Technical Guidance On the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act

Prepared for the
National Marine Fisheries Service
by

V. R. Restrepo (Convener),
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.

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U.S. Department of Commerce
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
Rolland E. Schmitten, Assistant Administrator for Fisheries

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PREFACE

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) contains a set of ten National Standards for fishery conservation and management. National Standard 1 states,

> "*Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry.*"

The MSFCMA requires the Secretary of Commerce to "*establish advisory guidelines (which shall not have the force and effect of law), based on the national standards, to assist in the development of fishery management plans.*" These advisory guidelines, known as the National Standard Guidelines (NSGs), were first published in the *Federal Register* as a proposed rule on August 4, 1997, and revised in the final rule published on May 1, 1998. Section 600.310 of the guidelines contains the text pertaining to National Standard 1. Because the NSGs were written for a non-technical audience, they do not provide detailed guidance for the stock assessment scientists who will ultimately be requested to develop many of the conservation and management measures called for, particularly in the Section relating to National Standard 1, and particularly in light of the widely perceived need to adopt a precautionary approach to the management of marine fisheries. The main purpose of this paper is therefore to provide technical guidance on the use of precautionary approaches to implementing National Standard 1 of the MSFCMA in accordance with the NSGs.

This paper was prepared by a team of scientists from the National Marine Fisheries Service (NMFS) with experience in conducting stock assessments, providing scientific advice for fishery management, and developing precautionary approaches to managing fisheries. The technical guidance provided below is partly the product of their combined expertise. In addition, this guidance also reflects the work and group discussions of over 80 scientists who participated in the Fifth NMFS National Stock Assessment Workshop (February 24-26, 1998, Key Largo, Florida), which focused on the theme "Providing Scientific Advice to Implement the Precautionary Approach under the MSFCMA." Proceedings from that workshop will be published in a complementary NOAA Technical Memorandum.

This technical guidance is provided essentially for those aspects of scientific fishery management advice that have biological underpinnings, such as the response of fish populations to exploitation. The drafting team recognizes that there are many other important aspects to managing fisheries, such as socioeconomic factors, which are key to defining optimum yield, and which Fishery Management Councils must consider. Unfortunately, no formal operational protocol is routinely used to incorporate socioeconomic benchmarks into management advice. As such, the implementation of the MSFCMA would benefit greatly from complementary guidelines that address non-biological aspects of fisheries management in a quantitative framework.

EXECUTIVE SUMMARY

The 1998 Guidelines for National Standard 1 (Optimum Yield) of the Magnuson-Stevens Fishery Conservation and Management Act, 50 CFR Part 600, state: *"In general, Councils should adopt a precautionary approach to specification of OY."* Because of the technical nature of the task, NMFS convened a panel of scientists to provide technical guidance on specifying OY that is consistent with the Guidelines (NSGs). The technical guidance is contained in this document.

The precautionary approach implements conservation measures even in the absence of scientific certainty that fish stocks are being overexploited. In a fisheries context, the precautionary approach is receiving considerable attention throughout the world primarily because the collapse of many fishery resources is perceived to be due to the inability to implement timely conservation measures without scientific proof of overfishing. Thus, the precautionary approach is essentially a reversal of the "burden of proof".

The precautionary approach in fisheries is multi-faceted and broad in scope. The discussions in this document are not so broad in scope, and are limited to providing guidance to managers and scientists for specifying OY and for developing reference points to guide management decisions.

A common element in the application of the precautionary approach to fisheries management worldwide is the definition of "limits" intended to safeguard the long-term productivity of a stock. Several international agreements and documents that deal with the precautionary approach identify maximum sustainable yield (MSY) levels as a minimum standard for defining management limits. The Magnuson-Stevens Act encompasses this concept in that it constrains OY to be no greater than MSY.

The NSGs identify two limits for fishery management (referred to as "thresholds") that are necessary to maintain a stock within safe levels, capable of producing MSY: A maximum fishing mortality threshold (MFMT) and a minimum stock size threshold (MSST). The MFMT and MSST are intended for use as benchmarks to decide if a stock or stock complex is being overfished or is in an overfished state. In the NSGs, these two limits are intrinsically linked through an "MSY Control Rule" that specifies how fishing mortality or catches could vary as a function of stock biomass in order to achieve yields close to MSY. If the maximum fishing mortality limit is reduced as biomass decreases, then the minimum stock size limit decreases (although the MSST cannot become lower than ½ of the equilibrium biomass under a constant-fishing mortality MSY control rule). Thus, the shape of the MSY control rule is an important consideration for developing status determination criteria for overfishing.

A default MSY control rule is recommended in Section 2 of this document. Noting that Councils have considerable flexibility in defining the shape of the MSY control rule for each stock under their jurisdiction, and that different control rule shapes pertain to different management objectives, the recommended default could be used in the absence of more specific analyses. The default makes use of estimates of the constant fishing mortality rate resulting in MSY, F_{MSY}, and of the corresponding average spawning

biomass, B_{MSY}. The limit F, MFMT, is set equal to F_{MSY} at higher stock sizes; if the stock decreases much below B_{MSY}, the limit F is reduced proportionately (the reduction starts at a fraction of B_{MSY} related to the level of natural mortality). It is anticipated that estimates of F_{MSY} and B_{MSY} will be either unavailable or unreliable for many stocks. For this reason, Section 2 also presents a discussion of useful proxies.

Another common element in the application of the precautionary approach to fisheries management worldwide is the specification of "targets" that are safely below limits. Setting OY at its limit (MSY in the Magnuson-Stevens Act) would not normally be precautionary because there could be a high probability of exceeding the limit year after year. Under the precautionary approach, the target should be set below the limit taking uncertainty and other management objectives into consideration. Development of control rules requires communication between fisheries managers, scientists, industry and the public. If performance criteria for target control rules can be defined, then a range of alternative control rules can be developed and evaluated in terms of precautionary behavior and other desirable economic or operational characteristics for management, once precautionary constraints have been met.

Control rules are pre-agreed plans for making management decisions based on stock size. The pre-agreed nature of the measures ensures that management actions are implemented without delay, and it is possible to respond rapidly to changing conditions. As with MSY control rules, Councils have considerable flexibility in defining targets. Section 3 presents a recommended default target control rule that could be used in the absence of more specific analyses. The default sets the target fishing mortality rate 25% below the default limit proposed in Section 2. The 25% reduction constitutes a safety margin that may not perform well for all stocks in terms of preventing overfishing. The performance of the default target can only be evaluated on a case-by-case basis and will depend on (a) the accuracy and precision of stock size, B_{MSY} and F_{MSY} estimates, (b) natural variability in population dynamics, and (c) errors in the implementation of management regulations. Age-structured deterministic models suggest that, for a large combination of life history parameters, the recommended default can result in high stock sizes (around 130% of B_{MSY}) at the expense of relatively small foregone yields (achieving around 95% of MSY). It is recognized that no single policy can fully address all of the considerations to be encountered in the wide variety of fisheries subject to the Magnuson-Stevens Act. Nevertheless, the default target will be useful in a variety of situations and should at least serve to encourage development of more suitable policies for individual fisheries.

The default target control rule may not be applicable for many stocks that are already below the MSST (i.e., that are already overfished). In such cases, the NSGs require that special plans be implemented to rebuild the stocks up to the B_{MSY} level within a time period that is related to the stock's productivity. This document does not propose a default rebuilding plan, because the time to rebuilding may depend on each stock's current level of depletion. Instead, the document presents the four key elements that should be considered in rebuilding plans: An estimate of B_{MSY}, a rebuilding time period, a rebuilding trajectory, and a transition from rebuilding to more optimal management. The default target control rule may be adapted into a rebuilding plan for each overfished stock, for example, by allowing only a very low fishing mortality when the stock is below the MSST in order to rebuild the stock within the rebuilding time period.

This document also discusses a number of special considerations, such as changes in the selectivity of fishing gear, mixed-stock situations, changes in productivity due to the environment, and the appropriateness of various proxies for MSY-related parameters. One consideration of particular importance relates to setting limits and targets for data-poor stocks, i.e., those having very limited information. While the document provides defaults for these cases as well, it is imperative to improve the ability to make informed decisions through enhanced data collection and analyses.

Specification of MSY control rules, status determination criteria, and precautionary target control rules is a challenging exercise. Key to this process is communication between managers, scientists, users and the public. In the face of conflicting objectives (avoiding overfishing while achieving high long-term yields), it is essential to understand the tradeoffs associated with alternative control rules and the importance of the weights assigned to the different objectives or performance criteria. Simulation frameworks can facilitate the necessary interaction. In addition, simulation tools should be used to examine the performance of management systems as a whole, including data collection, assessments, control rules, and implementation of management tactics.

1. INTRODUCTION

1.1 The MSFCMA and the National Standard Guidelines

1.1.1 The MSY[1] Control Rule and Status Determination Criteria

A brief recap of key points from §600.310 of the NSGs will help to focus the task at hand. In discussing the concept of maximum sustainable yield (MSY), the NSGs include the following definitions in paragraph (c)(1):

> "*MSY is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions*."

> "*MSY control rule means a harvest strategy which, if implemented, would be expected to result in a long-term average catch approximating MSY*."

> "*MSY stock size means the long-term average size of the stock or stock complex, measured in terms of spawning biomass or other appropriate units, that would be achieved under an MSY control rule in which the fishing mortality rate is constant*."

Paragraph (c)(2) expands upon the meaning and importance of the MSY control rule, providing considerable flexibility in the process:

> "Because MSY is a theoretical concept, its estimation in practice is conditional on the choice of an MSY control rule. In choosing an MSY control rule, Councils should be guided by the characteristics of the fishery, the FMP's objectives, and the best scientific information available. The simplest MSY control rule is to remove a constant catch in each year that the estimated stock size exceeds an appropriate lower bound, where this catch is chosen so as to maximize the resulting long-term average yield. Other examples include the following: Remove a constant fraction of the biomass in each year, where this fraction is chosen so as to maximize the resulting long-term average yield; allow a constant level of escapement in each year, where this level is chosen so as to maximize the resulting long-term average yield; vary the fishing mortality rate as a continuous function of stock size, where the parameters of this function are constant and chosen so as to maximize the resulting long-term average yield. In any MSY control rule, a given stock size is associated with a given level of fishing mortality and a given level of potential harvest, where the long-term average of these potential harvests provides an estimate of MSY."

Although the MSFCMA mandates use of MSY, paragraph (c)(3) of the NSGs allows for cases in which MSY cannot be estimated directly:

> "When data are insufficient to estimate MSY directly, Councils should adopt other measures of productive capacity that can serve as reasonable proxies for MSY, to the extent possible. Examples include various reference points defined in terms of

[1] MSY and other terms that appear throughout this document are defined in the Glossary (Appendix B).

relative spawning per recruit. For instance, the fishing mortality rate that reduces the long-term average level of spawning per recruit to 30-40 percent of the long-term average that would be expected in the absence of fishing may be a reasonable proxy for the MSY fishing mortality rate. The long-term average stock size obtained by fishing year after year at this rate under average recruitment may be a reasonable proxy for the MSY stock size, and the long-term average catch so obtained may be a reasonable proxy for MSY. The natural mortality rate may also be a reasonable proxy for the MSY fishing mortality rate. If a reliable estimate of pristine stock size (i.e., the long-term average stock size that would be expected in the absence of fishing) is available, a stock size approximately 40 percent of this value may be a reasonable proxy for the MSY stock size, and the product of this stock size and the natural mortality rate may be a reasonable proxy for MSY."

In discussing the concept of overfishing, the NSGs use the MSY control rule to define a pair of "status determination criteria" (SDC) in paragraph (d)(2):

> "Each FMP must specify, to the extent possible, objective and measurable status determination criteria for each stock or stock complex covered by that FMP and provide an analysis of how the status determination criteria were chosen and how they relate to reproductive potential. Status determination criteria must be expressed in a way that enables the Council and the Secretary to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished. In all cases, status determination criteria must specify both of the following:
>
> > "(i) <u>A maximum fishing mortality threshold or reasonable proxy thereof</u>. The fishing mortality threshold may be expressed either as a single number or as a function of spawning biomass or other measure of productive capacity. The fishing mortality threshold must not exceed the fishing mortality rate or level associated with the relevant MSY control rule. Exceeding the fishing mortality threshold for a period of 1 year or more constitutes overfishing.
> >
> > "(ii) <u>A minimum stock size threshold or reasonable proxy thereof</u>. The stock size threshold should be expressed in terms of spawning biomass or other measure of productive capacity. To the extent possible, the stock size threshold should equal whichever of the following is greater: One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold specified under paragraph (d)(2)(i) of this section. Should the actual size of the stock or stock complex in a given year fall below this threshold, the stock or stock complex is considered overfished."

Section 2 of this document focuses on technical guidance for establishing MSY and limit control rules and the associated minimum stock size and maximum fishing mortality thresholds.

1.1.2 The Precautionary Approach in Specifying Management Targets

The MSFCMA does not use the term "precautionary approach" *per se*. However, in discussing the concept of optimum yield (OY), the NSGs call for the use of a precautionary approach in paragraph (f)(5):

> "In general, Councils should adopt a precautionary approach to specification of OY. A precautionary approach is characterized by three features:
>
> > "(i) Target reference points, such as OY, should be set safely below limit reference points, such as the catch level associated with the fishing mortality rate or level defined by the status determination criteria. Because it is a target reference point, OY does not constitute an absolute ceiling, but rather a desired result. An FMP must contain conservation and management measures to achieve OY, and provisions for information collection that are designed to determine the degree to which OY is achieved on a continuing basis--that is, to result in a long-term average catch equal to the long-term average OY, while meeting the status determination criteria. These measures should allow for practical and effective implementation and enforcement of the management regime, so that the harvest is allowed to reach OY, but not to exceed OY by a substantial amount. The Secretary has an obligation to implement and enforce the FMP so that OY is achieved. If management measures prove unenforceable--or too restrictive, or not rigorous enough to realize OY--they should be modified; an alternative is to reexamine the adequacy of the OY specification. Exceeding OY does not necessarily constitute overfishing. However, even if no overfishing resulted from exceeding OY, continual harvest at a level above OY would violate national standard 1, because OY was not achieved on a continuing basis.
> >
> > "(ii) A stock or stock complex that is below the size that would produce MSY should be harvested at a lower rate or level of fishing mortality than if the stock or stock complex were above the size that would produce MSY.
> >
> > "(iii) Criteria used to set target catch levels should be explicitly risk averse, so that greater uncertainty regarding the status or productive capacity of a stock or stock complex corresponds to greater caution in setting target catch levels. Part of the OY may be held as a reserve to allow for factors such as uncertainties in estimates of stock size and DAH. If an OY reserve is established, an adequate mechanism should be included in the FMP to permit timely release of the reserve to domestic or foreign fishermen, if necessary."

Section 3 of this document focuses on technical guidance for specifying precautionary targets that would be consistent with the NSGs. The subsection below provides more comprehensive information on the precautionary approach as it has been and is being considered in different fisheries fora, and discusses elements of the approach that are not identified in the National Standard 1 Guidelines.

