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Failure to eliminate overfishing and attain optimum yield in the New England groundfish fishery

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Under US law, fishery management is required to eliminate overfishing and attain optimum yield (OY). In New England, many groundfish stocks continue to be overfished, and the fishery continues to harvest less than OY. The reasons for the shortfalls are rooted in the socio-economic structure of the management regime, and technical and scientific issues that constrain the management system. The most recent change in the management regime (days-at-sea to catch shares) and performance relative to OY and the prevention of overfishing are analyzed along with metrics used to gauge performance. The commonly used age-based production model gives a problematic perception of stock abundance. Structural issues that seem to impair achieving OY are the adherence to the single-species interpretation of multiple-species yield and the use of the $F_{x\%}$ proxy. Simpler approaches to stock assessment are discussed. A management system that creates feasible goals and uses improved and simpler metrics to measure performance is needed to facilitate attainment of management goals.

Keywords: fishery management, optimum yield, overfishing, performance.

Introduction

This paper assesses the performance of the current management of the New England groundfish fishery, which harvests 13 species, relative to overfishing and optimum yield (OY). ["harvested species" refers to the 13 species, which comprise 20 stocks, which were assigned an annual catch limit (sub-ACL) in the northeast multispecies fishery during fishing year (FY) 2012 (NOAA, 2012).] In 2010, the management of this fishery transitioned from the days-at-sea (DAS) system to a type of catch-share programme known as "sector management" (NEFMC, 2008). In addition to the change in management strategy, fixed or hard-catch limits, as required by the Magnuson–Stevens Reauthorization Act (MSRA, 2006), were applied to all stocks (and stock complexes). The sector system and hard catch limits were implemented simultaneously through Amendment 16 to the Northeast Multispecies Fishery Management Plan (Groundfish FMP). The management measures were designed to "achieve mortality targets, provide opportunities to target healthy stocks, mitigate (to the extent possible) the economic impacts of the measures, and improve administration of the fishery" (NEFMC, 2009).

The establishment of hard catch limits, through the sector-management system, was touted to have ended overfishing. [In an article written by the Associated Press and published by the Huffington post on 8 January 2011, Dr Steven Murawski stated that overfishing had ended for all US fish stocks (Lindsay, 2011).] However, the new system has neither eliminated overfishing nor resulted in the attainment of OY. These failures are due to a complex of socio-economic and technical factors. Among these, two are critical: (i) the stated goals of management and (ii) the metrics used to assess management performance.

We begin by providing an overview of the stated goals of US fishery management, specifically the mandate to end overfishing and achieve the OY in the context of the most recent change in the groundfish management regime (changes over a longer period are reviewed by Sissenwine and Murawski, 2013). We demonstrate that recent catch has been far less than the established catch limits; despite this apparent "underfishing", overfishing remains extensive. With respect to stated management goals, we point out that the commonly used age-based production model (ABPM) devised by Shepherd (1982) gives a problematic perception of stock abundance relative to maximum sustainable yield (MSY). We conclude that a management system needs to be designed that creates feasible goals and uses improved and simpler metrics to measure performance.

Stated goals of US fishery management

The guiding principles for US fishery management can be found in the MSRA, specifically the National Standards. The first national standard states that "conservation and management measures shall prevent overfishing while achieving, on a continued basis, the optimum yield from each fishery for the United States fishing industry" [§301, 98–623(1)]. Two objective statements can be extracted from this standard: (i) prevent overfishing and (ii) achieve OY.

Before 1976, US fishery management was oriented towards controlling multispecies catches of large domestic and foreign fishing fleets. After 1976, the Fishery Conservation and Management Act (FCMA) oriented managers to achieve OYs for domestic fleets, which was broadly defined in terms of biological, economic, and social considerations (Rothschild, 1983). However, as fishery management evolved, the prevention of overfishing relative to MSY became the primary goal of management. Even though the attainment of OY remained in the "plain language of the law", it has been rigidly constrained by regulations that give precedence to the requirement to prevent overfishing.

The focus on preventing overfishing intensified when the Magnuson–Stevens Act was reauthorized in 2006. New language was introduced in an evident attempt to strengthen the prevention of overfishing. This included the addition of a requirement for regional fishery management councils to set ACLs for all federally managed fish stocks [§302, 109–479(6)]. The reauthorization also required the Science and Statistical Committee (SSC) associated with each council to set acceptable biological catch (ABC) limits for each stock [§302, 101–627, 109–479 (g)(B)]. ACLs adopted by a council cannot exceed the recommended ABC set by its SSC [§302, 109–479(6)].

