On implementing maximum economic yield in commercial fisheries

C. M. Dichmont[a,1], S. Pascoe[a], T. Kompas[b], A. E. Punt[a,c], and R. Deng[a]

[a]Commonwealth Scientific and Industrial Research Organization (CSIRO) Marine and Atmospheric Research, Cleveland, Queensland 4163, Australia; [b]Crawford School of Economics and Government, Australian National University, Canberra, Australian Capital Territory, 0200, Australia; and [c]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020, USA

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Economists have long argued that a fishery that maximizes its economic potential usually will also satisfy its conservation objectives. Recently, maximum economic yield (MEY) has been identified as a primary management objective for Australian fisheries and is under consideration elsewhere. However, first attempts at estimating MEY as an actual management target for a real fishery (rather than a conceptual or theoretical exercise) have highlighted some substantial complexities generally unconsidered by fisheries economists. Here, we highlight some of the main issues encountered in our experience and their implications for estimating and transitioning to MEY. Using a bioeconomic model of an Australian fishery for which MEY is the management target, we note that unconstrained optimization may result in effort trajectories that would not be acceptable to industry or managers. Different assumptions regarding appropriate constraints result in different outcomes, each of which may be considered a valid MEY. Similarly, alternative treatments of prices and costs may result in differing estimates of MEY and their associated effort trajectories. To develop an implementable management strategy in an adaptive management framework, a set of assumptions must be agreed among scientists, economists, and industry and managers, indicating that operationalizing MEY is not simply a matter of estimating the numbers but requires strong industry commitment and involvement.

bioeconomic modeling | fisheries dynamics | fisheries governance | fisheries management

Worldwide, during the last 2 decades, fisheries management has undergone a paradigm shift from a focus on managing the resource to a focus on managing the resource users. Although resource conservation remains paramount, the perceived failure of biologically oriented management (1) aimed at controlling how much of the resource is removed annually has resulted in increased attention to instruments that provide appropriate social and economic incentives. Because fishing other than for subsistence purposes is an economic activity, the level of profitability is of key interest to most fishers. Using instruments that align fishers' objectives with those of management has been found to be a significant factor underlying stock recovery in most fisheries where recovery has occurred (2). With this change in focus have come an increased interest in incorporating economic analyses into fisheries policy development and, more recently, an increased interest in social considerations as well.

Economists have long argued that a fishery that maximizes its economic potential also usually will satisfy its conservation objectives (3, 4). This scenario is encapsulated in the concept of maximum economic yield (MEY), a long-run equilibrium concept that refers to the level of output and the corresponding level of effort that maximize the expected economic profits in a fishery. In most cases, this scenario results in yields and effort levels that are less than at maximum sustainable yield (MSY) and in stock biomass levels greater than at MSY (4, 5). Lower levels of fishing effort also generally result in fewer adverse environmental impacts. Developed initially in the context of single-species fisheries (3), MEY was extended to multispecies fisheries under the assumption that the species are caught in fixed proportions. The optimal catch and biomass for any single species in a multispecies fishery may be greater or less than at MSY (5).

Most countries manage their fisheries to achieve a combination of biological, economic, social, and political objectives (6, 7), For example, the US Sustainable Fisheries Act, the European Common Fisheries Policy, and even United Nations Convention of the Law of the Sea all recognize the need to determine target yields considering economic, environmental, and social implications. However, there often is little clarity about how to define and balance these objectives. Maximizing economic returns per se from fisheries generally has not been considered a primary target for fisheries management in most countries. Further, economic efficiency is a concept that is poorly understood by most policy makers and also by many fisheries economists in practice (8).

In contrast, the Australian Fisheries Management Act 1991 includes maximizing economic efficiency as an explicit objective, and the associated Australian Fisheries Harvest Policy (9) states that the target reference point for a resource should be MEY or a relevant proxy. Hence, in the case of Australian Commonwealth fisheries policy, maximizing economic efficiency has become synonymous with maximizing fisheries profits. Although the extent to which maximizing fisheries profits actually corresponds to achieving economic efficiency is debatable (8, 10), it does provide a move to more explicit recognition that natural resources can be used more efficiently, as can the resources used in their utilization.