1.2 The Precautionary Approach in Fisheries Management

1.2.1 Evolution: International Agreements

The United Nations Convention on the Law of the Sea (1982) provided several mechanisms to promote responsible management of marine fisheries; however, it was not until the 1990s that work began on developing a precautionary approach to fisheries management. In 1991, the Committee on Fisheries (COFI) of the Food and Agriculture Organization (FAO) requested FAO to develop an International Code of Conduct for Fisheries. Subsequently, FAO and the government of Mexico sponsored an International Conference on Responsible Fishing, held in Cancun in May 1992. Resolutions formulated in Cancun were presented at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. The Rio meeting highlighted the importance of the precautionary approach in the Rio Declaration and Agenda 21. For example, Principle 15 of the Rio Declaration states that "*in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"

Several binding and non-binding agreements embodying the precautionary approach were developed and concluded over the period 1991-1996. The most comprehensive of these is the FAO Code of Conduct for Responsible Fisheries, concluded in late 1995 (FAO 1995a). The Code of Conduct addresses six key themes: Fisheries management, fishing operations, aquaculture development, integration of fisheries into coastal area management, post-harvest practices and trade, and fisheries research. In total, there are 19 general principles and 210 standards in the Code. While a precautionary approach is integral to all themes, it is applied particularly to fisheries management, as detailed in Article 7.5. Paragraph 7.5.1 includes a statement to the effect that:

> "*States should apply the precautionary approach widely to conservation, management, and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment.*"

The same paragraph also emphasizes that the absence of adequate scientific information is not a reason for postponing or failing to take conservation and management measures. The remaining paragraphs include similar provisions to those in Article 6 of the UN Straddling Stocks Agreement (see below); for example, determination of stock-specific target and limit reference points (Caddy and Mahon 1995), the need to take action if they are exceeded, and the need to take account of uncertainties and impacts on non-target and associated or dependent species. In addition, guidelines are given for adopting a cautious approach in the case of new or exploratory fisheries, and for implementing emergency management measures when resources are seriously threatened due to environmental factors or fishing activity.

The Code of Conduct is a voluntary, non-binding agreement. However, it contains sections that are similar to those in two binding agreements: The Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (the Compliance Agreement), and the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (the Straddling Stocks Agreement; UN 1995).

The Compliance Agreement was adopted at the FAO Conference at the 27th session in November 1993. The agreement specifies the obligations of Parties whose fishing vessels fish on the high seas, including the obligation to ensure that such vessels do not undermine international fishery conservation and management measures. The Compliance Agreement is considered to be an integral part of the Code of Conduct. The United States implemented the Compliance Agreement through the High Seas Fishing Vessel Compliance Act of 1995.

The Straddling Stocks Agreement was negotiated over a similar period to the Code of Conduct and the content and wording on many issues, including those related to the precautionary approach and General Principles, is similar to that in the Code of Conduct. Although the Straddling Stocks Agreement is strictly applicable to straddling fish stocks and highly migratory fish stocks, much of it is also relevant to fishing within national exclusive economic zones.

Annex II of the Straddling Stocks Agreement (UN 1995) provides guidelines for the application of precautionary reference points. Paragraph 2 states, “Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points.” Paragraph 5 stipulates, “Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low,” and imposes the further constraint that target reference points should not be exceeded on average. Paragraph 7 states that “The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points.” This combination of requirements implies that fishing mortality should always be well below the level associated with maximum sustainable yield (F_{MSY}).

More detailed treatments of the historical development of the precautionary approach are contained in ICES (1997a), Serchuk *et. al.* (1997), Thompson and Mace (1997), and Mace and Gabriel (in prep.).

1.2.2 <u>The Overall Scope of the Precautionary Approach</u>

According to the Code of Conduct (FAO 1995a), precaution is required in development planning, management, research, technology development and transfer, legal and institutional frameworks, fish capture and processing, fisheries enhancement, and aquaculture. Thus the precautionary approach is multi-faceted and broad in scope.

The 1995 FAO Technical Guidelines on the Precautionary Approach (FAO 1995b) groups guidelines on the precautionary approach into three primary subject areas of relevance to capture fisheries: Fisheries management, fisheries research, and fisheries technology. The next three subsections summarize the main issues covered under each area and, while they do not include every aspect of the guidelines, they highlight the large number and diversity of issues involved.

Fisheries Management

The precautionary approach to fisheries management requires:

- prudent foresight;
- taking into account unknown uncertainty by being more conservative;
- establishment of legal or social frameworks for all fisheries, including rules to control access, data reporting requirements, and management planning processes;
- implementation of interim measures that safeguard resources until management plans are finalized;
- avoidance of undesirable or unacceptable outcomes such as overexploitation of resources, overdevelopment of harvesting capacity, loss of biodiversity, major physical disturbances of sensitive biotopes, and social or economic dislocations;
- explicit specification of management objectives including operational targets and constraints;
- prospective evaluation; and
- sound procedures for implementation, monitoring and enforcement.

Fisheries Research

Research needed to implement precautionary management should strive to:

- provide data and analyses of relevance to fisheries management;
- emphasize the roles that fisheries scientists and others must play in helping managers develop objectives;
- provide scientific evaluation of consequences of management actions;
- develop operational targets, constraints and criteria that are both scientifically usable and managerially relevant;
- incorporate both biological and socio-economic elements;
- ensure that data are accurate and complete;
- monitor fisheries;
- conduct research on which management processes and decision structures work best;
- incorporate uncertainty into assessments and management;
- address reversibility and irreversibility in ecosystems;
- formulate implementation guidelines;
- be multi-disciplinary in nature, including social, economic, and environmental sciences, and addressing management institutions and decision-making processes; and
- investigate environmentally-friendly fishing gears.

Fisheries Technology

A precautionary approach to fisheries technology would:

- not use technology to cause capacity to increase further in already overcapitalized fisheries;
- use technology to improve sustainability, prevent damage to the environment, improve economic and social benefits, and improve safety;
- evaluate the effects of new technologies and gears;
- educate fishers and consumers towards responsible practices;
- consider impacts on non-target species and ecosystems;
- evaluate fishing gears with respect to selectivity by size and species, survival of escapees, ghost fishing, effects on habitat, contamination, pollution, generation of debris, safety and occupational hazards, user conflicts, employment, monitoring and enforcement costs, techno-economic factors (infrastructure and service requirements, product quality), and legal factors (existing legislation, international agreements, civil liberties);
- consider proper procedures for introducing new technology or changes to existing technology;
- promote research to encourage improvement of existing technologies and to encourage development of appropriate new technologies, and;
- encourage research into responsible fisheries technology.

From these three lists, it is obvious that biological reference points and control rules are but one part in the overall framework of the precautionary approach. Although in some respects they can be considered a primary focus of any precautionary management strategy, they need to be put in proper perspective. Other needs may be just as important; for example, development of access control systems to ensure that fishing capacity is commensurate with resource productivity, evaluation of alternative management systems and institutions, improvements in the quality and reliability of data, improved monitoring and enforcement, design of "environmentally-friendly" fishing gear, and education of fishers and consumers.

Regarding research in support of management decisions, it is important that decisions made in stock assessments regarding model choice, estimation techniques and selection of parameters be transparent. Care should be taken when using the term “precautionary” in relation to the science underpinning advice to managers. The scientists’ primary role is to provide scientifically-based options that managers can use to achieve management goals. It is perfectly reasonable for managers to select a "precautionary" management target (e.g., F = lower 80% CI of the probability distribution for F_{MSY}) based on advice from scientists that this choice will achieve the management objectives, but it is not reasonable for scientists to add non-transparent conservatism or precaution into the estimation process (e.g., by claiming that the lower 80% CI of the distribution of F_{MSY} is the best estimate of F_{MSY}).

1.3 Control Rules and Reference Points in the Context of the Precautionary Approach

According to the Code of Conduct for Responsible Fisheries (FAO 1995a),

"*States and subregional or regional fisheries management organizations and arrangements should, on the basis of the best scientific evidence available, inter alia, determine:*

"*stock specific target reference points, and, at the same time, the action to be taken if they are exceeded; and*

"*stock-specific limit reference points, and, at the same time, the action to be taken if they are exceeded; when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded.*"

Thus, two critical components of precautionary management are the specification of limit and target reference points, and pre-agreed management measures to be implemented as a function of stock conditions relative to those reference points. The pre-agreed nature of the measures ensures that management actions are implemented without delay, and it is possible to respond rapidly to changing conditions. Otherwise, management actions could be dependent on the achievement of consensus while stock conditions continue to deteriorate. The MSFCMA makes it clear that effective management actions must be implemented promptly.

<u>Limit reference points</u> are intended to constrain harvests so that the stock remains within safe biological limits, and is capable of producing maximum sustainable yield. Management should proceed so that the risk of exceeding the limit reference points is very low. The minimum standard for limit reference points should be the fishing mortality rate that generates MSY, according to Annex II of the Straddling Stocks Agreement. This is consistent with the revised MSFCMA, which states that the terms "overfishing" and "overfished" mean a rate or level of fishing mortality that jeopardizes the stocks's capacity to produce MSY. Thus, the MSFCMA definition of overfishing and the Annex II standards for precautionary limit reference points both imply that F_{MSY} should be an upper bound on fishing mortality, although the MSFCMA does not define F_{MSY} as an undesirable outcome to be avoided.

[<u>NOTE</u>: Nomenclature within the National Standard Guidelines differs somewhat from that in various FAO documents. *Limit* reference points in the FAO text correspond to *threshold* levels in the National Standard Guidelines and in some literature, such as the review of overfishing definitions by Rosenberg *et. al.* (1994). In the FAO text and much of the international literature, the word threshold is used in the context of establishing "buffers", to trigger action before limit reference points are reached. Such buffers are not equivalent to the thresholds defined in the NSGs, but are analogous to the "interim thresholds" referred to in the preamble to the final rule issuing the NSGs. This document uses the word limit in the same sense as the FAO text. However, in order to maintain consistency with the language of the NSGs, "threshold" is used when referring specifically to the limit reference points that define the act overfishing and an overfished state in the NSGs --the Maximum Fishing Mortality Threshold, MFMT, and the Minimum Stock Size Threshold, MSST--]

Target reference points are intended to achieve management objectives, and represent desirable outcomes to be attained. Target reference points should not be exceeded more than 50% of the time, nor on average. A target biomass level for stocks that require rebuilding could be the biomass that would produce MSY. The FAO guidelines on the precautionary approach (FAO 1995b) indicate that the constraints of limit reference points have precedence over targets, and target reference points may require adjustment so that the probability of violating the constraints while meeting the target would be small. The idea that limits have precedence over targets is consistent with the revised MSFCMA, in which OY corresponds to a target level, but is constrained to be less than or equal to MSY.

A control rule describes a variable over which management has some direct control as a function of some other variable(s) related to the status of the stock. In many discussions of the topic, a control rule describes a reference fishing mortality rate as a function of stock size, and such is the main focus of Sections 2 and 3 of this paper. In general, however, control rules do not have to be cast in terms of fishing mortality rates or biomass levels. Simply put, a control rule seeks to identify measures of "good" and "bad" stock condition (by comparing perceived stock status with biological reference points), as well as the actions that will make the stock condition change from "bad" to "good." There are two types of precautionary elements that can be considered in implementing a control rule for management targets: The reference points to be used, and the type of management reaction to be implemented. The degree of precaution achieved in implementing such a control rule is determined by a combination of the probability of going from a "good" stock condition to a "bad" one (overfishing), and the action to be taken when the stock is overfished. Naturally, the current stock condition affects the probability of overfishing, and hence the degree of precaution.

Development of control rules requires interaction between fisheries managers and scientists. In addition, public participation is important because the public and fishing industry are more inclined to support management measures on which they have been consulted and which they understand clearly (FAO 1995b). If managers can define acceptable performance criteria for target control rules, then a range of alternative control rules can be developed and evaluated in terms of precautionary behavior and other desirable economic or operational characteristics for management, once precautionary constraints have been met (this approach is explained in Section 3.2). For example, performance criteria could be formulated as the application of a target control rule with "probability of less than X% of reducing the resource below Y% of K within a period of Z years" (Butterworth and Bergh 1993). The effects of other criteria, e.g., "no more than W% change in catch from year to year" could also be evaluated once precautionary constraints were met. An alternative to maximizing performance, constrained by the degree of precaution defined by managers, is to define performance itself in terms of precaution (i.e., the approach in Section 3.1) so that precaution is built directly into optimizing the management objective. With either approach, it is clear that the nature of tradeoffs between the various performance criteria of interest requires substantial interaction between managers and scientists, and open consultation with the public.

Target control rules will vary depending on the quality and quantity of available data, as well. Thus, it is unreasonable to expect that target control rules will be perfectly uniform over all stocks. Specification of objectives and performance criteria will enable the development of control rules that will have more acceptable operational implications and still meet precautionary criteria.

Rebuilding plans are special forms of target control rules, to be implemented when stocks have fallen below limit biomass levels. Rebuilding plans should include quantifiable milestones to measure progress toward recovery during the plan's implementation. The precautionary approach counsels that rebuilding action be undertaken immediately, rather than deferred to the end of the proposed rebuilding period.

2. LIMIT CONTROL RULES AND STATUS DETERMINATION CRITERIA

This section provides technical guidance for specifying what the National Standard Guidelines refer to as "MSY control rules" (Section 1.1.1), which are used to set the criteria for determining whether a stock is being overfished or the stock is in an overfished state. Also included are recommended defaults for cases lacking detailed analyses, and guidance on the use of proxies. In presenting these defaults, our intention is not to inhibit the use of other control rules, but rather to suggest a useful starting point or a "fall-back" position.

2.1 General Approach

2.1.1 Control Rules

A control rule describes a variable over which management has some direct control as a function of some other variable(s) related to the status of the stock. That is, the control rule represents a pre-agreed plan for adjusting management actions depending on the condition of the stock. In broad terms, the management actions may be designed as strategies to achieve (a) a fixed exploitation rate (to harvest a constant fraction of the stock each year), (b) constant escapement (e.g., to maintain a constant spawning stock size), or (c) constant catch. However, control rules do not have to adhere strictly to any of these three strategies, and managers may prefer control rules that achieve different results depending on the condition of the stock.

In many discussions of the topic, a control rule describes a reference fishing mortality rate *F* as a function of stock size *B*, although it is also possible to use catch as the dependent variable. In fact, either option can be expressed in terms of the other, and it is useful to present both. Figure 1 illustrates three possible functional forms for target control rules in terms of both fishing mortality and catch: The two-parameter "logarithmic" form

$$F(B) = a + b\ln(B) ,$$

the three-parameter "linear-linear" form

$$F(B) = a + b\min(0, B - c) ,$$

and the three-parameter "linear-hyperbolic" form

$$F(B) = \frac{ac}{\max(B,c)} + b\min(0, B - c) ,$$

where *a*, *b* and *c* are parameters that determine the magnitude of *F* depending on the value of *B*.