In order to implement the requirements of the MSRA, significant modifications were made to the Groundfish FMP. Perhaps, the most significant change to management was the transition from DAS effort limits to the sector system. Before May 2010, the groundfish fishery was managed using DAS. However, problems arose because attempts to control overfishing resulted in a continued ratcheting down of the number of days a boat could fish. The DAS system was widely criticized because it not only created DAS limits that were economically infeasible (e.g. 25 d boat^{-1} year^{-1}), but it also did not prevent overfishing.

If management of the New England groundfish fishery is to be successful, then (i) the stated goals must be clearly defined and feasible and (ii) the selected performance metrics need to provide the meaningful measures of stock status relative to goals (i.e. if overfishing is a criterion, then overfishing reference points must be a meaningful measure of overfishing).

Performance metrics

We review the performance of the groundfish fishery relative to the current interpretation of National Standard 1. In particular, we consider the overfishing and attainment of OY.

Overfishing

The terms "overfishing" and "overfished" are defined within the MSRA as "a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce maximum sustainable yield on a continuing basis" [§3, 104–297(34)]. The National Standard 1 Guidelines distinguish between these two terms. According to the Guidelines, the term "overfished" relates to the biomass of a stock or stock complex, and "overfishing" pertains to a rate or level of the removal of fish from a stock or stock complex [50 CFR Part 600, Section (2)(i)(A)]. The National Standard 1 Guidelines further require each council to specify status determination criteria "in a way that enables the Council to monitor each stock or stock complex in the FMP, and determine annually, if possible, whether overfishing is occurring and whether the stock or stock complex is overfished" [50 CFR Part 600, Section (e)(2)(ii)].

Performance with regard to overfishing for the 37 stocks that are managed by the New England Fishery Management Council (NEFMC), or jointly with the Mid-Atlantic Fishery Management Council (MAFMC), is summarized in Table 1. The prevalence of overfished and overfishing is significant. In 2011, 11 stocks were classified as overfished, with ten subject to overfishing. In other words in 2011, roughly 27% of the stocks were subject to overfishing and 30% of stocks were overfished. Of the ten stocks subject to overfishing, 100% fall under the Groundfish FMP, and 10 of the 11 stocks, or 91%, that are considered overfished are also managed as part of the Groundfish FMP.

Attainment of OY

The MSRA states that "the term 'optimum', with respect to the yield from a fishery, means the amount of fish which—(A) 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; (B) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor; and (C) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery" [§3, 104–297 (33)].

A reasonable operational definition of OY is the prescribed catch limit for each stock. It seems reasonable that catching the entire catch limit would provide the maximum benefit while achieving conservation objectives. We interpret a failure of a fishery to catch the catch limit as underfishing.

Under the Groundfish FMP, the sum of annual total allowable catch (TAC) limits (2005–2009) for each species or ACL (2010/2011), which we collectively refer to as catch limits, differ greatly from the annual landings of all managed stocks (Figure 1). The aggregate catch limit increased sharply from 2006 to 2007, whereas total landings remained roughly constant. The 2007 increase was primarily attributed to the increased catch limit for Georges Bank haddock (*Melanogrammus aeglefinus*; roughly 35 000 t in 2006 and 90 000 t in 2007).

It is evident that the annual difference between the sum of ACLs and total landings is substantial. In quantitative terms, underfishing has resulted in a cumulative lost opportunity of 550 217 t of fish that could have been caught from 2005 to 2011. If we assume a price of $1.50 per pound, underfishing of groundfish, from 2005 to 2011, equates to a loss of approximately $1.8 billion dollars (USD).

Costly risk aversion

The 2006 MSRA, and the corresponding National Standard 1 Guidelines, established the requirement for all federally managed stocks to have an overfishing limit (OFL), which, for practical purposes, is equivalent to MSY. ABC and ACLs are also required. The ACL is the actual quantity of fish that can be caught, and it is generally less than the ABC—the ABC is generally set less than the OFL. The basic idea in setting the ACL and ABC below the OFL is that it provides "insurance" that catch will not exceed the OFL. In

Table 1. Status of stocks managed by the NEFMC or jointly with the MAFMC.

