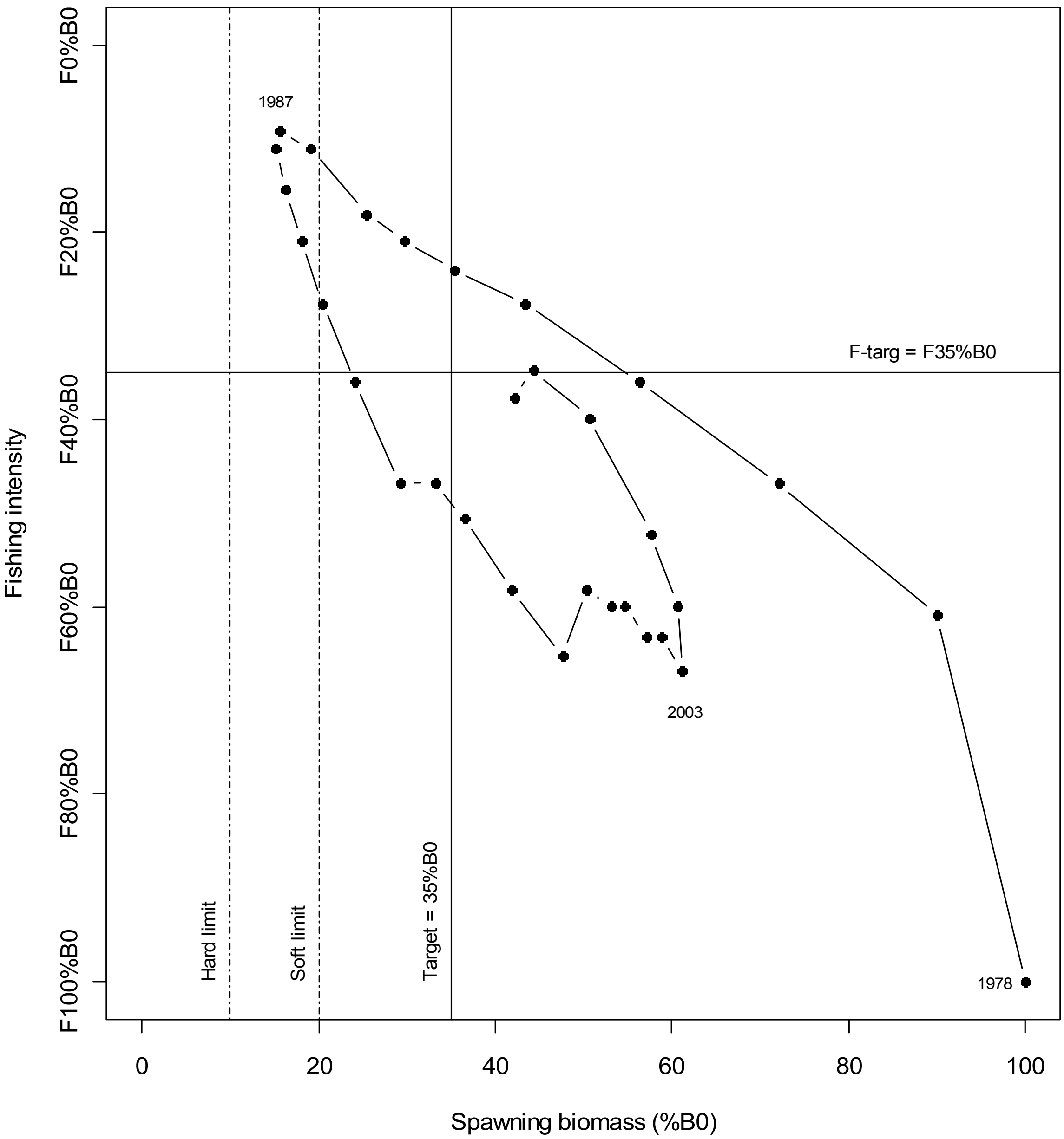


Figure 4: Estimated annual fishing-intensity and spawning-biomass from 1977-78 to 2007-08. The median MCMC estimates are plotted for each year. The biomass target and the associated fishing intensity target are plotted as solid lines.

Spawning biomass and fishing intensity are currently estimated to be above the target biomass and below the fishing intensity target (**Figure 4**). There has been a small reduction in estimated fishing intensity from 2006-07 when the fishing intensity target was slightly exceeded (**Figure 4**). Fishing intensity is now estimated to be much lower than the peak value in 1987 when the intensity was at $F_{10\%B0}$ (i.e., the level which would lead to an equilibrium spawning biomass of 10% B_0 under deterministic recruitment).

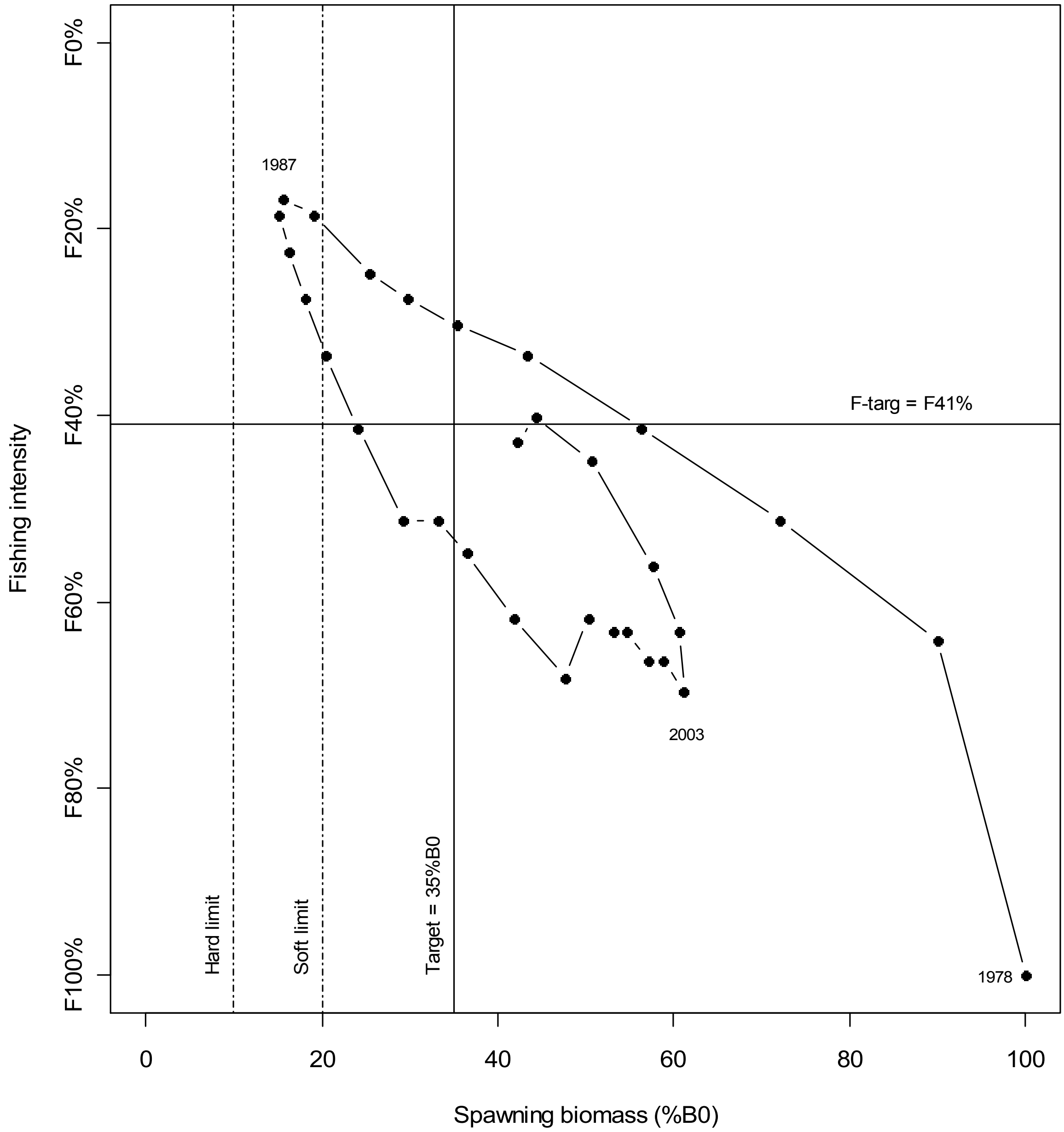


Figure 5: Estimated annual fishing-intensity and spawning biomass from 1977-78 to 2007-08. The median MCMC estimates are plotted for each year. The biomass target and the associated fishing intensity target are plotted as solid lines.

Spawning biomass and fishing intensity are currently estimated to be above the target biomass and below the associated fishing intensity target (**Figure 5**). There has been a small reduction in estimated fishing intensity from 2006-07 when the fishing intensity target was slightly exceeded (**Figure 5**). Fishing intensity is now estimated to be much lower than the peak value in 1987 when the intensity was at $F_{18\%}$ (i.e., spawning biomass per recruit at 18% of the virgin level).

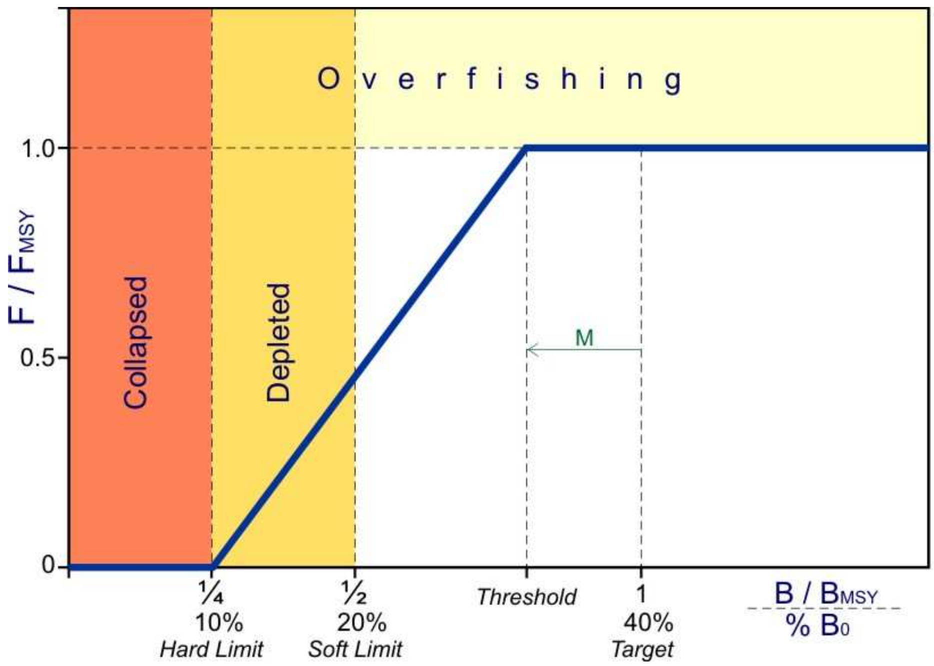
Control rules

A control rule specifies the requirements for management actions that should be invoked depending on the status of fish stocks relative to various biological (or other) reference points. **Figure 6** provides an illustrative example based on examples prevalent in the international fisheries management and science literature (**Appendix VII**), modified to reflect the particular reference points adopted in the Harvest Strategy Standard. This example is strictly applicable only for high information stocks where it is possible to estimate biomass relative to B_{MSY} and fishing mortality relative to F_{MSY} (or some other measure of fishing intensity). However, it can also be adapted to other, lower information situations.

Figure 6 introduces the notion of a biomass (or proxy) threshold. A threshold sits between the target and the limit. It represents a specified proportion (<1) of the average target biomass or fishing mortality or fishing intensity rate, or CPUE, or other appropriate proxy. It is a trigger point indicating the need for strengthened management actions to prevent fisheries and stocks from falling too far below the target, and to keep them away from the soft (and hard) limits. In **Figure 6**, the threshold is depicted at (1-M) B_{MSY}, where M is natural mortality (as recommended by Restrepo *et al*. 1998).

A threshold of (1-M) B_{MSY} is intended to reflect the extent that stocks fished at F_{MSY} (or a related level) might be expected to fluctuate. The extent to which stocks fluctuate is generally positively correlated with their rate of natural mortality (M). Stocks with high values of M have fewer age classes and therefore variation in incoming recruitment tends to result in larger fluctuations in overall stock size. In other words, stocks with higher M generally have larger fluctuations. In addition, stocks with higher M have higher productivity and, if all else is equal, they are capable of rebuilding faster. Therefore, it makes sense to relate default thresholds to natural mortality. Simulation experiments have suggested that fluctuations in stocks that are fished perfectly at F_{MSY} are mostly in the range $B_{MSY} \pm M\ B_{MSY}$ for reasonable combinations of life history parameters. This is the reason for suggesting a default threshold of (1–M) B_{MSY}, if a threshold is adopted as part of a harvest strategy.

Low productivity stocks display attributes that support threshold levels being placed at a relatively high proportion of the target level. Natural fluctuations in stock size are generally lower for low productivity stocks, due to the higher number of age classes making up the stock. However, the flip side of the coin is that low productivity stocks generally have less capacity to rebound from low stock sizes.



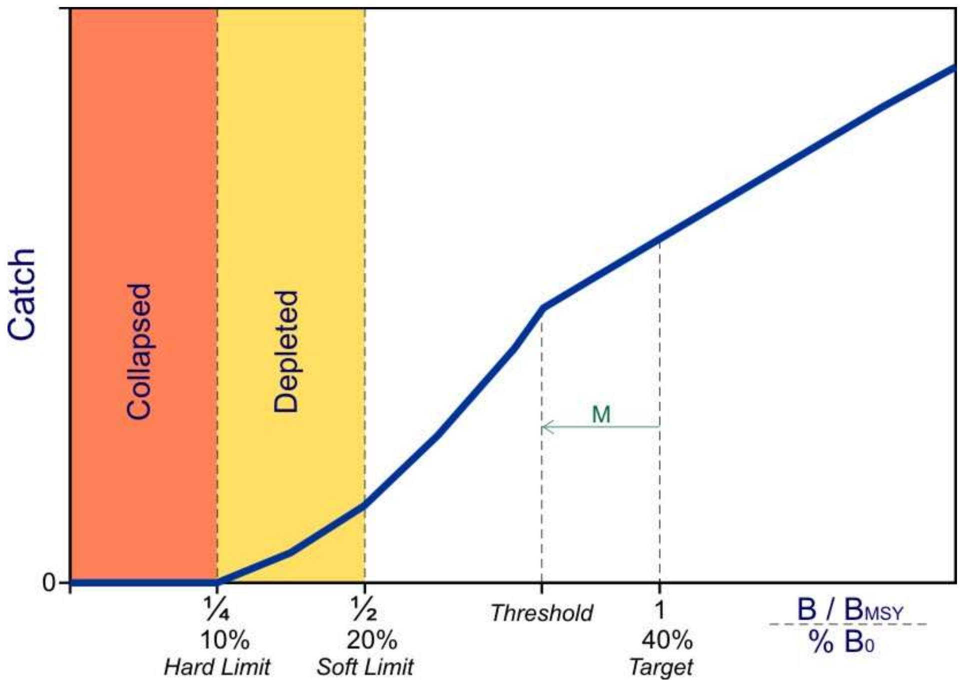


Figure 6. Illustrative example of a harvest strategy control rule that would be in conformance with the Harvest Strategy Standard. The top graph illustrates the control rule applicable for a fishing mortality based strategy, while the bottom graph translates the fishing mortality axis into related catch levels. M is natural mortality.

The illustrative harvest strategy control rule in **Figure 6** suggests that fishing mortality rates (or other measure of fishing intensity) may not need to be reduced until stock size falls below the threshold (top diagram). However, all points on the control rule line are management action points, as indicated in the bottom diagram that shows the corresponding catch levels. Hence, although the percentage of the stock biomass caught may remain constant down to the level of the threshold, TACs may need to be reduced to ensure that stocks fluctuate around target levels.

In the interval between the threshold and the soft limit, management actions to reduce catch are essential to prevent stocks declining to the level of the soft limit. These could consist of measures such as changes in minimum legal sizes of fish caught (through, for example, increases in the minimum allowable mesh size of fishing nets), and closures of areas with high levels of catches of juveniles, as well as reduction in TACs.

Figure 6 is primarily for illustrative purposes, to provide an example of one type of control rule that is likely to achieve the requirements of the Harvest Strategy Standard. The Harvest Strategy Standard itself does not require the use of a threshold.

Figure 7 shows the relationship between the target, threshold, soft limit and hard limit specified in **Figure 6**, relative to fluctuations in spawning biomass for a simulated stock of moderate productivity (M = 0.2) fished perfectly with a fishing mortality rate equal to F_{MSY}. This figure illustrates the basis for the threshold, soft limit and hard limit: the threshold should encompass most of the range of natural fluctuations; the soft limit should generally be near or below this range; and the hard limit should be well below the natural range of fluctuations for a well-managed stock.

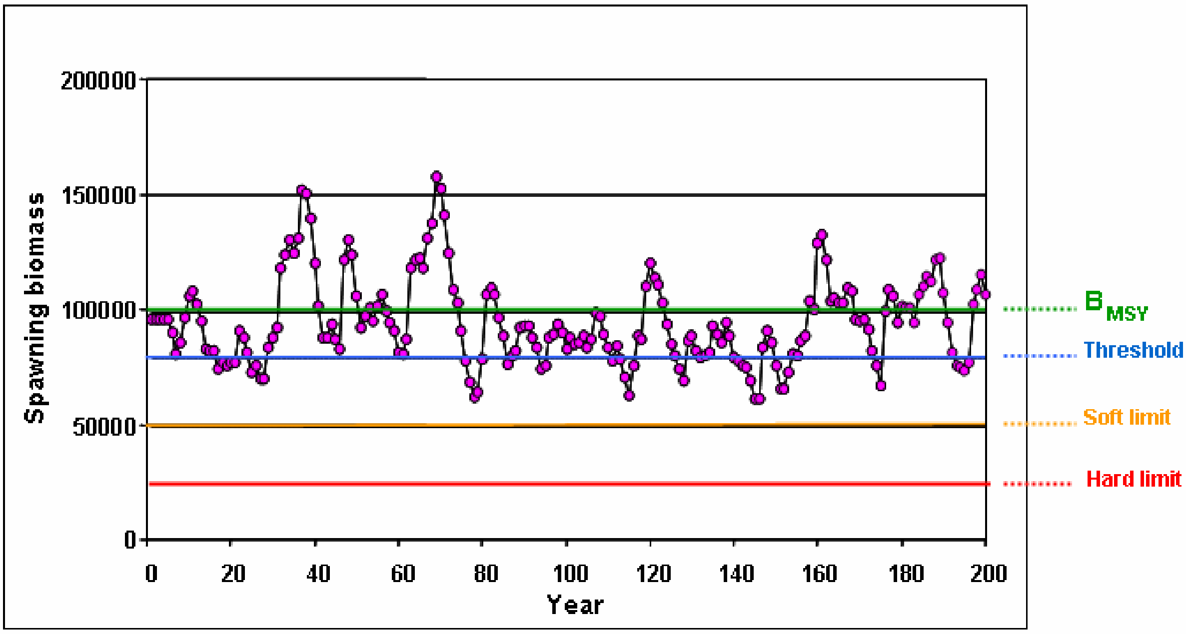


Figure 7. Relationship of a target (B_{MSY}), threshold ((1-M) B_{MSY}), soft limit (½ B_{MSY}), and hard limit (¼ B_{MSY}) to fluctuations in spawning biomass for a moderate productivity stock fished at F_{MSY}.