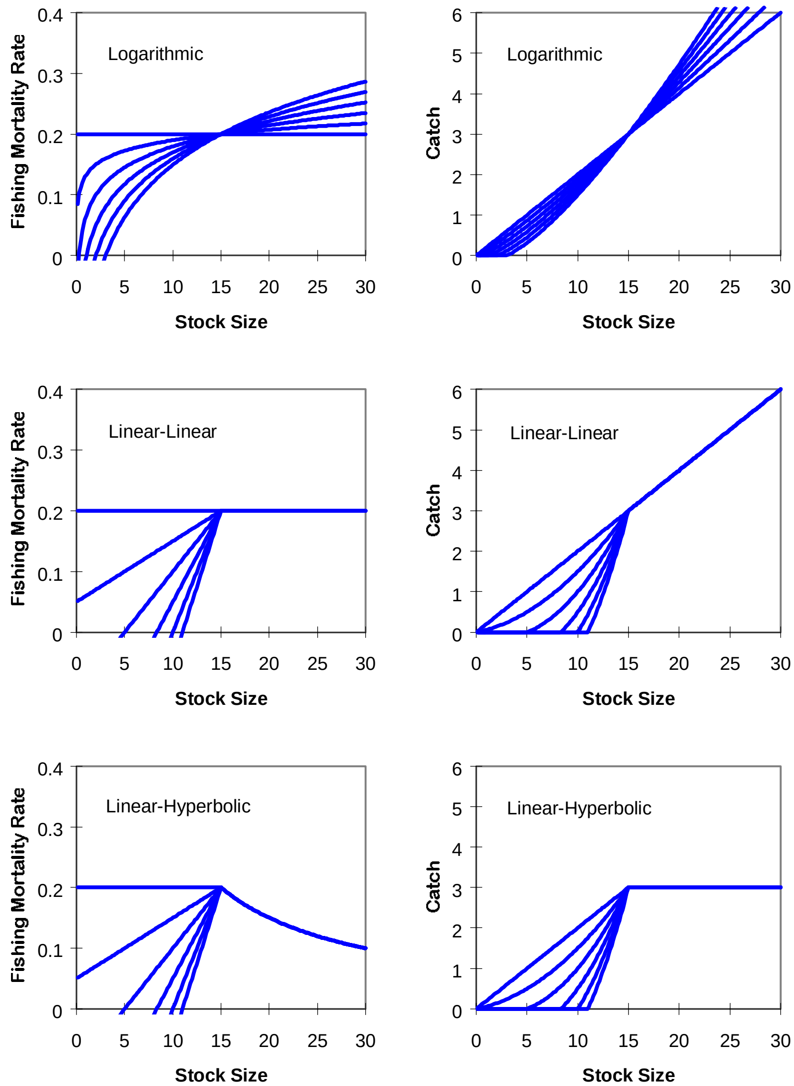

Figure 1. Some families of control rules. Each panel shows a family of control rules conforming to a particular functional form and passing through a common (arbitrary) point.

The logarithmic form forces the fishing mortality rate to vary smoothly with stock size. The linear-linear form forces the fishing mortality rate to be constant when the stock exceeds a specified size. The linear-hyperbolic form forces the catch to be constant when the stock exceeds a specified size (for the special case where catch is computed as the product of stock size and the fishing mortality rate). Figure 1 shows six examples for each form of control rule, where the six examples of the linear-linear form (middle panels of Figure 1) are indistinguishable from one another at values of $B>c$, as are the six examples of the linear-hyperbolic form (lower panels of Figure 1).

The control rules shown in Figure 1 are only a subset of the many shapes possible that could be specified. For instance, an asymptotic (mono-molecular) equation would be an alternative to the smooth logarithmic control rule in which *F* would be capped at high levels of biomass.

2.1.2 MSY Control Rules and the Status Determination Criteria

A special case of control rule is the MSY control rule. Referring to control rules of the type described above and illustrated in the left half of Figure 1, NMFS' guidelines for National Standard 1 state that such an MSY control rule gives

> "*...fishing mortality rate as a continuous function of stock size, where the parameters of this function are constant and chosen so as to maximize the resulting long-term average yield.*"

For example, any of the control rules listed above could be transformed into an MSY control rule by fixing the value of one or perhaps two of the control parameters (say, *b* in the case of the logarithmic control rule or *b* and *c* in the case of the linear-linear or linear-hyperbolic control rules) independently and setting the remaining control parameter (say, *a*) at the value that maximizes long-term average yield, conditional on the value of the independent control parameter(s) (see Section 3.1). For example, in either the logarithmic or linear-linear forms, setting b=0 gives a control rule in which the fishing mortality rate is equal to the constant *a* (i.e., a control rule in which fishing mortality is independent of stock size). Setting *a* at the value that maximizes long-term average yield for this special case results in a very simple form of MSY control rule. However, substituting the same value of *a* into a control rule where b>0 would generally *not* result in an MSY control rule, because the yield-maximizing value of one control parameter will typically be dependent on the value of the other(s) (Thompson in prep.).

Under the guidelines for National Standard 1, the MSY control rule serves two important purposes: (1) It constitutes the maximum fishing mortality threshold (MFMT), above which overfishing is considered to be occurring; and (2) it determines the minimum stock size threshold (MSST), below which the stock is considered overfished. Thus, the MSY control rule is key to defining limit reference points. The role of the MSY control rule in determining the MSST can be seen in the following definition:

> "*To the extent possible, the stock size threshold should equal whichever of the following is greater: One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold ...*"

For example, all of the logarithmic control rules shown in the upper-left panel of Figure 1 happen to constitute MSY control rules under a particular model (Thompson in prep.). These control rules are reproduced in Figure 2 together with a set of vertical dotted lines, each of which indicates the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock were consistently exploited according to the corresponding MSY control rule. The vertical dotted line labeled "A" corresponds to the control rule labeled "A," the vertical dotted line labeled "B" corresponds to the control rule labeled "B," and so forth. The more the control rule departs from the horizontal (control rule "F"), the lower the stock can fall and still be expected to recover within 10 years. This result conforms with intuition, because curves with greater departure from the horizontal exert less fishing pressure at low stock sizes, thus increasing the rate of rebuilding at those stock sizes.

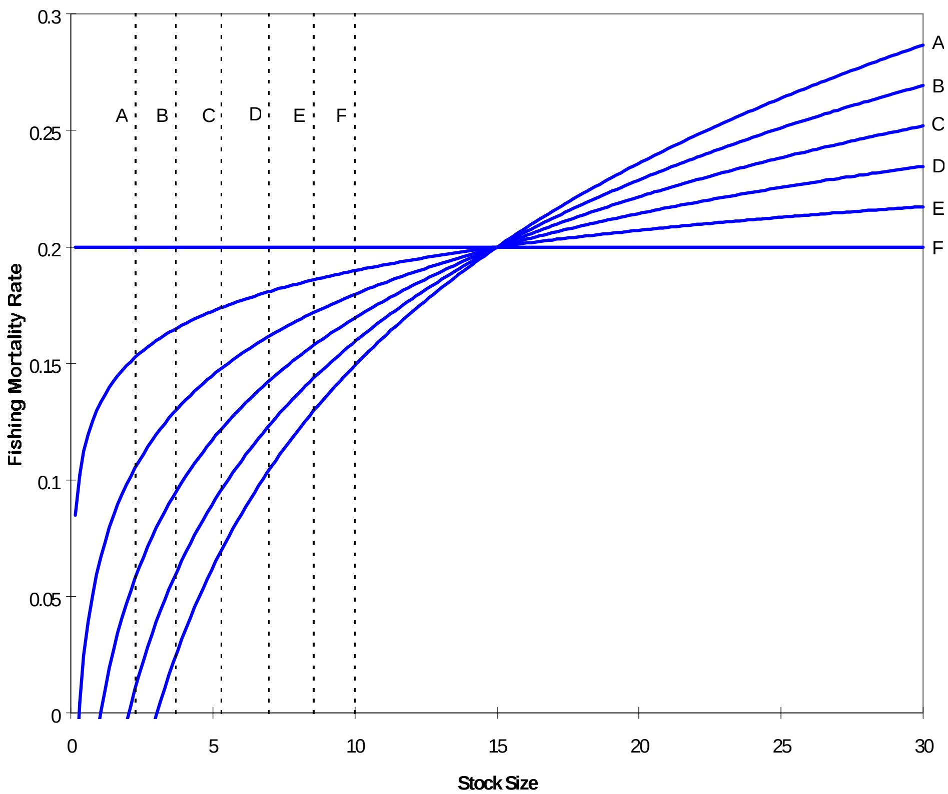

Figure 2. Example MSY control rules (solid curves) and associated stock sizes at which rebuilding would be expected within 10 years (dotted lines). The curve labeled "A" is associated with the line labeled "A," etc.

The dependence of the MSST on the MSY control rule is also illustrated in Figure 3 for a linear-linear type of control rule. Here, the MSY control rule sets MFMT constant for biomass levels above B_{MSY} and decreases it linearly with biomass below B_{MSY}. The solid lines labeled a, b and c represent three such MSY control rules and the dashed lines indicate the corresponding MSST levels (shown in relative units), i.e., the values of biomass at which rebuilding to B_{MSY} would take 10 years when fishing at the MFMT (in reality, the actual position of these levels will vary with the life-history characteristics of the species in question). The ascending parts of these example control rules can be interpreted as built-in plans for rebuilding from the MSST to B_{MSY} — for a fixed rebuilding time period (e.g., 10 years), the stronger reductions in limit fishing mortality at low biomass allow for rebuilding from lower biomass limits.

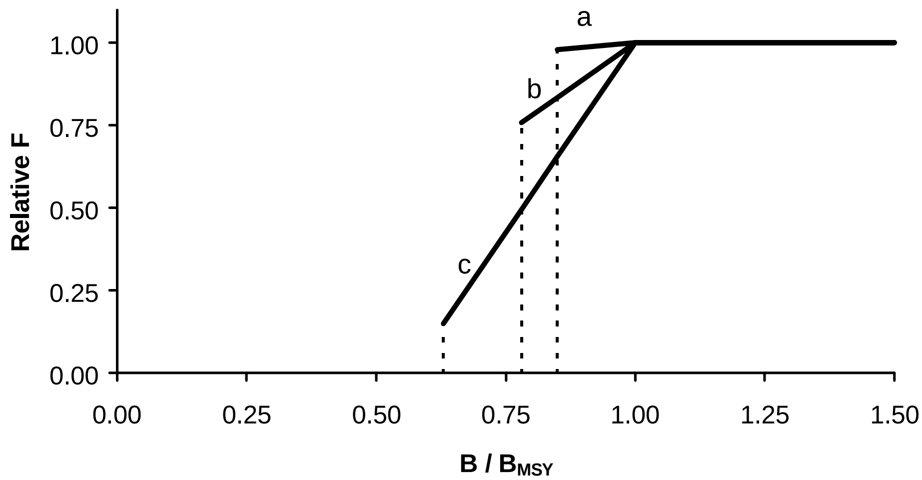

Figure 3 Hypothetical example illustrating the relationship between Minimum Stock Size Threshold (intersection of the dashed lines with the X-axis) and a linear-linear MSY control rule (solid lines, which define the Maximum Fishing Mortality Threshold). Each of the three rules labeled a, b and c, is scaled relative to its own maximum.

2.1.3 Choosing an MSY Control Rule

One factor that might go into choosing an MSY control rule is the resulting location of the MSST. For example, if a Council wished to minimize the range of stock sizes within which special rebuilding plans would be required, it would probably opt for an MSY control rule that afforded a good deal of "built-in" rebuilding, that is, an MSY control rule in which fishing mortality was greatly decreased at low stock sizes. Of course, in no case could the MSST fall below one-half of the MSY level.

Another factor that might go into choosing an MSY control rule is the tradeoff between magnitude of yield and constancy of yield. In general, a horizontal MSY control rule (e.g., control rule "F" in Figure 2) would be expected to result in a lower long-term average yield but a less variable yield than an MSY control rule in which fishing mortality was strongly related to stock size (e.g., control rule "A" Figure 2). Councils have considerable flexibility in choosing how to weight their preferences for these and other performance criteria. NMFS' guidelines for National Standard 1 give the following advice:

> "*In choosing an MSY control rule, Councils should be guided by the characteristics of the fishery, the FMP's objectives, and the best scientific information available.*"

2.1.4 Recommended Default MSY Control Rule

As implied above, specifying an MSY control rule is a flexible process that should involve a great deal of communication between scientists and managers so that the tradeoffs between the relevant performance criteria are understood. Due to the demands imposed by the timetable of required FMP amendments or other factors, it is desirable to propose a limit control rule that can be used as a default for defining SDC in the absence of more detailed analyses.

We recommend a default MSY control rule of the form (see Figure 4):

$$F(B) = \frac{F_{MSY}\, B}{c\, B_{MSY}} \quad \text{for all } B \le c\, B_{MSY}$$

$$F(B) = F_{MSY} \quad \text{for all } B \ge c\, B_{MSY},$$

where c=max(1-M, 1/2), F_{MSY} is the fishing mortality rate that maximizes long-term yield under a constant-F policy, and B_{MSY} is the equilibrium biomass expected when fishing constantly at F_{MSY}. Setting c=max(1-M, 1/2), where M is the natural mortality rate of the exploited age classes, seems reasonable insofar as 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).

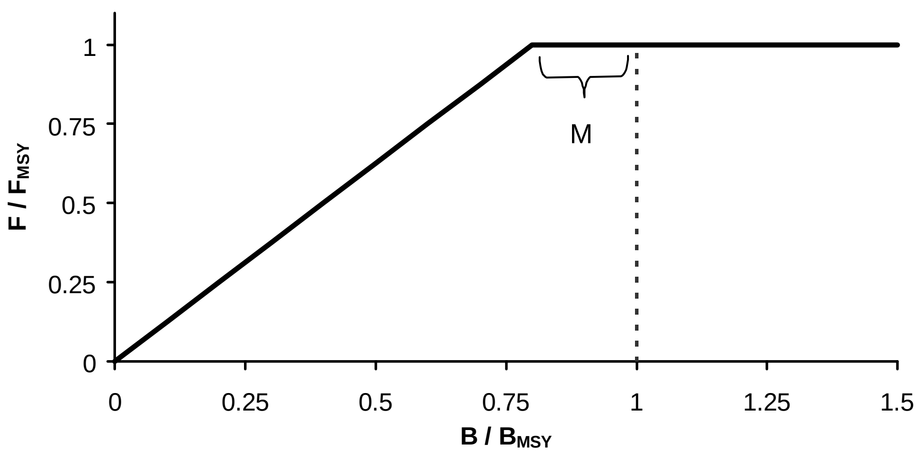

Figure 4. Recommended default MSY control rule.

Note that a control rule of this shape, and parameterized as suggested, may not exactly achieve the maximum long-term yield. The reason for this is that, in an MSY control rule of this form, $F(B)$ would be somewhat larger than F_{MSY} in the flat part of the function (the degree of departure from F_{MSY} is likely to be small in many cases, but is unknown *a priori* in the absence of detailed analyses). Nevertheless, $F(B)$ can be used to define an approximate MFMT.

As noted in Section 2.1.2, the MSST is determined in part by the MSY control rule and is constrained to be greater than ½B_{MSY}. However, for a given MSY control rule, the precise location of the MSST with respect to B_{MSY} may depend on the dynamics of the particular stock. Estimating the location of the MSST with respect to the MSY stock size can be fairly difficult in some situations and may require the use of simulation tools. If needed, we recommend that the point cB_{MSY} in the default MSY control rule be used as a default proxy for the MSST.