FMP	Species	Stock	Jurisdiction	Overfishing?	Overfished?
Atlantic herring	Atlantic herring	Northwestern Atlantic coast	NEFMC	No	No
Atlantic sea scallop	Sea scallop	Northwestern Atlantic coast	NEFMC	No	No
Deep-sea red crab	Deep-sea red crab	Northwestern Atlantic coast	NEFMC	No	Unknown
Northeast multispecies	Acadian redfish	Gulf of Maine/Georges Bank	NEFMC	No	No, rebuilding
	American plaice	Gulf of Maine/Georges Bank	NEFMC	No	No, rebuilding
	Atlantic cod	Georges Bank	NEFMC	Yes	Yes
	Atlantic cod	Gulf of Maine	NEFMC	Yes	No, rebuilding
	Atlantic halibut	Northwestern Atlantic coast	NEFMC	No	Yes
	Haddock	Georges Bank	NEFMC	No	No
	Haddock	Gulf of Maine	NEFMC	No	No
	Ocean pout	Northwestern Atlantic coast	NEFMC	No	Yes
	Offshore hake	Northwestern Atlantic coast	NEFMC	Undefined	Undefined
	Pollock	Gulf of Maine/Georges Bank	NEFMC	No	No
	Red hake	Gulf of Maine/Northern Georges Bank	NEFMC	No	No
	Red hake	Southern Georges Bank/Mid-Atlantic	NEFMC	Undefined	No
	Silver hake	Gulf of Maine/Northern Georges Bank	NEFMC	No	No
	Silver hake	Southern Georges Bank/Mid-Atlantic	NEFMC	No	No
	White hake	Gulf of Maine/Georges Bank	NEFMC	Yes	Yes
	Windowpane flounder	Gulf of Maine/Georges Bank	NEFMC	Yes	Yes
	Windowpane flounder	Southern New England/Mid-Atlantic	NEFMC	Yes	No, rebuilding
	Winter flounder	Georges Bank	NEFMC	Yes	No, rebuilding
	Winter flounder	Gulf of Maine	NEFMC	No	Unknown
	Winter flounder	Southern New England/Mid-Atlantic	NEFMC	Yes	Yes
	Witch flounder	Northwestern Atlantic coast	NEFMC	Yes	Yes
	Yellowtail flounder	Cape Cod/Gulf of Maine	NEFMC	Yes	Yes
	Yellowtail flounder	Georges Bank	NEFMC	No	Yes
	Yellowtail flounder	Southern New England/Mid-Atlantic	NEFMC	Yes	Yes
Northeast skate complex	Barndoor skate	Georges Bank/Southern New England	NEFMC	No	No, rebuilding
	Clearnose skate	Southern New England/Mid-Atlantic	NEFMC	No	No
	Little skate	Georges Bank/Southern New England	NEFMC	No	No
	Rosette skate	Southern New England/Mid-Atlantic	NEFMC	No	No
	Smooth skate	Gulf of Maine	NEFMC	No	No, rebuilding
	Thorny skate	Gulf of Maine	NEFMC	No	Yes
	Winter skate	Georges Bank/Southern New England	NEFMC	No	No

Overfishing is defined as having a fishing mortality above the threshold, overfished implies a biomass below the specified threshold (stock-specific overfishing and overfished definitions can be found at: http://www.nmfs.noaa.gov/sfa/statusoffisheries/2011/RTC/2011_RTC_Append3.pdf). Rebuilding stocks are defined as having a biomass above the threshold, but not having reached the target biomass of B/B_{MSY} of 100% (NMFS, 2011). Undefined means that a threshold has not been established, unknown implies that data are insufficient to make a determination of status. Table modified from NOAA (2011).

other words, it is intended to be a guarantee against overfishing. The difference between the OFL and the ABC is called a "buffer".

A relatively simple, *ad hoc*, and somewhat arbitrary buffer is applied for New England groundfish stocks. The New England SSC concluded that "in the absence of better information on what an appropriate buffer should be between OFL and the ABC, a relatively simple ABC was applied to all groundfish stocks". Retrospective inconsistencies in most groundfish assessments precluded a probabilistic approach to ABCs. Given the guidance for specifying ABC as the lesser of 75% F_{MSY} or $F_{Rebuild}$, and the definition of OY in the current Multispecies FMP as that associated with 75% F_{MSY}, the SSC recommended that the Council consider this ABC specification be applied to all groundfish stocks (Carmichael and Fenske, 2011).

We can estimate the magnitude of the buffer as the difference between the OFL and ABC for all regulated groundfish stocks. The sum of the ABCs was roughly 63% of the sum of the OFLs in 2010 (Figure 2), representing an "opportunity cost" of 56 776 t of fish in 2010. The monetary value of the 2010 groundfish buffer was roughly $188 million, based on an ex-vessel value of $1.50 per pound. If we remove the three stocks that contribute the most, in terms of weight, to the OFL and ABC—redfish (*Sebastes fasciatus*), pollock (*Pollachius virens*), and Georges Bank haddock—we find that the buffer still represents a significant cost, roughly 14 000 t, with a potential ex-vessel value of $46 million.

Although buffers are intended to reduce the risk of overfishing a particular fish stock by reducing catch to a level that allows for some errors in the assessment, we find, in retrospect, that many stocks continue to be overfished despite significant buffers that do not seem to be cost-effective.

