PERSPECTIVE:
FISHERIES MANAGEMENT

Defining Overfished Stocks: Have We Lost The Plot?

Ray Hilborn and Kevin Stokes

Hilborn is a professor in the School of Aquatic and Fishery Sciences at the University of Washington, Seattle, and can be contacted at rayh@uw.edu. Stokes is is a private consultant based in Wellington, New Zealand.

ABSTRACT: In recent years, there has been increasing emphasis on prevention of overfishing and agencies such as the National Oceanic and Atmospheric Administration now report the proportion of stocks that are overfished as a primary indicator of the agencies' performance. Almost all national and international legislation makes specific reference to maximum sustainable yield (MSY) and most definitions of overfishing are related in some way to achievement of MSY. We show that many of the definitions of overfishing now being adopted by fisheries agencies are increasingly unrelated to achievement of MSY and have become, to a great extent, arbitrary. We argue that overfishing definitions and management targets are generally better based on levels of historical stock size rather than the growing trend to setting targets in relation to theoretical unfished stock sizes.

Definiendo stocks sobrepescados: ¿se ha perdido el argumento?

RESUMEN: Recientemente se le ha dado especial énfasis a la prevención de la sobrepesca y agencias como la Nacional de Administración Oceánica y Atmosférica reportan como su principal indicador de desempeño, la proporción de stocks sobreexplotados. Casi toda la legislación existente, nacional e internacional, hace referencia específica al Rendimiento Máximo Sostenible (RMS) y la mayor parte de las definiciones de sobrepesca se relacionan de alguna forma a la adquisición de dicho nivel de rendimiento. En la presente contribución se muestra que muchas de las definiciones de sobrepesca que adoptan las agencias de pesquerías, se alejan cada vez más del nivel de RMS y que se han convertido, en buena medida, en algo arbitrario. Se discute que las definiciones de sobrepesca y objetivos de manejo generalmente tienen una mejor base en los niveles históricos del tamaño del stock que en la tendencia creciente de establecerlos en relación al tamaño teórico del stock en estado virgen.

While concern about overfished stocks has long been an important issue in fisheries management, in the last decade this concern has become institutionalized so that now many agencies report on the portion of their stocks that are overfished or depleted. In the United States in 2006, 25% of 187 stocks that were assessed were classified as overfished. (NMFS 2006). Closely related to definitions of "overfished" is the concept of the biomass that produces maximum sustainable yield (BMSY) and MSY. BMSY has become central to the definitions of reference points for fisheries management, which are now widely considered an essential part of well-managed fisheries. The term "overfished" is usually used to refer to a low level of stock abundance, and "overfishing" to high exploitation rates.

In this article, we review the scientific analysis and the legislative history of concern about overfishing and show that the current standards adopted in many jurisdictions have little if any basis in the science or the legislation. We suggest that many stocks now (or potentially) classified as overfished, depleted, or collapsed are producing at very close to their maximum sustainable yield and meeting the intent of national and international legislation. Agencies need to carefully distinguish between stocks that are at low abundance, and stocks that are fished so hard that their sustainable yield is significantly reduced.

Most national and international fisheries legislation makes specific reference to maximum sustainable yield. For example the United Nations Convention on Law of the Sea (UNCLOS) provided the template for much current legislation, and makes explicit mention of "levels which can produce the maximum sustainable yield," which is commonly expressed as BMSY.

> Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global. (UNCLOS Article 61.3)

The underlying theory of MSY and BMSY emerged in the 1930s with the work of Russell (1931), Hjort et al. (1933), Graham (1935), and others, and was codified in the classic books of the 1950s by Beverton and Holt (1957) and by Ricker (1958). Most commonly the potential sustainable yield (or surplus production) can be related to either the fishing mortality rate, or the stock size in "yield curves" as shown in Figure 1.

Emerging from these two yield curves are the three key concepts around maximum sustainable yield, the MSY itself, the biomass that produces MSY (BMSY) , and the fishing mortality rate that produces MSY (FMSY). The prescription for maximizing fisheries was quite simple—either hold the stock size at or around BMSY, or the fishing mortality rate at FMSY.

By the 1960s, MSY was a key element of the basic science of fisheries management.

> The basic idea was enshrined in national policy documents, incorporated in international treaties, and, in effect, became synonymous in most people's minds with sound management. Most fishery managers and politicians engaged in a steady dialogue of explaining why they had to compromise a bit on MSY for "social reasons" but, in so doing, they usually sounded apologetic. They knew they were sinning. (Larkin 1977:2)

They were "sinning" because they were allowing the fish stocks to be at biomasses that produced less surplus production than would be produced at BMSY. The "sin" was a loss in surplus production.

