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ARTICLE

Estimating Proxy Economic Target Reference Points in Data-Poor Single-Species Fisheries

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Abstract
Bioeconomic models have been developed and applied to a range of fisheries around the world. However, an even greater number of fisheries are relatively data poor, and development of traditional bioeconomic models is not feasible. For small-scale fisheries, the cost of data collection and model development may exceed the additional value these models may generate. Fisheries biologists have grappled with similar issues and have developed a range of data-poor methods for estimating reference points related to fishing mortality based on life history characteristics and other indicators. In other cases, catch and effort data may be sufficient to estimate sustainable biomass levels. However, model-derived economic target reference points require robust biological models as well as appropriate economic information, both of which are often unavailable. In this paper, we extend the data-poor work to move from biological to economic target reference points for single-species fisheries. We show that the relationship between economic (maximum economic yield) and biological (maximum sustainable yield) reference points depends primarily on the cost : revenue ratio, and that, where unavailable, these can be inferred from fisheries characteristics. We show that good estimates of biomass- and effort-based economic target reference points can be achieved with limited data.

The use of biological reference points as indicators to guide fisheries management is well established (Caddy and Mahon 1995; Caddy 2004). While numerous types of biological reference points exist (Mace 1994), the most commonly applied are target and limit reference points, usually expressed in terms of either the biomass of the stock or the level of fishing mortality that achieves given outcomes. Limit reference points indicate levels that are to be avoided, while a target reference point represents the fishery status that management is aiming to achieve (Mace 1994). While maximum sustainable yield (MSY) is the most commonly applied target reference point in fisheries management (Caddy and Mahon 1995; Hutchings

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et al. 2010; Froese et al. 2011), there is increasing interest in maximum economic yield (MEY) as an alternative target. The MEY represents the level of fishing effort and catch that maximizes economic profits in the fishery over time (Dichmont et al. 2010; Grafton et al. 2010). This is usually seen as a level of fishing activity that will maximize the welfare generated by fisheries, although this has been debated in the recent literature (Bromley 2009; Christensen 2010). As MEY generally involves a lower level of fishing effort, it is more conservative in terms of biomass than is MSY and is often considered to be more environmentally beneficial in terms of reduced bycatch and habitat damage (Grafton et al. 2007; Dichmont et al. 2008). Even if MEY is not adopted as a target for management, its identification may provide useful management information in terms of the trade-offs between economic returns, ecological gains, and the social implications of alternative management targets.

The estimation of MEY requires an understanding of both the key economic and biological variables relevant to the fishery. Where this has been applied the approach has relied on the development of detailed bioeconomic models of the fishery under consideration (e.g., Kompas et al. 2009; Punt et al. 2011). However, due to the costs of systematic data collection for individual fisheries, a range of fisheries exists for which some or all of these variables may be missing due to insufficient data (Bentley and Stokes 2009; Smith et al. 2009). This raises the issue of how to develop a set of reference points for such data-poor fisheries; this subject is increasingly recognized as an important concern for fisheries management around the world (e.g., Pilling et al. 2009; Brooks et al. 2010).

This is currently a significant issue in Australia, which has adopted an objective of maximizing net economic returns as the primary objective in commonwealth-managed fisheries (Dichmont et al. 2010) and the level of biomass that achieves MEY (B_{MEY}) as the most appropriate target reference point compatible with this objective. Where economic information is missing, the Australian Commonwealth Fisheries Harvest Strategy Policy and Guidelines suggests a default value of 1.2 times the biomass that achieves MSY (B_{MSY}) as a proxy for the target reference point (DAFF 2007), where B_{MSY} is also estimated when necessary through data-poor methods. This recognizes that the biomass at MEY is greater than that at MSY, but 1.2 is a relatively arbitrary scaling factor and does not take into account the effects of different prices and cost structures in different fisheries.

To ensure sustainable exploitation of these data-poor fisheries, there is a need to develop innovative methods for incorporating economic considerations into harvest strategies without the possibility of developing full bioeconomic models and to quantitatively define proxies for target reference points. The aim of this paper was to present a means of deriving a less arbitrary scaling factor than the default value of $1.2B_{MSY}$ in contexts where both biological and economic information is limited. Also, the ability to estimate B_{MSY} may be limited in most fisheries, but a range of simple methods exists to estimate fishing mortality at MSY (F_{MSY}), even with very limited catch and effort data, based on assumptions about some of the biological characteristics of the species (Garcia et al. 1989; Zhou et al. 2012b). Given this, we also derived proxy target reference points of F_{MEY} based on F_{MSY} as an addition to the B_{MEY}/B_{MSY} ratio.