2.1.5 The Role of Selectivity

A fact often overlooked is that the enumeration of MSY depends on partial recruitment patterns. In theory, assuming no variability in life-history parameters, there could be a "global" MSY that can be achieved by totally avoiding fishing until each cohort reaches the age (size) at which losses due to natural mortality exceed contributions from growth and reproduction, and then harvesting all fish of that age (size) instantaneously. However, such knife-edge selection and deterministic life-history parameters are unrealistic, such that the “global” MSY referred to by the NSGs should be treated as a purely theoretical concept.

Calculations of MSY are generally based on the current partial recruitment pattern exhibited by the fishery. "Partial recruitment" patterns reflect both the relative *availability* of fish of different ages or sizes (i.e., their distribution in time and space relative to that of the fishery) and of the relative *selectivity* of fish of different ages or sizes exhibited by the mix of gears used in the fishery. For any particular partial recruitment pattern, there is a unique estimate of MSY (all other things being constant). What this means is that estimates of MSY will change if management actions or environmental factors alter the partial recruitment of the fishery in any way. Management actions that can affect MSY include reallocation of quotas between sectors, increases or decreases in size limits, gear modifications and seasonal changes in the fishery. Environmental factors that can alter MSY include those that influence growth rates and other life history characteristics, and those that influence fish movements and distribution, and therefore availability. Estimates of MSY can vary over a large range due to these factors. It is often possible to substantially increase sustainable yields by changing the selectivity pattern to improve yield per recruit. Similarly, potential sustainable yield is dissipated when the fishery is managed in such a way that yield per recruit is reduced, even though management may still be based on “MSY.”

Clearly, the magnitude of MSY is an important management issue, as is the exploitation pattern, since it affects the magnitude of MSY. Indeed, these are important issues in developing rebuilding plans for overfished stocks. However, initial specification of control rules should be based upon existing partial recruitment patterns, i.e., the existing mix of gears, allocation decisions and management regulations. If the partial recruitment pattern used for defining the MFMT is substantially different from that in the fishery, then the Councils and the Secretary will be unable to monitor and evaluate the condition of the stock relative to the definition of overfishing.

2.2 Situations Requiring the Use of Proxies

As noted in Section 1.1, the MSFCMA allows for the use of proxies in situations where there is insufficient knowledge to implement approaches such as that in Section 2.1. In general, proxies will be needed when MSY-related parameters cannot be estimated from available data, or when their estimated values are deemed to be unreliable for various reasons (e.g., extremely low precision, insufficient contrast in the data, or inadequate models). This documents refers to "data-moderate" and "data-poor" situations as those that require the use of proxies.

There are no standards for measuring the level of data richness for a stock. This document offers the following guidance to categorize stocks (note that cases involving a stock complex are likely to be of mixed data richness):

> Data-rich cases: Reliable estimates of MSY-related quantities and current stock size are available. Control rules typically involve parameters such as F_{MSY}, B_{MSY}, etc. Stock assessments may be sophisticated, and provide a reasonably complete accounting of uncertainty.
>
> Data-moderate cases: Reliable estimates of MSY-related quantities are either unavailable or of limited use due to peculiar life history, poor data contrast, or high recruitment variability, but reliable estimates of current stock size and all critical life history (e.g., growth) and fishery (e.g., selectivity) parameters are available. Control rules typically involve parameters such as $F_{35\%}$, $B_{35\%}$, etc., or other proxies for MSY-related benchmarks. Stock assessments may range from simple to sophisticated and uncertainty can be reasonably characterized and quantified. (It should be noted that there may be cases when proxies would be useful in "data-rich" situations, i.e., when the proxies are believed to be more robust or reliable than the estimates of MSY parameters. Thus, the term "data-moderate" might be better interpreted as meaning "information-moderate").
>
> Data-poor cases: Reliable estimates of MSY-related quantities are unavailable, as are reliable estimates of either current stock size or certain critical life history or fishery parameters. Control rules typically involve parameters such as M, historical average catch, etc. Stock assessments are minimal, and measurements of uncertainty may be qualitative rather than quantitative.

The list of proxies presented in the following sections is not all-inclusive and scientists are encouraged to develop and examine alternatives.

2.2.1 Data-Moderate Situations

The most widely used biological reference points are those derived from age-structured stock-recruitment models or surplus production models (MSY, F_{MSY}, f_{MSY}), yield per recruit analysis ($F_{0.1}$ and F_{max}), spawning per recruit analysis (various percentages of maximum SPR and associated fishing mortality rates such as $F_{20\%}$, $F_{30\%}$, $F_{35\%}$, and $F_{40\%}$), and stock-recruitment relationships (slope at the origin, or the spawning biomass below which recruitment markedly drops) (Caddy and Mahon 1995). In general, reference points from YPR and SPR analyses are the simplest to calculate because they require fewer inputs (stock recruitment data in particular). For this reason, YPR and SPR reference points are often used as proxies for other reference points that do require stock and recruitment data.

Proxies for F_{MSY}

F_{max} was one of the earliest measures used as a proxy for F_{MSY}. However, it was often believed to be an overestimate of F_{MSY}, because it does not account for the fact that recruitment must decline at some point for low spawning stock sizes, and because F_{max} is unreasonably large (or even infinite) for some sets of growth and mortality parameters. Computer models have also demonstrated that F_{max} typically overestimates F_{MSY} if a Beverton-Holt (1957) stock-recruitment relationship applies, although F_{MSY} can sometimes exceed F_{max} with a Ricker (1958) curve. $F_{0.1}$ (Gulland and Boerema 1973) was developed as an alternative to F_{max} which could result in nearly the same yield per recruit but with lower levels of exploitation. Today, $F_{0.1}$ is commonly interpreted as a conservative or cautious proxy for F_{MSY}, although this is not always the case (Mace 1994; Mace and Sissenwine 1993).

Another class of reference points that has gained prominence are those based on $F_{\%SPR}$. In particular, values in the range $F_{20\%}$ to $F_{30\%}$ have frequently been used to characterize recruitment overfishing thresholds (Rosenberg *et. al.* 1994), while values in the range $F_{30\%}$ to $F_{40\%}$ have been used as proxies for F_{MSY}. These uses are supported by Goodyear (1993); by Mace and Sissenwine (1993), who advocated $F_{20\%}$ as a recruitment overfishing threshold for well-known stocks with at least average resilience and $F_{30\%}$ as a recruitment overfishing threshold for less well-known stocks or those believed to have low resilience; and by Clark (1991; 1993), who advocated $F_{35\%}$ as a robust estimator of F_{MSY} applicable over a wide range of life histories, or $F_{40\%}$ if there is strong serial correlation in recruitment. Note, however, that much of the work on $F_{\%SPR}$ has presupposed a moderate amount of resilience to fishing pressure. Moderate resilience may not be a viable assumption for long-lived species and those with low reproductive output. For example, recent analyses of west coast rockfish (*Sebastes* spp.) stocks are showing the high SPR levels in the range of 50% to 60% are needed to sustain these fisheries (A. MacCall, personal communication). Similar high SPR levels may be necessary to protect many species of sharks and other species that have low productivity.

F_{med} (Sissenwine and Shepherd 1987) may be a useful proxy for different biological reference points, depending on the level of exploitation of the stock from which the stock-recruitment data were estimated. If the stock has been maintained near B_{MSY}, then F_{med} may be considered a reasonable proxy for F_{MSY}.

Proxies for B_{MSY}

The equilibrium biomasses corresponding to the above-mentioned fishing mortality reference points can be used as proxies for B_{MSY}. In addition, B_{MSY} has been approximated by various percentages of the unfished biomass, B_0, usually in the range 30-60% B_0 (higher percentages being used for less resilient species, and lower percentages for more resilient species). Referring (in the preamble) to estimates based on two shapes of production models, the NSGs recommend $0.4B_0$ as a reasonable proxy for B_{MSY}. However, this value may be too low for species with low fecundity such as many species of sharks.

B_{MSY} can also be approximated by the mean recruitment (R_{mean}) multiplied by either (a) the level of spawning per recruit at F_{MSY} — namely SPR(F_{MSY}), or some proxy thereof; or (b) 30-60% $SPR_{F=0}$ (the percentage being determined by the stock's resilience to fishing). The danger with using the first approach to develop an MSY control rule of the type in Section 2.1.4 is that, if F_{MSY} is overestimated, then SPR(F_{MSY}) and B_{MSY} will both be underestimated. Thus, the MFMT could be too high and the MSST too low.

If catch and CPUE data are available, production models may provide useful proxies, such as $CPUE_{MSY}$, which can be used as a relative index of B_{MSY} (in addition, the nominal effort (e.g., in boat-months) corresponding to F_{MSY} can be used as a relative index of F_{MSY}).

Proxies for B_0

Where B_0 is unknown, it can be approximated by the product of average recruitment and $SPR_{F=0}$ (Myers *et al.* 1994). However, this approximation may be unrealistic because it assumes that there have been no density-dependent changes in growth, survival, or age at maturity during the "fishing down" period.

Proxies for MSY

The equilibrium yield corresponding to the above-mentioned F and/or B reference points can be used as a proxy for MSY.

Inadequate proxies for F_{MSY} and B_{MSY}

The literature offers a number of estimators of, or approximations to, the "ultimate" limit reference point at which a stock is likely to collapse (variously called $F_{extinction}$, F_{ext}, F_{τ} (Mace 1994), F_{crash} (ICES 1997a)). In terms of fishing mortality, these estimators include F_{med} (if calculated from data collected during a period when the stock was overexploited), F_{high} (the fishing mortality corresponding to the 90th percentile of survival ratios), $F_{20\%}$, and F_{loss} (the fishing mortality corresponding to the lowest observed spawning stock — Cook in press). In terms of biomass, these estimators include some definitions of MBAL (the minimum biologically acceptable level of spawning biomass; Serchuk and Grainger 1992), $B_{50\%R}$ (the spawning biomass corresponding to 50% of the maximum recruitment in a stock recruitment relationship; Mace 1994; Myers *et al.* 1994), $B_{90\%R,90\%R/S}$ (the biomass corresponding to the intersection of the 90th percentile of observed recruitment and the 90th percentile of survival; Serebryakov 1991; Shepherd 1991), and B_{loss} (the biomass corresponding to the lowest observed spawning stock; ICES 1997a). In the absence of a reasonable basis for it, the use of these estimators as proxies for F_{MSY} or B_{MSY} should be avoided because they are likely to be poor approximations.

Recommended data-moderate defaults

The recommended data-moderate default MSY control rule is that of Section 2.1.4, using proxies for F_{MSY} and B_{MSY} as described below.

It is recommended that fishing mortality rates in the range $F_{30\%}$ to $F_{60\%}$ be used as general default proxies for F_{MSY}, when the latter cannot be reliably estimated. In the absence of data and analyses that can be used to justify alternative approaches, it is recommended that $F_{30\%}$ be used for stocks believed to have relatively high resilience, $F_{40\%}$ for stocks believed to have low to moderate resilience, and $F_{35\%}$ for stocks with "average" resilience (Mace and Sissenwine 1993). For stocks with very low productivity (such as rockfish and most elasmobranchs), fishing mortality rates in the range $F_{50\%}$ to $F_{60\%}$ are recommended as proxies for F_{MSY}. Less-preferred alternatives (in order of preference) are to use $F_{0.1}$, M, F_{max}, or F_{med} (however, if F_{med} is calculated from data collected when the stock was fluctuating around B_{MSY}, then it would be a good proxy for F_{MSY}). The equilibrium or average biomass levels corresponding to these fishing mortality rates should then be used as proxies for B_{MSY}, in the same order of preference. The default limit control rule would then be defined with fishing mortality set to this default level when biomass exceeds $(1-M)*B_{MSY}$ or ½ B_{MSY}, whichever is greater, and would decline linearly to zero for biomass levels below this level (see Figure 4). The recommended default MSST corresponds to ½ B_{MSY} (the absolute lowest limit triggering the need for a rebuilding plan) for species with $M \geq 0.5$; but occurs at a larger biomass for species with smaller M.

2.2.2 Data-Poor Situations

If there are insufficient or inadequate data to conduct YPR and SPR analyses, or if estimates of F and B cannot be obtained for comparison with YPR and SPR reference points, there are few options for defining meaningful targets and limits. Priority should be given to bringing the knowledge base at least up to "data-moderate" standards.

Proxies for F_{MSY}

The natural mortality rate M has often been considered to be a conservative estimate of F_{MSY}; however, it is becoming more and more frequently advocated as a target or limit for fisheries with a modest amount of information. In fact, in several fisheries, F=0.8*M and F=0.75*M have been suggested as default limits for data-poor cases (Thompson 1993, NMFS 1996).

Proxies for B_{MSY}

The equilibrium biomass corresponding to F=M or F=0.8*M can be used as a proxy for B_{MSY}. However, in most data-poor situations, it will not be possible to calculate this quantity.

Proxies for B_0

Some function of CPUE might conceivably be used as a relative index of initial biomass. If information (perhaps anecdotal) exists on resource conditions prior to or shortly after the onset of fishing, some inferences of initial biomass (B_0) may be possible. Because the geographic area occupied by a stock may contract with declines in abundance, the contrast between present and early geographic distributions of the resource may be used to obtain a rough approximation of pre-fishery abundance. Early sport fishing records may provide useful information on resource conditions prior to intense exploitation (MacCall 1996). Estimates of early CPUE may relate to B_0, but care must be taken to correct for the general tendency for CPUE to underestimate declines in resource abundance. For example, this may require geographic stratification, correction for temporal changes in fleet composition (e.g., loss of less efficient vessels as catch rate declines) and a variety of behavioral and biological interactions (see Section 3.5.5). Nonequilibrium production modeling (Hilborn and Walters 1992; Prager 1994) also may provide an inference of initial CPUE for the fishery.

Proxies for MSY

If there is no reliable information available to estimate fishing mortality or biomass reference points, it may be reasonable to use the historical average catch as a proxy for MSY, taking care to select a period when there is no evidence that abundance was declining.

Recommended data-poor defaults

In data-poor cases it is recommended that the default limit control rule be implemented by multiplying the average catch from a time period when there is no quantitative or qualitative evidence of declining abundance ("Recent Catch") by a factor depending on a qualitative estimate of relative stock size:

Above B_{MSY}:	Limit catch = 1.00*(Recent catch).
Above MSST but below B_{MSY}:	Limit catch = 0.67*(Recent catch).
Below MSST (i.e., overfished):	Limit catch = 0.33*(Recent catch).

The multipliers 1.0, 0.67 and 0.33 were derived by dividing the default precautionary target multipliers in Section 3.3.1 by 0.75, in order to maintain the 0.75 ratio recommended as the default distance between the limit and target reference points for stocks above $(1\text{-}M)*B_{MSY}$. Since it probably will not be possible to determine stock status relative to B_{MSY} analytically, an approach based on "informed judgement" (e.g., a Delphi approach) may be necessary.