At the same time that the basic precepts of MSY were being incorporated in national policy and international treaty, the science was moving on, recognizing the varied objectives and complexities of management, leading to a "requiem for MSY" (Larkin 1977), and a call for "optimal yield" rather than maximum sustained yield (Roedel 1975). In the 1980s John Gulland prepared a not too tongue-in-cheek definition of MSY as:

> A quantity that has been shown by biologists not to exist, and by economists to be misleading if it did exist. The key to modern fisheries management. (John Gulland, pers. comm.)

Punt and Smith (2001) recount the death, crucifixion, and final resurrection of MSY in the 1990s as organizations sought to come to grips with the legislation they had inherited from the religion of MSY generated in the 1950s. It has certainly long been recognized that what may be overfished from one perspective may be well managed from another (Cunningham and Whitmarsh 1981) .

In each jurisdiction, management agencies have attempted to provide operational definitions of legislation in which MSY, BMSY, and/or FMSY have become enshrined. In the United States, the governing legislation is the Magnuson-Stevens Fisheries Management and Conservation Act (2007), which specifies:

> (1) 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.

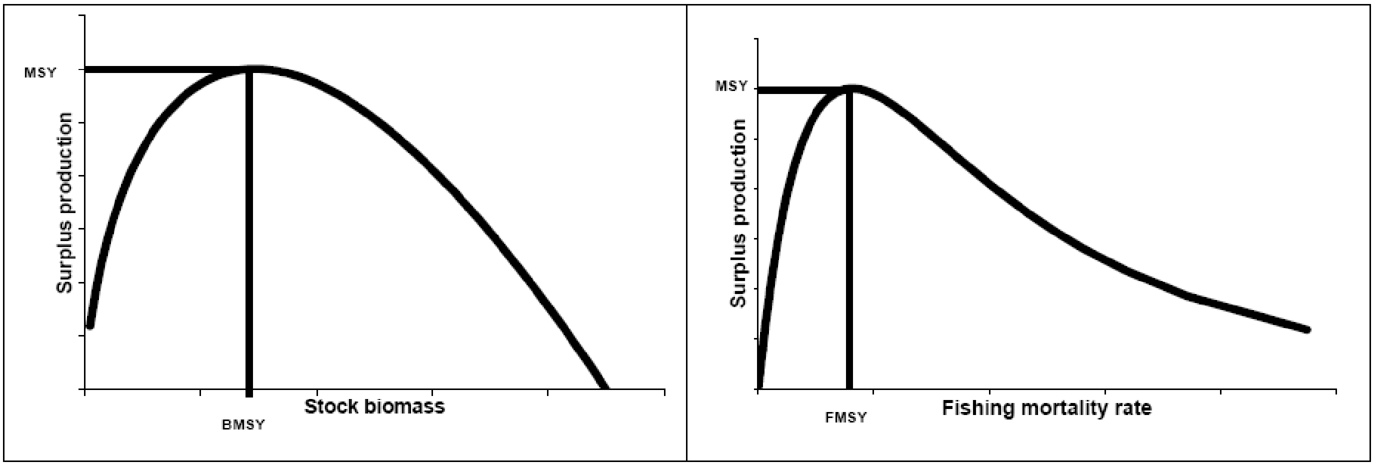
Here we see the clear intent to prevent the loss of yield due to overfishing. However there needs to be an operational definition and this is provided in the NOAA "National Standard Guidelines" (NOAA 2005:36251)

> (xxi) MSY stock size (BMSY) means the long-term average stock abundance level of the core stock or stock assemblage, measured in terms of spawning biomass or other appropriate [sic], that would occur while fishing according to the MSY control rule. The MSY stock size is the target stock size to which depleted stocks must be rebuilt.

The most important feature of this definition of BMSY is that it is a function of the management policy, the "MSY control rule" (such as a constant harvest rate policy). Under a MSY control rule, the stock will fluctuate above and below the target BMSY and would be expected to be below BMSY half of the time. However, it is recognized that the yield will be close to MSY over a significant range of stock sizes around MSY and that so long as the MSY control rule keeps the stock within that range, yield will be near MSY. One could argue that any stock size below BMSY is "overfished," that is, the stock size is less than the stock size that will produce MSY. However, in recognition that

> (1) the yield curve is always reasonably flat in the region of BMSY, and
>
> (2) natural fluctuations in recruitment make it impossible for most stocks to hold the population exactly at BMSY, most agencies define a stock

Figure 1. Two yield curves. The panel on the left relating average surplus production (sustainable yield) to stock biomass, the curve on the right surplus production to fishing mortality rate.