From bioeconomic theory, we showed that the relationships B_{MEY}/B_{MSY} and F_{MEY}/F_{MSY} largely depend on the ratio of costs to revenue at MSY. A stochastic simulation was developed using a simple bioeconomic model, and the results were used to develop a regression tree to determine simple "rules of thumb" that can be used to indicate appropriate reference points given these costs shares. Individual vessel data covering a wide range of Australian fisheries were used to derive further "rules of thumb" to indicate what the cost share at MSY could be given the characteristics of the fishery.

Estimating MEY in Data-Poor Fisheries: A Brief Review

Maximum economic yield in a fishery can be defined as the point at which the sustainable fishing effort level and catches in the fishery entail maximum profits or as the greatest difference between total revenues and total costs of fishing (Kompas 2005; Grafton et al. 2007). The main determinants of MEY in a statics analysis (i.e., without taking into account the adjustment delays that may be required to achieve any catch–effort combination and the instability that often characterizes real fisheries) are illustrated in Figure 1. The MEY point will change with input and output prices, as will the associated level of profits, and identifying MEY in any given fishery requires an assessment procedure that allows these changes to be tracked (Kompas et al. 2009). The dynamic nature of the MEY objective, as well as its instability due to changes in the key economic drivers of a fishery such as input and output prices, should be fully accounted for in such assessment procedures (Dichmont et al. 2010; Grafton et al. 2010).

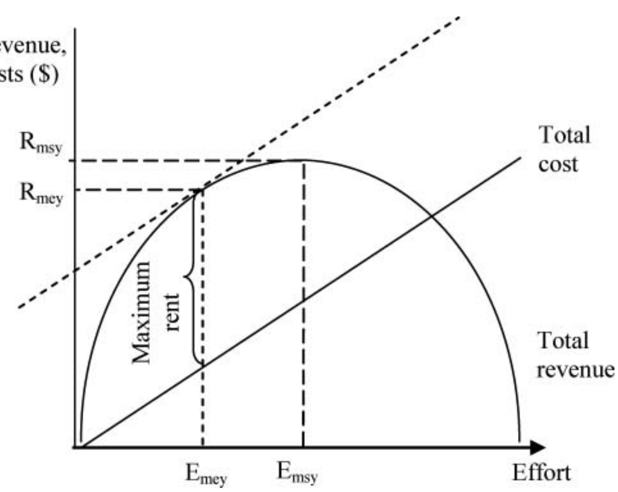

FIGURE 1. Standard equilibrium model of MEY in fisheries.

While the concept has long been proposed by fisheries economists as a target that should drive fisheries management (Gordon 1954; Scott 1955; Clark 1973), its identification had largely remained a theoretical exercise until recent years, as it had not been formally adopted as a policy objective internationally. With its inclusion in the Australian Commonwealth Fisheries Harvest Strategy Policy (ministerial direction to the Australia Fisheries Management Authority under Section 91 of the Fisheries Administration Act 1991 issued by the Australian Government Minister for Fisheries, Forestry, and Conservation in December 2005) and growing debates on its relevance as an operational management objective in other parts of the world (Dichmont et al. 2008; Bromley 2009; Christensen 2010; Norman-López and Pascoe 2011), the problem of estimating MEY in real fisheries has attracted growing attention. First attempts at identifying MEY as an actual management target have highlighted the empirical difficulties that need to be addressed, and these relate in particular to the alternative treatments of prices and costs, which may result in differing estimates of MEY and associated adjustment trajectories (Dichmont et al. 2010).

It has been possible to overcome these difficulties in the context of valuable, data-rich fisheries, to which the analysis was first applied. However, MEY may also be applied as a management objective in a broader set of fisheries, including some that are less well monitored and researched. This requires identification of possible approaches to applying this objective in data-poor contexts.

Empirical approaches.—Empirical analysis of MEY in data-rich fisheries has largely focused on the development of bioeconomic models. These have been developed for a wide variety of fisheries and for fisheries in most regions of the world (Armstrong and Sumaila 2001; Ulrich et al. 2002; Doole 2005; Kompas et al. 2010a; Kar and Chakraborty 2011). Such models require, at a minimum, underlying stock dynamics models as well as information on costs of different fishing activities and prices of the main species. Models range in type from those based on static equilibrium that assume a single homogenous fleet (Chae and Pascoe 2005; Kompas et al. 2010b) to complete ecosystem-based approaches (Fulton et al. 2007) or multispecies and multifleet models (Ulrich et al. 2007; Pelletier et al. 2009; Punt et al. 2011). These models are case-specific such that general rules that could be applied in data-poor contexts cannot readily be derived. While the models themselves could be adapted to other fisheries, these would require sufficient appropriate data to populate the model parameters. For management purposes, the reliability of these models is intrinsically linked to the data on which they were based, and acceptance of these models by industry and managers is also greatly influenced by data quality and quantity (Dichmont et al. 2010).