PART II. IMPLEMENTATION GUIDELINES

Implementation of the Harvest Strategy Standard is currently well underway, through

a) incorporation in Fisheries Plans and/or associated Annual Operating Plans, and
b) assessment of stock status relative to management targets, soft limits, hard limits and overfishing thresholds in the two annual Fisheries Assessment Plenary reports.

Fisheries Plans and/or Annual Operating Plans will incorporate the core elements of the Harvest Strategy Standard. They will specify the objectives that are to be achieved in individual fisheries. A key component is the determination of a target level for each QMS fish stock which is at the least consistent with that specified in the Harvest Strategy Standard. In the absence of a plan for a given stock, where an assessment of that stock is undertaken or updated and/or management advice is provided to the Minister, the Harvest Strategy Standard must be taken into account. In such situations, the goal is to ensure that actions consistent with the Harvest Strategy Standard are implemented.

Reference points and management targets

The Ministry's annual Fisheries Assessment Plenary documents will be the authoritative sources of stock-specific estimates of MSY-compatible reference points and associated soft and hard limits and overfishing metrics. Fisheries Plans will be the authoritative source of stock-specific targets, as these are developed. Science Working Groups will evaluate fishery performance relative to stock-specific targets, limits and overfishing metrics.

Current estimates of MSY-compatible reference points and related targets, limits and overfishing metrics may need to be revised in some cases as a result of implementing the Harvest Strategy Standard. In the event that a target is revised upwards (e.g. to a higher target biomass level or a lower fishing mortality or fishing intensity target), an appropriate transition period for achieving the revised target should be implemented. This will require an appropriate rebuilding plan to be developed and actioned to ensure that the stock rebuilds to the revised target level, within a timeframe appropriate to the characteristics of the species and the fishery.

Roles and responsibilities of Science Working Groups (SWGs)[13] and Fisheries Managers

The following requirements are subject to the existence of sufficient information.

Targets

1. SWGs will be asked to provide their best estimate, or range of estimates, of B_{MSY}, F_{MSY}, MSY, or relevant proxies for each of these.

2. Targets will be set by fisheries managers based on estimates of MSY-compatible reference points, but modified by relevant factors.[14]

---

[13] Science Working Groups, usually Fisheries Assessment Working Groups (FAWGs), that already include representatives of all interested stakeholder groups including fisheries managers.
[14] Generally, relevant factors are likely to result in targets that are "better" than MSY-compatible reference points (see footnote 2).

3. SWGs will define and report on performance measures related to these targets; these assessments will be reported via annual Fisheries Assessment Plenaries and other mechanisms.

4. SWGs will determine whether or not overfishing is occurring, where overfishing is deemed to occur when the average fishing mortality or exploitation rate (or other measure of fishing intensity) has exceeded F_{MSY} or an appropriate proxy.[15]

Limits

1. SWGs will estimate [16] the probability that current and/or projected biomass is below either the soft or the hard limit.

2. If the probability that a stock is below the soft limit exceeds 50%, the stock will be determined to be depleted and SWGs may be requested to develop a formal, time-constrained rebuilding plan.

3. If the probability that a stock is below the hard limit exceeds 50%, the stock will be determined to be collapsed and SWGs may be requested to investigate the implications of closing target fisheries and/or curtailing or closing fisheries that incidentally catch the species concerned.

4. If the probability that either limit has been breached exceeds 50%, the Ministry will provide advice to the Minister on a range of management actions that may include a formal, time-constrained rebuilding plan or closure of target fisheries and curtailment or closure of fisheries that incidentally catch the species concerned.

Rebuilding plans

1. SWGs will estimate [16] the probability that current and/or projected biomass is below ½ B_{MSY} or 20% B_0, whichever is higher.[17] If this probability is greater than or equal to 50%, SWGs should calculate T_{min}. [18]

2. SWGs will work with fisheries managers to define and evaluate alternative rebuilding plans that will rebuild the stock back to the target with a 70% probability within a timeframe ranging from T_{min} to 2 * T_{min}. This is likely to be an iterative process.

3. The Ministry will provide advice to the Minister on a range of rebuilding plans that satisfy the T_{min} to 2 * T_{min} time constraint (or an alternative that can be adequately justified), and the specified probability levels.

4. Once a rebuilding plan has been implemented, SWGs will regularly evaluate and report on the performance of the rebuilding plans.

---

[15] A 3-5 year running average will be deemed to be appropriate for evaluating whether or not "overfishing" has been occurring.

[16] Such "estimation" may either be quantitative, or based on expert judgement, or a combination.

[17] Corresponding MSY-compatible reference points (including proxies) are acceptable. Guidance on estimating these reference points will be continually developed and added to the Operational Guidelines.

[18] T_{min} is the number of years required to rebuild a stock in the absence of fishing and is a function of three primary factors: the biology of the species, the extent of stock depletion below the target, and the prevailing environmental conditions.

5. The Ministry will provide advice to the Minister on appropriate TACs to achieve the rebuilding plan.

Actions when current biomass is likely to be above soft and hard limits but below targets (or thresholds)

1. SWGs will provide best estimates and confidence intervals for current biomass and/or fishing mortality (or related biological reference points). [19]

2. If current biomass is estimated [16] to be between the target (or the threshold [20]) and the soft limit, SWGs should work with fisheries managers to define and evaluate the TAC consequences of:

   - reducing fishing mortality proportionately to the estimated decrease in biomass below the target or threshold (or taking steps to approximate this for low information stocks), in order to avoid breaching either the soft or hard limits,

   and/or

   - reducing catch super-proportionately to the estimated decrease in biomass below the target or threshold (or taking steps to approximate this for low information stocks), in order to avoid breaching either the soft or hard limits.

3. If current biomass is estimated [16] to be above some threshold,[20] SWGs will work with fisheries managers to define and evaluate the TAC consequences of:

   - maintaining a constant F that will achieve the target biomass on average (or taking steps to approximate this for low information stocks),

   and/or

   - reducing catch proportionately to the estimated decrease in biomass towards the threshold (or taking steps to approximate this for low information stocks),

   and/or

   - increasing catch proportionately to the estimated increase in biomass above the threshold (or taking steps to approximate this for low information stocks).

---

[19] When more than one model result is presented, it may be necessary to either choose a single "base case" or to weight alternative runs and calculate an overall weighted average "best estimate" of current biomass.

[20] A default "threshold" of $(1 – M) * B_{MSY}$, where M is the natural mortality of the exploited age classes, was suggested by Restrepo *et al*. (1998), on the basis that "one would expect a stock fished at F_{MSY} to fluctuate around B_{MSY} on a scale related to M (small fluctuations for low M and large fluctuations for high M)". However, alternative thresholds can be justified depending on a) management objectives, and b) stock or species-specific modelling to determine an appropriate lower confidence interval of the range of natural fluctuations around B_{MSY} or an alternative target. The most important consideration is that management action must be taken to avoid a stock reaching either the soft or hard limits.

Implications

There are few, if any, implications of applying this standard to New Zealand fish stocks that have been managed so as to fluctuate around targets based on MSY-compatible reference points or better, provided that the assumptions and methods used to calculate the reference points are valid. For stocks where this has not been achieved, TAC reductions may need to be considered in the short term to achieve the Harvest Strategy Standard. For stocks for which targets are not in conformance with international best practice, it will be necessary to develop new estimates, along with appropriate harvest strategies, to achieve the targets and avoid the associated limits.

APPENDIX I. Glossary of Common Technical Terms

Abundance index: A quantitative measure of fish density or abundance, usually as a time series. An **abundance index** can be specific to an area or to a segment of the **population** (e.g., mature fish), or it can refer to abundance stock-wide; the index can reflect abundance in numbers or in weight (**biomass**).

Age-structured stock assessment: An assessment of the **status** of a fish **stock** that uses an assessment model to estimate how the numbers at age in the stock vary over time.

Bayesian analysis: an approach to stock assessment that provides estimates of uncertainty (**posterior** distributions) of the quantities of interest in the assessment. The method allows the initial uncertainty (that before the data are considered) to be described in the form of **priors**. If the data are informative, they will determine the posterior distributions; if they are uninformative, the posteriors will resemble the priors. The initial model runs are called **MPD** (mode of the posterior distribution) runs, and provide point estimates only, with no uncertainty. Final runs (Markov Chain Monte Carlo runs or **MCMCs)**, which are often very time consuming, provide both point estimates and estimates of uncertainty.

$\boldsymbol{B_{BEG}}$**:** The estimated **stock biomass** at the beginning of the fishing year.

$\boldsymbol{B_{CURRENT}}$**:** Current **biomass** (usually a **mid-year biomass**).

Biological Reference Point (BRP): A benchmark against which the **biomass** or abundance of the **stock** or the **fishing mortality rate** (or **exploitation rate** or other measure of **fishing intensity**), or **catch** itself can be measured in order to determine **stock status**. These reference points can be **targets**, **thresholds** or **limits** depending on their intended use.

Biomass: Biomass refers to the size of the **stock** in units of weight. Often, **biomass** refers to only one part of the **stock** (e.g., **spawning biomass, recruited biomass** or **vulnerable biomass**, the latter two of which are essentially equivalent).

$\boldsymbol{B_{LIM}}$**: Biomass limit reference point:** the point beyond which the risk to the stock is regarded as unacceptably high (terminology used, for example, by ICES).

$\boldsymbol{B_{MEY}}$**: Biomass at maximum economic yield**: average biomass corresponding to maximum economic yield as estimated from the assessment model applied.

$\boldsymbol{B_{MSY}}$**:** The average **stock biomass** that results from taking an average catch of **MSY** under various types of **harvest strategies**. Usually expressed in terms of spawning **biomass**, but sometimes expressed as **recruited** or **vulnerable biomass.**

$\boldsymbol{B_o}$**: Virgin biomass**. This is the theoretical **carrying capacity** of the **biomass** of a fish **stock**. In some cases, it refers to the average **biomass** of the **stock** in the years before fishing started. More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. Usually expressed in terms of spawning **biomass**, but sometimes expressed as **recruited** or **vulnerable biomass.** $\boldsymbol{B_0}$ is often estimated from stock modelling and various percentages of it (e.g. 40% $\boldsymbol{B_0}$) are used as **biological reference points (BRPs)** to assess the relative status of a **stock**.

Bycatch: Refers to fish species, or size classes of those species, that are caught in association with key target species.

***B_{YEAR}*:** Estimated or predicted **biomass** in the named year (usually a **mid-year biomass**).

Carrying capacity: The average **stock** size expected in the absence of fishing. Even without fishing the **stock** size varies through time in response to stochastic environmental conditions. See ***B_o*: virgin biomass**.

Catch (C): The total weight (or sometimes number) of fish caught by fishing operations.

CAY: Current annual yield is the one year **catch** calculated by applying a reference **fishing mortality**, **$F_{ref,}$** (or other measure of **fishing intensity**) to an estimate of the fishable **biomass** at the beginning of the fishing year. Also see **MAY**.

CCAMLR: The Convention for the Conservation of Antarctic Marine Living Resources.

Collapsed: Stocks that are below the **hard limit** are deemed to be **collapsed**.

CCSBT: Commission for the Conservation of Southern Bluefin Tuna. The Regional Fisheries Management Organisation (RFMO) responsible for the assessment and management of Southern Bluefin Tuna, of which New Zealand is a member.

Cohort: Those individuals of a **stock** born in the same spawning season. For annual spawners, a year's **recruitment** of new individuals to a **stock** is a single cohort or **year-class**.

Control rules: (also referred to as **harvest control rules** and **decision rules**) agreed responses that management must make under pre-defined circumstances regarding stock status.

CPUE: Catch per unit effort is the quantity of fish caught with one standard unit of fishing effort; e.g. the number of fish taken per 1000 hooks per day or the weight of fish taken per hour of trawling. CPUE is often assumed to be an **abundance index**.

Customary catch: Catch taken by tangata whenua to meet their customary needs.

CV: Coefficient of variation. A statistic commonly used to represent variability or uncertainty. For example, if a **biomass** estimate has a CV of 0.2 (or 20%), this means that the error in this estimate (the difference between the estimate and the true biomass) will typically be about 20% of the estimate.

Depleted: Stocks that are below the **soft limit** are deemed to be **depleted**. Stocks can become **depleted** through **overfishing**, or environmental factors, or a combination

Ecologically sustainable development: using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life now and in the future, can be increased.

EEZ: An **Exclusive Economic Zone** is a maritime zone over which the coastal state has sovereign rights over the exploration and use of marine resources. Usually, a state's EEZ extends to a distance of 200 nautical miles (370 km) out from its coast, except where resulting points would be closer to another country.

Equilibrium: A theoretical model result that arises when the **fishing mortality (**or other measure of **fishing intensity)**, **exploitation pattern** and other fishery or **stock** characteristics (growth, natural mortality, **recruitment**) do not change from year to year.

Exploitable biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called **recruited biomass** or **vulnerable biomass**.

Exploitation pattern: The relative fraction of each age or size class of a **stock** that is vulnerable to fishing.

Exploitation rate: The proportion of the **recruited** or **vulnerable biomass** that is caught during a certain period, usually a fishing year.

***F*:** The **fishing mortality rate** is that part of the **total mortality rate** applying to a fish **stock** that is caused by fishing.

$F_{0.1}$: A biological **reference point**. It is the **fishing mortality rate** at which the increase in **equilibrium yield per recruit** in weight per unit of effort is 10% of the **yield per recruit** produced by the first unit of effort on the unexploited **stock** (i.e., the slope of the **yield per recruit** curve for the $F_{0.1}$ rate is only 1/10th of the slope of the **yield per recruit** curve at its origin).

F_{HIGH}: developed by ICES as a **reference point** that is equal to the inverse of the 10^{th} percentile of the **recruits per spawning biomass** observed in the fishery, year classes fished at this level will on average replace themselves for the **recruits per spawning biomass** observed in 10% of the years.

Fishing down: The consequence of fishing on a **virgin stock** is to reduce stock biomass down to an average level corresponding to an "optimal" rate at which the stock is to be exploited. The period over which fishing reduces the stock from its initial level to a target level is referred to as the **fishing down** phase.

Fishing intensity: A broadening of the term, **fishing mortality rate**, to take account of related metrics that can be used to determine whether or not **overfishing** has been or is occurring.

Fishing year: For most fish stocks, the fishing year runs from 1 October in one year to 30 September in the next. The second year is often used as shorthand for the split years. For example, 2005 is shorthand for 2004-05.

F_{LIM}: Fishing mortality limit reference point: the point above which the removal rate from the stock is too high (terminology used, for example, by ICES).

F_{LOW}: Two ICES (International Council for the Exploration of the Sea) Working Groups on Fish Stock Assessment contrived **F_{HIGH}** and **F_{LOW}** reference points as the fishing mortality that produces a spawning biomass per recruit that is equal to the inverse of the 10^{th} and 90^{th} percentile of the **recruits per spawning biomass** observed in the fishery. **Year classes** fished at this level will on average replace themselves for the recruits per spawning biomass observed in 10% and 90% of the years (respectively).

F_{MAX}: A biological **reference point**. It is the **fishing mortality rate** that maximises **equilibrium yield per recruit**. **F_{MAX}** is the **fishing mortality rate** that defines **growth overfishing**. In general, **F_{MAX}** is different from **F_{MSY}** (the **fishing mortality**

that maximises **sustainable yield**), and is always greater than or equal to F_{MSY}, depending on the **stock-recruitment relationship**.

F_{MED}**:** is a proxy for **recruitment overfishing**. F_{MED} is the equivalent of the recruits per **spawning stock biomass** that have been above the replacement level in half the years. The usefulness of this **reference point** is dependant on the level of exploitation of the stock in question. It will result underestimation of $\mathbf{F_{MED}}$ if the stock has only been lightly exploited. $\mathbf{F_{MED}}$ is viewed as a **limit reference point** as **fishing mortality rates** higher than $\mathbf{F_{MED}}$ lead to stock decline. $\mathbf{F_{MED} = F_{REP}}$.

F_{MEY}**:** The **fishing mortality** corresponding to the maximum (**sustainable**) economic yield.

F_{MSY}**:** A **biological reference point**. It is the **fishing mortality rate** that, if applied constantly, would result in an average catch corresponding to the **Maximum Sustainable Yield** (**MSY**) and an average biomass corresponding to B_{MSY}.

F_{REP}**:** A **biological reference point** that corresponds to the **fishing mortality rate** that on average allows for replacement of successive generations over the observed range of S-R data. $\mathbf{F_{REP} = F_{MED}}$.

$F_{\%SPR}$ (e.g. $F_{20\%}$, $F_{30\%}$, $F_{40\%}$)**:** A level of **fishing mortality** that reduces the **spawning (biomass) per recruit** to *x*% of the unfished spawner-per-recruit **(SPR)** level.

Generation time: the average time taken for an individual to replace itself within a **stock** or **population**.

Growth overfishing: Growth overfishing occurs when the **fishing mortality rate** is above F_{MAX}. This means that individual fish are caught before they have a chance to reach their maximum growth potential.

Hard limit: A biomass limit below which fisheries should be considered for closure.