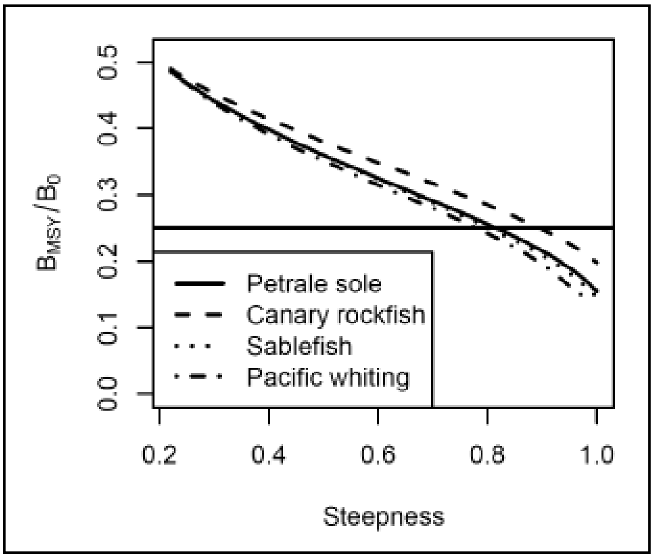
> as overfished only if it is well below BMSY. The U.S. National Standard Guidelines specify half BMSY as a guideline for the level that constitutes overfished, although fishery management councils are free to choose their own definition. The National Standards have also replaced the term “overfished” with “depleted.”

The Australians also define overfished as half BMSY (Department of Agriculture Fisheries and Forestry 2007; Rayns 2007). Their “harvest strategy standards” state they should have a “scientifically robust harvest strategy designed to achieve a sustainable target level and that does not result in overfishing or overfished stocks.”

DEFINING BMSY

The population dynamics models that have become standard in fisheries management can easily be used to calculate BMSY as a function of the biological parameters of growth, survival, vulnerability to fishing gear, and recruitment. For stocks where the information is high and these parameters can be estimated, it is common to calculate BMSY as a function of the theoretical level the stock would achieve in the unfished state, sometimes called “virgin biomass” or more commonly B0, indicating the biomass under an exploitation rate of 0. It turns out that only one life history parameter is really important in determining the ratio of BMSY to B0, and that is the amount of compensation in the spawner-recruit curve (Hilborn 2010). Compensation is now frequently described as a parameter called steepness, the proportion of the unfished average recruitment that would be obtained at 0.2 B0 (Myers et al. 2002). Figure 2, from Punt et al. (2008) shows the relationship between steepness and the ratio between BMSY and B0 for four species of groundfish with diverse life histories (natural mortality rate, age at maturity, vulnerability curve) managed by the Pacific Fisheries Management Council (PFMC) in the United States.

Figure 2. The relationship between steepness and the ratio of BMSY to B0 for four different fish life histories. Reproduced with permission from Figure 3 of Punt et al. 2008.



Punt et al. (2008) have done all of their calculations based on a Beverton-Holt spawner recruit curve, which is the standard assumption in almost all organizations we are familiar with. The Ricker spawner recruit curve does behave differently, because at higher steepness values the recruitment initially rises as spawning stock declines, and steepness can be, in theory, greater than 1.0. Most agencies prefer not to use Ricker recruitment curves, perhaps because the assumptions that lead to its derivation are cannibalism or redd superimposition that are viewed as unlikely, or perhaps because the idea of recruitment increasing with declining stock size is counterintuitive. However, if one does use the Ricker curve, then the level of BMSY/B0 is in the range of 30–40% regardless of steepness (unpublished results of authors). Throughout the rest of this article we will use the Beverton-Holt assumption as is consistent with most agency practice.

Also shown in this figure is the horizontal line at 0.25 B0, which is the PFMC default definition of “overfished” for groundfish. It is immediately obvious that for most stocks, if steepness was greater than about 0.8, stocks that are at BMSY would be classified as overfished! U.S. fishery management councils are free to choose their own definitions for overfished, and the PFMC 25% B0 definition is clearly at odds with the National Standards guideline of half BMSY.