The Northern Prawn Fishery (NPF) provides an important case study on operationalizing MEY. The NPF is a multispecies trawl fishery based on several tropical shrimp species. This fishery has a long history of collaborative management involving industry, the Australian Fisheries Management Authority (AFMA), and scientists. It also has strong statutory fishing rights in the form of tradable input (gear) units with the Total Allowable Effort set annually. In recent years, almost all (96%) of the fleet has formed an incorporated company (NPF Industry Pty. Ltd.) in which voting rights are based on the unit holdings in the fishery. Day-to-day management of the fishery has devolved to the company, with the main role of AFMA being to audit the company's decisions. In contrast, advice on strategic directions and the development of, for example, harvest strategies are

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[1]To whom correspondence should be addressed at: CSIRO Marine and Atmospheric Research, 233 Middle Street, Cleveland, Qld 4163, Australia. E-mail: cathy.dichmont@csiro.au.

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In the 1990s and early 2000s, the main aim of management in the NPF was to recover over-exploited stocks and to eliminate excess fishing capacity. Declining profitability in the fishery resulting from increased competition in world markets from farmed shrimp and rising input costs such as fuel focused the attention of the industry on commercial viability as well as on biological sustainability. The expectation now is that the fishery will transition to an MEY target over a reasonably short period (7–10 years). This target shift was initiated at the request of the industry before the official government policy change and reflects the highly commercial nature of the fishery. To this end, bioeconomic modeling has been undertaken in collaboration with industry and managers to estimate the appropriate catch and effort trajectories to achieve MEY in the NPF (11). This modeling has highlighted hitherto unconsidered complexities and challenges that need to be overcome when implementing MEY. In this paper, we highlight some of these issues.

Results

The modeling analyses and subsequent discussions with industry representatives and fishery managers identified a number of challenges to implementing MEY in practice. These challenges are illustrated through a number of simulations using the bioeconomic model of the NPF.

Issue 1: Specifying the Model. MEY was developed originally as an equilibrium concept. In reality, fisheries are not in equilibrium, nor are species caught in fixed proportions. Operationalizing MEY requires developing models that take the dynamics of stocks, costs, and prices into account. Maximizing the net present value of profits over time is a more appropriate objective and is consistent with the concept of MEY. In the past, dynamic bioeconomic models capable of such analyses generally have been relatively simplistic in their assumptions because the results were more illustrative of the benefits of moving toward an economic target than an attempt to identify the target per se (12, 13).

In these and many other dynamic bioeconomic models, considerable attention is given to how the size of the fish stock changes over time (e.g., as a result of natural and fishing mortality, growth, and recruitment). For example, in the case of the NPF, the population dynamics are modeled on a weekly time-step, account is taken of key biological processes, and bycatch of other prawn species is modeled explicitly (11, 14). However, in most dynamic bioeconomic models, fleet dynamics are represented in a crude or ad hoc manner or are missing entirely. Little prior consideration has been given to how to estimate or select desired levels of inputs and outputs in multispecies fisheries where fishers can alter the combinations of species caught (at least to some extent) by changing when, where, and how they fish, even though most fisheries are of this type. Detailed models of how fleets adjust over time are difficult to formulate and parameterize. Over time, vessels may enter and exit a fishery, invest and disinvest (affecting their technical efficiency, fishing power, and cost structure), and change their behavior in response to changing economic incentives (e.g., changing both the level and spatial allocation of fishing effort). Although models exist to capture at least some of these factors (15, 16), no bioeconomic model has been able to include all of them comprehensively. In the case of the NPF, the industry recently had undergone a major restructuring, and license numbers were limited, so the assumption that no vessels would enter or leave during the transition period to MEY was considered reasonable. (This assumption is examined later.) However, other behavioral or vessel/gear changes may occur and are not captured in the model analysis.

Issue 2: Defining the Boundaries. In most countries where economic performance is identified as an objective of fisheries management, the objective usually is related vaguely to maximizing or improving the returns to society from the use of the resource. However, MEY is a partial-equilibrium optimum and relates only to the fishery. In most fisheries, vessel numbers need to be decreased substantially to achieve MEY. The associated reduction in crew numbers and in regional economic activity associated with the fishing industry may result in a net economic loss even though the fishery experiences a substantial increase in economic profits (8). The traditional economic response to this scenario is that the loss in regional economic activity is ephemeral, because the resources previously consumed in fishing are freed up to be used more productively in other sectors. However, short-term factors have been highly influential in management decision making in some major fisheries (17). In the case of the NPF, this effect on associated economic activities was not considered an issue because considerable fleet adjustment had already taken place, and the trajectory to MEY was not expected to require further fleet reductions.