Harvest strategy: For the purpose of the Harvest Strategy Standard, a harvest strategy simply specifies **target** and **limit reference points** and management actions associated with achieving the targets and avoiding the limits.

ICCAT: International Commission for the Conservation of Atlantic Tuna.

ICES: International Council for the Exploration of the Sea.

Input controls: Refers to fisheries management regulations that limit the amount of effective fishing effort applied to fish stocks through, for example, restrictions on mesh size or related gear restrictions, closed areas and limits on vessel size and capacity (compare with **output controls**).

Length frequency: The distribution of numbers at length from a sample of the **catch** taken by either the commercial fishery or research fishing. This is often estimated based on a sample. Sometimes called a **length composition**.

Length-structured stock assessment: An assessment of the **status** of a fish **stock** that uses an assessment model to estimate how the numbers at length in the stock vary over time.

Limit: A **biomass** or **fishing mortality** or **fishing intensity reference point** that should be avoided with high probability. The Harvest Strategy Standard defines both **soft limit**s and **hard limit**s.

M**:** The **natural mortality rate** is that part of the **total mortality rate** applying to a fish **stock** that is caused by predation and other natural events.

Maturity: Refers to the ability of fish to reproduce.

Maturity ogive: A curve describing the proportion of fish of different ages or sizes that are mature.

MAY: Maximum average yield is the average maximum **sustainable** yield that can be produced over the long term under a constant **fishing mortality** or **fishing intensity** strategy, with little risk of **stock** collapse. A constant **fishing mortality** or **fishing intensity** strategy means catching a constant percentage of the **biomass** present at the beginning of each fishing year. **MAY** is the long-term average annual catch when the catch each year is the **CAY**. Also see **CAY**.

Management strategy: A systems approach that links together a stock assessment process and management and monitoring controls, and sometimes also includes research and enforcement needs.

Management Strategy Evaluation: A procedure whereby alternative management strategies are tested and compared using simulations of **stock** and fishery dynamics.

MCMC: Markov Chain Monte Carlo. See **Bayesian analysis**.

MCY: Maximum constant yield is the maximum sustainable yield that can be produced over the long term by taking the same catch year after year, with little risk of stock collapse.

MEY: Maximum economic yield: The sustainable catch or effort level for a commercial fishery that allows net economic returns to be maximised. Note that for most practical discount rates and fishing costs **MEY** will imply that the equilibrium stock of fish is larger than that associated with **MSY**. In this sense **MEY** is more environmentally conservative than **MSY** and should in principle help protect the fishery from unfavorable environmental impacts that may diminish the fish population.

Mid-year biomass: The biomass after half the year's catch has been taken.

Model: A conceptual and simplified idea of how the 'real world' works.

Monte Carlo simulation: is an approach whereby the inputs that are used for a calculation are re-sampled many times assuming that the inputs follow known statistical distributions. The **Monte Carlo** method is used in many applications such as **Bayesian** analyses, parametric bootstraps and stochastic **projections**.

MPD: Mode of the (joint) posterior distribution. See **Bayesian analysis**.

MSY: For the purposes of the Harvest Strategy Standard, **maximum sustainable yield** is the largest long-term average catch or yield that can be taken from a **stock** under prevailing ecological and environmental conditions. It is the maximum use that a renewable resource can sustain without impairing its renewability through natural growth and reproduction.

MSY-compatible reference points: MSY-compatible references points include $\boldsymbol{B_{MSY}}$, $\boldsymbol{F_{MSY}}$ and **MSY** itself, as well as analytical and conceptual **proxies** for each of these three quantities.

NAFO: Northwest Atlantic Fisheries Organization.

Output controls: Refers to fisheries management regulations that limit the amount of **catch** taken from fish stocks through, for example, the implementation of a **TAC**.

Overexploitation: A situation where observed **fishing mortality** (or **exploitation** or other measures of **fishing intensity**) **rates** exceed **targets**.

Overfished: Stocks that are below a biomass limit, such as the **soft limit**, are frequently referred to as "overfished" (e.g. in the United States). However, the term "**depleted**" should generally be used in preference to "overfished" because stocks can become depleted through a combination of **overfishing** and environmental factors, and it is usually impossible to separate the two.

Overfishing: Overfishing is deemed to be occurring if $\boldsymbol{F_{MSY}}$ (or other measures of **fishing intensity**, or relevant **proxies**) is exceeded on average.

Population: A group of fish of one species that shares common ecological and genetic features. The **stocks** defined for the purposes of **stock assessment** and management do not necessarily coincide with self-contained populations.

Population Dynamics: In general, refers to the study of fish **stock** abundance and how and why it changes over time.

Posterior: a mathematical description of the uncertainty in some quantity (e.g., a biomass) estimated in a **Bayesian** stock assessment.

Pre-recruit: An individual that has not yet entered the fished component of the **stock** (because it is either too young or too small to be vulnerable to the fishery).

Prior: available information (often in the form of expert opinion) regarding the potential range of values of a parameter in a **Bayesian analysis**. Uninformative priors are used where there is no such information.

Production model: A **population model** that describes how the **population biomass** changes from year to year (or, how **biomass** changes in **equilibrium** as a function of **fishing mortality** or **fishing intensity**), but which does not keep track of the age or length frequency of the population. The simplest production functions aggregate all of the biological characteristics of growth, **natural mortality** and reproduction into a simple, deterministic **model** using three or four parameters. Production models are primarily used in simple data situations, where total catch and effort data are available but age-structured information is either unavailable or deemed to be less reliable (although some versions of production models allow the use of age-structured data).

Productivity: Productivity is a function of the biology of a species and the environment in which it lives. It depends on growth rates, **natural mortality**, **age of maturity**, maximum average age and other relevant life history characteristics. Species with high **productivity** are able to sustain higher rates of **fishing mortality** than species with lower **productivity**. Generally, species with high productivity are more resilient and take less time to rebuild from a **depleted** state.

Projection: Predictions about trends in stock size and fishery dynamics in the future. Projections are made to address "what-if" questions of relevance to management. Short-term (1-5 years) projections are typically used in support of decision-making. Longer term projections become much more uncertain in terms of absolute quantities, because the results are strongly dependent on **recruitment,** which is very difficult to predict. For this reason, long-term projections are more useful for evaluating overall management strategies than for making short-term decisions.

Proxy: A surrogate for B_{MSY}, F_{MSY} or **MSY** that has been demonstrated to approximate one of these three metrics through theoretical or empirical studies.

q: Catchability is the proportion of fish that are caught by a defined unit of fishing effort. The constant relating an **abundance index** to the true biomass (the **abundance index** is approximately equal to the true biomass multiplied by the catchability).

QMA: Quota management areas are geographic areas within which fish stocks are managed in the **EEZ**.

Quota Management System (QMS): The **QMS** is the name given to the system by which the total commercial catch from all the main fish **stocks** found within New Zealand's 200 nautical mile **EEZ** is regulated.

Rebuilding plan: A series of catch or **fishing mortality** or **fishing intensity** levels designed to rebuild a **depleted** stock (i.e. a **stock** that has fallen below the **soft limit**) back to the **target**.

Recruit: An individual that has entered the fished component of the **stock**. Fish that are not recruited are either not catchable by the gear used (e.g., because they are too small) or live in areas that are not fished.

Recruited biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called **exploitable biomass** or **vulnerable biomass**.

Recruitment: The addition of new individuals to the fished component of a **stock**. This is determined by the size and age at which fish are first caught.

Recruitment overfishing: occurs when excessive fishing effort or catch reduces the **spawning stock biomass** to a level below which future **recruitment** levels may be jeopardised; this spawning biomass level should correspond closely to the **biomass limit reference point**.

Reference point: see **Biological Reference Point**.

Selectivity ogive: Curve describing the relative vulnerability of fish of different ages or sizes to the fishing gear used.

Soft limit: A **biomass** limit below which the requirement for a formal, time-constrained **rebuilding plan** is triggered.

Spawning biomass: The total weight of sexually mature fish in a **stock** that spawn in a given year.

Spawning (biomass) per Recruit (SPR): The expected lifetime contribution to the **spawning biomass** for the average recruit to a fishery. For a given exploitation pattern, rate of growth, maturity schedule and **natural mortality**, an **equilibrium** value of SPR can be calculated for any level of **fishing mortality** (or **fishing intensity)**. SPR decreases monotonically with increasing **fishing intensity**. Refer to the Operational Guidelines Appendices for a more detailed explanation.

Stock: The term has different meanings. Under the Fisheries Act, it is defined with reference to units for the purpose of fisheries management. For the purposes of the Harvest Strategy Standard, a biological stock is a population of a given species that forms a reproductive unit and spawns little if at all with other units. However, there are many uncertainties in defining spatial and temporal geographical boundaries for such biological units that are compatible with established data collection systems. For this reason, the term "**stock**" is often synonymous with an assessment / management unit, even if there is migration or mixing of some components of the assessment/management unit between areas.

Stock assessment: The application of statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the **status** of the **stock** relative to defined benchmarks or **reference points** (e.g. B_{MSY} and/or F_{MSY}).

Stock-recruitment relationship: An equation describing how the expected number of recruits to a stock varies as the **spawning biomass** changes. The most frequently used stock-recruitment relationship is the Beverton and Holt equation, in which the expected number of recruits changes very slowly at high levels of spawning **biomass**.

Stock status: Refers to a determination made, on the basis of **stock assessment** results, about the current condition of the **stock** and of the fishery. Stock status is often expressed relative to **biological reference points** such as B_{MSY} or B_0 or F_{MSY} or $F_{\%SPR}$. For example, the current biomass may be said to be above or below B_{MSY} or to be at some percentage of B_0. Similarly, **fishing mortality** may be above or below F_{MSY} or $F_{\%SPR}$.

Stock structure: (1) Refers to the geographical boundaries of the **stocks** assumed for assessment and management purposes (e.g., albacore tuna may be assumed to be comprised of two separate **stocks** in the North Pacific and South Pacific), (2) Refers to boundaries that define self-contained **populations** in a genetic sense, (3) refers to known, inferred or assumed patterns of residence and migration for stocks that mix with one another.

Surplus production: The amount of **biomass** produced by the **stock** (through growth and **recruitment**) over and above that which is required to maintain the [total **stock]** **biomass** at its current level. If the catch in each year is equal to the surplus production then the **biomass** will not change.

Sustainability: Pertains to the ability of a fish **stock** to persist in the long-term. Because fish **populations** exhibit natural variability, it is not possible to keep all **stock** and fishery attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fishery and **stock** will persist in a constant **equilibrium** state. Because of natural variability, even if F_{MSY} could be achieved exactly each year, catches and **stock biomass** will oscillate around their average **MSY** and B_{MSY} levels, respectively. In a more general sense, sustainability refers to providing for the needs of the present generation while not compromising the ability of future generations to meet theirs.

Sustainable yield: the average catch that can be removed from a **stock** over an indefinite period without causing a further reduction in the **biomass** of the **stock**. This could be either a constant yield from year to year, or a yield that fluctuates in response to changes in abundance.

TAC: Total Allowable Catch is the total regulated catch from a **stock** in a given time period, usually a fishing year.

TACC: Total Allowable Commercial Catch is the total regulated commercial catch from a **stock** in a given time period, usually a fishing year.

Target: Generally, a **biomass** or **fishing mortality** (or other measure of **fishing intensity**) level that management actions are designed to achieve with at least a 50% probability.

Threshold: Generally, a **biological reference point** that raises a "red flag" indicating that **biomass** has fallen below the **target**, or **fishing mortality** (or other measure of **fishing intensity**) has increased above its **target**, to the extent that additional management action may be required in order to prevent the stock from declining further and possibly breaching the **limit**.

T_{min}: the number of years required to rebuild a **stock** in the absence of fishing; this is a function of three primary factors: the biology of the species, the extent of **stock depletion** below the target, and the prevailing environmental conditions.

Vulnerable biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called **exploitable biomass** or **recruited biomass**.

WCPFC: Western and Central Pacific Fisheries Commission. A Regional Fisheries Management Organisation (RFMO) responsible for assessing and managing highly migratory species (e.g., tunas, billfish and pelagic sharks) in the western and central Pacific.

Year class (cohort): Fish in a **stock** that were born in the same year. Occasionally, a **stock** produces a very small or very large year class which can be pivotal in determining **stock** abundance in later years.

Yield: Catch expressed in terms of weight.

Yield per Recruit (YPR): The expected lifetime **yield** for the average recruit. For a given **exploitation pattern**, rate of growth, and **natural mortality**, an **equilibrium** value of YPR can be calculated for each level of **fishing mortality**. YPR analyses may play an important role in advice for management, particularly as they relate to minimum size controls.

Z: Total mortality rate. The sum of **natural** and **fishing mortality rates**.

APPENDIX II. Equilibrium Implications of Fishing at 75% F_{MSY}

The simple, deterministic model described in Mace (1994) was used to evaluate the consequences of fishing at the default target of 75% F_{MSY}. Since the calculations were deterministic and the equilibrium biomass associated with a fishing mortality rate below F_{MSY} will always exceed B_{MSY}, it was not necessary to take explicit account of the behaviour of the default target at biomass levels below B_{MSY}. This model is age-structured with natural mortality constant over all ages, knife-edge recruitment and maturity, growth rates represented by a von Bertalanffy growth function, and recruitment represented by either a Beverton-Holt relationship or a Ricker relationship. The procedures used to run the model were the same as those described in Mace (1994), except that the outputs of primary interest were the equilibrium yield at 75% F_{MSY} (abbreviated Y75), the equilibrium biomass at 75% F_{MSY} (B75), the ratio Y75/MSY, and the ratio B75/B_{MSY}. Since the biomass is calculated as the average level present during the course of the fishing year, the ratio B75/B_{MSY} is equivalent to 1.333*(Y75/MSY). These calculations were performed for all combinations of natural mortality (M) = 0.1, 0.2, and 0.3; Brody growth coefficient in von-Bertalanffy equation (K) = 0.1, 0.2, and 0.3; age of recruitment (t_r) equal to age of maturity (t_m), both knife-edged at ages 3, 5, 7, and 9 years; and extinction parameter (τ) = 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50 (where 100*τ represents the level of %SPR corresponding to the slope at the origin of a stock-recruitment relationship) with a Beverton-Holt stock-recruitment relationship for which maximum (asymptotic) recruitment was fixed at 10^8 recruits for all parameter combinations. Additional runs combining M and/or K = 0.4 with the other parameter values were also conducted.

Even though some of these parameter combinations resulted in rather unlikely sets of life history characteristics, the ratios calculated were remarkably consistent across parameter combinations: Y75/MSY ranged between 0.949 and 0.983 and B75/B_{MSY} ranged between 1.265 and 1.311. Selected results for these and other variables are shown in **Table A1**.

Similar calculations were conducted for a Ricker stock-recruitment function with maximum recruitment fixed at 10^8. Parameter values and combinations were the same as those used with the Beverton Holt stock-recruitment function, except that only one age of recruitment was used (t_r = 5). For this formulation, Y75/MSY ranged between 0.940 and 0.963, and B75/B_{MSY} ranged between 1.253 and 1.284 (**Table A1**).

Table A1. Equilibrium yield and biomass levels corresponding to F_{MSY} and 0.75 F_{MSY} (selected results from 600 parameter and model combinations). SRR: stock-recruitment relationship (B-H = Beverton-Holt, R = Ricker).

SRR	M	K	τ	t_r	FMSY	0.75* FMSY	MSY	BMSY	Y75	Y75/ MSY	B75/ BMSY
B-H	0.1	0.1	0.05	5	0.091	0.068	12096	133565	11770	0.973	1.298
B-H	0.1	0.1	0.20	5	0.051	0.038	7223	141068	6941	0.961	1.281
B-H	0.1	0.1	0.50	5	0.022	0.016	2279	105381	2175	0.955	1.273
B-H	0.1	0.2	0.05	5	0.147	0.110	30719	209012	30007	0.977	1.302
B-H	0.1	0.2	0.20	5	0.074	0.056	17594	237692	16946	0.963	1.284
B-H	0.1	0.3	0.05	5	0.200	0.150	45966	229351	45008	0.979	1.306
B-H	0.1	0.3	0.20	5	0.091	0.068	25388	278511	24494	0.965	1.286
B-H	0.2	0.1	0.05	5	0.189	0.141	7042	37333	6873	0.976	1.301
B-H	0.2	0.1	0.20	5	0.099	0.075	4120	41422	3964	0.962	1.283
B-H	0.2	0.2	0.05	9	0.501	0.375	45113	90125	44315	0.982	1.310
B-H	0.2	0.2	0.05	5	0.300	0.225	23231	77558	22744	0.979	1.306
B-H	0.2	0.2	0.05	3	0.194	0.145	13215	68123	12873	0.974	1.299
B-H	0.2	0.2	0.20	9	0.195	0.146	23811	122170	23012	0.967	1.289
B-H	0.2	0.2	0.20	5	0.141	0.106	13090	92667	12619	0.964	1.285
B-H	0.2	0.2	0.20	3	0.107	0.080	7831	73125	7529	0.961	1.282
B-H	0.2	0.2	0.50	9	0.069	0.052	6897	99668	6568	0.952	1.270
B-H	0.2	0.2	0.50	5	0.055	0.041	3961	72352	3764	0.950	1.267
B-H	0.2	0.2	0.50	3	0.045	0.034	2456	54969	2331	0.949	1.266
B-H	0.2	0.3	0.05	5	0.405	0.304	39200	96819	38446	0.981	1.308
B-H	0.2	0.3	0.20	5	0.175	0.131	21411	122555	20667	0.965	1.287
B-H	0.3	0.1	0.05	5	0.329	0.246	5447	16579	5331	0.979	1.305
B-H	0.3	0.1	0.20	5	0.159	0.119	3105	19555	2992	0.964	1.285
B-H	0.3	0.2	0.05	5	0.499	0.374	20371	40864	19984	0.981	1.308
B-H	0.3	0.2	0.20	5	0.217	0.163	11226	51639	10833	0.965	1.287
B-H	0.3	0.3	0.05	9	0.926	0.695	61113	65962	60059	0.983	1.310
B-H	0.3	0.3	0.05	5	0.651	0.489	36410	55889	35756	0.982	1.309
B-H	0.3	0.3	0.05	3	0.395	0.297	19438	49150	19011	0.978	1.304
B-H	0.3	0.3	0.20	9	0.337	0.253	31391	93032	30363	0.967	1.290
B-H	0.3	0.3	0.20	5	0.264	0.198	19555	73941	18888	0.966	1.288
B-H	0.3	0.3	0.20	3	0.195	0.146	11114	57070	10707	0.963	1.285
B-H	0.3	0.3	0.50	9	0.115	0.087	8917	77240	8492	0.952	1.270
B-H	0.3	0.3	0.50	5	0.096	0.072	5738	59609	5458	0.951	1.268
B-H	0.3	0.3	0.50	3	0.077	0.058	3399	44086	3228	0.950	1.267
R	0.2	0.2	0.05	5	0.669	0.502	30262	45243	29096	0.962	1.282
R	0.2	0.2	0.20	5	0.190	0.142	23630	124380	22459	0.950	1.267
R	0.2	0.2	0.50	5	0.061	0.045	9037	149062	8522	0.943	1.257
R	0.3	0.3	0.05	5	1.458	1.094	50728	34784	48840	0.963	1.284
R	0.3	0.3	0.20	5	0.358	0.268	35826	100105	34121	0.952	1.270
R	0.3	0.3	0.50	5	0.107	0.080	13120	122951	12385	0.944	1.259

APPENDIX III. Relationship between Fishing Mortality Rates and Exploitation Rates

Fishing mortality rates (F) are instantaneous rates, akin to the concept of compound interest, but measured on an exponential scale. They are used as a mathematical convenience to deal with the fact that several sources of mortality are acting simultaneously. Natural mortality rates (M) are also expressed in instantaneous terms. The sum of fishing mortality and natural mortality is the total instantaneous mortality, Z. Instantaneous rates range from 0 to ∞. A simple formula is required to annualise instantaneous rates. For example, the exploitation rate (E), which is the annualised fishing mortality rate (expressed as a percentage), is obtained by:

$$E = \frac{F}{Z}(1 - e^{-Z}) * 100\%$$

where e is the exponentiation function, and the other symbols are defined above.