The most exhaustive surveys of recruitment compensation were performed in the meta-analysis of Myers and colleagues (e.g., Myers et al. 1999, 2002). Table 1 shows the distribution of estimates of steepness for the three taxa of marine fish for which greater than 10 stocks had sufficient data to allow estimation (Myers et al. 1999). These stocks all show quite high steepness, with mid-points between 0.7 and 0.8. Referring back to Figure 2, this would imply that BMSY for these stocks is, on average, in the range of 25-30% of B0 and, using the NOAA guidelines of half BMSY, stocks would be deemed to be overfished if they were at 12–15% B0.

Not all estimates of steepness have found such high values (see e.g., Dorn 2002), and the PFMC now uses a value of 0.6 as a default option for most groundfish stocks on the Pacific coast where many stocks appear to be quite unproductive compared to the North Atlantic stocks that dominated Myers’ analysis. This default value of steepness (0.6) would imply that BMSY is about 30% of B0 and, in turn, that stocks would be classified as overfished at about 15% of B0.

While it is possible to define BMSY for stocks where all biological parameters are defined, for most stocks there is uncertainty in the spawner-recruit relationship and other parameters, particularly the natural mortality rate. In addition there may be major uncertainty associated with issues like model structure. Often, several alternative stock assessment models are proposed that may, for example, weight data sources differently. Therefore, any realistic estimate of BMSY would, of necessity, be probabilistic and reflect the underlying uncertainty. This poses great difficulty

Table 1. The estimated values of steepness for the three major marine fish taxa. From Myers et al. (1999).

Taxon	Number of data sets	Lower 20% bound	Midpoint	Upper 80% bound
Clupeidae	39	0.49	0.71	0.86
Gadidae	49	0.67	0.79	0.87
Pleuronectidae	14	0.71	0.80	0.87

for anyone seeking to answer simple questions like "Is this stock overfished?"

CONFRONTING UNCERTAINTY THROUGH MANAGEMENT STRATEGY EVALUATION

One approach to dealing with uncertainty is development of management strategies, that is, rules of how data will be collected, analyzed and used in setting harvest regulations (see e.g., Butterworth 2007). Part of the process is evaluating the performance of alternative strategies across a range of possible stock dynamics. A management strategy can often be found that performs well across the kinds of uncertainty in BMSY discussed previously. For instance, the management strategy adopted for rock lobsters (*Jasus edwardsii*) in New Zealand was shown to perform well under several alternative hypotheses even though these hypotheses had totally non-overlapping estimates of BMSY (Paul Starr, New Zealand Seafood Industry Council, pers. comm.). Management strategies are generally adopted based on their expected results in terms of yield, stock abundance, and catch rates. They are rarely based on estimates of BMSY or B0, in part because they are designed to be robust to uncertainty in these quantities, but some do make explicit reference to BMSY (Punt et al. 2008). Most management strategies that have been adopted can be said to be consistent with the intent of the legislative frameworks in that they are designed to avoid overfishing, but may not refer explicitly to BMSY.

One approach to developing management strategies is to use historical stock size as targets or breakpoints in the harvest control rules. Within the historical record, we usually know when stocks were abundant and productive, and for overfished stocks we know we would like to rebuild to those levels. Many stocks also have been historically fished to low abundance, and we know we would not want to go that low again. There is no need to tie our management strategies to unknowable quantities like B0 when we often have very well known reference points that can be broadly understood and applied. In the case of New Zealand rock lobster, different models produced widely different estimates of BMSY and no particular estimate of BMSY was considered to be credible. However, participants in the fishery and long-term managers were familiar with a period in the late 1970s/early 1980s when yields and abundance as measured by CPUE were considered good. In this fishery they believe that CPUE is a good index of abundance. The target CPUE for the harvest control rule was set to the CPUE in that period. Similarly, when the Commission for the Conservation of Southern Bluefin Tuna was considering a target for stock rebuilding, it chose the abundance in 1980 because it had been a period of good abundance and economic performance. These reference points can be absolute biomass from assessments, or survey indices.