Confounding results: concurrent overfishing and underfishing

The establishment of hard catch limits, through the sector management system, was touted to have ended overfishing during FY 2010. [In an article written by the Associated Press and published by the Huffington Post on 8 January 2011, Dr Steven Murawski stated that overfishing had ended for all US fish stocks (Lindsay, 2011).] In 2010, catch of all managed groundfish species was under the prescribed catch limits; in fact, only 37% of the aggregate catch limit was caught. We also point out that these catch limits were precautionary (see previous section on buffers).

In contrast, recent stock assessments suggest that 6 of the 14 managed stocks were subject to overfishing in 2010. For nearly half of the managed groundfish stocks in 2010, catch relative to

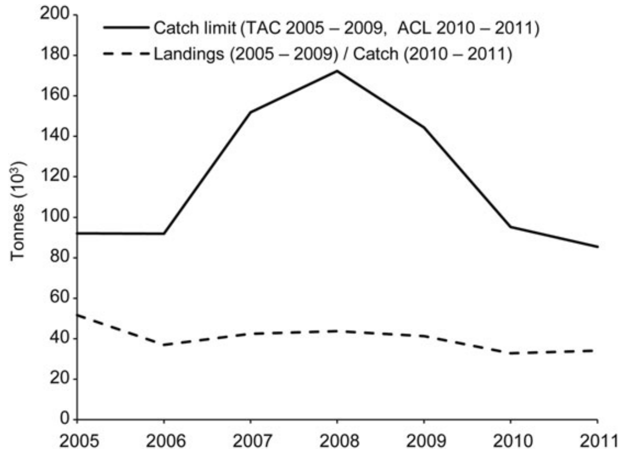

Figure 1. Trends in the sum of annual groundfish (fish regulated under the Northeast Multispecies FMP) catch limits and landings from 2005 to 2011 are depicted. From 2005 to 2009, groundfish were managed under the DAS system—stock-specific TACs were applied, but the fishery was regulated by input control measures. In 2010 and 2011, the groundfish ACL is depicted. Landings remained relatively constant from 2006 to 2009 after decreasing from 2005 to 2006. Landings in 2010 and 2011 were less than in 2009. Note that this figure depicts the catch limit and landings for regulated groundfish species; the complex of regulated stocks was not consistent over the depicted time-period. In 2010 and 2011, total catch (landings and discards) is substituted for landings. Data obtained from NERO (2012).

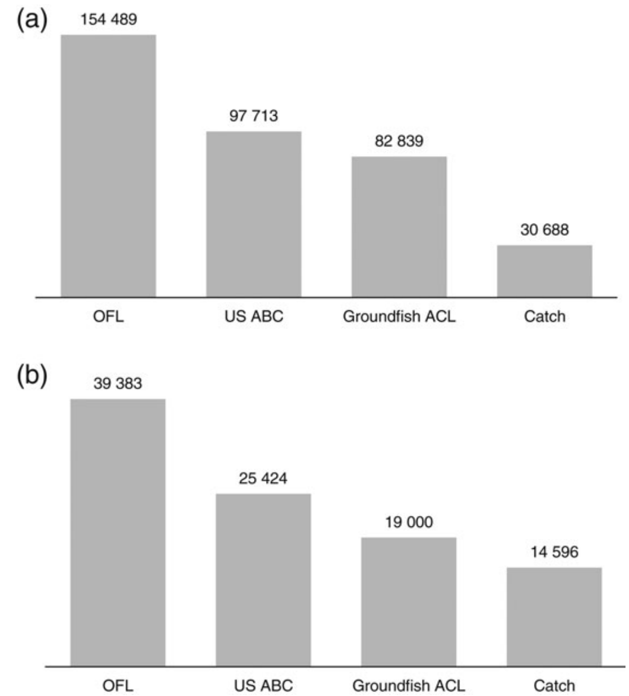

Figure 2. 2010 OFL, US ABC, groundfish ACL, and total catch (t). In (a), all groundfish species are included; in (b), Georges Bank haddock, redfish, and pollock have been removed. These figures show that the difference between the estimated OFL, ABC, ACL, and consequent 2010 catch.

catch limits suggested the fishery was underfished, but updated stock assessments suggested the stock was subject to overfishing. This scenario begs the question: how can we have the confounding result that stocks are simultaneously underfished and overfished?