The relationship between F and exploitation rate depends on the value of M, as shown in the table below. Zero fishing mortality equates to zero exploitation rate, while infinite fishing mortality equates to 100% exploitation rate. For low F (≤ 0.3) and low M (≤ 0.2), the exploitation rate expressed as a proportion is similar to the fishing morality rate.

Table A2: Relationship between fishing mortality rates and exploitation rates

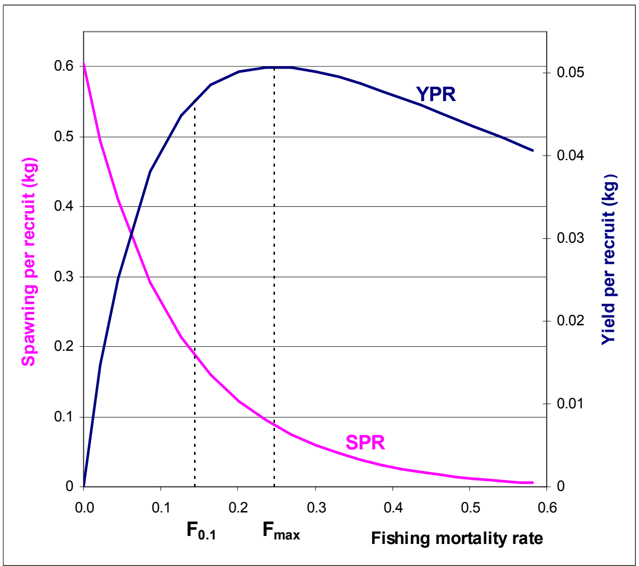
M	F	Z= F+M	Exploit-ation rate (%)	M	F	Z= F+M	Exploit-ation rate (%)	M	F	Z= F+M	Exploit-ation rate (%)
0.1	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.3	0.0	0.3	0.0
	0.05	0.15	4.6		0.05	0.25	4.4		0.05	0.35	4.2
	0.1	0.2	9.1		0.1	0.3	8.6		0.1	0.4	8.2
	0.15	0.25	13.3		0.15	0.35	12.7		0.15	0.45	12.1
	0.2	0.3	17.3		0.2	0.4	16.5		0.2	0.5	15.7
	0.25	0.35	21.1		0.25	0.45	20.1		0.25	0.55	19.2
	0.3	0.4	24.7		0.3	0.5	23.6		0.3	0.6	22.6
	0.35	0.45	28.2		0.35	0.55	26.9		0.35	0.65	25.7
	0.4	0.5	31.5		0.4	0.6	30.1		0.4	0.7	28.8
	0.45	0.55	34.6		0.45	0.65	33.1		0.45	0.75	31.7
	0.5	0.6	37.6		0.5	0.7	36.0		0.5	0.8	34.4
	0.6	0.7	43.1		0.6	0.8	41.3		0.6	0.9	39.6
	0.7	0.8	48.2		0.7	0.9	46.2		0.7	1	44.2
	0.8	0.9	52.7		0.8	1	50.6		0.8	1.1	48.5
	0.9	1	56.9		0.9	1.1	54.6		0.9	1.2	52.4
	1	1.1	60.6		1	1.2	58.2		1	1.3	56.0
	1.1	1.2	64.1		1.1	1.3	61.6		1.1	1.4	59.2
	1.2	1.3	67.2		1.2	1.4	64.6		1.2	1.5	62.1
	1.3	1.4	70.0		1.3	1.5	67.3		1.3	1.6	64.8
	1.4	1.5	72.5		1.4	1.6	69.8		1.4	1.7	67.3
	1.5	1.6	74.8		1.5	1.7	72.1		1.5	1.8	69.6
	2	2.1	83.6		2	2.2	80.8		2	2.3	78.2
	2.5	2.6	89.0		2.5	2.7	86.4		2.5	2.8	83.9
	3	3.1	92.4		3	3.2	89.9		3	3.3	87.6
	5	5.1	97.4		5	5.2	95.6		5	5.3	93.9
	10	10.1	99.0		10	10.2	98.0		10	10.3	97.1

APPENDIX IV. Yield per Recruit and Spawning Biomass per Recruit Analyses, with Associated Reference Points

Yield per recruit calculations (left diagram, YPR curve, plotted on the right-hand axis) are based on growth (average weights at age), natural mortality at age, and the extent to which fish of a given age are vulnerable to a fishery (e.g. small juvenile fish may not be fully vulnerable to a fishery, either because they mostly occur in different areas, or because they are too small to be retained by fishing gear). As fishing mortality rates (essentially the percentage of a stock removed by fishing in a given fishing year) increase above zero, yield per recruit increases rapidly at first, then reaches a peak and usually begins to decline.

Yield per recruit curves are most commonly expressed in terms of fishing mortality, but the relationship between fishing mortality and exploitation rate is relatively straightforward and the shape of the curves resulting from the two different metrics is similar. The fishing mortality rate that corresponds to the maximum yield per recruit is called F_{MAX}. E_{MAX} is simply the equivalent quantity expressed as an exploitation rate (see **Appendix III**). Neither value can be estimated when the yield per recruit curve is flat-topped, as is often the case. For this reason, and because yield per recruit calculations do not take account of the likelihood that the number of recruits declines with declining spawning biomass, $F_{0.1}$ is often preferred over F_{MAX} as a biological reference point. $F_{0.1}$ is the fishing mortality rate at which the slope of the yield per recruit curve as a function of fishing mortality is 10% of its value at the origin. $F_{0.1}$ is always less than F_{MAX}.

Spawning (biomass) per recruit calculations (left diagram, SPR curve, plotted on the left-hand axis; right diagram, plotted by itself in terms of a percentage of the maximum) are based on the same information as yield per recruit calculations, with the addition of a maturity ogive, which expresses the proportion of individuals of a given age that are mature. Spawning per recruit is essentially the *mature* fish that are left over after fishing has taken place (spawning per recruit can also be expressed in terms of the number of eggs and related metrics). Note that the catch can include immature fish so yield per recruit and spawning per recruit are not necessarily directly complementary.



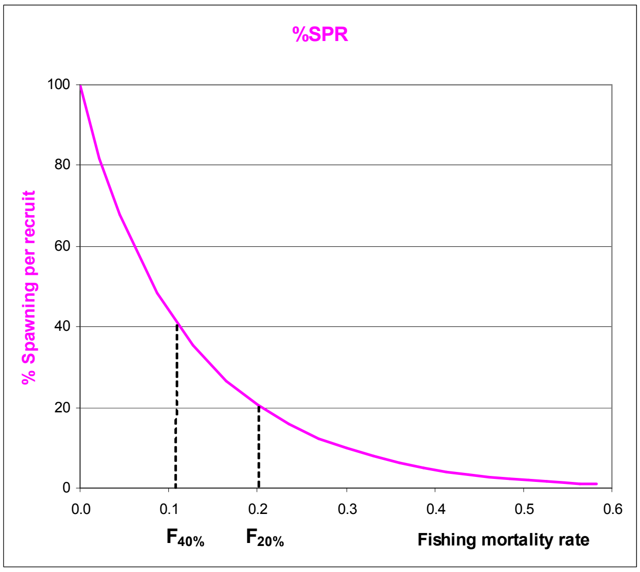


Figure A1: Yield per recruit and spawning biomass per recruit as a function of fishing mortality, with associated candidate reference points or benchmarks.

Spawning (biomass) per recruit is always at a maximum when there is no fishing. Thereafter, it decreases rapidly as fishing mortality rates increase. It is often plotted as a percentage of its maximum (right diagram) in order to estimate biological reference points that are in a common currency across different species. These reference points are expressed as $F_{\%SPR}$, the exploitation rate corresponding to a specified percentage of the maximum spawning (biomass) per recruit. For example, the two reference points plotted on the right diagram are the fishing mortality rates corresponding to 40% and 20% of the maximum SPR. SPR reference points of the order of $F_{20\%}$ - $F_{35\%}$ are frequently used as targets for relatively high productivity species, whereas those of the order of $F_{40\%}$ - $F_{60\%}$ may be used as targets for low productivity species.

APPENDIX V. Methods of Estimating Maximum Constant Yield (MCY) from the Ministry of Fisheries (2011) Fisheries Assessment Plenary

Methods for estimating MCY are outlined in Ministry of Fisheries (2011), beginning on page 27. These methods have not been revised since 1992 and need to be updated in the future.

"Methods of Estimating *MCY*

It should be possible to estimate ***MCY*** for most fish stocks (with varying degrees of confidence). For some stocks, only conservative estimates for ***MCY*** will be obtainable (e.g., some applications of Method 4) and this should be stated. For other stocks it may be impossible to estimate ***MCY***. These stocks include situations in which: the fishery is very new; catch or effort data are unreliable; strong upwards or downwards trends in catch are not able to be explained by available data, (e.g., by trawl survey data or by catch per unit effort data).

When catch data are used in estimating ***MCY*** all catches (commercial, illegal, and non-commercial) should be included if possible. If this is not possible and the excluded catch is thought to be a significant quantity, then this should be stated.

The following examples define ***MCY*** 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 Quota Management System) should play a part in determining which data sets are to be included in the analysis.

As a general rule it is preferable to apply subjective judgements to input data rather than to the calculated ***MCY***s. For example, rather than saying "with the official catch statistics the ***MCY*** is ***X*** tonnes, but we think this is too high because the catch statistics are wrong" it would be better to say "we believe (for reasons given) that the official statistics are wrong and the true catches were probably such and such, and the ***MCY*** based on these catches is ***Y*** tones".

Background information on the rationale behind the following calculation methods can be found in Mace (1988a) and other scientific papers listed at the end of this document.

1. New fisheries

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

where B_0 is an estimate of virgin recruited biomass. If there are insufficient data to conduct a yield per recruit analysis $F_{0.1}$ should be replaced with an estimate of natural mortality (M). 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 $0.5MB_0$ (Gulland 1971). However various authors (including Beddington and Cooke 1983; Getz et al. 1987; Mace 1988a) have shown that $0.5MB_0$ 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 down.

It is preferable to estimate ***MCY*** from a stochastic population model (Method 5), if this is possible. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply $F_{0.1}B_0$ may be somewhat higher or somewhat lower than **0.25**. This depends primarily on the steepness of the assumed stock recruitment relationship (*see* Francis 1992 for a definition of steepness).

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

2. Developed fisheries with historic estimates of biomass

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

where 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***). This formulation assumes that $F_{0.1}$ approximates the average productivity of a stock.

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 population model

$$MCY = 2/3\ MSY$$

where ***MSY*** is the deterministic maximum equilibrium yield.

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***.

If it is possible to estimate ***MSY*** then it is generally possible to estimate ***MCY*** from a stochastic population model (Method 5), which is the preferable method. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply ***MSY*** varies between about **0.6** and **0.9**. This depends on various parameters of which the steepness of the assumed stock recruitment relationship is the most important.

If the current biomass is less than the level required to sustain a yield of 2/3 ***MSY*** then

$$MCY = 2/3\ CSP$$

where ***CSP*** is the deterministic current surplus production.

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

$$MCY = cY_{av}$$

where ***c*** is the natural variability factor (defined below) 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, $\boldsymbol{Y_{av}} = \boldsymbol{MAY}$. If the population was under-exploited the method gives a conservative estimate of ***MCY***.

Familiarity with stock demographics and the history of the fishery is necessary for the determination of an appropriate period on which to base estimates of $\boldsymbol{Y_{av}}$. The period chosen to perform the averaging will depend on the behaviour of the fishing mortality or fishing effort time series, the prevailing management regime, the behaviour of the catch time series, and the lifespan of the species.

The period should be selected so that it contains no systematic changes in fishing mortality (or fishing effort, if this can be assumed to be proportional to fishing mortality). Note that for species such as orange roughy, where relatively static aggregations are fished, fishing mortality cannot be assumed to be proportional to effort. If catches during the period are constrained by a TACC then it is particularly important that the assumption of no systematic change in fishing mortality be adhered to. The existence of a TACC does not necessarily mean that the catch is constrained by it.

The period chosen should also contain no systematic changes in catch. If the period shows a systematic upward (or downward) trend in catches then the ***MCY*** will be under-estimated (over-estimated). It is desirable that the period be equal to at least half the exploited life span of the fish."

"Natural Variability Factor

Fish populations are naturally variable in size because of environmental variability and associated fluctuations in the abundance of predators and food. Computer simulations (e.g., Mace 1988a) have shown that, all other things being equal, the ***MCY*** for a stock is inversely related to the degree of natural variability in its abundance. That is, the higher the natural variability, the lower the ***MCY***.

The natural variability factor, ***c***, provides a way of incorporating the natural variability of a stock's biomass into the calculation of ***MCY***. It is used as a multiplying factor in method 5 below. The greater the variability in the stock, the lower is the value of ***c***. Values for ***c*** should be taken from the table below and are based on the estimated mean natural mortality rate of the stock. It is assumed that because a stock with a higher natural mortality will have fewer age-classes it will also suffer greater fluctuations in biomass. The only stocks for which the table should be deviated from are those where there is evidence that recruitment variability is unusually high or unusually low."

Natural mortality rate ***M***	**Natural variability factor** ***c***
<0.05	1.0
0.05–0.15	0.9
0.16–0.25	0.8
0.26–0.35	0.7
>0.35	0.6

APPENDIX VI. Status Determination Criteria used for United States Fisheries

This Appendix gives a summary of the US "status determination criteria" for stocks subject to overfishing, overfished or approaching an overfished condition". It is a summary of definitions contained in Appendices 3 and 4 of the 2006 report on the Status of U.S. Fisheries. Stocks with long or complex definitions have been omitted for brevity. MSST is the minimum stock size threshold and MFMT is the maximum fishing mortality threshold. In the context of the New Zealand Harvest Strategy Standard, the use of the term "threshold" in US fisheries management is the equivalent of the New Zealand "soft limit."