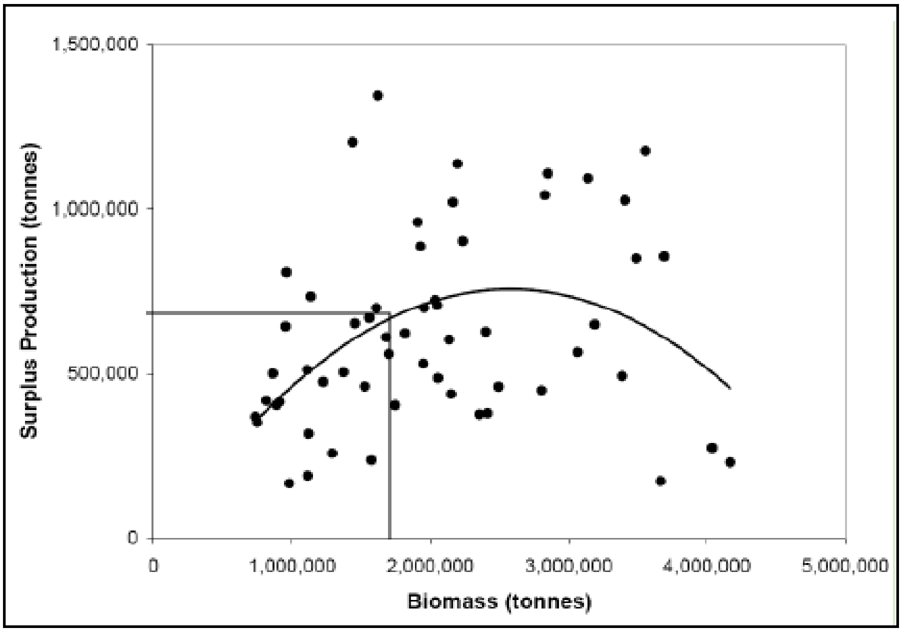
A closely related approach is simply to examine the historical relationship between stock size and surplus production, as shown in Figure 3 for the northeast Arctic cod (*Gadus morhua*) stock (Walters et al. 2008). Each dot is the estimated surplus production calculated from the catch and estimated biomass of the stock assessment. The solid line is a simple quadratic fit and the thin line is the stock size estimated in the last year of the assessment and the associated expected surplus production. The biomass where the quadratic curve reaches its highest point, roughly 2,700,000 tons, could be considered the target for fisheries management. While this approach can be viewed as a classic method for estimating BMSY and does depend on a stock assessment model, it is an empirical approach that makes no attempt to estimate B0 and sets targets based on historical estimates of surplus production.

DEFINING OVERFISHED

Returning to the theory of overfishing and the evolution of the legislative frameworks, it has always been recognized that MSY is not obtained from a single stock size, but over a range of stock sizes. The yield curves are usually quite flat over a range of stock sizes (Hilborn 2010) and management agencies have generally set biomass levels to define stocks as being overfished as a fraction of BMSY. In the U.S. National Standards and Australian terminology, the overfished threshold is called "Blim," and the default value in both places is half of BMSY. Once a stock falls below Blim, it is considered overfished. So long as the stock biomass is greater than Blim, the stock is considered to be within the bounds of normal management unless overfishing is occurring and the stock is under a rebuilding plan.

The U.S. legislation is designed to avoid managing stocks at biomasses so low that significant potential yield is being lost. Paragraph (6) of the Magnuson-Stevens Act states:

Figure 3. The relationship between stock biomass and surplus production for the northeast Arctic cod stock from northern Norway. The thin vertical lines indicates the biomass and expected average surplus production in 2003, the last year the data were available.



> A national program for the conservation and management of the fishery resources of the United States is necessary to prevent overfishing, to rebuild overfished stocks.

Paragraph (34) states:

> The terms "overfishing" and "overfished" mean a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis.

A major purpose of the act is to prevent overfishing, where overfishing is synonymous with reducing yield. Thus, lost yield is, presumably, the basis for the NOAA choice of half of BMSY as the default overfished threshold. The sustainable yield at half BMSY ranges from about 83–93% of MSY for steepness from 0.5 to 0.9 and it would certainly be reasonable to adopt a definition of being overfished as any stock size where the expected yield is (say) 80% or less than MSY.

If the purpose of definitions of "overfished," and associated thresholds, is to identify stocks that are at levels where potential yield is being lost, the "sin" that Larkin referred to earlier, then thresholds such as the 25% B0 adopted by the Pacific Fisheries Management Council for groundfish are inappropriate. With a steepness of 0.6, well below the median range of 0.7–0.8 identified by the work of Myers et al. (1999), stocks would typically be producing 98% of MSY—hardly a loss of yield that is measurable or significant. Even with a steepness of 0.3 (well below the 20th percentile of steepness estimates for any class of fish identified by Myers et al. 2002; Table 1), the stock would still be producing 75% of MSY.