Issue 3: The Best Outcome May Not Be Practical. Without constraints on fishing activity, a dynamic bioeconomic model will suggest that it is economically optimal to reduce fishing effort in the short term to achieve a higher, longer-term stream of benefits when biomass is currently less than the economic optimum and the discount rate is finite. This scenario may involve closing the fishery or substantially reducing harvest for several years. However, this approach does not account for the costs associated with effort reduction or fishery closure. Closing the fishery would be optimal only if the vessels had a viable alternative use or if the stock were severely depleted (such that any fishing effort would prevent recovery) (18). Most alternative fisheries in Australia and the rest of the world already are closed to new entrants, so the capital has few alternative uses following fishery closure. Fixed costs still will be incurred, and fishers will need a means of covering these costs. Labor also is problematic. Displacing labor is less difficult than displacing capital, but regaining a skilled labor force when a fishery reopens or requires increases in effort can be difficult (19). Given these considerations, closing a fishery for a short period, although potentially optimal in the "model world," is generally unacceptable in real life.*

We can go further and suggest that forcing a fishery to be unprofitable in the short term is also impractical, even if longer-term gains would be realized. Although a theoretical economist would argue that fishing is still worthwhile, the ability of fishers, many of whom may have experienced low levels of profitability in the past, to survive a period of negative profits may be limited because vessels still need to cover their variable costs. To impose such a situation knowingly on a fleet when an alternative path may exist in which profits are consistently nonnegative is likely to lead to litigation and delays. Consequently, limits on effort reduction in any particular year must be imposed, and the resultant constrained optimal trajectory will diverge from the unconstrained optimum. In the case of the NPF, as would be expected, setting a minimum constraint that fleet profits must be nonnegative in each year resulted in a different estimate of the optimal trajectory of catch and effort than in the unrestricted case (Fig. 1), although the optimal equilibrium yields of the species were similar (Table 1). (More detailed model outputs for each simulation are presented in the *SI Text*.)

Similarly, setting a minimum effort level for each fleet—a suggestion made by the industry and incorporated into the current

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*This is also demonstrated to be suboptimal theoretically. When no such alternative use exists for vessel or human capital, the optimal equilibrium stock level (and associated catch rates) will depend on the existing level of capital as well as the other biological and economic parameters (18).