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
NON-FEDERAL FISHERY MANAGEMENT PLANS		
Northern Shrimp	$F_{TARGET} > F_{50\%}$ ($F_{LIMIT} = F_{20\%}$)	$B_{CURRENT} < B_{THRESHOLD}$ (B_{LIM} = 6000 Metric Tons)
Striped Bass	$F > F_{MSY}$	Female SSB < Threshold SSB
Tautog	F=M	Undefined
Weakfish	$F_{THRESHOLD} > F_{20\%}$ ($F_{TARGET} = 0.31$)	$B_{CURRENT} < SSB_{20\%}$
Atlantic Croaker	$F > F_{MSY}$ ($F_{TARGET} = 0.75\ F_{MSY}$)	$B_{CURRENT} <$ 70% SSB_{MSY} ($B_{TARGET} = SSB_{MSY}$)
CONTAINED IN FEDERAL FISHERY MANGEMENT PLANS		
Atlantic Scallop	When either one of the three conditions apply; $F > F_{MAX}$ ($F_{MSY\ proxy}$) when $B_{CURRENT} \leq B_{MAX}$ ($B_{MSY\ proxy}$); fishing mortality exceeds the level that has a 50% probability of achieving B_{MAX} in 10 years when the stock biomass is below B_{MAX} but above ½B_{MAX}, and in that case overfishing occurs when F is above a level to rebuild in 5 years; or F is greater than zero and the stock biomass is below ¼B_{MAX}	$B_{CURRENT} <$ ½ B_{MAX}
NORTH-EAST MULTISPECIES		
Cod -Gulf of Maine, Georges Bank	$F > F_{MSY}$	Total stock biomass < ½ B_{MSY}
Haddock - Gulf of Maine	Relative exploitation index > F_{MSY}	Total stock biomass < the survey proxy for ½ B_{MSY}
Haddock - Georges Bank	$F > F_{40\%}$	SSB < ½ B_{MSY}
American Plaice	″	″
Redfish	$F > F_{50\%}$	SSB < ½ B_{MSY}, where B_{MSY} is based on total biomass

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Witch Flounder	F > the $F_{MSY\ proxy}$ ($F_{40\%}$)	Total stock biomass < ½ B_{MSY}
Yellowtail Flounder - Georges Bank, Southern New England/Mid Atlantic, Cape Cod/Gulf of Maine	F > F_{MSY}	″
White Hake	F > $F_{MSY\ proxy}$	Total stock biomass < ½ $B_{MSY\ proxy}$
Pollock	F > $F_{MSY\ proxy}$, a relative exploitation index	Total stock biomass < the survey proxy for ½ B_{MSY}
Ocean Pout	F > $F_{MSY\ proxy}$	Total stock biomass < ½ $B_{MSY\ proxy}$
Atlantic Halibut	F > F_{MSY} catch YPR proxy	Total stock biomass < ½ B_{MSY}
Windowpane Flounder - Gulf of Maine/Georges Bank, Southern New England/ Middle Atlantic	F > $F_{MSY\ proxy}$ of a relative exploitation index	Total stock biomass < ½ $B_{MSY\ proxy}$
Winter Flounder - Gulf of Maine, Georges Bank, Southern New England	F > F_{MSY}	Total stock biomass < ½ B_{MSY}
Silver Hake - Gulf of Maine/Northern Georges Bank, Southern Georges Bank/ Middle Atlantic	F > $F_{MSY,}$ proxy exploitation index	Total stock biomass < ½ $B_{MSY\ proxy}$
Red Hake -Gulf of Maine/ Northern Georges Bank	F > F_{MSY}	″
ATLANTIC HERRING		
Atlantic Herring	If $B_{CURRENT} \geq B_{MSY}$ overfishing occurs when $F>F_{MSY}$. If $B_{CURRENT} < B_{MSY}$ overfishing occurs when F > 50% probability of rebuilding to B_{MSY} in 5 years.	Total stock biomass < ½ $B_{MSY\ proxy}$
MONKFISH		
Monkfish -Northern and Southern Stocks	F > $F_{THRESHOLD}$, which is set equal to F_{MAX}.	Survey index< $B_{THRESHOLD}$ = ½ B_{TARGET}
SPINY DOGFISH		
Spiny Dogfish	F > $F_{THRESHOLD}$	$B_{CURRENT}$ > ½ SSB_{MAX}
SUMMER FLOUNDER, SCUP and BLACK SEA BASS		
Summer Flounder	F > the threshold of F_{MAX} (F_{MAX} is used as a proxy for F_{MSY})	Total stock biomass < ½ B_{MSY} (the minimum biomass threshold).
Scup	″	Biomass index < $B_{THRESHOLD}$
Black Sea Bass	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
BLUE FISH (except Gulf of Mexico)		
Bluefish	F > the threshold F_{MSY}	Minimum biomass < ½B_{MSY}
ATLANTIC SURFCLAM and OCEAN QUAHOG		
Surfclam	$F > F_{MSY} = M$	$B_{CURRENT}$ < ½ $B_{MSY\ proxy}$
Ocean Quahog	When the overfishing target is exceeded which is $F_{TARGET} = F_{0.1}$	Minimum stock biomass < ½ B_{MSY} or ¼ B_0 (threshold)
ATLANTIC MACKEREL, SQUID, and BUTTERFISH		
Illex Squid	$F>F_{MSY}$	Minimum biomass < ½ B_{MSY}
Loligo Squid	$F > F_{MAX}$ (F_{MAX} is a proxy for F_{MSY})	〃
Atlantic Mackerel	$F > F_{MSY}$	SSB < a set metric tonnage
Atlantic Butterfish	$F > F_{MSY}$ Overfishing is defined as $F_{0.1}$	Minimum biomass < ½ B_{MSY}
TILEFISH		
Golden TileFish (except south Atlantic and Gulf of Mexico)	$F > F_{MSY}$	Total stock biomass < ½ B_{MSY} (minimum biomass threshold)
GOLDEN CRAB OF THE SOUTH ATLANTIC		
Golden Crab	$F > F_{MSY}$	$B_{CURRENT}$ < MSST (minimum stock size threshold) (where MSST = (1-M)*B_{MSY})
SOUTH ATLANTIC SNAPPER-GROUPER		
Tilefish	F > MFMT = F_{MSY}	Stock size < MSST (where MSST = (1-M)*B_{MSY})
Snowy Grouper	〃	〃
Black Sea Bass	〃	〃
Red Porgy	〃	〃
Gag	F > MFMT = F_{MSY} (where $F_{MSY} = F_{30\%\ SPR}$)	〃
Greater Amberjack	〃	〃
Vermilion Snapper	F > MFMT = F_{MSY}	Stock size < MSST = (1-c)B_{MSY} (where c is the lesser of M or ½ M)
Nassau Grouper	F > MFMT = F_{MSY} (where $F_{MSY} = F_{40\%SPR}$)	Stock size < MSST (where MSST = (1-M)*B_{MSY})
Red Snapper	F > MFMT = F_{MSY} (where $F_{MSY} = F_{30\%SPR}$)	〃
Speckled Hind	〃	〃
Scamp	〃	〃
White Grunt	〃	〃
Gray Triggerfish	〃	〃
Red Grouper	〃	〃
Black Grouper	〃	〃
Yellowedge Grouper	〃	〃

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Warsaw Grouper	″	″
Wreckfish	″	″
Lane Snapper	″	″
Mutton Snapper	″	″
Gray (Mangrove) Snapper	″	″
Queen Triggerfish	″	″
Ocean Triggerfish	″	″
Yellow Jack	″	″
Blue Runner	″	″
Crevalle Jack	″	″
Bar Jack	″	″
Lesser Amberjack	″	″
Almaco Jack	″	″
Banded Rudderfish	″	″
Atlantic Spadefish	″	″
Black Margate	″	″
Porkfish	″	″
Margate	″	″
Tomtate	″	″
Smallmouth Grunt	″	″
French Grunt	″	″
Spanish Grunt	″	″
Cottonwick	″	″
Sailors Choice	″	″
Bluestriped Grunt	″	″
Hogfish	″	″
Puddingwife	″	″
Black Snapper	″	″
Queens Snapper	″	″
Schoolmaster	″	″
Blackfin Snapper	″	″
Cubera Snapper	″	″
Mahogany Snapper	″	″
Dog Snapper	″	″
Silk Snapper	″	″
Blueline Tilefish	″	″
Bank Sea Bass	″	″
Rock Hind	″	″
Graysby	″	″
Coney	″	″
Red Hind	″	″
Misty Grouper	″	″
Yellow Mouth Grouper	″	″
Tiger Grouper	″	″
Yellowfin Grouper	″	″
Sheepshead	″	″
Grass Porgy	″	″
Jolthead Porgy	″	″
Saucereye Porgy	″	″
Whitebone Porgy	″	″
Knobbed Porgy	″	″
Longspine Porgy	″	″
Scup	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
SOUTH ATLANTIC SNAPPER-GROUPER and REEF FISH RESOURCES OF THE GULF OF MEXICO		
Goliath Grouper	$F > F_{40\% \text{ Static SPR}}$	Stock size < MSST
Yellowtail Snapper	$F > MFMT = F_{MSY}$	Stock size < MSST = $(1-c)B_{MSY}$ (where c is the lesser of M or ½ M)
ATLANTIC COAST RED DRUM		
Red Drum	$F > MFMT = F_{MSY}$ (where $F_{MSY} = F_{30\%SPR}$)	Stock size < MSST (where MSST $=(1-M)*B_{MSY}$)
CORAL, CORAL REEFS, AND LIVE / HARD BOTTOM HABITATS OF THE SOUTH ATLANTIC REGION		
Fire Corals, Hydrocorals, Octocorals, Stony Corals and Black Corals	An annual level of harvest that exceeds the optimum yield.	Stock size < MSST (where MSST $=(1-M)*B_{MSY}$)
DOLPHIN WAHOO		
Wahoo	$F > F_{MSY}$ (where $F_{MSY} = F_{30\% \text{ Static SPR}}$)	$B_{CURRENT}$ < MSST (where MSST = $(1-M)*B_{MSY}$. Recovered when $B_{CURRENT} \geq B_{MSY}$)
DOLPHIN WAHOO AND COASTAL MIGRATORY PELAGICS OF THE GULF OF MEXICO AND SOUTH ATLANTIC		
Dolphin	$F > F_{MSY}$ (where $F_{MSY} = F_{30\% \text{ Static SPR}}$)	$B_{CURRENT}$ < MSST (where MSST = $(1-M)*B_{MSY}$. Recovered when $B_{CURRENT} \geq B_{MSY}$)
King Mackerel – Gulf Group	$F > MFMT = F_{MSY}$ (where $F_{MSY} = F_{30\%SPR}$)	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$ or 80% B_{MSY})
King Mackerel – Atlantic Group	″	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$ or 85% B_{MSY})
Spanish Mackerel – Gulf Group	″	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$ or 70% B_{MSY})
Spanish Mackerel – Atlantic Group	″	″
Little Tunny	$F > F_{30\% \text{ Static SPR}}$	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$) (South Atlantic)
Cobia	$F > MFMT = F_{MSY}$ (where $F_{MSY} = F_{30\%SPR}$)	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$ or 70% B_{MSY})
Cero Mackerel	$F > F_{30\% \text{ Static SPR}}$	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$)
Bluefish – Gulf of Mexico only	″	″
SPINY LOBSTER FISHERY OF THE SOUTH ATLANTIC AND GULF OF MEXICO		
Spiny Lobster	$F > F_{MSY}$ (where $F_{MSY} = F_{20\% \text{ SPR}}$)	Stock size < MSST (where MSST = $(1-M)*B_{MSY}$)

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
REEF FISH OF THE GULF OF MEXICO		
Red Snapper	F > MFMT = F_{MSY}	Stock size < MSST (where MSST = (1-M)*B_{MSY})
Red Grouper	″	Stock size < MSST (where MSST = (1-c)*B_{MSY}, where c is the lesser of M or ½ M)
Greater Amberjack	F > $F_{30\% \text{ Static SPR}}$	″
Vermillion Snapper	MFMT = F_{MSY}	Stock size < MSST (where MSST = (1-M)B_{MSY})
Nassau Grouper	F > $F_{40\% \text{ Static SPR}}$	Undefined
Gag	F > $F_{30\% \text{ Static SPR}}$	″
Gray Triggerfish	″	″
Lesser Amberjack	″	″
Almaco Jack	″	″
Banded Rudderfish	″	″
Queen Snapper	″	″
Mutton Snapper	″	″
Schoolmaster	″	″
Blackfin Snapper	″	″
Cubera Snapper	″	″
Gray (Mangrove) Snapper	″	″
Dog Snapper	″	″
Mahogony Snapper	″	″
Lane Snapper	″	″
Silk Snapper	″	″
Wenchman	″	″
Goldface Tilefish	″	″
Blackline Tilefish	″	″
Anchor Tilefish	″	″
Blueline Tilefish	″	″
Tilefish	″	″
Rock Hind	″	″
Speckled Hind	″	″
Yellowedge Grouper	″	″
Red Hind	″	″
Misty Grouper	″	″
Warsaw Grouper	″	″
Snowy Grouper	″	″
Black Grouper	″	″
Yellowmouth Grouper	″	″
Scamp	″	″
Yellowfin Grouper	″	″
Hogfish	″	″
Dwarf Sand Perch	″	″
Sand Perch	″	″
Gulf of Mexico Red Drum	″	″
SPINY LOBSTER AND QUEEN CONCH FISHERIES OF THE PUERTO RICO AND U.S. VIRGIN ISLANDS		
Spiny Lobster	F > MFMT = F_{MSY} (If data are not sufficient to estimate F_{MSY} M is used as a proxy)	Stock size < MSST (where MSST = (1-c)*B_{MSY}, where c is the lesser of M or ½ M)

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Queen Conch	F > MFMT = F_{MSY}	″
REEF FISH OF THE PUERTO RICO AND U.S. VIRGIN ISLANDS		
Snapper Unit 1 (Silk Snapper, Blackfin Snapper, Black Snapper, Vermillion Snapper)	F > MFMT = F_{MSY}	Stock size < MSST (where MSST = (1-c)*B_{MSY}, where c is the lesser of M or ½ M)
Snapper Unit 2 (Queen Snapper, Wenchman)	″	″
Snapper Unit 3, (Gray Snapper, Lane Snapper, Mutton Snapper, Dog Snapper, Schoolmaster, Mahogany Snapper)	″	″
Snapper Unit 4 (Yellowtail Snapper)	″	″
Grouper Unit 1 (Nassau Grouper)	″	″
Grouper Unit 2 (Goliath Grouper)	″	″
Grouper Unit 3 (Red Hind, Coney, Rock Hind, Graysby, Creole-fish)	″	″
Grouper Unit 4 (Red Grouper, Yellowedge Grouper, Misty Grouper, Tiger Grouper, Yellowfin Grouper)	″	″
WASHINGTON, OREGON AND CALIFORNIA GROUNDFISH		
Lingcod	Yield > F_{MSY} (The default F_{MSY} proxy used for setting acceptable biological catches (ABC) is $F_{45\%}$ for other groundfish such as sablefish and ling cod)	$B_{CURRENT}$ < 25% $B_{0,}$ or if $B_{CURRENT}$ < 50%B_{MSY}
Cabeson South	″	″
Kelp Greenling – Oregon	″	″
California Scorpionfish	″	″
Pacific Cod	″	″
Pacific Ocean Perch	Yield > F_{MSY} (The default F_{MSY} proxy used for setting ABC is $F_{50\%}$ for rockfish incl. thornyheads)	″
Bocaccio	″	″
Canary rockfish	″	″
Cowcod	″	″
Darkblotched rockfish	″	″
Widow rockfish	″	″
Yelloweye rockfish	″	″
Bank rockfish	″	″
Shortspine thornyhead	″	″
Longspine thornyhead	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Yellowtail rockfish	″	″
Chillipepper rockfish	″	″
Black rockfish –North	″	″
Blackgill rockfish	″	″
Gopher rockfish	″	″
Silvergrey rockfish	″	″
Shortbelly rockfish	"	The last assessment was conducted prior to the current sustainable fisheries act, hence no overfishing definitions available
Pacific Whiting	Yield > F_{MSY} (The default F_{MSY} proxy used for setting ABC is $F_{40\%}$ for flatfish and Whiting)	″
Drover sole	″	″
English sole	″	″
Petrale sole	″	″
Starry flounder	″	″
Arrowtooth flounder	″	The last assessment was conducted prior to the current sustainable fisheries act, hence no overfishing definitions available
Sablefish	Yield > F_{MSY} (The default F_{MSY} proxy used for setting ABC is $F_{45\%}$ for other groundfish such as sablefish and ling cod)	″
COASTAL PELAGIC SPECIES		
Jack Mackerel	Yield > ABC which is based on the default MSY control rule used for monitored species, is at least at 25% of estimated MSY	When the biomass level is low enough to jeopardise the capacity of the stock to produce MSY on a continuing basis
Northern Anchovy – Central and Northern Subpopulations	″	″
WEST COAST HIGHLY MIGRATORY SPECIES (HMS)		
Skipjack Tuna – Eastern Pacific	$F > F_{MSY} B / c B_{MSY}$ if the stock biomass $\leq c B_{MSY}$ or $F > F_{MSY}$ if the stock biomass $> c B_{MSY}$ (where c is equal to the greater of 1-M and 0.5)	Stock biomass $< c B_{MSY}$ (where c is equal to the greater of 1-M and 0.5)
Yellowfin Tuna – Eastern Pacific	″	″
Albacore – North Pacific	″	″
Bigeye Tuna – Eastern Pacific	″	″
Bluefin Tuna – Pacific	″	″
Common Thresher Shark – North Pacific	″	″
Bigeye Thresher Shark – North Pacific	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Pelagic Thresher Shark – North Pacific	″	″
Short Fin Mako Shark – North Pacific	″	″
PELAGIC FISHERIES OF THE WESTERN PACIFIC		
Yellowfin Tuna – Central Western Pacific	$F > F_{MSY}$ B / c B_{MSY} if the stock biomass ≤ c B_{MSY} or $F > F_{MSY}$ if the stock biomass > c B_{MSY} (where c is equal to the greater of 1-M and 0.5)	Stock biomass < c B_{MSY} (where c is equal to the greater of 1-M and 0.5)
Skipjack Tuna – Central Western Pacific	″	″
Striped Marlin – Central Western Pacific	″	″
Albacore – South Pacific	″	″
Indo-Pacific Blue Marlin – Pacific	″	″
Shortbill Spearfish – Pacific	″	″
Wahoo – Pacific	″	″
Kawakawa – Tropical Pacific	″	″
Moonfish (Opah) – Pacific	″	″
Other tuna relatives (Auxis spp, Scomber spp and Allothunnus spp,) – Tropical Pacific	″	″
Black Marlin – Pacific	″	″
Pomfrets – Pacific	″	″
Sailfish – Pacific	″	″
Oilfish family – Western Pacific	″	″
Longfin Mako – North Pacific	″	″
Silky Shark – Tropical Pacific	″	″
Oceanic Whitetip Shark – Tropical Pacific	″	″
Salmon Shark – North Pacific	″	″
PELAGIC FISHERIES OF THE WESTERN PACIFIC and WEST COAST HMS		
Albacore – North Pacific	$F > F_{MSY}$ B / c B_{MSY} if the stock biomass ≤ c B_{MSY} or $F > F_{MSY}$ if the stock biomass > c B_{MSY} (where c is equal to the greater of 1-M and 0.5)	Stock biomass < c B_{MSY} (where c is equal to the greater of 1-M and 0.5)
Dolphinfish (Dorado or Mahimahi) – Pacific	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Bluefin Tuna – Pacific	″	″
Common Thresher Shark – North Pacific	″	″
Bigeye Thresher Shark – North Pacific	″	″
Pelagic Thresher Shark – North Pacific	″	″
Shortfin Mako Shark – North Pacific	″	″
Bigeye Tuna – Western Pacific	″	″
Swordfish – North Pacific	″	″
Blue Shark – North Pacific	″	″
CRUSTACEANS OF THE WESTERN PACIFIC		
Lobster complex (Red and Green spiny lobster and Common, Chinese and Giant slipper lobster) – Northwestern Hawaiian Islands	$F > F_{MSY}\ B / B_{MSY}$ if the stock $B \leq B_{MSY}$, or $F > F_{MSY}$ if the stock $B > B_{MSY}$	Stock biomass < c B_{MSY} (where c is equal to the greater of 1-M and 0.5). CPUE is used as a proxy for B
BOTTOMFISH AND SEAMOUNT GROUNDFISH OF THE WESTERN PACIFIC		
Bottomfish multi-species complex – Hawaiian Archipelago, American Samoa, Northern Mariana Islands, Guam	$F > F_{MSY}\ B / c\ B_{MSY}$ if the stock $B \leq c\ B_{MSY}$, or $F > F_{MSY}$ if the stock $B > c\ B_{MSY}$ (where c is equal to the greater of 1-M and 0.5.). Effort is used as a proxy for F	Stock biomass < c B_{MSY} (where c is equal to or greater than 1-M and 0.5. CPUE is used as a proxy for B)
Seamount Groundfish complex – Hancock Seamount	″	″
CORAL REEF ECOSYSTEMS OF THE WESTERN PACIFIC		
Coral reef ecosystem multi-species complex, Bigeye Scad, Mackerel Scad, – Hawaiian Archipelago, American Samoa, Northern Mariana Islands, Guam, and Remote Pacific Islands	$F > F_{MSY}\ B / c\ B_{MSY}$ if the stock $B \leq c\ B_{MSY}$, or $F > F_{MSY}$ if the stock $B > c\ B_{MSY}$ (where c is equal to the greater of 1-M and 0.5.). Effort is used as a proxy for F	Stock biomass < c B_{MSY} (where c is equal to or greater than 1-M and 0.5. CPUE is used as a proxy for B)
GULF OF ALASKA GROUNDFISH		
Walleye Pollock - Western/Central	F > MFMT	Stock biomass < MSST (where MSST is the greater of; ½$B_{MSY;}$ or the minimum stock size at which rebuilding to the MSY level