Other agencies have also adopted default definitions of BMSY and of being overfished using standard "default" values. In fisheries managed by the Australian Commonwealth Government, 40% B0 is taken as the default BMSY value, modified to a target of 48% B0 by economic arguments, and 20% B0 is taken as a default level at which directed fishing should be closed (Department of Agriculture Fisheries and Forestry 2007). These default values can be replaced by stock-specific parameters where available, and when stocks fall below the lower limit, a stock specific rebuilding plan is usually put in place, with allowances for bycatch in other fisheries.

Australia and other agencies have often cited Myers et al. (1994) as the definitive paper supporting 20% B0 as a threshold for overfishing, but this is a serious misinterpretation of the results of that paper. Myers et al. (1994) showed that the recruitment does decline for most stocks at low stock sizes where data were available and the authors of that paper say that:

> …it [their analysis] should help dispel the widely-held notion that observed recruitment is "usually independent of spawning biomass."

The paper does not in any way, however, suggest that 20% B0 is a useful threshold for defining overfishing. Indeed, Myers et al. (1994) caution specifically against using 20% B0:

> Methods based on 20% B0 were included in this study because they have been widely applied (Beddington and Cooke 1983; Francis 1992); however, based on both empirical and theoretical considerations we do not recommend them for general use. These methods often placed the critical point well beyond the range of the observations (e.g., in 36% of cases for BHv). In addition, they suffer from two other related problems: inaccuracies in the estimates of virgin biomass, and the inappropriateness of applying the 20% level universally. Estimates of virgin biomass calculated by the method used here are inaccurate because they assume stationarity (e.g., no density-dependent processes) to calculate the F = 0 replacement line and generally rely on extrapolating the S-R data beyond the range of the observations. Similarly, a threshold of 20% B0 will not be universally applicable since different stocks have different degrees of compensation (i.e., density-dependence) in recruitment and other life-history processes. (Myers et al. 1994:204)

The later work of Myers and others, especially Myers et al. 1999 and Myers et al. 2002, as shown in Table 1, provides a much more solid framework for understanding the relationship between biomass and sustainable yield, and thus definitions of overfishing.

The problems in using B0 are severe. B0 is almost always estimated by taking estimated recruitments and extrapolating to a population size that would occur if these recruitments were allowed to mature in the absence of fishing. This usually done by multiplying average recruitment times spawning biomass per recruit in the absence of fishing. Such an approach completely ignores the possibility of density-dependent somatic growth and mortality, yet both phenomena are expected to occur for ecological reasons. Density-dependent growth has been documented as a frequent occurrence in exploited populations (Lorenzen and Enberg 2002). Density-dependent mortality is difficult to measure but has been documented at a range of life history stages (Myers 1995; Rose et al. 2001) and is expected from any trophic analysis of an ecosystem.

We can explore the impact of spawner-recruit compensation (steepness) further. Table 2 shows the relationship between steepness and several key parameters for a cod-like fish stock with a natural mortality rate of 0.2, von-Bertalanffy growth (k) of 0.2, maturing at age 5, and becoming vulnerable to fishing at age 4. These results are derived from the deterministic yield curve, but stochastic simulation shows similar results. This simple example shows, in particular, that BMSY for the range of most of the observed steepnesses of exploited marine fishes (i.e., steepness 0.6 or higher) is at 31% B0 or less, and for most stocks in Myers' analysis (with steepness in the range 0.7 to 0.9) is near or under 20% B0. At half BMSY, the yield is almost always quite high, and there is effectively no lost yield due to overfishing at a value of 25% B0 except for steepness values less than 0.5. Further, it shows, based on Myers et al. 1999 meta-analysis using 0.7 as an average steep-

Table 2. The relationship between steepness and several BMSY related parameters for a cod-like fish stock.

Steepness	BMSY	Yield at 1/2 BMSY	SBPRMSY	Yield at 25% B0
0.3	0.45	0.75	0.77	75%
0.4	0.38	0.73	0.61	87%
0.5	0.36	0.83	0.52	93%
0.6	0.31	0.85	0.42	98%
0.7	0.26	0.87	0.34	100%
0.8	0.22	0.88	0.26	100%
0.9	0.16	0.93	0.19	97%*

*BMSY is less than 25% B0 and this lost yield represents underfishing rather than overfishing ness, that 25% B0 would be a good default assumption for BMSY, and that, on average, little sustainable yield would be expected to be lost with stock sizes as low as 12% BMSY. The PMFC and Australian Government have adopted 40% B0 as a standard for BMSY. Others (e.g., New Zealand) appear to be following suit. This is unrealistic based on the biology of exploited fish species. We should note, however, that the flat yield curve means that the expected yield at stock sizes higher than BMSY is also close to MSY and there would be little loss of yield from harvest policies that consistently maintain the stock above BMSY.