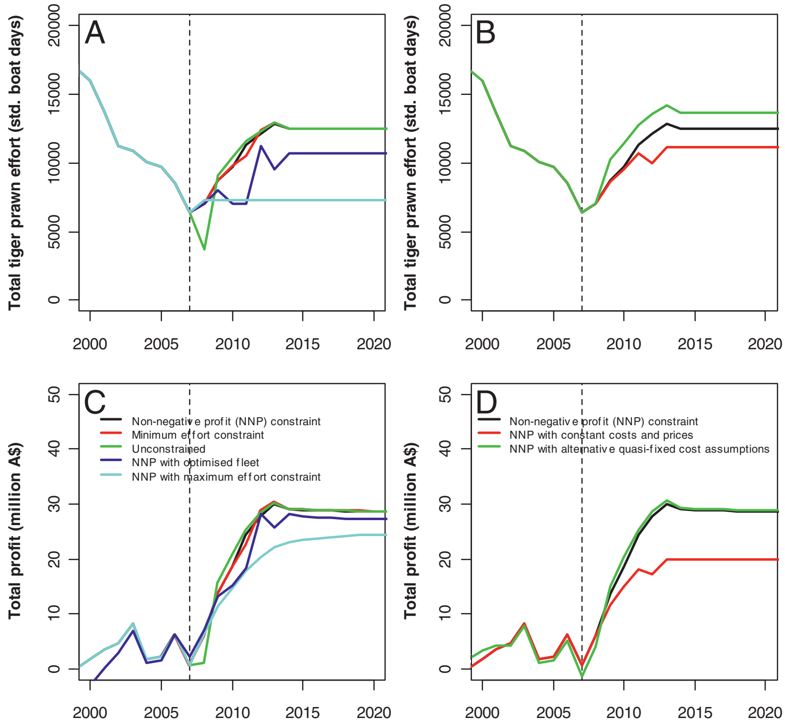

Fig. 1. Optimal effort trajectory and annual profit estimates under the different assumptions. Vertical dotted lines mark the last year of data (2007). The model estimates the trajectory over the period 2008–2014, with MEY being defined as the equilibrium catch achieved in 2014 that maximizes profits over a 50-year period (2008–2058). Estimates are presented only to 2020, because these estimates are unchanged after 2014. (*A*) Optimal effort trajectories given different assumptions about effort constraints. (*B*) Optimal effort trajectories given different assumptions about prices and costs. (*C*) Optimal profits given different assumptions about effort constraints. (*D*) Optimal profits given different assumptions about costs and prices.

management system—provided an outcome similar to the profit-based constraint.

The ability of fishers to apply fishing effort is limited also. Although underutilized capacity exists in most fisheries, once this capacity is fully used, individual vessels are technologically unable to apply more fishing effort and take more catch, or doing so is not economically viable (i.e., the additional costs exceed the value of the additional catch). The optimal trajectory in the previous analyses assumed in effect that vessels were unrestricted in their ability to fish, with unrealistic levels of fishing effort being needed for some weeks during the fishing season. Restricting total effort to a realistic level, given the season length, resulted in an entirely different effort trajectory (Fig. 1) and set of optimal yields (Table 1). Allowing new boats to enter the fishery results in a lower effort trajectory and set of optimal yields than given in the scenario in which effort is unrestricted, because additional fixed costs are involved. Profits also are lower than in the unrestricted case but are greater than when vessel numbers are fixed but vessels are restricted in their annual levels of effort.

Issue 4: The Need for Accurate Economic Data. From the experiences in the NPF, as well as economic theory, optimal effort, biomass, and yields are functions of both input (e.g., fuel) and output (e.g., prawn) prices as well as of biological parameters (4). Although historical biological parameters can be assumed to be valid for the immediate future, economic parameters may vary considerably over time. For most fisheries, prices generally are assumed to be invariant with the quantity landed.[†] Consequently, most previous bioeconomic models have assumed that prices and costs remain constant (in real terms) over time (12, 13, 15–17). However, when prices are expected to change over time, the optimal trajectory and final MEY will depend on the future price, and this price must be anticipated well in advance (21).[‡] Hence, expectations about future price movements cannot be ignored if model results are to be used for management purposes. Accurate forecasts of these variables are critical but in most instances will be subject to high levels of uncertainty. The economic environment can change substantially even over a short time period, as seen in the substantial oil market fluctuations during 2008 and the recent economic crisis, rendering previous forecasts invalid. Fluctuations in exchange rates affect both costs of imports and the prices received for exports. Reduced demand in importing countries may result in the domestic market being flooded, with subsequent price implications.

This uncertainty is likely to increase with the length of the forecast period. For the NPF analysis, which is based on a relatively short-lived species, a 7-year time period was considered necessary to enable stocks to recover to the optimal levels. For long-lived species, we would expect forecasts for a relatively long period to be required, because MEY would take longer to achieve. Although the importance of future profits is reduced as a

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[†] This assumption is generally made when the fishery is supplying a relatively small proportion of the total supply of a species to the market. At the level of the market, demand for most species is relatively inelastic (i.e., prices vary by a greater degree than the quantity supplied), but at the level of the firm, prices are relatively inflexible (i.e., prices are less responsive to the quantity supplied) (20).

[‡] It has been demonstrated that, when the fleet is unconstrained (i.e., capital is perfectly malleable), the optimal stock size in each year along the recovery path is dependent only on the current rate of change in price, and not on price changes predicted in the future (5, 21). Hence, the decision rule is "myopic" in that it does not consider past or future prices. However, when capital is nonmalleable – as is the case in most fisheries – the optimal policy is no longer myopic, and the recovery path is highly dependent on the future price (5, 21).