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
		would be expected to occur within 10 years if the stock were exploited at MFMT)
Pacific Cod	″	″
Arrowtooth Flounder	″	″
Pacific Ocean Perch (Includes Western, Central and Eastern)	″	″
Northern Rockfish – Western/Central	″	″
Flathead Sole	″	″
Dusky Rockfish	″	″
Dover Sole	″	″
Rex Sole	″	″
Rougheye Rockfish	″	″
Other Slope Rockfish Complex (consists of Blackgill Rockfish, Bocaccio, Chillipepper, Darkblotched Rockfish, Greenstriped Rockfish, Harlequin Rockfish, Northern Rockfish (Eastern GOA only), pygmy Rockfish, Redbanded Rockfish, Redstriped Rockfish, Sharpchin Rockfish, Silvergrey Rockfish, Splitnose Rockfish, Stripetail Rockfish, Vermillion Rockfish and Yellowmouth Rockfish)	″	″
Walleye Pollock – Eastern	″	No B_{MSY} estimate exists, therefore MSST is not defined.
Atka Mackerel	″	″
Shortspine Thornyhead	″	″
Yelloweye Rockfish	″	″
Shallow Water Flatfish Complex (Consists of, Alaska Plaice, Butter Sole, C-O Sole, Curlfin Sole, English Sole, Northern Rock Sole, Pacific Sanddab, Petrale Sole, Sand Sole, Southern Rock Sole, Speckled Sanddab, Starry Flounder and Yellowfin Sole)	″	″
Big Skate	″	″
Longnose Skate	″	″
Other Skate Complexes (Consists of Alaska Skate, Aleutian Skate, Bering Skate, Deepsea	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Skate, Roughshoulder Skate, Roughtail Skate and White blotched Skate)		
Shortraker Rockfish	″	″
BERING SEA/ALEUTIAN ISLANDS GROUNDFISH		
Walleye Pollock – Eastern Bering Sea	F > MFMT	Stock biomass < MSST (where MSST is the greater of; ½B_{MSY}, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were exploited at MFMT)
Walleye Pollock – Aleutian Islands	″	″
Pacific Cod	″	″
Yellowfin Sole	″	″
Greenland Turbot	″	″
Arrowtooth Flounder	″	″
Rock Sole	″	″
Flathead Sole	″	″
Pacific Ocean Perch	″	″
Atka Mackerel	″	″
Alaska Plaice	″	″
Northern Rockfish	″	″
Rougheye Rockfish	″	No B_{MSY} estimate exists, therefore MSST is not defined.
Walleye Pollock – Bogoslof	″	″
Shortraker Rockfish	″	″
Other Rockfish Complex (sp. not detailed)	″	″
Other Flatfish Complex (sp. Not detailed)	″	″
Squid Complex (sp. not detailed)	″	″
Other Species Complex (sp. not detailed)	″	″
GULF OF ALASKA GROUNDFISH and BERING SEA/ALEUTIAN ISLANDS GROUNDFISH		
Sablefish	F > MFMT	Stock biomass < MSST (where MSST is the greater of; ½B_{MSY}, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were exploited at MFMT)
BERING SEA / ALEUTIAN ISLANDS KING and TANNER CRABS		
Blue King Crab – Pribilof Islands and Saint Mathews Islands	F > M	Stock size < MSST (which is equal to ½ B_{MSY})
Red King Crab – Bristol Bay and Pribilof Islands	″	″
Snow Crab – Bering Sea	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Tanner Crab – Eastern Bering Sea	″	″
Blue King Crab – Saint Lawrence Island	″	Overfishing not defined
Red King Crab – Aleutian Islands, Dutch Harbour	″	″
Tanner Crab – Adak (Western Aleutians)	″	″
Tanner Crab – Eastern Aleutian Islands	″	″
Tanner Crab – Western Aleutian Islands Grooved	″	″
Golden King Crab – Aleutian Islands	″	″
Red King Crab – Aleutian Islands, Adak	″	″
Red King Crab – Norton Sound	″	″
Golden King Crab – Northern Districts	″	″
Golden King Crab – Pribilof Islands	″	″
Scarlet King Crab – Aleutian Islands	″	″
Tanner Crab – Eastern Aleutian Islands Grooved	″	″
Tanner Crab – Eastern Aleutian Islands Triangle	″	″
Tanner Crab – Eastern Bering Sea Grooved	″	″
Tanner Crab – Eastern Bering Sea Triangle	″	″
Alaska Weathervane Scallop	The level of F that jeopardises the long term capacity of the stock or stock complex to produce MSY on a continuing basis	Stock size < MSST = $½B_{MSY}$
Pacific Halibut	The rate of fishing that exceeds the constant exploitation yield.	Stock biomass < minimum spawning biomass = $20\%B_0$
ATLANTIC HIGHLY MIGRATORY SPECIES		
Blue Marlin – Atlantic	F > MFMT (which is set at $F_{LIM} = F_{MSY}$)	Stock biomass < MSST (which is set at MSST = B_{LIMIT} = $(1-M)B_{MSY}$ when M,0.5; MSST = B_{LIM} = $½B_{MSY}$ when M >0.5)
White Marlin – Atlantic	″	″
Sailfish – West Atlantic	″	″
Bigeye Tuna – Atlantic	″	″
Albacore – North Atlantic	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Bluefin Tuna – West Atlantic	″	″
Yellowfin Tuna – Atlantic	″	″
Swordfish – North Atlantic	″	″
Sandbar Shark	″	″
Blacktip Shark – Gulf of Mexico, Atlantic	″	″
Large Coastal Shark Complex (in addition to the above 3 sharks this complex consists of, Spinner Shark, Silky Shark, Tiger Shark, Bull Shark, Lemon Shark, Nurse Shark, Scalloped Hammerhead Shark, Great Hammerhead Shark, Smooth Hammerhead Shark. In addition, several LCS species cannot be retained in commercial or recreational fisheries and include, Dusky Shark, Bignose Shark, Galapagos Shark, Night Shark, Caribbean Reef Shark, Narrowtooth Shark, Sand Tiger Shark, Bigeye Sand Tiger Shark, Whale Shark, Basking Shark and White Shark)	″	″
Fine Tooth Shark	″	″
Atlantic Sharpnose Shark	″	″
Blacknose Shark	″	″
Bonnethead Shark	″	″
Small Coastal Shark Complex (in addition to Finetooth Shark, Atlantic Sharpnose Shark, Blacknose Shark and Bonnethead Shark the SCS consists of Atlantic Angel Shark, Caribbean Sharpnose Shark and Smalltail Shark)	″	″
Shortfin Mako Shark	″	″
Porbeagle Shark	″	″
Blue Shark	″	″
Dusky Shark	″	″
Longbill Spearfish – West Atlantic	″	″

Stock	**Overfishing Definition** (Overfishing is said to occur when the following scenario is estimated)	**Overfished [depletion] definition** (A stock is overfished when the following scenario is estimated.)
Skipjack Tuna – West Atlantic	″	″
Pelagic Shark Complex (in addition to Shortfin Mako Shark, Blue Shark and Porbeagle Shark, the PSC consists of; Oceanic Whitetip Shark, and Thresher Shark. This complex also consists of stocks that cannot be retained in recreational or commercial fisheries which include; Bigeye Thresher Shark, Bigeye Sixgill Shark, Longfin Mako, Sevengill Shark, and Sixgill Shark)	″	″

APPENDIX VII. International and Historical Context for Harvest Strategies

Notion of MSY

1 The concept of Maximum Sustainable Yield (MSY) was derived in the 1930s. MSY is a biological reference point that relates to both a target biomass level (B_{MSY}) and a target fishing mortality rate (F_{MSY}). The MSY concept was embodied in international law in 1982 in the United Nations Convention on the Law of the Sea. Subsequently, it has been adopted in many national fisheries acts. In New Zealand, this formally occurred in 1996, although MSY-compatible reference points were used in fisheries assessments well before this date (see the "Guide to Biological Reference Points for 2006-07 Fisheries Assessment Meetings", a version of which has been in Ministry of Fisheries fisheries assessment documents dating from 1988).

2 Despite attacks on its overall applicability in fisheries, MSY has survived as a key biological reference point because it is intuitive (able to be understood by the general public) and operational, and no-one has come up with a superior, operational, widely applicable reference point. It provides a balance or compromise between the competing interests of sustainability and utilisation. Different techniques for estimating MSY have evolved, some of which require relatively few data and some that require extensive data. No other approaches are as universally used or accepted as MSY-compatible reference points.

3 It does, however, have some noted limitations. First, there are often estimation problems, although this may in part reflect the reliability of the underlying data, which is problematic for all stock assessment approaches. The suitability of MSY-compatible reference points as management targets is sometimes challenged. It tends to reflect a single species management approach (i.e. assessing the status of each stock individually) that does not take ecosystem and other considerations into account. Certainly non-commercial fishers often consider that a B_{MSY} target results in the available biomass being too low to adequately provide for their interests (although to some extent that can be addressed in New Zealand through setting a target above B_{MSY}). Environmentalists (and others) have advocated that B_{MSY} should be interpreted as a limit, rather than a target.

4 MSY is also seen as being overly constraining in terms of the range of harvest strategies that may be identified for different fisheries. In New Zealand, the Fisheries Act (1996) prescribes rebuilding of stocks that are below the B_{MSY} target or the fishing down of biomass when stocks are above B_{MSY}. Taken literally, it does not allow for a great deal of flexibility.

5 Despite these limitations, the scientific and management roles of MSY-compatible reference points have continued to evolve. The initial view was that MSY was a constant catch could be achieved in all years. MSY is now more clearly seen as a long-term average based on a constant fishing mortality rate or other MSY-based harvest strategy. Rather than being static, natural populations continually fluctuate in size, both with and without fishing activity. As a result, harvest strategies based on MSY-compatible reference points will generally result in variable annual catches and at any point in time the current biomass will either be below or above the B_{MSY} level. Thus, B_{MSY} must also be thought of as a long-term average.

Harvest Control Rules

6 A relatively recent development in fisheries science and management is the consideration of a number of biological reference points in addition to biomass targets such as B_{MSY}. In particular, the notion of overfishing *thresholds* and *limits* has become commonplace. These concepts have arisen due to recognition that targets are frequently exceeded (for a multitude of reasons; e.g. uncertainties about data and stock assessments, political and short-term financial considerations, and environmental fluctuations). More risk-averse management strategies have been developed in part because of the ongoing overfishing of many stocks worldwide, but also in response to growing acceptance of the precautionary approach and pressure to incorporate ecosystem considerations into the management of fisheries.

7 Of particular significance is the 1995 United Nations Fish Stocks Agreement. While this agreement relates to the management of populations that straddle more than one national boundary and highly migratory stocks that are found over a wide region, it establishes in international law some key principles that are of wider application. The agreement specifies guidelines for the application of precautionary reference points [see **Appendix VIII**]. The key points are that:

a) Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries that are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives (Annex II, para 2);

b) Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low ... [and] that target reference points are not exceeded on average (Annex II, para 5); and

c) The fishing mortality rate that generates maximum sustainable yield shall be regarded as a minimum standard for limit reference points (Annex II, para 7).

8 International developments in fisheries science have resulted in a proliferation of reference points that have been adopted for different fisheries and in different jurisdictions. Most prevalent are fishing mortality-based reference points (e.g. F_{MSY}, F_{MAX}, $F_{0.1}$, F=M, $F_{REPLACEMENT}$, $F_{EXTINCTION}$, $F_{X\%SPR}$ (e.g. $F_{20\%}$, $F_{30\%}$, $F_{40\%}$), F_{LIMIT} or F_{LIM}, $F_{PA,}$ and F_{BUF}) and biomass-based reference points (B_{MSY}, 30-60% B_0, B_{LIMIT} or, B_{PA}, B_{BUF}). Others include yield-based reference points (e.g. MSY) and recruitment-based reference points.

9 One example of the incorporation of biological reference points into a framework commonly referred to internationally as a harvest control rule, is depicted below. The harvest strategy standard proposed for New Zealand essentially reflects the same basic underlying approach.

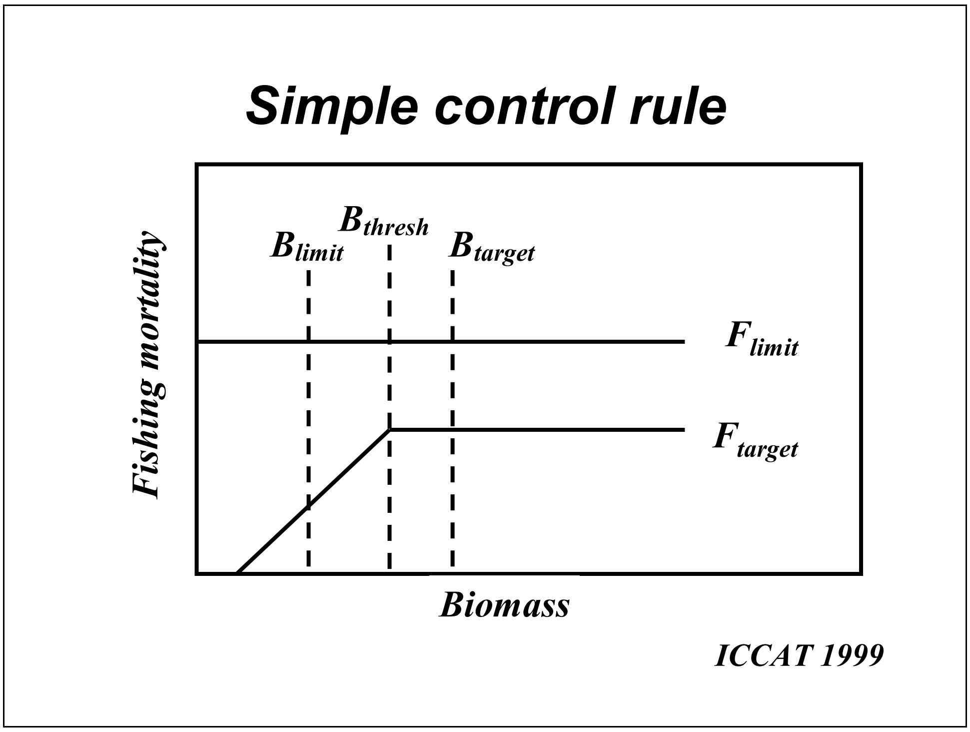


Figure A2. ICCAT harvest control rule.

10 The Australia Fisheries Management Authority (AFMA) has recently implemented a Harvest Strategy Policy. The framework of this strategy contains many of the attributes proposed in New Zealand's Harvest Strategy Standard. In Australia, harvest strategies have been designed to meet legislative objectives, and to provide optimum utilisation of resources consistent with Ecologically Sustainable Development (ESD) objectives. The harvest strategies are precautionary in nature. The guiding principles are:

a) A target reference point (corresponding to 40% of unfished biomass) and a limit reference point (corresponding to 20% of unfished biomass);

b) Decreased exploitation rates for low stock sizes;

c) Exploitation rates are decreased as uncertainty about stock size increases;

d) No targeted fishing below the minimum biomass level; and

e) Four fishery tiers, depending on the amount and type of information available to assess stock status.

11 Another variation on the same basic theme is the precautionary approach framework developed by the Northwest Atlantic Fisheries Organisation (NAFO) in 2003. The darker the shade the greater the risk of stock collapse. General actions that would be useful for defining specific harvest control rules in each zone form part of the NAFO framework.

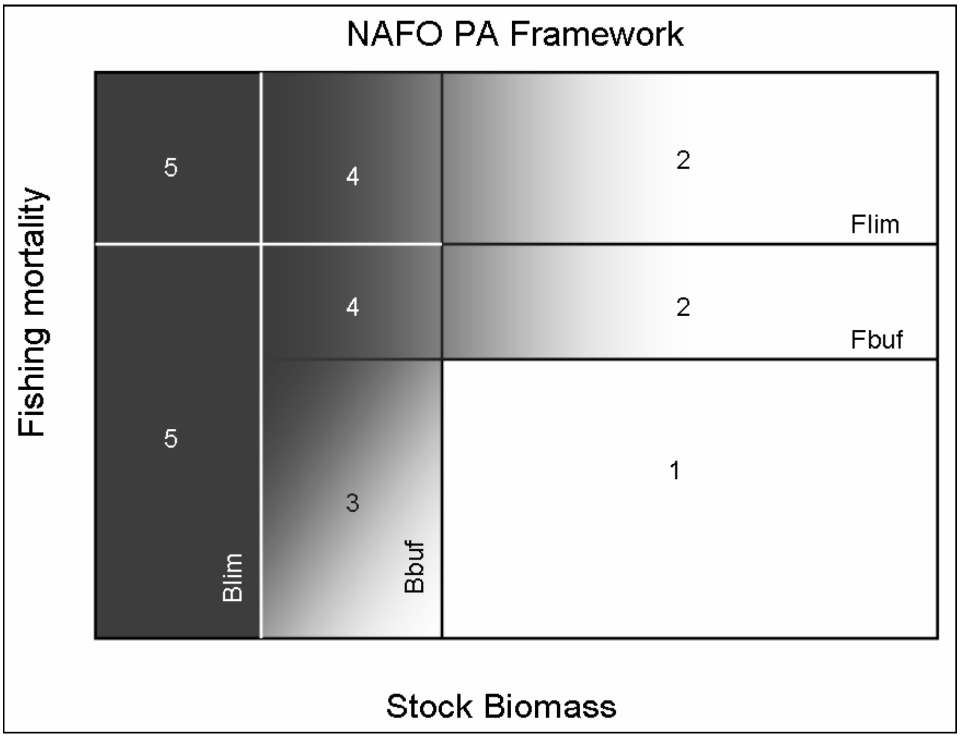


Figure A3: NAFO precautionary approach framework
(1 = Safe Zone, 2 = Overfishing Zone, 3 = Cautionary *F* Zone, 4 = Danger Zone, and 5 = Collapse Zone)

Management Strategies

12 Fisheries management strategies that are not necessarily limited solely to MSY-compatible reference points (generally because of the perceived limitations of such approaches as optimal management objectives) have also been developed. Two such approaches are the ecosystem based fisheries management approach that is being developed by the Department of Fisheries and Oceans (DFO), Canada, and the management strategy evaluation (MSE) approach that has been adopted in some instances in Australia, South Africa and New Zealand.