A simple analysis suggests that the projections, from which managers base their catch advice, have been biased. The NEFMC's SSC concluded at a 2012 meeting that: "Overall, the projections were biased high, meaning the projected stock increased more than the realized stock. This resulted in catches at or below recommended ABCs having fishing mortality rates above what was expected from the projections. For some stocks, this resulted in overfishing occurring despite the fishery catching less than the recommended ABC. The SSC reiterates its concern with medium term projections for these stocks and recommends conducting assessments more regularly so that projections are for shorter periods into the future". [Excerpt from a 24 September 2012 memo from the Scientific and Statistical Committee to Paul Howard (NEFMC Executive Director). Memo subject: Groundfish ABC for FY2013–2015. Source link: http://www.nero.noaa.gov/regs/2013/March/13mulfw50appendixi.pdf].

Of particular importance is the understanding that uncertainty in the stock assessment creates uncertainty in the overfishing definition. To illustrate, the New England groundfish stock assessments *per se* do not seem to be giving accurate results, and projections do not appear to track the abundance of stocks (Table 2). This means that there is something wrong with the data, the assessment/projection technique, or both.

One way of thinking about these uncertainties is that they can be sufficiently large so that, for any particular stock, we actually do not know if it is or is not overfished. For example, a particular stock may be declared to be overfished. Yet, because of errors in the reference point or in the estimation of fishing mortality or stock size, the stock might not be overfished. To be accurate, it would be better to declare that stock is "nominally" overfished, or "nominally" not overfished.

Table 2. Estimates of the deviation between the 2010 SSB projected in the 2008 GARM III assessment (terminal year 2007) and the updated SSB based on the 2011 Groundfish Stock Assessment Update (terminal year 2010).

Stock	Projected 2010 SSB (t)	Updated 2010 SSB (t)	Difference	% difference
CC–GOM yellowtail flounder	7 100	2 900	−4 200	−59
GB cod	30 000	10 000	−20 000	−67
GB haddock	280 000	170 000	−110 000	−39
Plaice	22 500	17 500	−5 000	−22
Witch flounder	6 100	4 100	−2 000	−33
Redfish	260 000	310 000	+50 000	+19
GOM haddock	5 900	2 900	−3 000	−51

Values were estimated from figures presented in Appendix 5, pp. 781–789 (NEFSC, 2008). CC–GOM, Cape Cod–Gulf of Maine; GB, Georges Bank.

Projections of stock size presented at the 2008 Groundfish Assessment Review Meeting III (GARM III) deviated by as much as 67% based on the 2012 Update of 13 Groundfish Stock Assessments (Table 2). For all stocks, with the exception of redfish, the bias resulted in an apparent overestimation of spawning–stock biomass (SSB) and underestimation of F (NEFSC, 2008). It is important to note that some managers believe that these large discrepancies owe to substantial misreporting, discarding, and catches that are allocated to incorrect stock areas, which further underscores a lack of confidence in the current stock assessment and management system. The magnitude of the bias in the model output suggests that these short-term projections are an unreliable basis for setting catch limits and biomass targets.

Interpreting performance: effect of model choice

Direct reading of the MSRA specifically indicates that MSY should be used to gauge whether a stock is overfished. Such models in fisheries are usually referred to as production models. Inasmuch as production model theory is not explicitly used in New England groundfish assessments, the choice of a particular model or theoretical structure and how the results from the model or theoretical structure relate to MSY and F_{MSY} becomes fundamentally important. There are three issues. The first relates to the choice of a model to represent the interaction of population vital statistics and fishing; the second relates to the choice of x in $F_{x\%}$; and the third relates to the method for estimating model parameters.

The ABPM used in New England to estimate the optimal F was first developed by Shepherd (1982). Rothschild and Jiao (2009, 2011, 2013) and Rothschild *et al.* (2012) provide detailed review and analysis of the model. There are three important points. First, the model does not estimate MSY. As shown by Clark (1991, 1993), the model generates the estimates of F that provide "not MSY, but at least 75% MSY". (This means there could be circumstances where the application of ABPM results in a level of F that corresponds with 75% MSY. Then, applying the buffer would result in 75 × 75% MSY.) In other words, 25% of MSY could be wasted by the use of the ABPM. Second, the ABPM is not valid for non-equilibrium conditions. Since most fisheries are in a state of non-equilibrium, implementing the ABPM approach can be viewed as a theoretical exercise. Third, and perhaps most important, the ABPM arguably contains more parameters than any other fishery model; hence, its application is contrary to the principals of parsimony applied in modern statistics.

Choice of *x* in $F_{x\%}$

The constant x is defined by Shepherd as the value of F that needs to be maintained to sustain a stock at x% of its unfished biomass. $F_{40\%}$ is a commonly used reference point in New England (and in other locations as well). Theoretically, the application of $F_{40\%}$ means that a stock will be maintained at 40% of its unexploited biomass. Although Clark (1991, 1993) pointed out that the $F_{x\%}$ reference point was warranted only when MSY is difficult to compute, it is always used, disregarding Clark's advice.