We suggest two logical ways to define stocks that are overfished. The first would be to use a lost-yield threshold, with 80% being an obvious suggestion based on Table 2. This would mean that overfished would be less than half BMSY for stocks with steepness > 0.5, and higher than half BMSY for stocks with steepness below 0.5. An alternative definition would be based on the range of stock sizes that are predicted to occur from a FMSY harvest strategy. Again, one could choose the 80% probability distribution as the bounds, so that there would be only a 10% chance of a stock managed by FMSY being classified as "overfished."

ACCOUNTING FOR RISK AND DEPENSATION

The use of 20% B0 as a standard for defining stocks as being overfished developed during the 1980s and 1990s (Beddington and Cooke 1983; Francis 1992); the conventional wisdom being that "bad things" might happen when stocks go below this level. "Something bad" may be declines in recruitment or, even worse, depensatory recruitment or survival when populations get to low abundance. In New Zealand, the concern about going below 20% B0 has become institutionalized, so that the definition of BMSY requires that the stock not go below 20% B0 more than 10% of the time under a MSY harvest strategy (so-called CAY or MCY policies—see e.g., Sullivan et al. 2005). This has the effect of defining BMSY as a larger number than calculated from the yield curves as shown earlier.

The primary concern about being below 20% B0 is recruitment overfishing, and the analysis from Table 2 shows that only for the lowest steepness values is there significant lost yield at that level. In the sense of the legislative history and the wording of UNCLOS, 20% B0 is almost certainly a level that produces very close to the maximum sustainable yield for most fish stocks.

The second possible concern about lower stock sizes is depensation. Two papers have explored the evidence for depensatory mechanisms in recruitment across a wide range of fisheries. Myers et al. (1995) and Liermann and Hilborn (1997) both used the spawner-recruit database assembled by Myers and found little evidence for depensatory recruitment processes. There is good evidence that recruitment declines at low stock abundance, but not in a depensatory fashion that could lead to collapse. Walters and Kitchell (2001) have argued that community shifts could lead to depensatory dynamics only after stocks had been at low abundances for many years. Shelton and Healey (1999) argued that this could have happened with the northern cod in Eastern Canada. However, the northern cod stock was pushed to a very small fraction of B0, and there remains little evidence for depensatory dynamics as a frequent phenomenon in exploited fish populations.

REFERENCE POINTS FOR MANAGEMENT

Many jurisdictions have now defined formal harvest strategies built around three key biomass reference points: a target biomass about which the stock is meant to fluctuate, a "hard" limit where directed fishing should stop, and a "soft" limit (between the target and the hard limit) below which a formal rebuilding plan be put in place and generally where stocks are considered overfished or depleted. In the PFMC groundfish management plan, 40% of the theoretical unfished biomass (B0) is considered the target, 25% B0 is the soft limit and formal definition of being overfished, and 10% B0 is the hard limit. In Australia, the target defaults to 1.2 x BMSY (48% B0); the hard limit is half BMSY (20% B0). NOAA has adopted half BMSY as a standard guideline for levels that constitute being overfished.

All of the calculations and discussion of MSY-related reference points thus far have concerned the issue of yield and concern about lost yield from overfishing. This is a totally distinct issue from what reference points should be used in formulating management policies. There are many good reasons that management agencies and fishing entities would like to operate fish stocks at biomasses larger than BMSY. For instance, the economics of fishing are generally more profitable at larger stock biomasses (Grafton et al. 2007) and there are fewer ecological impacts (Worm et al. 2009). Thus it may be quite reasonable to set target biomass well above BMSY, and to have fishing mortality rates reduced when the stock drops below BMSY. There may have been significant ecosystem changes that mean the data from the past are not relevant to the current productivity of the stock. To some extent this is simply reverting back to the 1970s and replacing MSY as a fisheries objective with an "optimum yield" that considers economic and ecological impacts in addition to biomass harvested. However, it must be recognized that the idea of using BMSY as a lower limit is completely arbitrary, and is not related to yield and or overfishing. It is simply that BMSY is a concept people (think they) are familiar with.