13 DFO has defined ecosystem-based management (EBM) as “the management of human activities so that ecosystems, their structure (e.g. diversity of species), function (e.g. productivity) and overall environmental marine environmental quality, are maintained at appropriate temporal and spatial scales. EBM recognises that human activities must be managed in consideration of the interrelationships between organisms, their habitats and the physical environment” (DFO 2004). FAO prefers the term “ecosystem approaches to fisheries” (EAF; FAO 2003). Most if not all, aspects of ecosystem approaches result in management strategies that are more conservative than those developed for single-stock MSY-based approaches (i.e. they generally result in target fishing mortality rates that are considerably lower than F_{MSY}).

14 Management strategy evaluation (MSE), rather than focusing solely on biological

reference points, seeks to take into account the robustness of alternative management procedures and socio-economic implications of management decisions. "Management strategy evaluation attempts to model and simulate the whole management process. It makes projections about the state of the fishery resources and other ecosystem parameters for a number of years into the future under a variety of decision-rule options. The management measure and rules that achieve the best results in terms of specified objectives can then be selected and applied. This procedure greatly assists in identifying management strategies that are resilient to uncertainties in scientific understanding. Precautionary management measures and decision rules can be identified by testing the performance of the measure against a range of possible complexities that are likely to be operating in the fishery identified using a selection of appropriate reference points that include acceptable levels of risks" (FAO Technical Guidelines for Responsible Fisheries, No.4, Suppl.2, 2003).

15 The adoption of an MSE has been advocated to provide a framework in which the following issues can be addressed (Campbell, CSIRO Marine Research, 2002):

a) "Decisions being made in the face of high uncertainty about the status, dynamics and future trends of the resources, and similar levels of uncertainty about the social and economic status, dynamics and future behaviour of the fishery or fisheries;

b) Decisions being made in the absence of any long-term strategy and, at best, poorly defined objectives which will usually also be conflicting; and

c) Decisions being made by individuals or groups which are unrepresentative or poorly representative of the full range of interest groups."

16 In South Africa, MSEs (referred to there as operational management procedures or OMPs) have been implemented since the early 1990s. Procedures are in place for all three of the country's major fisheries. "Butterworth *et al* (1997) describe a management procedure as a set of clearly defined decision rules specifying: i) exactly how the regulatory mechanism, for example a TAC, is to be set, ii) what data are to be collected for this purpose, and iii) exactly how these data are to be analysed and used to this end. This set of rules is to be pre-agreed upon by the parties involved, typically the management agency and the fishing industry. The set of rules is chosen by comparing the anticipated performance of a range of possible sets in terms of agreed performance criteria which would typically include risk to the stock, rewards in the form of catch or profits and the medium to long-term stability of these rewards. Comparison of performance allows explicit consideration of, and agreement upon, trade-offs between conflicting objectives. The anticipated performance is tested by applying the rules to a dynamic model of the resource and fishery, referred to as an operating model. Once agreed to, the management procedure should be implemented for a number of years (typically 3 to 5). Thereafter the procedure is reviewed and modified as necessary in the light of any changes in understanding of the resource or fishery that may have occurred in the interim. The revised procedure would then be implemented for the next three to five year period". (Campbell, 2002).

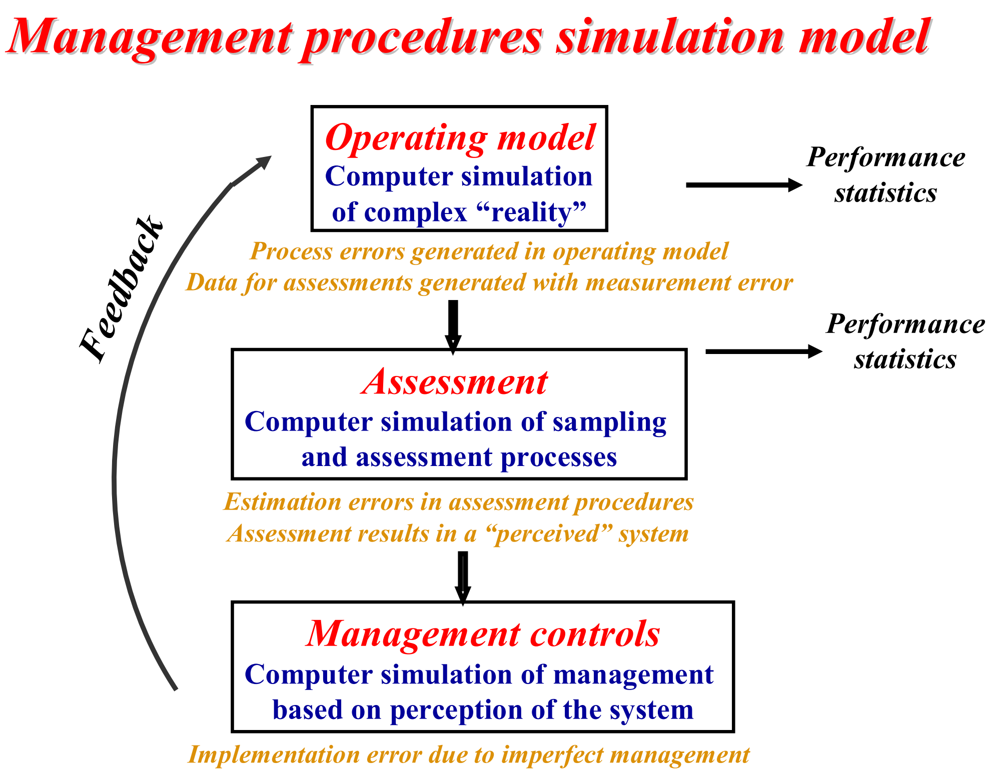


Figure A4: Example of a Management Strategy Evaluation (MSE) or, equivalently, a Management procedure or Operational Management Procedure (OMP). **From** ICCAT (1999).

<u>Relationship between Harvest Control Rules and MSEs</u>

17 The outcome of an MSE is a TAC that may or may not incorporate MSY-based reference points for a stock; however, this does not necessarily mean that the MSE/OMP approach is inconsistent or incompatible with the proposed Harvest Strategy Standard. The Harvest Strategy Standard does not constrain MSEs from being adopted.

18 The potential inter-relationship between harvest controls rules and MSEs is reflected in the approach adopted by AFMA. As noted earlier, AFMA has implemented a harvest strategy policy. Detailed testing of the harvest strategies is to be carried out through a two year MSE project.

<u>Overall Consistency of New Zealand Approach</u>

19 The New Zealand Harvest Strategy Standard is generally consistent with the overall direction internationally both in terms of fisheries science and fisheries management. The Harvest Strategy Standard adopts target, soft limit, and hard limit biological reference points.

20 The development of a Harvest Strategy Standard is not inconsistent with Management Strategies; they can represent different elements of an overall fisheries management framework. The layers of a Management Strategy are depicted below (Source: International Council for the Exploration of the Sea, report of the Study Group on

Management Strategies, 2006). The Harvest Strategy Standard operates at the level of a harvest control rule. The New Zealand equivalent of the four inner layers together depicted in the ICES diagram is a Fisheries Plan.

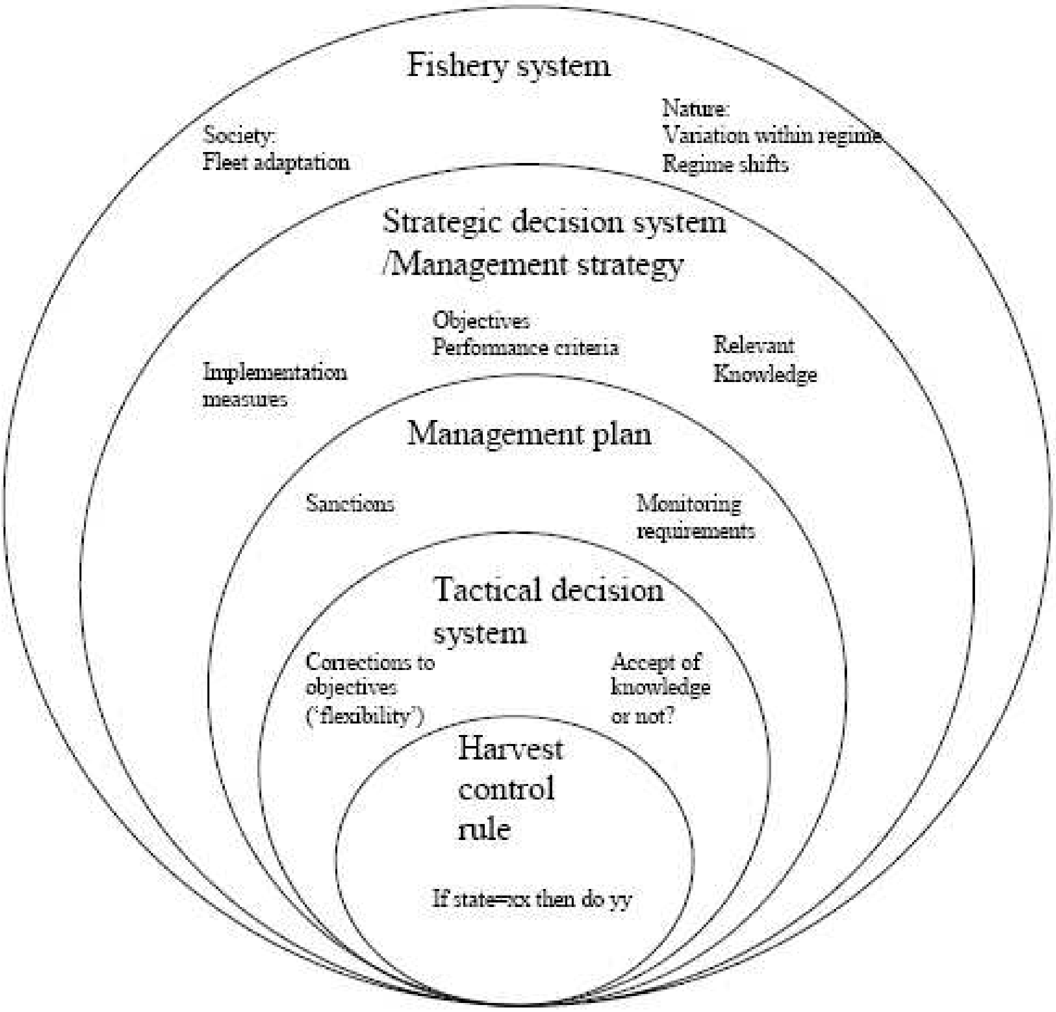


Figure A5: Management Strategy Layers (ICES, 2006)

APPENDIX VIII. 1995 United Nations Fish Stocks Agreement, Annex II

“Guidelines for the Application of Precautionary Reference Points in Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

1. A precautionary reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management.

2. Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives.

3. Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

4. Management strategies shall seek to maintain or restore populations of harvested stocks, and where necessary associated or dependent species, at levels consistent with previously agreed precautionary reference points. Such reference points shall be used to trigger pre-agreed conservation and management action. Management strategies shall include measures which can be implemented when precautionary reference points are approached.

5. Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average.

6. When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. Provisional reference points may be established by analogy to similar and better-known stocks. In such situations, the fishery shall be subject to enhanced monitoring so as to enable revision of provisional reference points as improved information becomes available.

7. The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target.”

APPENDIX IX. Literature used in the Development of the Harvest Strategy Standard

Aprahamian, M.W., R.J. Waytt and B.A. Shields. 2006. Use of biological reference points for the conservation of Atlantic salmon (*Salmo salar*) in the River Lune, North West England. *Fisheries Management*. 13: 21-30.

Australian Fisheries Management Council (AFMA). 2007. Commonwealth Fisheries Harvest Strategy: Policy and Guidelines.

Australian Fisheries Management Council (AFMA). 2007. Orange Roughy Conservation Programme: Research and Monitoring Workshop 12 04 07 Melbourne.

Beddington, J.R. and R.M. May. 1977. Harvesting populations in a randomly fluctuating environment. *Science*. 197: 463-465

Beddington, J.R. and J.G. Cooke. 1983. The potential yield of fish stocks. *FAO Fish. Technical Paper*. 242.

Bentley, N., P.A. Breen, S.W. Kim and P.J. Starr. 2005. Can additional abundance indices improve harvest control rules for New Zealand rock lobster (*Jasus edwardsii*) fisheries? New Zealand Journal of Marine and Freshwater Research 39: 629-644.

Bergh, M.O. and D.S. Butterworth. 1987. Towards rational harvesting of the South African anchovy considering survey imprecision and recruitment variability. *South African Journal of Marine Science.* 5: 937-951.

Booth, A.J. 2003. *In pres*. Determination of cichlid specific reference points. *Fisheries Research*.

Booth, A.J. and T.J. Quinn. 2006. Maximum likelihood and Bayesian approaches to stock assessment when data are questionable. *Fisheries Research*. *80* p161-181.

Brouwer, S.L. and M.H. Griffiths. 2006. Management of *Argyrozona argyosona* (Pices: Sparidae) in South Africa based on per-recruit models. *African Journal of Marine Science*. 28(1): 89-98.

Butterworth, D.S. and P.B. Best. 1994. The origins of the choice of 54% of carrying capacity as the protection level for baleen whale stocks, and the implications thereof for management procedures. *Rep. International Whaling Commission.* 44: 491-497.

Caddy, J.F. and J. Csirke. 1983. Production modelling using mortality estimates. *Canadian Journal of Fisheries and Aquatic Sciences*. 40: 43-51.

Caddy, J.F. and Mahon, R. 1995. Reference points for fisheries management . *FAO Technical paper*. Rome, FAO 347: 83p.

Campbell, R. 2002. Management strategies, the determination of a TAE and the use of decision rules within the Eastern Tuna and Billfish Fishery. Background Document for the ET&BF Assessment Group meeting: Mooloolaba 5-6th March 2002.

Campbell, R., J. Prince, C. Davies, D. Kolody, N. Dowling, P. Ward and K. McLoughlin. 2007. Development of an Empirical-Indicator Based Harvest Strategy for the Australian Eastern Tuna and Billfish Fishery. WCPFC – SC3 Working paper.

CCAMLR. 1991. Report of the working group on Fish Stock Assessment. Scientific committee report SC-CAMLR-X, Hobart, Australia. Annex 6.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. *Canadian Journal of Fisheries and Aquatic Sciences* 48 (5): 734-750.

Clark, W.G. 1993. The effect of recruitment variability on the choice of a target level of a spawning biomass per recruit. p. 233-246 *in* G. Kruse, R.J. Marasco, C. Pautske and T.J. Quinn. Proceedings of the International Symposium on Management Strategies for Exploited Fish populations. Alaska Sea Grant College Program Report No. 93-02, University of Alaska Fairbanks.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured stock assessment. *Canadian Journal of Fisheries and aquatic science*. 56: 1721-1731.

Clark, W.G. 2002. $F_{35\%}$ Revisited 10 years later. *North American Journal of Fisheries Management*. 22: 251-257.

Clark, W.G. and S.R. Hare. 2003. A conditional constant catch policy for managing the Pacific Halibut Fishery. *North American Journal of Fisheries Management*. 24: 106-113.

Collie, J.S. and H. Gislason. 2001. Biological reference points for fish stocks in a multispecies context. *Canadian Journal of Fisheries and Aquatic Sciences*. 58: 2167-2176.

Corten, A. 1990. The choice of target fishing mortality in herring fisheries. ICES CM 1990/H 21: 6p.

Commission of the European Communities (EUWKREF). 2007. Northern Hake long-term management plans. Report of the sub-group meeting on balance between resources and their exploitation. *Lisbon 4-8 June 2007*. SGBRE-07-03.

DeLara, M., L. Doyen, T. Guilbaud, M.J. Rochet. 2007. Is a management framework based on spawning-stock biomass indicators sustainable? A viability approach. *ICES Journal of Marine Science*. 64: 761-767.

Deriso, R.B. 1985. Risk adverse harvesting strategies. pp 65–73 in M. Mangel (ed.): Resource Management. Lecture Notes in Biomathematics 61.

Die, D.J. and J.F. Caddy. 1997. Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries? *Fisheries Research*. 32: 69-79.

Dorn, M.W., M.W. Saunders, C.D. Wilson, M.A. Guttormsen, K. Cooke, R. Kieser and M.E. Wilkins. 1999. Status of the coastal Pacific hake/whiting stock in U.S. and Canada in 1998. *In*: Status of the Pacific Coast Groundfish Through 1999 and Recommended Acceptable Biological Catches for 2000, Stock Assessment and Fishery Evaluation, Appendix, Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 2224, Portland, OR, 97201.

Dorn, M.W. 2002. Advice on West Coast Rockfish harvest rates from Bayesian meta-analysis of Stock–Recruit Relationships. *North American Journal of Fisheries Management*. 22: 280-300.

Dorn, M.W., S. Barbeaux, M. Guttorsmen, B. Megery, A. Hollowed, M. Wikins, K. Spalinger. 2003. Assessment of Walleye Pollock in the Gulf of Alaska. *North Pacific Fishery Management Council Gulf of Alaska SAFE*. 33-148.

Doubleday, W.C. 1976. Environmental fluctuations and fisheries management. Int. Comm. Northwest Atl. Fish., Selected Papers (1): 141–150.

FAO 2003. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries No 4, Supplement 2. FAO Rome, Italy.

Food and Agriculture Organization (FAO) 1996. FAO Fishing Technology Service. Fishing Operations. *Technical guidelines for responsible fisheries.* Rome, FAO. 1: 26. 6 annexes.