A particular problem with the ABPM approach is that it relies heavily on the least known and most variable component of fishery theory—the stock–recruitment relationship. For example, it is well known that for populations that possess a dome-shaped stock–recruitment curve, the $F_{40\%}$ proxy will underestimate MSY (Figure 3). Further, for many groundfish stocks, the selection of unfished biomass targets (e.g. $F_{40\%}$) is arbitrary in the sense that "x" could be set at almost any level (e.g. 20, 32%) by the investigator.

In 2002, F_{MSY} was estimated for all New England groundfish stocks using several modeling approaches, and the "best model" was determined using conventional model-selection methods (NEFSC, 2002). Although F_{MSY} was directly estimated for some stocks, the proxy $F_{\%MSP}$ was used for most stocks. $F_{\%MSP}$ is the fishing mortality associated with a percentage of maximum spawning potential (MSP) and represents another metric. At the 3rd Groundfish Assessment Review Meeting (NEFSC, 2008), all F_{MSY} estimates were replaced with $F_{\%MSP.}$ However, F_{MSY} remains the legal definition of overfishing.

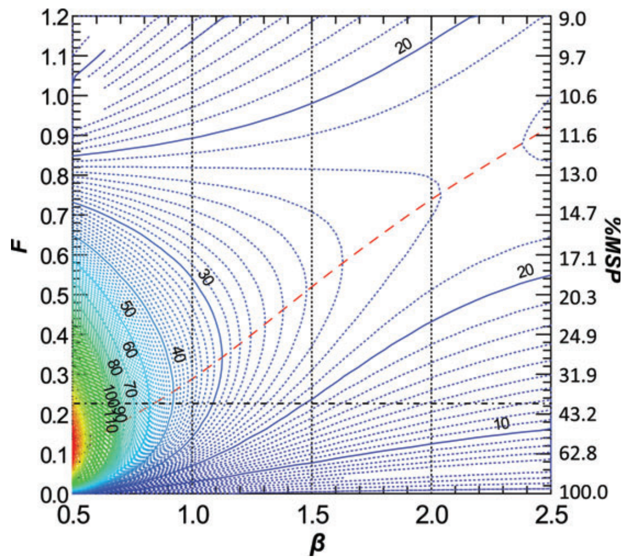

Figure 3. Yield vs. β and $F_{\%MSP}$ contour plot for a summer flounder-like fish stock with the Shepherd model of $\alpha = 3.4$, $K = 27.4$, and β ranging from 0.5 to 2.5. The horizontal dot-dashed line indicates 40% MSP. The dashed line represents the locus of maximum yield. The stock–recruit data for summer flounder (*Paralichthys dentatus*) were obtained from Terceiro (2009) and Rothschild *et al.* (2012).

Table 3. Assumptions and required inputs of various stock assessment models (ICES, 2012).

Model	Assumptions and inputs
ASAP: age-structured assessment program	Natural mortality (M), fishing selectivity, catch-at-age (or landing and discards separately), maturity, proportion of F and M before spawning, weight-at-age (catch, stock, SSB)
ASPIC: a stock production model incorporating covariates	Catch, cpue (e.g. survey indices)
Production model	Catch, cpue
VPA without tuning (virtual population analysis)	Natural mortality (M), fishing selectivity, catch-at-age Optional inputs for estimating biomass: maturity, proportion of F and M before spawning, weight-at-age (catch, stock, SSB)
VPA/ADAPT	Natural mortality (M), fishing selectivity, survey indices, catch-at-age Optional inputs for estimating biomass: maturity, proportion of F and M before spawning, weight-at-age (catch, stock, SSB)

Estimation of *F*

Virtual population analysis (VPA) is typically used to estimate F. But, the VPA in use in New England has been associated with a large "retrospective pattern". A retrospective pattern can be defined as an unexplained persistent bias and hence generates model output that is difficult to interpret and apply to management advice. In the case of Georges Bank yellowtail flounder (*Limanda ferruginea*), recent assessments have consistently overestimated the SSB. Thus, the retrospective pattern of the VPA model introduces significant uncertainty regarding the status of the stock. Catch limits generated from these models, in retrospect, are too high and result in overfishing.

As a specific example, consider the changes in the perception of the Cape Cod–Gulf of Maine yellowtail flounder stock spawning–stock size (CC–GOM yellowtail, Table 3). In 2008, the CC–GOM yellowtail flounder stock was assessed with 2007 as the last year of data. This assessment suggested that SSB of yellowtail would, by 2010, exceed 5000 t (5 and 95% confidence intervals from ~4000 to 7000 t, respectively). When the stock was assessed again in 2011, it appeared that although the SSB had increased, it was not of the magnitude originally projected. The 2011 estimate of the 2010 SSB was ~2900 t. Between the 2008 and 2011 assessment years, catch only exceeded the TAC in 1 year, so the difference between the 2008 and 2012 estimates of SSB are more likely attributed to a deficiency in the model or input data than a failure of management.