2.3 Multispecies Considerations in Implementing MSY Control Rules

Under the National Standard Guidelines, MSY is to be specified for each stock in a mixed-stock fishery, and if this is not possible, then "*MSY may be specified on the basis of one or more species as an indicator for the mixed stock as a whole or for the fishery as a whole.*"

Because productivity (growth, recruitment and mortality) of each species in a stock complex is likely to be different, there will be no single value of F_{MSY} that applies to all species within the assemblage. Likewise, catchability (vulnerability) of each co-occurring species by the gear is likely to be different. Thus, fishing rates for co-occurring species are not going to be reduced by equal amounts if effort within the fishery is reduced. Consequently, it will be difficult if not impossible to obtain F_{MSY} and B_{MSY} for several species simultaneously. Depending on which stock (or stocks) within the mixed-stock complex serve as indicators for the complex as a whole, remaining stocks within the complex may be variously over- or under-exploited with respect to their individual MSY levels. If the indicator stock is more productive than other species within the mixed-stock complex, some stocks within the complex may not be able to withstand the same level of fishing effort associated with the MSY control rule for the indicator species, and a precautionary approach becomes warranted in the face of uncertainty about productivity of non-indicator stocks (Section 3.5.1). Those stocks may be potentially at risk for protection under the Endangered Species Act (ESA) if the fishery continues to overfish those stocks, while maintaining productive indicator stocks at MSY levels.

The National Standard Guidelines allow exceptions to the requirement to prevent overfishing in the case of a mixed-stock complex. If one species in the complex is harvested at OY, overfishing of other components in the complex may occur if (1) long-term net benefits to the Nation will be obtained *and* (2) similar long-term net benefits cannot be obtained by modification of fleet behavior or gear characteristics or other operational characteristics to prevent overfishing *and* (3) the resulting fishing mortality rate will not cause any stock or ecologically significant unit to require protection under the ESA.

3. TARGET CONTROL RULES

NMFS' guidelines for National Standard 1 state,

"*Target reference points, such as OY, should be set safely below limit reference points, such as the catch level associated with the fishing mortality rate or level defined by the status determination criteria.*"

They also state,

"*...target harvest levels may be prescribed on the basis of an OY control rule similar to the MSY control rule ... but designed to achieve OY on average, rather than MSY. The annual harvest level obtained under an OY control rule must always be less than or equal to the harvest level that would be obtained under the MSY control rule.*"

The words “safely below” in the first quotation have a clear precautionary connotation as elaborated in the National Standard 1 text cited in Section 1.1.2. This section provides technical guidance for developing target control rules. As noted in the Preface, this technical guidance for defining management targets does not incorporate socioeconomic considerations other than aversion to the risk of overfishing.

In terms of accounting for uncertainty, two main approaches have been proposed for establishing a target control rule. Both employ probabilistic treatments of uncertainty, but differ in how probability is used. The first approach can be viewed as "decision-theoretic" because it uses the principles of decision theory to establish a target, given a specified level of relative risk aversion. The greater the level of relative risk aversion, the more conservative the precautionary target control rule will be. For example, if a substantial over-estimate of allowable harvest is perceived to be much more undesirable than an under-estimate of equal magnitude, the implied level of relative risk aversion is higher, and the resulting target fishing mortality will be lower, than if the two mis-estimates were perceived to be equally undesirable. In this approach, risk is defined as "expected loss" and is viewed as an objective function to be minimized. A risk-averse target control rule established under a decision-theoretic approach will also necessarily imply some probability of exceeding the limit, but this probability will generally vary on a case-by-case basis, even under a fixed level of relative risk aversion.

The second approach can be considered as "frequentist" because it uses the frequency of violating the limit to establish a target, given a specified time frame and a critical frequency level. The lower the critical frequency level, the more conservative the target control rule will be. For example, if it is unacceptable to have more than a 5% chance of violating the limit at any time within a 20-year period, the resulting target control rule will be more conservative than if it were acceptable to have a 10% chance of violating the limit within the same time period. In this approach, risk is defined as "frequency of violation" and is viewed as a constraint to be satisfied. A target control rule established under a frequentist approach will also necessarily imply some level of relative risk aversion, but this level will generally vary on a case-by-case basis, even under a fixed critical frequency level.

In Section 3.1 below, an example of a precautionary target control rule developed under the decision-theoretic approach is given. In Section 3.2, a general simulation framework, applicable to both the decision-theoretic and frequentist approaches, is presented.

3.1 A Decision-Theoretic Approach

The distinction between limit and target control rules can be thought of as a distinction between levels of relative risk aversion, and development of both limit and target control rules considered as an optimization problem in a decision-theoretic context. For example, a limit control rule might be defined by the optimum derived under a risk-neutral attitude, while a target control rule might be defined by the optimum derived under a risk-averse attitude. A simple and intuitive way to characterize this difference is in terms of stationary (i.e., long-term) yield: A risk-neutral solution maximizes the expectation of stationary yield (MESY) while a risk-averse solution maximizes the expectation of log stationary yield (MELSY; Thompson 1992 and 1996). When computing these expectations, uncertainty in parameter values should be considered along with uncertainty due to recruitment variability and other natural processes.

In the absence of fishing, stock size B at time t can theoretically range anywhere from zero to infinity, with some stock sizes being more probable than others. Stock size can be modeled as a probability density function (pdf) with parameter vector θ and an initial condition B_0 (in this section, B_0 is not used to denote pristine stock size, but rather the stock size at the start of a population projection). Thus, given an initial condition B=B_0, the probability that stock size falls between B_1 and B_2 at time t may be written in terms of the "transition distribution" $g_B(B|\theta;B_0;t)$ as follows:

$$Pr(B_1 \leq B(t) \leq B_2) \;=\; \int_{B_1}^{B_2} g_B(B|\theta;B_0;t)\,\mathrm{d}B\,.$$

As t approaches infinity, g_B describes the "stationary distribution" of stock size, which can be written as $g_B(B|\theta)$.

Next, consider a function which uses a parameter vector to map stock size B into a fishing mortality rate F. Such a function constitutes a control rule. A simple but useful control rule may be specified by two parameters, c and d (for example, the logarithmic form $F(B) = c + d\ln(B)$). For any control rule, yield Y will be a function of stock size conditional on the parameters of the control rule. The stationary distribution of stock size will also be conditional on the same control rule parameters. In the case of the two-parameter control rule, yield can be written as $Y(B|c,d)$, the transition distribution of stock size as $g_B(B|c,d;\theta;B_0;t)$, and the stationary distribution of stock size as $g_B(B|c,d;\theta)$.

Risk-neutral Optimization

A risk-neutral approach can be useful in defining a limit control rule. A risk-neutral solution maximizes the expectation of stationary yield (MESY) for one of the parameters of the control rule (for example *c*), conditional on the other parameters (for example *d*) being fixed, while simultaneously accounting for parameter uncertainty. The solution can be denoted by $c_{MESY}(d)$, meaning the optimum value of parameter *c* of the control rule that maximizes long-term yield conditional on parameter *d*. Mathematically, the solution is found by maximizing the marginal arithmetic mean long-term yield, $A_Y(c,d)$ with respect to *c*. This is achieved by differentiating the marginal arithmetic mean yield with respect to *c*, setting the resulting expression equal to zero, and solving with respect to *c*. The arithmetic mean yield can generally be computed by projecting the population over a long time horizon. Analytical expressions for arithmetic mean yield can also be obtained for some simple models; in many cases, the solution for $c_{MESY}(d)$ will need to be found numerically.

Risk-averse Optimization

A risk-averse approach can be useful for defining a target control rule. A risk-averse solution maximizes the expectation of log stationary yield (MELSY) for one of the parameters of the control rule conditional on the other parameters being fixed, while also accounting for parameter uncertainty.

Continuing with the example of optimizing *c* in a two-parameter control rule, the solution can be denoted by $c_{MELSY}(d)$, and is found by maximizing the marginal geometric mean yield, $G_Y(c,d)$ with respect to *c*. As with $A_Y(c,d)$, the geometric mean yield can be computed by means of simulation, or, in some simple cases, analytically.

An Example

Thompson (in prep.) provides a detailed example of using the decision-theoretic approach to define limit and target control rules based on maximizing the expected stationary yield or expected log stationary yield. In the deterministic case of that example, the population dynamics of the stock are regulated by a Gompertz-Fox model. The control rule is the two-parameter logarithmic form, giving the expression for change in population size as

$$\frac{\mathrm{d}B}{\mathrm{d}t} = aB\left(1 - \ln\left(\frac{B}{b}\right)\right) - (c + d\ \ln(B))\,B,$$

where *a* is a growth rate and *b* is a scale parameter.

By recasting the model as a stochastic differential equation that incorporates natural variability, analytical expressions can be derived for the risk-neutral and risk-averse solutions presented above (note, however, that the decision-theoretic approach is not limited to cases where an analytical solution is available, as the same approach can be followed using simulation tools such as those of Section 3.2). Figure 5 presents examples of limit and target control rules developed with the decision-theoretic approach for two levels of parameter uncertainty. The control rules shown in Figure 5 have the desirable precautionary property that the buffer between the limit and the target fishing mortality increases as the level of uncertainty surrounding parameter estimates increases.

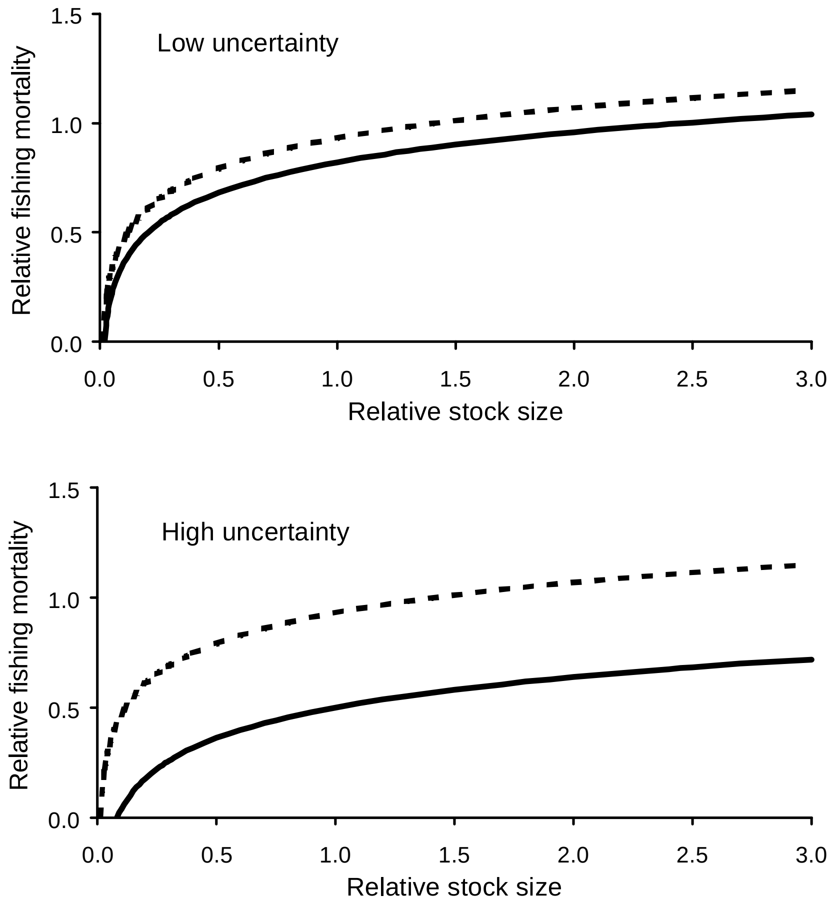

Figure 5. Example limit (dashed lines) and target (solid lines) control rules in a particular model derived with a decision-theoretic approach. The size of the buffer between the limit and target control rules is dictated by the amount of parameter uncertainty (compare upper and lower panels).

3.2 A General Simulation Framework

A fishery management strategy is the combination of data collection, stock assessment, control rules, and technical measures for implementing the harvest controls. Considerable work has been undertaken to develop simulation methods to evaluate the performance of management strategies (e.g.,de la Mare 1986; see Kirkwood and Smith 1996), with much attention often given to the way the various components of a strategy may interact with each other over time. For example, in a recent review of stock assessment methods, the National Research Council stated that "*Both harvesting strategies and decision rules for regulatory actions have to be evaluated simultaneously to determine their combined ability to sustain stocks*" (NRC 1998).

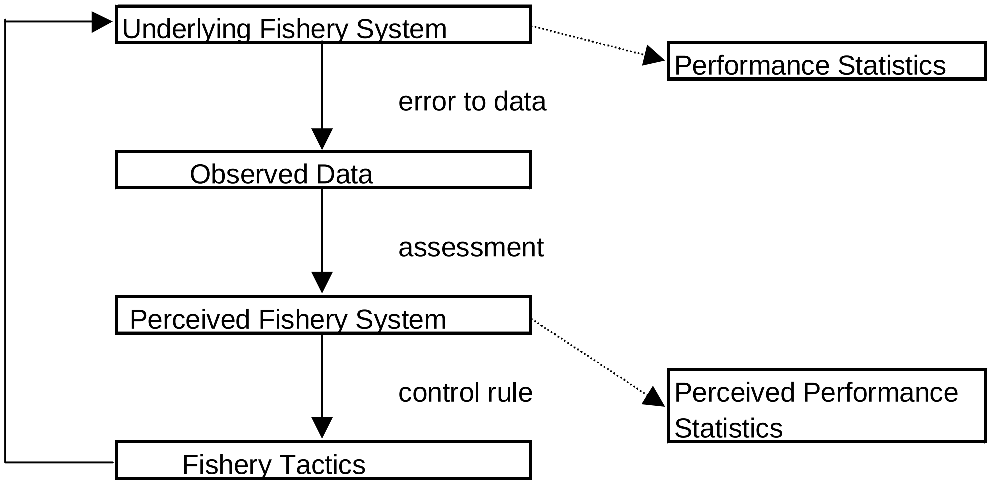

Figure 6. Schematic representation of a simulation framework for evaluating management strategies. Modified, with permission, from Section 4 of ICES (1997b).

The conceptual framework depicted in Figure 6 (taken from ICES 1997b), illustrates a flexible simulation approach for evaluating management strategies. The general technique is to simulate a "true" underlying fishery system of known characteristics, including natural variability. Monte Carlo simulation is used to sample observations with measurement error from the underlying system, and the sample observations are then used in a stock assessment. This allows repeated realizations of the "perceived" system, which may or may not differ substantially from the "true" system (depending partly on the degree of similarity between the true population dynamics and those assumed in the assessment procedure). Using a pre-specified target control rule (e.g., to set the Total Allowable Catch equal to the catch obtained by harvesting the perceived population at the F_{MSY} rate), a regulatory strategy can then be translated into specific fishery tactics (e.g., catch allocations for different fishing sectors). These tactics in turn affect the real underlying system in the next iteration, and so on.

A key step in the evaluation process is to identify the performance criteria that will be examined (see also Section 1.3). In the case of rebuilding an overfished stock, an important performance criterion might be the probability that $B \geq B_{MSY}$ after X years (e.g., 10 years) of implementing a target control rule (a similar approach was used in the guidelines for estimating "potential biological removals" [PBR] for the implementation of the 1996 amendments to the Marine Mammal Protection Act; Wade and Angliss 1997). In most applications, multiple criteria will probably need to be examined, such as the probability that the stock remains above MSST, the average annual yield, and the interannual variability in yield. Inclusion of multiple criteria is particularly useful when there are conflicting goals, such as preventing the stock from falling below B_{MSY} while at the same time achieving yields as close to MSY as possible. Figure 7 depicts an example from ICES (1997b), in which simulation starts with a stock at an equilibrium biomass equal to $\frac{1}{2}B_{MSY}$, the limit F is set to F_{MSY}, and the precautionary target F is set below F_{MSY}

by a given percentage. The figure illustrates the tradeoffs between increasing the chances of rebuilding in a 10-year period and sacrificing average yield.