Food and Agriculture Organization (FAO) 2001. BAYES-SA, Bayesian stock assessment methods in Fisheries management – User manual. www.FAO.ORG Corporate Document Repository Y1958E.

Food and Agriculture Organization (FAO) 2003a. Fish Stock Assessment Manual, FAO Fisheries Technical document prepared by E.L Cadima. www.FAO.ORG Corporate Document Repository.

Food and Agriculture Organization (FAO) 2003b. Fish Stock Assessment Manual, FAO Fisheries Technical document prepared by J.A Gulland. www.FAO.ORG Corporate Document Repository 96215E.

Food and Agriculture Organization (FAO) 2007. FAO 2007. Report and documentation of the Expert Consultation on Deep-sea Fisheries in the High Seas. Bangkok, Thailand, 21-23 November 2006. *FAO Fisheries Report* No. 289. Rome, Italy.

Francis, R.I.C.C. 1992. Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). *N.Z. Fisheries Research Assessment Document* 92/8.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using Orange Roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences.* 49: 922-930.

Gabriel, W., M.P. Sissenwine and W.J. Overholtz. 1989. Analysis of Spawning Stock Biomass per Recruit: An example for Georges Bank Haddock. *North American Journal of Fisheries Management*. 9: 383-391.

Gatto, M. and S. Rinaldi. 1976. Mean value and variability of fish catches in fluctuating environments. *J. Fish. Res. Bd. Can*. 33: 189–193.

Getz, W.M., R.C. Francis and G.L. Swartzman. 1987. On managing variable marine fisheries. C*an. J. Fish. Aquat. Sci.* 44: 1370–1375.

Goodman, D., M. Mangel, G. Parkes, T. Quinn, V. Restrepo, T. Smith, K. Stokes. 2002. Scientific Review of the Harvest Strategy Currently Used in the BSAI and GOA Groundfish Fishery Management Plan. *Draft report prepared for the NPFMC.* 139 p.

Graham, M. 1935. Modern theory of exploiting a fishery, an application to North Sea trawling. *Journal du Conseil, Conseil International pour l'Exploration de la Mer*. 10: 264-274.

Gulland, J.A. 1971. (comp.) The Fish Resources of the Ocean. West Byfleet, Surrey, Fishing News (Books) Ltd., for FAO, 255 pp. Rev. ed. of FAO Fish Tech. Pap., (97): 425 p. (1970).

Hall, D.L., R. Hilborn, M. Stocker and C.J. Walters. 1988. Alternative harvest strategies for Pacific herring (*Clupea harengus pallasi*). *Canadian Journal of Fisheries and Aquatic Science.* 45: 888-897.

Helser, T.E., I.J. Stewart, G.W. Fleischer, S. Martell. 2006. Stock assessment of Pacific Hake (Whiting) in U.S. and Canadian Waters in 2006. *Northwest Fisheries Science Centre*. February 16 2006.

Helser, T.E. 2007. Supplemental SCC report *Scientific and Statistical Committee Report in Pacific Whiting Harvest Specifications and Management Measures for 2007* March 2007 Agenda Item E.3.b.

Hersoug, B. 1996. Social considerations in fisheries planning and management – real objectives or defence of the status quo? Is Fisheries Management in Crisis, p 19-24. Ed. by K. Crean, and D. Symes. Fishing News Books, Oxford. p222.

Hilborn, R., A. Parma, M. Maunder. 2002. Exploitation rate reference points for west coast rockfish: are they robust and are there better alternatives? *North American Journal of Fisheries Management*. 22: 365-375.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* 81: 898–903.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* **4**: 1-23.

ICCAT 2000. Report of the meeting of the ICCAT and ad hoc working group on the precautionary approach. Collected Volume of Scientific Papers ICCAT 51(6): 1941-2056.

ICCAT. 2007. International Commission for the Conservation of Atlantic Tunas. http://www.iccat.es/.

ICES 2006. Report of the study group on management strategies. ICES Headquarters, 23-27 January 2006. ICES CM 2006/ACFM:15.

ICES 2003. Report of the study group on the further development of the precautionary approach to fisheries management. ICES Headquarters, 2-6 December 2002. ICES Council Meeting Documents, No. 2003.

Johnston, S.J. and D.S. Butterworth. 2005. Evolution of operational management procedures for the South African West Coast rock lobster (*Jasus lalandii*) fishery. New Zealand Journal of Marine and Freshwater Research 39: 687-702.

ICES. 2007. Report of the Workshop on Limit and Target Reference Points [WKREF], 29 January – 2 February 2007, Gdynia, Poland. ACFM: 0.5: 89.

Jacobson, L.D., S.X. Cardin, J.R. Weinberg. 2002. Tools for Estimating Surplus Production and F_{MSY} in any Stock Assessment Model. *North American Journal of Fisheries Management*. 22: 326-338.

Jakobsen, T. 1992. Biological reference points for North-East Arctic cod and haddock. *ICES Journal of Marine Science*. 49: 155-155.

Jakobsen, T. 1993. The Behaviour of F_{LOW}, F_{MED}, F_{HIGH}, in response to variation in parameters used for their estimation. *Special Publication Canadian Journal of Fisheries and Aquatic Sciences*.120: 119-125.

Johnston, S.J. and D.S. Butterworth. 2005. Evolution of operational management procedures for the South African West Coast rock lobster (*Jasus lalandii*) fishery. New Zealand Journal of Marine and Freshwater Research 39: 687-702.

Kell, L.T., D.J. Die, V.R. Restrepo, J-M. Fromentin, V. Ortiz De Zarate, P. Pallares. 2003. An evaluation of management strategies for Atlantic tuna stocks. *Scientia Marina*. 67: 353-370.

Kell, L.T. and J.M. Fromentin. 2007. Evaluation of the robustness of maximum sustainable yield based management strategies to variations in carrying capacity or migration pattern of Atlantic bluefin tuna (*Thunnus thynnus*). *Canadian Journal of Fisheries and Aquatic Sciences*. 64: 837-847.

Kirkwood, G.P. 1981. Allowing for risks in setting catch limits based on MSY. *Math. Biosci.* (53): 119–129.

Kutsukawa, T. 2004. Numerical investigation of the optimal control rule for decision-making in fisheries management. *Fisheries Science*. 70: 123-131.

Lande, R., B.E. Saether, S. Engen. 1997. Threshold harvesting for sustainability of fluctuating resources. *Journal of Ecology*. 78: 1341-1350.

Leaman, B.M. 1993. Reference points for Fisheries Management. The Western Canadian experience. *In* Risk Evaluation and Biological Reference points for Fisheries Management. *Ed* J. Smith, J.J. Hunt and D. Rivard. *Special Publication Canadian Journal of Fisheries and Aquatic Science*. 120: p442.

Lodge, M.W., D. Anderson, T. Løbach, G. Munro, K. Sainsbury, A. Willock. 2007. Recommended Best Practices for Regional Fisheries Management Organizations. Report of an independent panel to develop a model for improved governance by Regional Fisheries Management Organizations. The Royal Institute of International Affairs, Chatham House. ISBN: 978 86203 188 3.

MacCall, A. 1999. Production model analysis of groundfish productivity (distributed at the PFMC workshop February 1999, Newport, OR.).

McAllister, M.K. and G.P. Kirkwood. 1998. Using Bayesian decision analysis to help achieve a precautionary approach for managing developing fisheries. *Canadian Journal or Fisheries and Aquatic Sciences*. 55: 2642-2661.

McAllister, M.K. and C.H. Kirchner. 2001. Development of Bayesian stock assessment methods for Namibian orange Roughy *Hoplostethus atlanticus*. *South African Journal of Marine Science*. 23: 241-264.

Mace, P.M. and M.P. Sissenwine. 1993. How much Spawning per Recruit is Enough? *Special Publication Canadian Journal of Fisheries and Aquatic Sciences*.120: 101-118.

Mace, P.M. 1988a. The relevance of MSY and other biological references points to stock assessments in New Zealand. *N.Z. Fisheries Assessment Research Document* 88/30.

Mace, P.M. 1988b. A survey of stock assessment methods and results. *N.Z. Fisheries Assessment Research Document* 88/6.

Mace, P.M. 1994. Relationships between Common Biological Reference points used as Thresholds and Targets of Fisheries Management Strategies. *Canadian Journal of Fisheries and Aquatic Sciences*. 51: 110-122.

Magnuson-Stevens Fishery Conservation Management Act National Oceanic and Atmospheric Administration. As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479). http://www.nmfs.noaa.gov/msa2005/docs/MSA_amended_msa%20_20070112_FINAL.pdf.

May, R.M., J.R. Beddington, J.W. Horwood and J.G. Shepherd. 1978. Exploiting natural populations in an uncertain world. *Math. Biosci*. 42: 219–252.

Mertz, G. and R.A. Myers. 1996. Influence of fecundity on recruitment variability of marine fish. *Canadian Journal of Fisheries and Aquatic Science*. 53: 1618-1625.

Ministry of Fisheries. 2011. Report from the Fishery Assessment Plan, May 2011: stock assessments and yield estimates. *Ministry of Fisheries*, Wellington, New Zealand. 1178p.

Murawski, S.A., P.J. Rago, E.A. Trippel. 2001. Impacts of demographic variation in spawning characteristics on reference points for fishery management. *ICES Journal of Marine Science*. 58: 1002-1014.

Musick, J.A. 1999. Criteria to define extinction risk in marine fishes. *Fisheries* **24**: 6-14.

Myers, R.A. and G. Mertz. 1998. The limits of exploitation: A precautionary approach. *Ecological* Applications. 8: 5165-5169.

Myers, R.A., K.G. Bowen, N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. *Canadian Journal of Fisheries and Aquatic Sciences*. 56: 2404-2419.

Myers, R.A., N.J. Barroenan, R. Hilborn, D.G. Kehler. 2002. Inferring Bayesian priors with limited direct data: application to risk analysis. *North American Journal of Fisheries Management*. 22: 351-364.

NAFO 2003. Scientific Council Meeting – March/April 2003: Report of NAFO scientific council on the precautionary approach to fisheries management. NAFO SCS Doc. 03/05.

NOAA. 2007. Monkfish Assessment Summary for 2007: Northeast Data Poor stocks working group. *US Department of Commerce. National Marine Fisheries Services, Woods Hole Lab, Massachusetts* August.

North Pacific Fishery Management Council (NPFMC). 2007. http://www.fakr.noaa.gov/npfmc/.

Parrish, R.H. 2000. A synthesis of the surplus production and extrapolation rates of 10 west coast groundfish species. (Distributed at the March 2000 PFMC workshop in Seattle, WA.)

Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. *Reviews in Fish Biology and Fisheries*. 2. 321-338.

Pacific Fishery Management Council. 2006. Report of the Groundfish Harvest Policy Evaluation workshop, Southwest Fisheries Science Center, La Jolla, California.

Pacific Fishery Management Council. 2007. www.pcouncil.org/acronyms.html.

Piet, G.J. and J.C. Rice. 2004. Performance of precautionary reference points in providing management advice on North Sea Fish Stocks. *ICES Journal of Marine Science*. 61: 1305-1312.

Pope, J.G. 1983. Analogies to the status quo TACs: their nature and variance, pp. 99–113 in W.G. Doubleday and D. Rivard, Sampling commercial catches of marine fish and invertebrates. C*an. Spec. Publ. Fish. Aquat.* Sci. 66.

Punt A.E. 1993. Use of spawner-biomass-per-recruit in the management of linefisheries. In: Beckley L.E., Van Der Elst R.P., (eds) *Fish, Fishers and Fisheries. Proceedings of the Second South African Marine Linefish Symposium, Durban, October 1992*. *Special Publication of the Oceanographic Research Institute South Africa*. 2: 80–89

Punt, A.E. 1995. The performance of a production-model management procedure. *Fisheries Research.* 21: 349-374.

Punt, A.E. 1997. The performance of VPA-based management. *Fisheries Research.* 29: 217-243.

Punt, A.E. and T.I. Walker. 1998. Stock assessment and risk analysis for the school shark off southern Australia. *Marine and Freshwater Research*. 49: 719-731.

Punt, A.E. 2000. Extinction of marine renewable resources: a demographic analysis. *Population Ecology* **42**: 19-27.

Punt, A.E. 2003. Evaluating the efficacy of managing West Coast groundfish resources through simulations. *Fishery Bulletin* . 101: 860-873.

Punt, A.E., D.C. Smith and M.T. Koopman. 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report to Fisheries Research and Development Corporation Project No. 2002/094. *Primary Research Victoria*, Queenscliff.

Quinn, T.J. II, R. Fagen and J. Zheng. 1990. Threshold management polices for exploited populations. *Canadian Journal of Fisheries and Aquatic Science*. 47: 2016-2029.

Radtke, K. 2003. Evaluation of the exploitation of Eastern Baltic cod (*Gadus morhua callarias L.*) stock in 1976–1997. *ICES Journal of Marine Science*. 60: 1114-1122.

Reed, W.J. 1983. Recruitment variability and age structure in harvested animal populations. *Math. Biosci.* 65: 239–268.

Reeves, J.E. 1974. Comparison of long-term yields from catch quotas and effort quotas under conditions of variable recruitment. ICNAF Res. Doc. 74/31.

Reynolds, J.D., N.K. Dulvy, N.B. Goodwin and J.A. Hutchings. 2005. Biology of extinction risk in marine fishes. *Proceedings of the Royal Society B*. 272: 2337-2344.

Restrepo, V.R., G.G. Thompson, P.M. Mace, W.L. Gabriel, L.L. Low, A.D. MacCall. R.D. Methot, J.E. Powers, B.L. Taylor, P.R. Wade and J.F. Witzig. 1998. Technical Guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act NOAA Technical Paper.

Rice, J.C., M.J. Rochet. 2005. A framework for selecting a suite of indicators for fisheries management. *ICES Journal of Marine Science*. 62: 516-527.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. *Bull. Fish. Res. Bd. Can.* 382 p.

Rochet, M.J. 2000. Does the concept of spawning per recruit make sense? *ICES Journal of Marine Science*. 57 1160-1174.

Rosenburg, A., P.M. Mace, G. Thompson, G. Darcy, W. Clark, J. Collie, W. Gabriel, A. MacCall, R. Methot, J. Powers, V. Restrepo, T. Wainwright, L. Botsford, J. Hoenig, K. Stokes. 1996. Scientific review of definitions of overfishing in U.S. Fishery Management Plans. *National Marine Fisheries Service Technical Memorandum*.

Schaefer, M. 1954. Some aspects of the Dynamics of populations important to the management of the commercial marine fisheries. *Inter-American Tropical Tuna Commission*. 1: 27-55.

Shepherd, J.G. 1984. Status quo catch estimation and its use in fishery management. Int. Council Expl. Sea CM 1984/G: 5.

Shepherd, J.G. 1991. Simple methods for short-term forecasting of catch and biomass. ICES *J. Mar. Sci*. 48: 67–78.

Sissenwine, M.P. 1977. The effects of random fluctuations on a hypothetical fishery. ICNAF, Selected Papers (2): 137–44.

Sissenwine, M.P. 1978. Is MSY an adequate foundation for optimum yield? *Fisheries* 3(6): 22–42.

Smith, S.J., J.J. Hunt and D. Rivard. 1993. Risk Evaluation and Biological Reference Points for Fisheries Management. *Canadian Special Publication of Fisheries and Aquatic Science.* NCR Research Press. 120: p438 ISBN 0660149567.

Siddeek, M.S.M. and J. Zheng. 2007. Evaluating the parameters of a MSY control rule for the Bristol Bay, Alaska, stock of red king crabs. *ICES Journal of Marine Science*. 64: 995-1005.

Tabash-Blanco, F.A. and E.A. Chavez. 2006. Optimizing harvest strategies of the white shrimp fishery in the Gulf of Nicoya, Costa Rica. *Crustaceana*. 79: 327-343.

The Scientific, Technical and Economic Committee for Fisheries (STEFC). 2007. Report of the sub-group meeting on balance between resources and their exploitation (SGBRE-07-03).

Thompson, G. G. 1993. A Proposal for a Threshold Stock Size and Maximum Fishing Mortality Rate. In *Risk Evaluation and Biological Reference Points for Fisheries Management*. Ed., S. J. Smith, J. J. Hunt, and D. Rivard, pp 303-320. Canadian Special Publication of Fisheries and Aquatic Sciences. 120.

Thompson, G.G. 1999. Optimizing harvest control rules in the presence of natural variability and parameter uncertainty. *NOOA Technical Memo.* NMFS-F/SPO-40.

Tracey, S.R., J.M. Lyle, M. Haddon. 2007. Reproductive biology and per-recruit analysis of striped trumpeter (*Latris lineate*) from Tasmania, Australia: Implications for management. *Fisheries Research*. 84: 358-367.

UNCLOS. 1982. United Nations Convention on Law of the Sea ANNEX II, 1995. http://www.un.org/Depts/los/index.htm.

UNSFA. 1995. UN Fish Stocks Agreement (Agreement for the Implementation of the Provisions of the United Nations Law of the Sea). http://www.un.org/Depts.los/convention_agreement/texts/fish_stocks_agreement/CONF164_37.htm.

Vetter, E.F. 1988. Estimation of natural mortality in fish stocks: a review. *Fish. Bull.* 86(1): 25–43.

Wang, Y., L. Qun, Y. Zhenjiang. 2006. A Bayesian analysis on the anchovy stock (*Engraulis japonicus*) in the Yellow Sea. *Fisheries Research*. 82: 87-94.

Walters, C.J., V. Christensen, S.J. Martell and J.F. Kitchell. 2005. Possible ecosystem impacts of applying MSY policies from single species assessment. *ICES Journal of Marine Science.* 62: 58-568.

Walters, C.J., S.J.D. Martell. 2004. Fisheries Ecology and Management. Princeton University Press. ISBN 0691115451.

Weyl, O.L.F., A.J. Booth, K.R. Mwakiyongo, D.S. Mandere. 2005. Management recommendations for *Copadichromis chrysonotus* (Pices:Cichlidae) in Lake Malombe, Malawi, based on per-recruit analysis. *Fisheries Research*. 71: 165-173.

Williams, E.H. and K.W. Shertzer. 2003. Implications of life-history invariants for biological reference points used in fishery management. *Canadian Journal of Fisheries and Aquatic Sciences*. 60: 710-720.