Table 1. MEY estimates for the 3 main target species given the different model assumptions

Assumption	Grooved[a]	Brown[b]	Endeavor[c]
	MEY estimates (in tons) for target species		
No constraints	1640	1265	837
Minimum effort constraint	1639	1267	838
Nonnegative profit (NNP) constraint	1639	1259	839
NNP with maximum effort constraint	1168	963	653
NNP with variable fleet	1590	1194	795
NNP with constant costs and prices	1552	1209	803
NNP with alternative quasi-fixed cost assumptions	1686	1286	866

[a] Grooved tiger prawn (*Penaeus semisulcatus*).
[b] Brown tiger prawn *(Penaeus esculentus*).
[c] Endeavor prawns (*Metapenaeus* spp.) as a group.

result of discounting, uncertainty around the MEY estimates could be substantial.

Assuming we have accurate cost information, what costs do we include in analyses? In the long run, all costs are variable. However, in the short term many costs are fixed, so the estimate of the optimal output can be based on variable costs alone, and fixed costs can be ignored. However, some sizeable costs, such as repairs and maintenance, are quasi-variable (or, alternatively, are quasi-fixed). That is, they are affected by the level of fishing activity in a given year, but some level of cost is incurred irrespective of the level of fishing activity or may depend on the cumulative activity over several years. Treating these costs as variable costs may underestimate the short-term optimal yield, whereas treating them as fixed costs may overestimate this yield.

The impact of different assumptions regarding the treatment of prices and costs on the estimation of MEY was examined. Assuming constant prices and costs (in real terms) resulted in estimates of optimal catches being around 5% lower for the 3 main species, whereas treating the quasi-variable costs as fixed (rather than variable) resulted in optimal catches being around 2–3% higher (Table 1). Furthermore, the optimal effort trajectory (and resultant "equilibrium" stock size) required to achieve MEY differed, depending on the assumptions regarding costs (Fig. 1).

The uncertainty about future prices and costs suggests the need for regular revision of the costs and prices on which management advice is based and hence of the catches and levels of fishing effort that are estimated to maximize new present value. For the NPF, a decision has been made to re-estimate the trajectory of catch and effort every second year; this decision was based on some additional modeling work that indicated that this revision would not compromise profits and sustainability but would reduce interannual variability in management advice.

Issue 5: A Good Target Is Not Enough. At best, model estimates of transitional paths indicate what should happen rather than what will happen. Fishers respond to the changing economic conditions and to the set of incentives generated by the management system under which they operate. Maximization of discounted profits cannot be achieved without changes in governance structures, such as those that remove the incentives to race to fish. However, changes in these structures may result in changes both in cost structures of the fleet and in the price received (22, 23), adding an additional level of complexity to the estimation of MEY. Additional models of fleet behavior must be considered, and a range of alternative cost assumptions also may be required to incorporate these factors. As noted earlier, the optimal yields are highly sensitive to these cost assumptions.

Even the best models of fisher behavior are unlikely to provide a perfect representation of how fleets are likely to respond to management changes, and even the best governance structures are unlikely to guarantee that the optimal trajectory is achieved. Given that the optimal trajectory is state-dependent, a new trajectory will need to be re-estimated regularly, taking into consideration what the management system actually achieved in terms of catch and effort in the fishery during the transition period, as compared with the goals it was aiming to achieve. For the NPF, the decision was made to have a continuously rolling transition period of 7 years, so that each time MEY is estimated (taking into account also the latest price and cost forecasts), the target trajectory is over a constant period rather than an ever-decreasing period. This rolling transition period may mean that a single-point estimate of MEY may never be achieved, but it is expected that the fishery will be able to come as close as possible to achieving optimal profits over time.