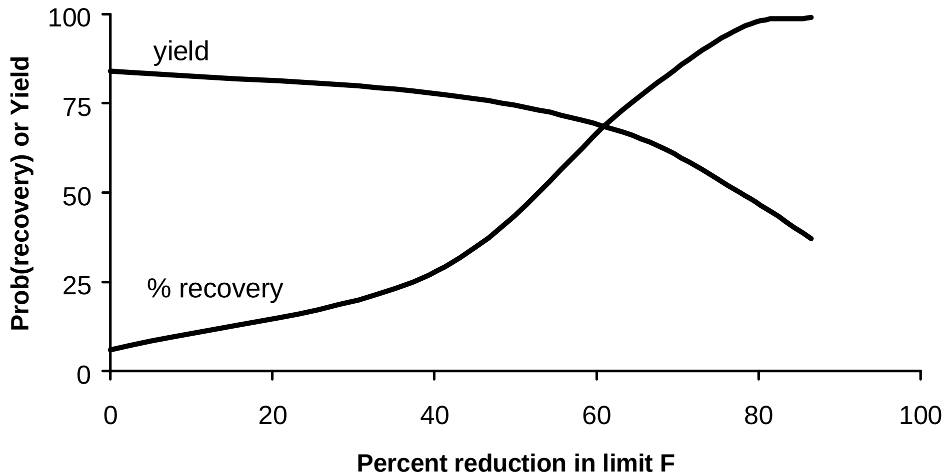

Figure 7 Tradeoffs between two conflicting performance criteria: Rebuilding an overfished stock and maximizing average yield during a 10-year period. Hypothetical example taken from ICES (1997b), data set 7, with limit $F = F_{MSY}$.

Simulation results such as those depicted in Figure 7 can be used to infer the degree of precaution required to achieve a desired outcome. In the example above, if at least a 50% probability of rebuilding to B_{MSY} was desired, then the rebuilding target F should be set at about ½F_{MSY}. Thus, the simulation approach can help determine how far apart (or how "safely below") targets have to be from limits to achieve management goals. In general, simulations should be conducted on a case-by-case basis to account for:

- Growth, reproductive and recruitment dynamics of the stock, including variability (process error);
- Initial conditions, including age-structure;
- Selectivity of the fishing gear(s);
- Types of observations sampled (e.g., age-structure data) and their variability;
- Stock assessment method used;
- Estimation of biological reference points (e.g., limit F) and their uncertainty; and
- Potential biases in the implementation of regulations determined by the control rule.

The simulation approach can also be used to evaluate the benefits to management from reduced uncertainty (Powers and Restrepo 1993). Figure 8 shows that the probability-of-rebuilding curve (from the previous example) is shifted upwards when there is increased in precision regarding current stock status and F_{MSY}.

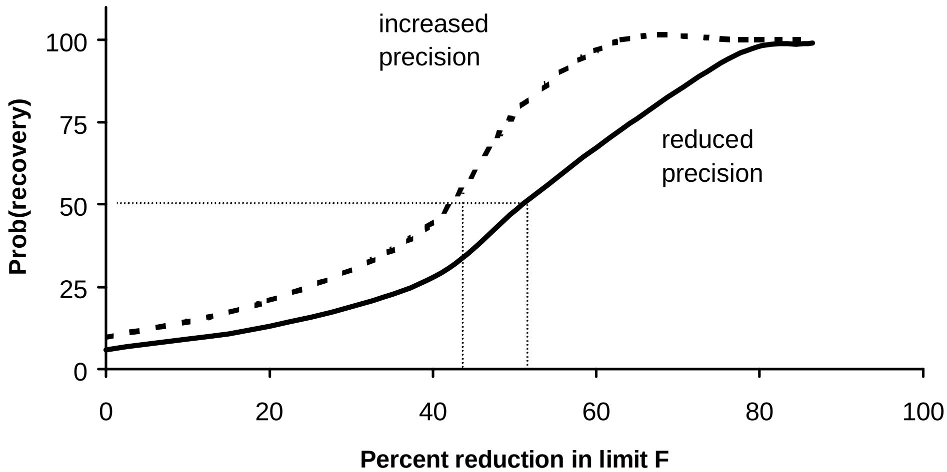

Figure 8 The effect of increased precision on the rebuilding example of Figure 7.

3.3 Recommended Default Target

Ideally, target control rules should be developed using approaches such as those in Sections 3.1 or 3.2. In setting a precautionary target control rule by means of the "frequentist" approach (Sections 3 and 3.2), we recommend that the probability of exceeding the MFMT be not greater than 20%-30%, and certainly smaller than 50%. Absent such analyses or a risk-averse solution as explained in Section 3.1, the following default target control rule is recommended.

The recommended target control rule (Figure 9) sets the target fishing mortality rate 25 percent below the limit fishing mortality (MFMT) recommended in Section 2.1.4. In equation form, the recommended default target is:

$$F(B) = \frac{0.75\ F_{MSY}\ B}{c\ B_{MSY}} \quad \text{for all } B \le c\ B_{MSY}$$

$$F(B) = 0.75\ F_{MSY} \quad \text{for all } B \ge c\ B_{MSY},$$

where c, F_{MSY} and B_{MSY} are as defined in Section 2.1.4.

The default provides a safety margin (or buffer) to ensure that the realized F does not exceed MFMT. The default target control rule also facilitates rebuilding of stocks by reducing F proportionately at stock sizes below $(1\text{-}M)B_{MSY}$. In some cases, however, the rebuilding rate from the default target will be insufficient to rebuild an overfished stock to B_{MSY} within the time period allowed by the NSGs (depending on the life history characteristics of the stock and the level of depletion). In such cases, stronger conservation measures will be required, as explained in Section 3.4.

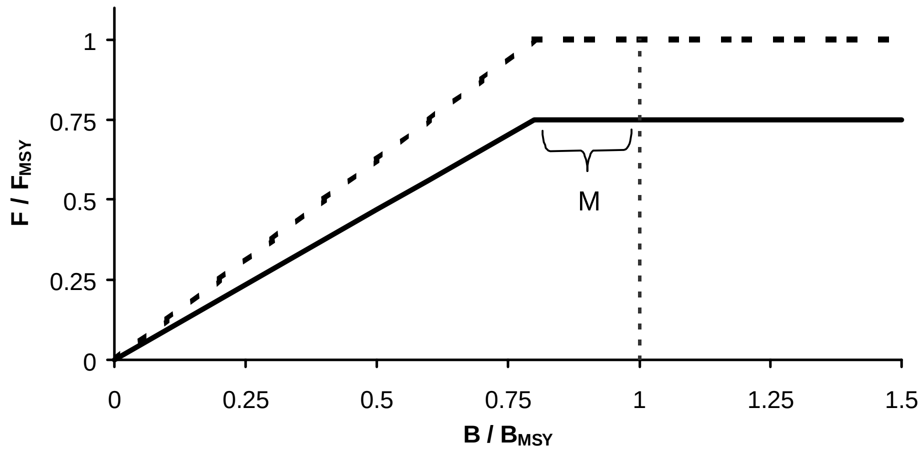

Figure 9. Recommended target (solid line) and limit (dashed line) control rules. The target may only be applicable for biomass levels at or above the minimum stock size threshold because it may not allow for sufficient rebuilding for stocks that are already overfished. Such stocks may require a more conservative target control rule for rebuilding (Section 3.4).

The equilibrium consequences of fishing at the default 75% F_{MSY} were evaluated using the deterministic model of Mace (1994) (see Appendix A). The results of this exercise indicate that fishing at 75% F_{MSY} would result in equilibrium yields of 94% MSY or higher, and equilibrium biomass levels between 125% and 131% B_{MSY} -- a relatively small sacrifice in yield for a relatively large gain in biomass (Table A1). Although it is likely that results would diverge for more complex models (e.g., those in which the ages of maturity and recruitment differed substantially, or those incorporating stochasticity), the calculations indicate that relatively small sacrifices in yields will result in relatively much larger gains in stock biomass. Increased biomass should in turn result in a number of benefits to the fishery, including increased CPUE, decreased costs of fishing, and decreased risk to the stock. Relative to fishing at F_{MSY}, fishing at 75% F_{MSY} will reduce the probability that a stock will decline to ½ B_{MSY}.

The deterministic simulation results presented in Appendix A should not be taken as being strictly applicable to every situation. Variability in the population dynamics parameters of a stock will affect the performance of fishing at 75% F_{MSY}. As well, the evaluation only pertains to cases where F_{MSY} can be reliably estimated. As such, the performance of the default target will depend on the robustness with which F_{MSY} can be estimated or approximated. Simulation tools such as those discussed in Section 3.2 could be used to investigate these issues.

It is recognized that no single policy can fully address all of the considerations to be encountered in the wide variety of fisheries subject to the MSFCMA. To the extent that this default target control rule may be inappropriate, it should at least serve to encourage development of more suitable policies for individual fisheries.

3.3.1 Data-Moderate and Data-Poor Situations

In data-moderate cases, the default target control rule may require the use of appropriate proxies for reference points such as those presented in Section 2.2.

In data-poor cases, the default policy may be interpreted qualitatively as follows:

Above B_{MSY}	Target catch = 0.75*(Recent catch).
Above MSST but below B_{MSY}	Target catch = 0.50*(Recent catch).
Below MSST (i.e., overfished)	Target catch = 0.25*(Recent catch).

Determination of the status of biomass relative to B_{MSY} preferably involves quantitative analysis, but in data-poor cases, applicable analytic methods may not be particularly sophisticated and include a variety of stock assessment methods developed in the 1960s and 1970s (e.g., Gulland 1983). In cases of severe data limitations, qualitative approaches may be necessary, including expert opinion and consensus-building methods (see also Section 2.2.2).

3.4. Rebuilding from Overfished Status

The National Standard 1 guidelines indicate that once biomass falls below the minimum stock size threshold (MSST), then remedial action is required "*to rebuild the stock or stock complex to the MSY level within an appropriate time frame*." Therefore, recommendations are presented here for determining the adequacy and efficacy of rebuilding plans.

A rebuilding plan is a strategy of selecting fishing mortality rates or equivalent catches that are expected to increase the stock size to the MSY level within a specified period of time. Components for a rebuilding plan typically include: (a) an estimate of B_{MSY}, (b) a rebuilding period, (c) a rebuilding trajectory, and (d) a transition from rebuilding to more "optimal" management (Powers 1996). Specifying a control rule in terms of fishing mortality rate and biomass incorporates these components.

Species life history characteristics will affect rebuilding plans in several ways. Some stocks may possess low productivity and will be incapable of recovering within 10 years[2], even in the absence of fishing mortality. Alternatively, a stock may be highly productive, in which case a rebuilding plan of 10 years will not be precautionary, i.e. the stock has the capability of reaching B_{MSY} well before 10 years.

Often productivity is correlated with the mean generation time of a stock (defined below), which is why the final rule issuing the NSGs link the maximum rebuilding time period to generation time when rebuilding cannot be achieved in 10 years. The minimum possible rebuilding period is constrained by a stock's status relative to B_{MSY} and its biological productivity. Linking the rebuilding period with generation time is important because it highlights the time span in the future during which recruitment will begin to depend primarily upon fish that have yet to be born, as opposed to spawners that already

[2] The MSFCMA requires that the rebuilding time period be as short as possible and not to exceed 10 years with a few exceptions, including cases where the biology of the stock or other environmental conditions dictate otherwise.

exist.

Rebuilding rates will also be affected by the partial recruitment pattern. Generally, greater rebuilding rates are possible by reducing mortality rates on juveniles than by equal mortality rate reductions on adult fish. However, this depends upon the relative growth and natural mortality between the age groups.

For all overfished resources, the overarching principle is that initial actions must provide a very high probability of preventing further stock declines and have a high probability of immediate improvement. Delaying action is not precautionary.

Generation time

Although the NSGs do not provide a definition of generation time, various definitions exist in the scientific literature (Caswell 1989). In the context of stock rebuilding time horizons, the definition of generation time used could refer to an unfished state. We recommend that the default definition of generation time, G, be (Goodyear 1995):

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a} ,$$

where a denotes age, A is the oldest age expected in a pristine (unfished) condition, E_a is the mean fecundity at age of females, and N_a is the average number of females per recruit alive at age a in the absence of fishing, i.e.,

$$N_a = N_1 \exp(-\sum_{j=1}^{a-1} M_j) ,$$

where M is the natural mortality rate. These expressions should be computed on an equilibrium per-recruit basis, i.e., setting $N_1 = 1$. When fecundity data are not available, G can be computed by replacing E_a with an age-specific vector of maturity ratios times body weight (as commonly used to compute spawning biomass).

The rebuilding plan

In the absence of data and analyses that can be used to justify alternative approaches, we recommend that a default rebuilding plan for stocks below the MSST be based upon the precautionary target control rule of Section 3.3 with the following extensions:

1) The maximum rebuilding period, T_{max}, should be 10 years, unless T_{min} (the expected time to rebuilding under zero fishing mortality) is greater than 10 years, when T_{max} should be equal to T_{min} plus one mean generation time.

2) The target rebuilding time period, T_{target}, should be as short as possible and lower than T_{max} (although it could be adjusted up to T_{max} under the circumstances described in §600.310(e)(4) of the NSGs). We suggest that T_{target} not exceed the midpoint between T_{min} and T_{max}; and,

3) If the stock is well below the MSST (e.g., $B \leq$ ½MSST), it may be necessary to set the fishing mortality rate as close to zero as possible (i.e., to that associated with unavoidable levels of bycatch) for a number of years.

Figure 10 illustrates what a rebuilding plan might look like for a severely-overfished stock. In region a, the rebuilding plan's *F* is set to zero. In region b, between ½MSST and B_{MSY}, the rebuilding *F* is set to 75% of the target *F* in the control rule of Section 3.3. In region c, the stock is rebuilt and the *F* is set again to the target of Section 3.3. Whether or not a zero *F* in region a and a 75% reduction in region b satisfy the requirement for rebuilding within the target time period largely depends on the initial level of stock depletion and the stock's productivity.

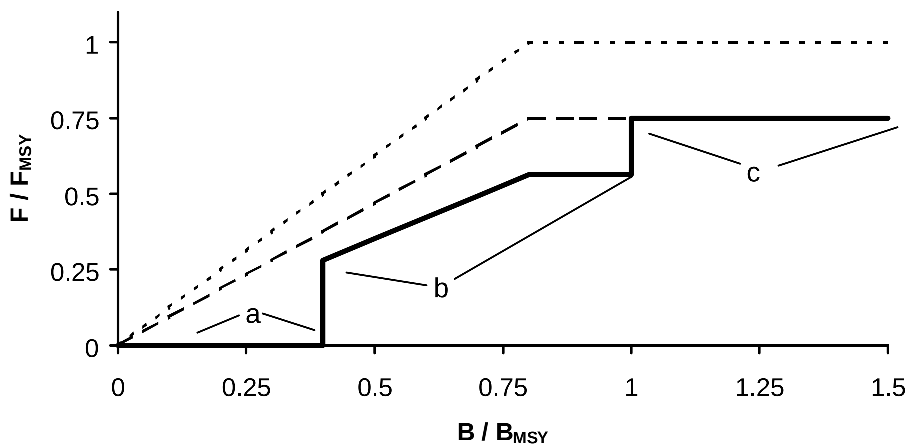

Figure 10. Example of a rebuilding plan (solid line) for a severely-overfished stock. The dotted and dashed lines represent the recommended default limit and target control rules of Sections 2.1.4 and 3.3, respectively. The regions a, b and c represent three phases in the rebuilding plan: part a is designed to initiate rebuilding with high probability; part b is designed to accelerate rebuilding compared to the rate of rebuilding that is built into the target control rule of Section 3.3; part c represents a transition to more "optimal" management.