The assumptions and complexity of different assessment models are listed in Table 3 (ICES, 2012). It is easy to see that the production model is the simplest in the sense that it relies on fewer assumptions and inputs. With few assumptions and inputs, model results are more transparent and cumulative errors less likely.

MSY, multiple species setting, and sustainability

As pointed out in the introduction, the attainment of MSY is a central goal of US fisheries legislation. This goal implies that production-model theory is the principle determinant of whether a stock is overfished or underfished (i.e. failure to take OY).

Production-model theory is generally intended to determine MSY and OY for a single stock. But, as is well known, the New England groundfish fishery harvests multiple stocks simultaneously. Further, the current approach used for assessment ignores the issue of non-independence among stocks, even though some stocks may strongly interact with the stock of interest. Interactive stocks may not even be groundfish. For example, there are reports in the literature where herring (*Clupea harengus*) are thought to be predators of cod (*Gadus morhua*) eggs and larvae; thus, there are

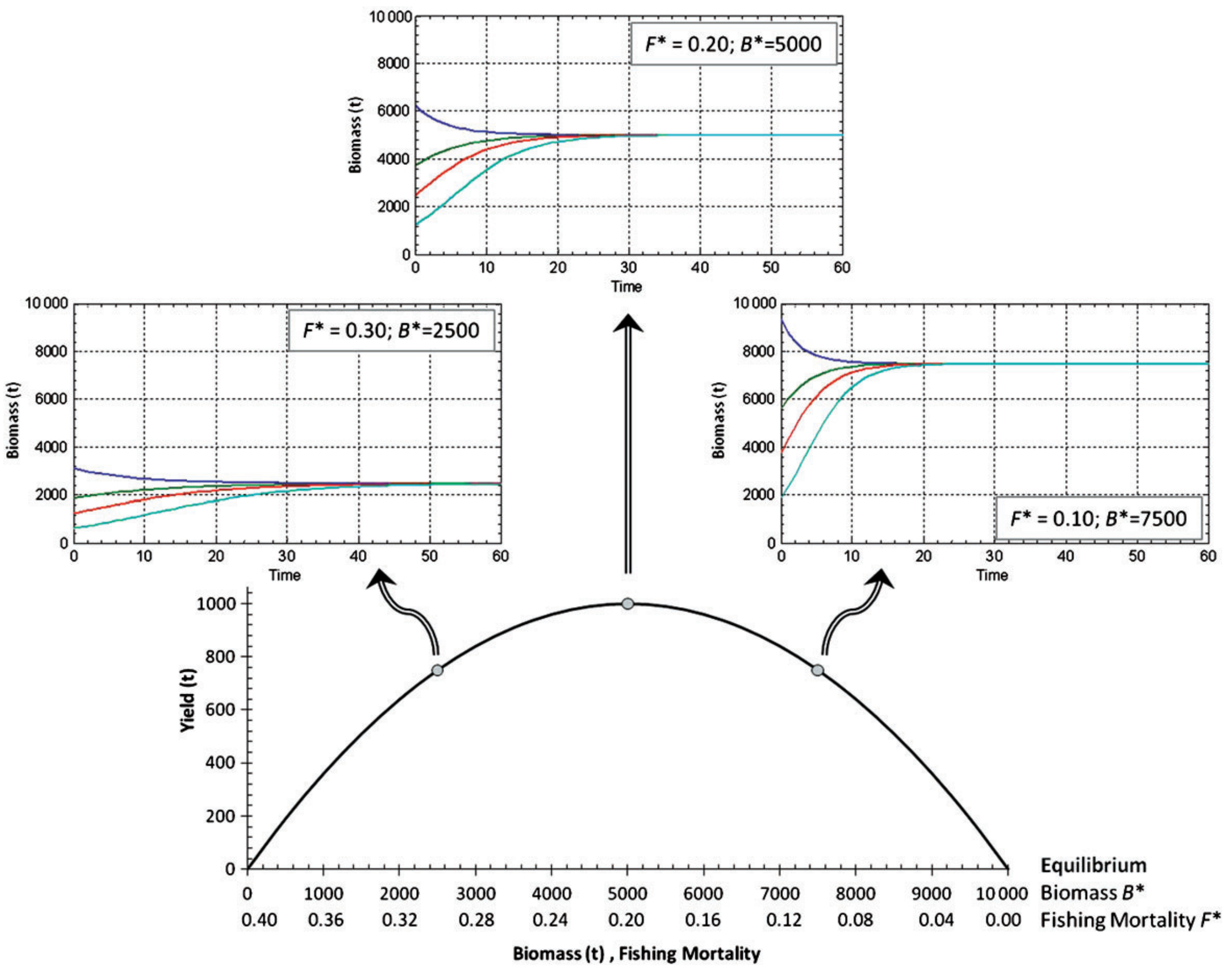

Figure 4. The relationship between yield and biomass or fishing mortality. The parabola shows equilibrium yield. Dynamic departures from the parabola are shown in the three panels. The dynamics show that yield is sustainable at any level of biomass; MSY in the center panel and sustainable yield in the right and left panels.