Issue 6: Implementation in a Comanagement Arena. Fishers and managers need to be able to participate in the decision-making and implementation phases of managing a fishery in countries where comanagement is seen as key to good fisheries management. However, profit maximization and MEY are concepts that are not well understood, even by scientists working in the fisheries field, and often are viewed with suspicion by industry, which equates lower catches with lower (rather than higher) profits. In contrast, fishers, scientists, and managers are reasonably aware of the strengths and weaknesses of MSY-type reference points and harvest strategies. MSY is a constant, irrespective of price and cost assumptions, reducing the management uncertainty faced by fishers. Although a range of effort trajectories may exist so that stock size fluctuates around that corresponding to MSY —with differing economic consequences—the end point generally is more stable. Fishers therefore are well able to participate in the decision-making and implementation phases of managing a fishery. The discussions focus on which harvest-control rules are preferable, and, once the rules are agreed upon, fishers are reasonably confident that the effort trajectory and biomass target will remain relatively unchanged and are able to plan their activities accordingly. In contrast, MEY is a moving target, because it changes with predictions of costs and prices, and practical considerations such as how to set harvest strategies against such a target have yet to be determined.

In the NPF, industry fully supported—and indeed proposed—the move to MEY, but many fishers were not aware of what this change actually entailed. This lack of understanding is not surprising, given the paucity of fisheries that could be looked at for examples. Once some of the complications and implications became apparent, even though the work was undertaken in a strong collaborative environment, some industry members started to have second thoughts about MEY. Without the strong institutional arrangement in the fishery, it is unlikely that implementation would have been possible. Time will cure these challenges as more examples similar to the NPF become available. Education of stakeholders about the reason for using MEY as a management target is critical, as is sharing of knowledge and experiences in modeling MEY.

Discussion

Fisheries management has been described as a "wicked problem" (24, 25), because interactions within and among the social, economic, and ecological systems are highly complex, nonlinear, and—to a large degree—unknown. Wicked problems have no technical solution and are never solved once and for all (25). They require governing interactions that are participatory, communicative, and adaptive (24, 26). Moving to MEY can be described only as making the problem more wicked, because a moving target is deliberately introduced into an already complex system characterized by a high degree of uncertainty. Hence, management is even less likely to be successful without stakeholder participation in the definition of the problem (including the assumptions used) and comanagement.

Two diametrically opposed schools of thought exist regarding the use of models to manage such a complex system. The first is that, because fisheries management is a wicked problem, the use of models to aid management of a complex system like a marine ecosystem impacted by a fishery is bound to fail. Among the reasons for this failure are that there is no clear definition of objectives, no optimal solution, and no objective answers and solutions. The opposite extreme is that, although fisheries management is a wicked problem, some form of management is needed,[§] and, even though an optimal solution may be impossible, a model-based adaptive management framework would allow one to move forward (27). The adaptive management loop involves iterative decision making, evaluating the outcomes from the previous decisions and adjusting subsequent actions on the basis of this evaluation.

From the social sciences, there is evidence that the complexities of management can be addressed only through direct involvement of stakeholders in the management process (26). This requirement, however, does not preclude the use of models to determine management strategies. Van Vugt (28) identifies 4 essential components for achieving effective environmental management: information, identity, institutions, and incentives. Stakeholders need to be informed about the current understanding of the environments and the limits to this understanding, and need to identify strongly with a core social group to seek the best outcomes for the group. Strong institutional arrangements are needed to enable stakeholders to influence management, and the management system must create the right incentives to achieve the stakeholders' objectives. In the NPF, the industry has a strong identity in the form of an incorporated company and was actively involved in determining which assumptions were to be applied in the modeling analyses, ensuring information was as accurate as possible, discussing results, and making final recommendations to the AFMA Commission. The industry was aware of the limitations of the model and accepted it as the best available science despite these limitations. The institutional arrangements for stakeholder involvement have been described as world's best practice (30), and rights-based management is in place in the fishery to provide the appropriate incentives to achieve the management objective. These factors are fundamentally important in ensuring that MEY will be achieved, but short-, medium-, and long-term catch and effort targets relating to this target (or the best estimate of the target) are essential also.

The analyses using the model identified a number of issues that have not been given much thought in previous bioeconomic modeling. Approaches generally have been ad hoc, largely because economic theory has little to add with regard to these issues in practice. Few dynamic bioeconomic models actually have been used to set management targets in the real world. This situation is in stark contrast to the biological assessments and reference points that now are almost the norm in fisheries management, and considerable investment has been undertaken to develop consistent and robust approaches. Varying assumptions about discount rate have been ignored in the analyses, as have changes in efficiency over time. It is well recognized that MEY is sensitive to discount rate assumptions (5), so this point does not need reiterating. Similarly, increases in efficiency, if ongoing over time, would result in any single equilibrium point being unachievable, because no sooner would it be reached than it would no longer be optimal. Although this argument may be realistic, we have already demonstrated that sufficient complications exist in setting management targets that the targets will require ongoing revision, so that any changes in efficiency can be factored into management. Even in the current model, price and cost forecasts were covered only the transition period to MEY, after which they were assumed to remain constant in real terms.