The role of uncertainty

Accounting for uncertainty in stock dynamics, current stock status and recruitment variability is important in developing rebuilding plans (Rosenberg and Restrepo 1994). As such, we suggest that the rebuilding plan should be designed to possess a 50% — or higher — chance of achieving B_{MSY} within T_{target} years, and a 90% — or higher — chance of achieving B_{MSY} within T_{max} years.

The intent of the MSFCMA is that overfished stocks be rebuilt quickly. For this reason, stock rebuilding should be monitored closely so that adjustments can be made when rebuilding milestones are not being met for whatever reason. For example, if target rebuilding *F*s are exceeded due to quota over-runs, subsequent target *F*s should typically be adjusted downwards to put the stock back on the rebuilding time table.

The magnitude and variability of future recruitment will affect the realized rebuilding trajectory. In cases when one or more very large year classes appear, it may be tempting to utilize them to increase short-term yield at the expense of slower stock rebuilding, hoping that subsequent year classes will be of similar — or at least average — magnitude. Such action would not be precautionary. Furthermore, the resulting change in fishing mortality would depart from the pre-agreed nature of the rebuilding control rule and therefore be inconsistent with the rebuilding plan.

3.5 Special Considerations

3.5.1 <u>Mixed-Stock Complexes</u>

The National Standard Guidelines provide for specification of a fishery-wide OY for a mixed-stock fishery, where management measures for separate target harvest levels for individual stocks may be specified, but are not required. Although the guidelines recommend that the sum of individual target levels be less than the fishery-wide OY, if individual OY levels are not specified, the entire OY could be removed from one or a few unproductive stock components and overfishing of these components would occur. Clearly, a precautionary approach should be used to minimize the risk of removing the least productive components in the mixed-stock fishery.

Biological reference points (or proxies) and precautionary target control rules for each stock in a mixed-stock complex should be developed whenever possible, even though information may be limited. At a minimum, fishing mortality should not exceed the limit (MFMT) for any individual stock in a mixed-stock complex, except as provided under the very stringent criteria specified in §600.310(d)(6) of the NSGs. The relevant target control rule should be implemented, regardless of the level of information from which the rule was developed. This should lessen the possibility of reducing less-productive stocks to levels at which they would require protection under the ESA, especially if relatively little were known about those stocks.

3.5.2 <u>Environmental Fluctuations</u>

Fish stocks undergo natural fluctuations in abundance. These fluctuations are principally due to year-to-year changes in recruitment which are often environmentally induced. Environmental influences can be inter-decadal in nature, with a low level of predictability. Harvest policies should prepare for these natural swings in abundance, which may be greater than half to double the target level of abundance.

It is convenient to classify the impacts of recruitment variability (independent of stock size) on implementation of target control rules into one of three types:

A. <u>Short-term</u> (year-to-year) fluctuations in recruitment are frequently difficult to measure until the fish have been in the population for several years. This causes uncertainty in the estimation of current stock abundance, thus introducing some random error in the implementation of the control rule.

B. Medium-term (3-10 year; Francis and Hare 1994, Jacobson and MacCall 1995) fluctuations in recruitment can impact rebuilding time frames. While the expected time to rebuilding may be calculated to be, say, less than 10 years, the actual time to rebuilding will be shorter or longer depending on the actual sequence of recruitments over the 10-year period. When recruitment is highly variable, the actual time to rebuilding will usually also be highly variable. This is one of the reasons why it is important to account for future recruitment uncertainty in developing rebuilding plans.

C. Longer-term (decadal) climate conditions appear to impact recruitment dynamics (Alheit and Hagen 1997, MacCall 1996), producing prolonged periods with above-average (or below-average) recruitment. In an evolutionary sense, fish stocks have adapted to this pattern, and harvest policies should attempt to preserve this adaptation. It may be therefore necessary to design control rules that conserve spawning stock abundance during prolonged periods of poor recruitment to preserve a stock's capability to produce higher recruitment when environmental conditions improve. In some cases, environmental effects may be directly integrated into the stock assessment and the control rule. However, one should be cautious in interpreting a long run of good or poor recruitments as indicative of an environmentally-driven change in stock productivity. In particular, for a period of declining abundance, the "burden of proof" should initially rest on demonstrating that the environment (as opposed to fishing) caused the decline, and that, therefore, the target control rule should be modified. However, if productivity has in fact declined, more conservative limit and target reference points will be needed .

3.5.3 Stock Definition Issues

A "stock" or "stock complex" is a management unit in the sense of the Magnuson-Stevens Act's first definition of the term "fishery": *"One or more stocks of fish that can be treated as a unit for purposes of conservation and management and that are identified on the basis of geographic, scientific, technical, recreational, or economic characteristics."*

Defining a "stock" on a scientific basis is a very difficult task. Many types of information are used to identify stocks: Distribution and movements, population trends, morphological differences, genetic differences, contaminants and natural isotope loads, parasite differences, and oceanographic habitat differences. Evidence of morphological or genetic differences in animals from different geographic regions normally indicates that the populations are reproductively isolated. Separate management is usually appropriate when such differences are found. Failure to detect differences experimentally, however, does not mean the opposite. Dispersal rates, though sufficiently high to homogenize morphological or genetic differences detectable experimentally between putative populations, may still be insufficient to deliver enough recruits from an unexploited population (source) to an adjacent exploited population (sink) to prevent local extinctions leading to contraction or fragmentation of range.

When the distribution of fishing effort corresponds spatially with the density of the target species, management errors caused by improper stock definition are likely to be small. However, for multispecies fisheries and particularly for by-caught species, fishing effort may be concentrated in only a portion of a species' range. The risk of local depletion leading to range contraction or fragmentation is particularly high for long-lived species with high site fidelity.

Careful consideration needs to be given to how stocks are defined scientifically. In the absence of adequate information on stock structure, a species' range within an ocean should be divided into stocks that represent useful management units. Examples of such management units include distinct oceanographic regions, semi-isolated habitat areas, and areas of higher density of the species that are separated by relatively lower density areas.

3.5.4 Special Life Histories

Delayed maturity, where fish become vulnerable to fishing before they are reproductively mature, can pose a risk of recruitment overfishing. Proxy policies such as $F_{0.1}$ and $F=M$ may be too high in such cases. SPR-based policies such as $F_{35\%}$ account for impacts on spawning potential and tend to provide more precaution in this respect (Clark 1991; Goodyear 1993). Protandric hermaphrodites may be considered as cases of late sexual maturity, and an SPR approach based on female maturity schedules should be adequate.

Species with life stages or behaviors that are highly vulnerable to fishing merit precautionary management. Groupers may be protogynous hermaphrodites, and form very large and predictable spawning aggregations that render them highly vulnerable to fishing, risking both depletion and disturbed population structure due to targeting on large males (Bannerot *et. al.* 1987). Precaution might require severe reductions in fishing pressure, and perhaps a ban on fishing during these vulnerable time periods. No-fishing areas (a.k.a. Marine Protected Areas) could also be appropriate for these species.

Fishes with low frequency variability in recruitment or with rare large recruitments may also require a precautionary reduction in fishing. Clark (1993) showed that an $F_{40\%}$ SPR-based fishing rate is preferable to his generally recommended $F_{35\%}$ policy if there is high serial correlation in annual recruitment. Management of rarely-recruiting species should adopt a very high SPR so that sufficient biomass survives the intervals between major recruitment events. Similarly, certain taxa (e.g., elasmobranchs) that are highly vulnerable to fishing due to their low productivity should be managed to ensure very high SPR.

3.5.5 Data Issues

The precautionary approach dictates that greater caution be used in the face of greater uncertainty. Thus, improved knowledge of stock dynamics and of the effects of fishing should result in higher benefits to the Nation through higher yields and lower risks of stock depletion (the relative benefits and costs of enhanced research can be evaluated with the methods presented in Sections 3.1 and 3.2).

As noted by FAO (1995b, section 4.2), a precautionary approach *"requires explicit specification of the information needed to achieve the management objectives, taking account of the management structure, as well as of the processes required to* *ensure that these needs are met."* Data should be collected to improve data quality from a lower tier to a higher tier level of data richness. Logbooks from commercial fishing operations may be useful, whereby daily fishing logs would record target catch and bycatch amount, by species, by fishing statistical area, by gear type, and by units of fishing effort. Any self-report information, such as that contained in logbooks, should be verifiable. Improved data collection systems should also be implemented for recreational fisheries. Scientific observer coverage should also be encouraged, whenever feasible, for independent scientific sampling of commercial and recreational catches.

Scientific (fishery-independent) surveys should also be conducted to estimate the distribution, relative or absolute abundance, age/length frequency, and other relevant biological characteristics of the stocks to improve data quality to a higher data quality tier. An important aspect of fishery-independent monitoring is that it can form the basis for addressing issues and questions that are not necessarily of immediate concern but may become important in the future.

Another important data issue is that of the appropriateness of certain types of data for use in assessment models. Although catch per unit of effort (CPUE) has a long history of use as a fishery-based index of abundance, it also has often proved insensitive to changes in true abundance, particularly when not properly standardized, and its uncritical use has contributed to the collapse of major world fisheries, including the northern cod (Hutchings 1996). Walters and Ludwig (1994) go so far as to say "We flatly recommend that catch/effort data never be used as a direct abundance index (assumed proportional to stock size)." Given the dangers of unvalidated CPUE, the precautionary approach would call for the burden of proof to be placed on demonstrating that CPUE is linearly related to abundance. Patterns such as that shown in Hutchings (1996) and other studies suggest that CPUE often varies approximately in proportion to the square root of abundance. Thus, in cases where a nonlinear relationship between catchability and stock biomass is suspected, it may be necessary to transform CPUE (e.g., by squaring it) before using it as an index of abundance (MacCall in prep.). In addition, standardization of CPUE series may fail to account for increases in fishing power due to the unavailability of appropriate data on gear/vessel configuration and fishing tactics for use in the analyses. In such cases, it is risky to assume that catchability remains constant over time and it may be necessary to adjust CPUE (e.g., by assuming a 3%-5% increase in fishing power per year) before using it as an index of abundance. Such adjustments to CPUE data, while difficult to justify in the absence of direct evidence, may be necessary to reduce the chances of overly-optimistic perceptions of stock status. These risks should be clearly communicated to managers and the public so that they understand that the CPUE adjustments may be necessary in order to avoid serious biases in the assessment. Of course, the preferred remedial action to take is to develop accurate fishery-independent indices of stock abundance.

3.5.6 <u>New Fisheries</u>

New fisheries should be viewed as data-poor cases. Initially, fishing should be largely exploratory in nature, and aimed at gathering sufficient information to bring the level of information content up to at least data-moderate standards. New fisheries present opportunities to estimate life history parameters such as natural mortality, which should be considered when planning for data collection. It is precautionary to develop new fisheries gradually from an unexploited state to a fully-exploited state over a period of more than one generation time in order to obtain information from intermediate stock sizes that may be vital to determining B_{MSY}. FAO (1995b, section 3.5) contains other recommendations for a precautionary approach to managing new fisheries.

3.5.7 Other Precautionary Tactics

A number of fishery management tools (or tactics) possess precautionary properties and may be useful mechanisms to ensure that limit reference points are not exceeded. For example, allowing fish to spawn at least once before becoming vulnerable to the fishing gear adds a measure of protection against biased estimates of stock status (Myers and Mertz 1998).

Marine Protected Areas (MPAs), wherein all fishing is prohibited, are an extension of area closures, and include precautionary properties (Bohnsack 1996). MPAs may allow a segment of the resource to preserve its unexploited life history, age structure, ecological relationships, etc., in the presence of exploitation. MPAs have limited benefit for highly mobile resources such as pelagic fishes. Somewhat analogous to an MPA is a "biomass reserve", where a fixed amount of the resource is set aside before applying a target management measure such as $F_{35\%}$. This alternative approach may reduce the need for precise specification of SPR in $F_{\%SPR}$ policies, offsets imprecision in stock assessments, and may be especially useful in managing rarely recruiting species that are easily subject to depletion.

Other tactics that may have precautionary properties include: (a) Use of "clean" gear types to minimize impacts of fisheries on the stocks, (b) restrictions on the physical characteristics of gear (such as mesh size, hook size, and other physical characteristics) to minimize impacts of fisheries on the stocks and damage to the habitat, (c) modifying fishing characteristics to minimize impacts of fisheries on the stocks and damage to the habitat, and (d) modifying fishing seasons to achieve conservation goals.

Adoption of any of the above or similar conservative tactics into an FMP does not guarantee that the NSGs' recommendations for achieving National Standard 1 will be satisfied. Nevertheless, it is important to consider these as management options that possess desirable conservation properties.

CONCLUDING REMARKS

Specification of status determination criteria and target control rules is a challenging exercise. Key to this process is communication among managers, scientists, industry and the public. In the face of conflicting objectives, it is essential to understand the tradeoffs associated with alternative control rules and the importance of the weights assigned to the different objectives or performance criteria. Simulation frameworks of the type highlighted in Section 3.2 can facilitate these interactions. Simulation tools should also be used to examine the performance of management systems as a whole, including data collection, assessments, control rules, and implementation of management tactics.

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REFERENCES

Alheit, J. and E. Hagen. 1997. Long-term climate forcing of European herring and sardine populations. Fish. Oceanogr. 6:130-139.

Bannerot, S., W. W. Fox, Jr., and J. E. Powers. 1987. Reproductive strategies and the management of snappers and groupers in the Gulf of Mexico and Caribbean. pp. 561-603 In: J. J. Polovina and S. Ralston [eds.] Tropical snappers and groupers: Biology and fisheries management. Westview Press, 659p.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. 2, vol. 19. U.K. Ministry of Agriculture, Food and Fisheries, London.

Bohnsack, J. A. 1996. Maintenance and recovery of reef fishery productivity. Pp. 283-313 In N. V. C. Polunin and C. M. Roberts [eds.] Reef Fisheries. Chapman and Hall, London.

Butterworth, D. S . and M. O. Bergh. 1993. The development of a management procedure for the South African anchovy resource. p. 83-99 *in* S. J. Smith, J. J. Hunt and D. Rivard [ed.]. Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Caddy, J. F., and R. Mahon. 1995. Reference points for fishery management. FAO Fish. Tech. Pap. 347. 82 p.

Caswell, H. 1989. Matrix population models. Sinauer Associates, Sunderland, MA. 328 p.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48:734-750.

Clark, W. G. 1993. The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. Pp. 233-246 In G. Kruse, D. M. Eggers, R. J. Marasco, C. Pautzke and T. Quinn II [eds.] Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program, P. O. Box 755040, Fairbanks AK.