ecological system drivers outside of the groundfish complex itself (Rothschild, 2011; Collie *et al.*, 2013).

However, even if the stocks were independent of one another, the nominal effort applied to each stock must interact, since an optimum nominal effort for any single stock is unlikely to be optimal for any other stock.

Put another way, on first principles, it is impossible to have an overarching optimal MSY for a real-world complex of stocks. This means that there is a problem in the current practice of generating management advice from a plethora of single-species production models. This is because each model can suggest a different level of nominal fishing effort, and it would be difficult to pick a level appropriate to each stock in a multispecies fishery.

As a matter of fact, some optimal combination of fishing mortalities could be selected. However, not all stocks would then be fished at MSY. But this would not be a violation of sustainability or affect the long-term productivity of the stock, since it is well known that maintenance of fishing mortality at fixed levels less than $F_{\max}$ results in sustained yields.

Eliminating the multispecies problem requires rephrasing the goals of management in a multispecies context. It seems that many feel that not attaining MSY for each species simultaneously is a contradiction of the principals of conservation; specifically, that fishing at a level above F_{MSY} (overfishing) is not sustainable. However, this is a specious notion in the context of the production model. As illustrated in Figure 4, it is possible to maintain a sustained yield for many levels of stock size.

Of course, the question arises as to what are the appropriate sustained population levels. Inasmuch as under this concept, sustainability or maximization are not issues, standard techniques in mathematical programming can be applied to determine the optimal sustainability level for each species or stock (Siegel *et al.*, 1979). To be certain, the understanding of how various species and stocks interact is limited, suggesting that substantially greater budgetary resources need to be applied to this difficult question.

Discussion

This symposium tracks the evolution of fishery management systems as they progress toward eliminating overfishing. However, in the United States, this goal is complicated by the requirement to attain OY.

It appears that fishery management has neither terminated overfishing nor corrected the failure to obtain OY in the New England groundfish fishery. The failure to attain these goals owes to a complexity of causes. However, basic foundation problems are immediately evident in two components of the management structure: (i) the *de facto* management goals and (ii) its performance measure.

With regard to the *de facto* management goal—prevent overfishing while constraining OY—there are two core problems that reside in the interpretation of the law (the National Standard Guidelines). The first is related to applying a single-species management goal to a multispecies fishery; the second is the development of a buffer system that constrains attainment of OY.

We have shown that the conservation issues that constrain the application of a multispecies method to the overfishing problem are non-existent. The efficiency of the attainment of OY can be greatly improved by rewriting legislation to measure performance in the reality of the multiple-species setting rather than in an artificial single-species context.

The buffer system introduced to prevent overfishing makes the attainment of OY difficult, if not impossible, to achieve. In fact, it is not generally realized, but the interpretation (specifically the most recent revision to the National Standard 1 Guidelines) of recent amendments to the MSRA imposes serious constraints to obtaining OY. It is not exactly certain how to determine the magnitude of the buffers, when a buffer is set too large, as is probably the case now; fish that could be harvested, but are not, are lost to the economy. The problem is that the accuracy of the magnitude of the buffer really depends on the quality of the stock assessments.

With respect to the performance measure, management implementation has really not followed the MSY direction. Rather, it has followed the Shepherd model direction. This is somewhat curious in the sense that the Shepherd model was only advocated to be used in situations where MSY was difficult to compute.

It would seem to make sense that as a point of departure, we should start with the production model, which is the basic model where MSY is relatively well defined. Production models have been applied in several settings. For example, Hilborn and Litzinger (2009) studied surplus production of cod stocks in the Atlantic, Cadrin (1999) examined the surplus production of yellowtail flounder, and Rothschild and Jiao (2013) compared the ABPM with the surplus production model for most of the New England groundfish stocks and found that the two approaches yielded substantial differences.

We conclude with the following recommendations: (i) change single-species to multispecies assessment models, (ii) develop methods of balancing overfishing protection with avoidance of underfishing, (iii) consider other well-known, less data-hungry assessment-model algorithms, and (iv) establish data-collection protocols for new management options.

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