The analyses and experiences in the NPF show that we are at the start of a long road if economic advice about fisheries is to progress beyond the theoretical and strategic realm and have an actual impact on tactical management decision making. Critical concepts such as how to determine MEY have not really been addressed in a comprehensive manner; almost every applied paper uses different assumptions about costs (which costs are fixed, which are variable, and which ones to use in which circumstances) and fleet dynamics over time. Different assumptions result in different estimates of MEY. In some cases, the assumptions are driven by the available data, but if an agreed methodology could be developed, there would be sufficient leverage to ensure the correct data were collected. Further, although some issues need to be addressed by economists, the operationalization of MEY needs input from natural scientists, industry, managers, and other stakeholders, and these groups also need to be involved in the development of operational harvest strategies.

For fisheries that do not have strong sense of identity and institutions, operationalizing MEY will make the present wicked problem even more wicked. The potential role of bioeconomic models for resolution of wicked problems is extremely limited (if not zero) without direct stakeholder involvement. This involvement includes understanding model assumptions and limitations, agreeing on parameters and scenarios, and being willing to accept model outcomes as a starting point for decision making and to adjust both expectations and activities as new information (e.g., input and output prices, stock information) comes to light. Stakeholder involvement in model development also can increase credibility by bringing multiple types of expertise to the table and can enhance legitimacy by providing greater transparency and greater access to the information-production process (31). Although models are not perfect, some form of direction is needed, and models provide a means for making open and transparent assumptions about where a fishery hopes to head and the proposed route for getting there. As seen in the NPF, several constraints (e.g., minimum effort and the timeframe over which the model was to run) were introduced into the analyses at the request of the industry to align the model results better with their expectations of the key features of the pathway.

As Box (32) noted, "Models, of course, are never true, but fortunately it is only necessary that they be useful. For this, it is usually needful only that they not be grossly wrong" (p. 2). Adaptive management provides an opportunity to adjust the model over time to ensure that it is not grossly wrong, hence ensuring its usefulness. Stakeholder involvement further improves the usefulness of models and is critical to their success as tools for fisheries management.

[§] One certainty is that no management leads to economic and biological overexploitation (3, 29).

The NPF provides a rare example in which management advice is based directly on the results of a dynamic bioeconomic model. Many of the issues identified reflect problems in the development of the economic theory underlying MEY rather than difficulties in resolving wicked problems, although the latter are substantial. In highlighting these issues, we hope to stimulate further thought into how they may be addressed. The benefits from resolving these issues are likely to be substantial from both an economic and a conservation perspective. In this matter, both theory and practice agree.

Methods

The analysis is based on an existing dynamic bioeconomic model of the fishery (11) designed to estimate future discounted profits as a measure of MEY that builds on more than 30 years of bioeconomic modeling in the fishery. The dynamic bioeconomic model requires the standard information needed to assess stock status, including fishery data and biological parameters, some method of projecting the population dynamics forward, and also forecasted information about costs and prices. The fishery has relatively good economic data and an established method for assessing stock status (14).

The model and its results have been accepted by industry, managers, and other scientific advisors to the fishery. Furthermore, the model's analyses and its application to management have gained international recognition, in that the United Nations Food and Agriculture Organization has declared the fishery to be among the best-managed fisheries in the world of any type and a global model for many aspects of fisheries management (30).

To set effort targets in the fishery, a set of prices and costs—both current and projected—and a set of assumptions about minimum effort levels was agreed upon by the modelers, industry, managers, and other stakeholders who had a role in the management of the fishery. The model used for setting the management targets assumed a minimum effort level equivalent to that in 2007 (an industry initiative), forecasts of prices and costs, and a requirement by the management authority that MEY be achieved by 2014. The resultant optimal effort trajectory, catches, relative stock sizes, and profits are presented in the *SI Text*.

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