Cook, R. M. in press. A sustainability criterion for the exploitation of North Sea cod. ICES J. Mar. Sci. (1998).

de la Mare, W.K. 1986. On the management of exploited whale populations. Ph.D. Thesis, University of York.

Food and Agriculture Organization (FAO). 1995a. Code of conduct for responsible fisheries. FAO Mimeo. Rome, FAO. 14 p.

Food and Agriculture Organization (FAO). 1995b. Precautionary approach to fisheries. Part I: Guidelines on the precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6-13 June 1995. FAO Tech. Pap. 350, Part 1. 52 p.

Francis, R. C. And S. R. Hare. 1994. Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science. Fish. Oceanogr. 3:279-291.

Goodyear, C.P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. P. 67-81 in S.J. Smith, J.J. Hunt, and D. Rivard [eds.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Goodyear, C.P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. NMFS/SEFSC Contribution MIA-95/96-05.

Gulland, J. A. 1983. Fish stock assessment: A manual of basic methods. John Wiley and Sons, New York. 223p.

Gulland, J.A. and L.K. Borema. 1973. Scientific advice on catch levels. Fish. Bull. 71:325-335.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, N.Y. 570 p.

Hutchings, J. A. 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. Can. J. Fish. Aquat. Sci. 53:943-962.

International Council for the Exploration of the Sea (ICES) 1997a. Report of the study group on the precautionary approach to fisheries management. ICES CM 1997/Assess:7. 37pp.

International Council for the Exploration of the Sea (ICES). 1997b. Report of the Comprehensive Fishery Evaluation Working Group. ICES CM 1997/Assess:15. 140 pp.

Jacobson, L. D. And A. D. MacCall. 1995. Stock-recruitment models for Pacific sardine (Sardinops sagax). Can. J. Fish. Aquat. Sci. 52:566-577.

Kirkwood, G.P., and A.D.M. Smith. 1996. Assessing the precautionary nature of fishery management strategies. FAO Fish. Tech. Pap. 350(2): 141-158.

MacCall, A.D. 1996. Patterns of low-frequency variability in fish populations of the California Current. CalCOFI Reps. 37:100-110.

MacCall, A.D. In prep. Use of decision tables to develop a precautionary approach to problems in behavior, life history and recruitment variability. Proceedings of the 5th National Stock Assessment Workshop, V. Restrepo [ed.]. NOAA Tech. Memo. NMFS-F/SPO-##. NMFS, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Can. J. Fish. Aquat. Sci. 51:110-122.

Mace, P.M. and W. Gabriel. In prep. Evolution, scope and current applications of the precautionary approach in fisheries. Proceedings of the 5th National Stock Assessment Workshop, V. Restrepo [ed.]. NOAA Tech. Memo. NMFS-F/SPO-##. NMFS, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910.

Mace, P.M. and M.P. Sissenwine. 1989. Biological reference points for New Zealand fisheries assessments. New Zealand Fish. Assess. Res. Doc. 89/11. 11pp.

Mace, P.M. and M.P. Sissenwine. 1993. How much spawning per recruit is enough? In S.J. Smith, J.J. Hunt and D. Rivard [eds.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. and Aquat. Sci. 120:101-118.

Myers, R.A., and G. Mertz. 1998. The limits of exploitation: A precautionary approach. Ecol. Appl. 8: S165-S169.

Myers, R.A., A.A. Rosenberg, P.M. Mace, N. Barrowman, and V.R. Restrepo. 1994. In search of thresholds for recruitment overfishing. ICES J. Mar. Sci. 51:191-205.

National Marine Fisheries Service (NMFS). 1996. Environmental Assessment/Regulatory Impact Review for Amendment 44 to the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area and Amendment 44 to the Fishery Management Plan for the Groundfish Fishery of the Gulf of Alaska to Redefine Acceptable Biological Catch and Overfishing, Appendix B. AKFSC, NMFS, 7600 Sand Point Way NE., Seattle, WA 98115-0070.

National Research Council (NRC). 1998. Improving Fish Stock Assessments. National Academy

Press, Washington D.C. 177 pp.

Powers, J.E. 1996. Benchmark requirements for recovering fish stocks. N. Amer. J. Fish. Manage. 16:495-504.

Powers, J.E., and V.R. Restrepo. 1993. Evaluation of stock assessment research for Gulf of Mexico king mackerel: Benefits and costs to management. N. Amer. J. Fish. Manage. 13: 15-26.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fish. Bull. 92: 374-389.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada, Bull. No. 119.

Rosenberg, A., P. 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, and K. Stokes. 1994. Scientific review of definitions of overfishing in U.S. Fishery Management Plans. NOAA Tech. Memo. NMFS-F/SPO-17. 205 pp.

Rosenberg, A.A., and V.R. Restrepo. 1994. Uncertainty and risk evaluation in stock assessment advice for U.S. marine fisheries. Can. J. Fish. Aquat. Sci. 51: 2715-2720.

Serchuk, F.M. and R.J.R. Grainger. 1992. Development of the basis and form of ICES fisheries management advice: historic background (1976-1990) and the new form of ACFM advice. ICES C.M. 1992/Assess:20. 13pp.

Serchuk, F., D. Rivard, J. Casey and R. Mayo. 1997. Report of the ad hoc working group of the NAFO Scientific Council on the precautionary approach. NAFO SCS Document 97/12.

Serebryakov, V.P. 1991. Predicting year-class strength under uncertainties related to survival in the early life history of some North Atlantic commercial fish. NAFO Sci. Counc. Stud. 16:49-56.

Shepherd, J.G. 1991. Report of special session. NAFO Sci. Counc. Stud. 16:7-12.

Sissenwine, M.P., and J.G. Shepherd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44: 913-918.

Thompson, G. G. 1992. A Bayesian approach to management advice when stock-recruitment parameters are uncertain. Fish. Bull. 90:561-573.

Thompson, G. G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. In S. J. Smith, J. J. Hunt, and D. Rivard [eds.] Risk evaluation and biological reference points for fisheries management, p. 303-320. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Thompson, G. G. 1996. Risk-averse optimal harvesting in a biomass dynamic model. Environmental Assessment/Regulatory Impact Review for Amendment 44 to the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area and Amendment 44 to the Fishery Management Plan for the Groundfish Fishery of the Gulf of Alaska to Redefine Acceptable Biological Catch and Overfishing, Appendix B. AKFSC, NMFS, 7600 Sand Point Way NE., Seattle, WA 98115-0070.

Thompson, G. G. In prep. Optimizing Harvest Control Rules in the Presence of Natural Variability and Parameter Uncertainty. Proceedings of the 5th National Stock Assessment Workshop, V. Restrepo [ed.]. NOAA Tech. Memo. NMFS-F/SPO-##. NMFS, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910. National Marine Fisheries Service, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910.

Thompson, G. G., and P. M. Mace. 1997. The evolution of precautionary approaches to fisheries management, with focus on the United States. NAFO SCR Doc. 97/26.

United Nations (UN). 1995. Agreement for the implementation of the provisions of the United Nations convention on the law of the sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks. United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. Sixth session. New York, 24 July - 4 August 1995. A/CONF. 164/37 8 September 1995.

Wade, P. R., and R. P. Angliss. 1997. Guidelines for assessing marine mammal stocks: report of the GAMMS Workshop April 3-5, 1996, Seattle, Washington. NOAA Tech. Memo. NMFS-OPR-12, 93 p.

Walters, C. And D. Ludwig. 1994. Calculation of Bayes posterior probability distributions for key population parameters. Can. J. Fish. Aquat. Sci. 51:713-722.

APPENDIX A

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 behavior 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 B

Glossary

Availability. Refers to the distribution of fish of different ages or sizes relative to that of the fishery.

B. Biomass, measured in terms of spawning capacity (in weight) or other appropriate units of production.

$\boldsymbol{B_0}$. Virgin stock biomass, i.e. the long-term average biomass value expected in the absence of fishing mortality. In Section 3.1, B_0 is used as the biomass at the start of a population projection.

$\boldsymbol{B_{MSY}}$. Long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY}.

BRP (Biological Reference Point). Benchmarks against which the abundance of the stock or the fishing mortality rate can be measured, in order to determine its status. BRPs can be categorized as limits or targets, depending on their intended use (see also Reference Points). There are also socio-economic reference points, but those are not treated in any detail in this document.

Catchability. Proportion of the stock removed by one unit of effective fishing effort (typically age-specific due to differences in selectivity and availability by age).

Control Rule. Describes a plan for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how *F* or yield should vary with biomass. In the NSGs, the "MSY control rule" is used to determine the limit fishing mortality, MFMT. Control rules are also known as "decision rules" or "harvest control laws" in some of the scientific literature.

CPUE (Catch per Unit of Effort). Measures the relative success of fishing operations, but is also sometimes used a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size. The use of CPUE that has not been properly standardized for temporal-spatial changes in catchability is highly undesirable.

DAH (Domestic Annual Harvest).

ESA (Endangered Species Act).

F. Instantaneous fishing mortality rate. Measures the effective fishing intensity for a given partial recruitment pattern.

$\boldsymbol{F_{0.1}}$. Fishing mortality at which the slope of equilibrium yield per recruit (YPR) is reduced to 10% of the slope when F=0.

$\boldsymbol{F_{high}}$. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 90th percentile observed survival ratio.

$\boldsymbol{F_{low}}$. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 10th percentile observed survival ratio.

$\boldsymbol{F_{max}}$. Fishing mortality at which the slope of equilibrium yield per recruit (YPR) is zero (may be undefined in some cases where the YPR-*F* curve is asymptotic).

$\boldsymbol{F_{med}}$. Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the median observed survival ratio.

$\boldsymbol{f_{MSY}}$. Effective fishing effort corresponding to F_{MSY}.

F_{MSY}. Fishing mortality rate which, if applied constantly, would result in MSY.

$F_{\blacktriangle}$ (also $F_{extinction}$, F_{crash}). Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the survival ratio at the origin of the stock-recruitment relationship. A stock fished at or above this level for a prolonged period of time is expected to collapse.

$F_{x\%}$. Fishing mortality rate that results in x% equilibrium spawning potential ratio.

FMP (Fishery Management Plan). A plan containing conservation and management measures for fishery resources, and other provisions required by the MSFCMA, developed by the Fishery Management Councils or the Secretary of Commerce.

Generation Time. In the context of the NSGs, generation time is a measure of the time required for a female to produce a reproductively-active female offspring for use in setting maximum allowable rebuilding time periods. Several estimators of generation time are available in the literature, and one is presented in Section 3.4.

Limit Reference Points. Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In much of the NSGs, limits are referred to as thresholds. In much of the international literature (e.g., FAO documents), “thresholds” are used as buffer points that signal when a limit is being approached.

M. Instantaneous natural mortality rate.

MESY (Maximum expected stationary yield). Maximum statistical expectation of long-term yield, considering uncertainties in parameter values and natural (process) variability.

MELSY (Maximum expected log stationary yield). Maximum statistical expectation of the logarithm of long-term yield, considering uncertainties in parameter values and natural (process) variability.

MFMT (Maximum Fishing Mortality Threshold). SDC for determining if overfishing is occurring. It will usually be equivalent to the *F* corresponding to the MSY Control Rule.

MSFCMA (Magnuson-Stevens Fishery Conservation and Management Act). U.S. Public Law 94-265, as amended through October 11, 1996. Available as NOAA Technical Memorandum NMFS-F/SPO-23, 1996.

MSST (Minimum Stock Size Threshold). The greater of (a) ½B_{MSY}, or (b) the minimum stock size at which rebuilding to B_{MSY} will occur within 10 years of fishing at the MFMT. MSST should be measured in terms of spawning biomass or other appropriate measures of productive capacity.

MSY (Maximum Sustainable Yield). Largest long-term average yield (catch) that can be taken from a stock (or stock complex) under prevailing ecological and environmental conditions. Any estimate of MSY depends on the population dynamics of the stock, the characteristics of the fisheries (e.g. gear selectivity), and the control rule used. In much of the traditional fisheries literature, MSY is estimated with a control rule in which *F* is independent of stock size. In the language of the NSGs, estimates of MSY will change depending on the shape of the control rule, but B_{MSY} and F_{MSY} pertain only to a constant-*F* control rule.

NSGs (National Standard Guidelines). Advisory guidelines developed by NMFS, based on the National Standards of the MSFCMA, intended to assist in the development of FMPs.

Published in the Federal Register[3] first as proposed rule on August 4, 1997, and then revised as final rule on May 1, 1998.

Overfished. According to the NSGs, an overfished stock or stock complex is one "whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding." A stock or stock complex is considered overfished when its size falls below the MSST. A rebuilding plan is required for stocks that are overfished.

Overfishing. According to the NSGs, "overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." Overfishing is occurring if the MFMT is exceeded for 1 year or more.

OY (Optimum Yield). The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a "ceiling" for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for rebuilding to B_{MSY}.

Partial Recruitment. Patterns of relative vulnerability of fish of different sizes or ages due to the combined effects of selectivity and availability.

Rebuilding Plan. A plan that must be designed to recover stocks to the B_{MSY} level within 10 years when they are overfished (i.e. when $B <$ MSST). Normally, the 10 years would refer to an expected time to rebuilding in a probabilistic sense.

Recent Catch. In the context of this document, this term should be interpreted as the average catch during a time period (e.g., 5 years) for which there is evidence of stable abundance. As this type of information is unlikely to be available in many data-poor cases, scientists could carefully consider defining Recent Catch as the median catch during the last 5, 10 or 15 years.

Reference Points. Values of parameters (e.g. B_{MSY}, F_{MSY}, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g. MSST) or targets for management (e.g. OY).

Risk. The probability of an event times the cost associated with the event (loss function). Sometimes "risk" is simply used to denote the probability of an undesirable result (e.g. the risk of biomass falling below MSST).

SDC (Status Determination Criteria). Objective and measurable criteria used to determine if a stock is being overfished or is in an overfished state according to NSGs.

Selectivity. Measures the relative vulnerability of different age (size) classes to the fishing gears(s).

SPR (1). Spawning output Per Recruit: Amount of per-capita spawning biomass (or other appropriate measure of reproductive output) obtained at a given value of F, conditional on values of partial recruitment, growth, maturity (and/or fecundity) and natural mortality. (2). Spawning Potential Ratio: The expected lifetime spawning output per recruit relative to the spawning output that would be realized in the absence of fishing, often expressed as

[3] Copies of the NSGs and other relevant documents that have appeared in the Federal Register can be obtained in the Web at http://www.nmfs.gov/sfa.

a percentage. Throughout this document, references to the second definition are associated with a percentage (%) sign.

Survival Ratios. Ratios of recruits to spawners (or spawning biomass) in a stock-recruitment analysis.

Target Reference Points. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g. OY). Target reference points should not be exceeded on average.

Uncertainty. Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Rosenberg and Restrepo (1994) identify 5 types: Measurement error (in observed quantities), process error (or natural population variability), model error (mis-specification of assumed values or model structure), estimation error (in population parameters or reference points, due to any of the preceding types of errors), and implementation error (or the inability to achieve targets exactly for whatever reason).

YPR (Yield per Recruit). Amount of per-capita yield obtained at a given value of *F*, conditional on values of partial recruitment, growth and natural mortality.