Punt et al. (2008) have shown that the management performance of different strategies that use threshold breakpoints (as the PFMC and Australian Government do) are broadly insensitive to the actual thresholds. So long as catches are reduced as stock size declines, the management strategies provide good yield. In particular, the lower thresholds where directed fishing is stopped are reasonably unimportant since a well-managed stock would rarely get to those levels. However, where they do matter a great deal is with most of the world's real fisheries, where many are at lower abundance than we would choose to operate if we had our choice. If one accepts that a good target for fisheries management is at abundances higher than BMSY—for ecological and economic reasons—then many commercial fisheries are below this target level. Worm et al. (2009) estimated two-thirds of the stocks they examined had biomass currently lower than BMSY. The two key questions then become:

(1) What is the value of rebuilding to higher stock abundances given we are at lower abundance, and

(2) How quickly should this rebuilding take place?

We can answer the first question biologically by looking at the yield curve, but we could only answer the second question if we had an objective such as maximum discounted yield or profit. In practice, rebuilding times have often/usually been dictated arbitrarily, with no underlying justification being given.

CONCLUSIONS

In the United States, and increasingly elsewhere, stopping stocks from becoming overfished, and stopping overfishing, have become the holy grails of fisheries management, yet the scientific community has been imprecise and perhaps even dishonest in defining what "overfished" actually is. As shown above many of the definitions of being overfished (or of overfishing) now in place cannot be justified on biological or legal grounds. A sort of "international group think" has taken over in which different jurisdictions cite other jurisdictions use of 20% B0, 40% B0, and B0 itself as a basis for policies without evaluating the legitimacy of these specific reference points.

It can be argued that the increasing concern about ecological impacts of fishing and the economics of fishing has led to a new concept of overfishing, and definitions like the PFMC's 25% B0 represent not overfishing from lost yield, but economic or ecological overfishing. The "new" overfishing would represent a reincarnation of "optimum yield" from the 1970s. This is a perfectly viable approach, but must be recognized as totally arbitrary unless supported with an underlying quantitative basis.

In practice, almost all justification of thresholds for overfishing claims to be based on legislation and the traditional concern about yield lost from overfishing. We have no doubt the general public perceives overfished stocks as having been fished so hard that they are not producing near their sustainable yield. It seems ironic that many agencies choose high thresholds for defining stocks as overfished and then use these thresholds to evaluate their own performance, making themselves look bad as a result.

We recommend that management agencies distinguish between stocks that are losing yield due to overfishing, and stocks that are at lower biomass than would be desired for ecological or economic reasons. The scientific data suggest that 25-30% B0 would be the most justifiable level for a default BMSY, and that 10% B0 would probably represent a typical level at which more than 10% of potential yield was being lost. In cases where the spawner-recruit steepness can be estimated, the guidelines could be replaced by the results from the yield curve.

What the standard approaches to biomass reference points in the United States and Australia fail to make clear is that they are tied to an almost unknowable quantity, the unfished biomass B0. Targets and limits for fisheries management based on historical stock sizes and stock productivity have the advantage that they are based on experience, are easily understood, and are not subject to the vagaries of model assumptions. While such targets and limits are not explicitly based on the empirical estimates of BMSY, they are completely consistent with the intent of most national and international fisheries legislation—to avoid loss of yield by overfishing.

The tension between B0-based targets and historically-based targets centers on the question of who should determine fisheries management targets. In the United States, especially with the recent reauthorization of the Magnuson-Stevens Act, there is a desire to have fisheries management be science-based, and having harvest strategies determined by model outputs such as a percent of B0 clearly puts the decision making in the hands of the scientists. We feel this is misguided for two reasons. First, scientists have no special knowledge regarding appropriate fisheries policy. Scientists should simply evaluate the consequences of alternatives being considered. Secondly, the stakeholders in a fishery and the political process should determine fisheries management choices; while the stakeholders understand historical levels of abundance, they seldom understand model outputs such as %B0. To the extent that there is no scientific way to determine what a "good" period of fisheries performance was, we view that as a positive step in putting decision-making back in the hands of the stakeholders.

It is likely that socially "optimal" harvest strategies may seek to hold stocks, on average, at high stock sizes for economic, ecological, or social reasons (Hilborn 2007). However, such choices need to be evaluated on a case-by-case basis, and there is a need to be very clear what it is that causes larger stock sizes to be socially desirable. At present, it seems that those advocating larger stock sizes for ecological reasons are using the legislative requirements to avoid lost yield from overfishing, and distorting the science in the process, as an excuse to achieve objectives not considered when the legislation was drafted.

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