Approaches based on nonbioeconomic models to estimate optimal fleet size in fisheries (i.e., the fleet size at MEY) have largely focused on the estimating fishing capacity and capacity utilization (Tingley et al. 2003; Felthoven and Morrison Paul 2004; Tingley and Pascoe 2005; Szakiel et al. 2006; Hoff and Frost 2007). These can be derived using vessel-level catch and effort data, but require assumptions as to what catch levels may be appropriate at MEY. At best, they can identify how much excess capacity may exist in the fishery but do not provide an indication as to what may be an optimal level of either effort or catch.

Several attempts at developing indicators of economic performance exist that can be used to assess whether fisheries are improving or deteriorating. These include information on license values (Arnason 1990), although most approaches require more detailed cost and earnings information (Whitmarsh et al. 2000). As with the capacity measures, these indicators alone do not provide information on what an optimal level of fishing effort or catch may be.

Harvest control rules (HCR) (Smith et al. 2009) have been applied across a broad range of fisheries, including data-poor fisheries. One such approach is based on the definition of trigger levels associated with the biological status of the resources that also reflect economic performance (Dowling et al. 2008). Several examples of trigger-based management systems exist that have an implicit economic consideration but no explicit economic analysis. These include the data-poor and low-value spanner crab *Ranina ranina* fishery in Queensland, Australia (Dichmont and Brown 2010; O'Neill et al. 2010), and the white banana prawn *Fenneropenaeus merguiensis* and red-legged banana prawn *F. indicus* fishery component of the Australian Northern Prawn Fishery, a relatively data-rich fishery but one in which modeling approaches have proven unreliable (Buckworth et al. 2013b). In both cases, appropriate triggers are determined through a comanagement arrangement involving industry, scientists, and managers. Similar approaches have been proposed for the definition of HCR for North Atlantic fisheries management for fisheries in which data are unreliable or unavailable, and thus complex analytical models cannot be applied (Kelly and Codling 2006).

METHODS

The aim of this study was to determine some general "rules of thumb" that may assist managers in identifying appropriate economic target reference points in data-poor fisheries, and in particular refine the existing "$1.2B_{MSY}$" default target reference point used in Australian fisheries. A simple bioeconomic model was developed from which the relationship between MEY and MSY reference points was estimated for varying combinations of biological and economic parameters. The output from the model was summarized using a regression tree approach. It determined simple "rules of thumb" that allowed an economic reference point to be derived from a biological reference point for a given fishery given the values of the parameters it exhibited. Finally, simple econometric models of the information required in applying these "rules of thumb" as a function of fishery characteristics were derived for a broad range of Australian fisheries.

A simple, theoretical, bioeconomic model.—The approach is developed based on a basic bioeconomic model incorporating a logistic biological growth model for a single-species fishery (Schaefer 1954, 1957) of the form

$$B_{t+1} = B_t + rB_t(1 - B_t/K) - C_t, \tag{1}$$

where B_t is the biomass in time period t, r is the instantaneous growth rate, K is the environmental carrying capacity, and C_t is the catch in time period t. Catch is assumed to be a linear function of fishing effort and the level of biomass, given by

$$C_t = qE_tB_t, \tag{2}$$

where q is a proportionality constant known as the catchability coefficient and E_t is the level of fishing effort in time t.

At equilibrium, $B_e = B_t = B_{t+1}$ and hence $C_e = rB_e(1 - B_e/K)$ where the right-hand side represents the annual growth in the population, also referred to as the surplus production as it is surplus to what is required to keep the population at a stable level of biomass (in the absence of fishing). The maximum equilibrium level of catch (the MSY) is given by

$$\frac{dC_e}{dB_e} = r - 2rB_e/K = 0, \tag{3}$$

and hence

$$B_{MSY} = K/2. \tag{4}$$

That is, MSY is achieved when the level of biomass is half the carrying capacity.

Equating catch to the surplus production in the population also allows the sustainable catch to be expressed as a function of fishing effort, given by

$$C = qEK - \frac{q^2K}{r}E^2. \tag{5}$$

From this

$$\frac{dC}{dE} = qK - 2\frac{q^2K}{r}E = 0, \tag{6}$$

and hence

$$E_{MSY} = r/2q. \tag{7}$$

The simple model assumes prices are independent of the quantity landed and are therefore constant. Similarly, the cost per unit of fishing effort is also assumed constant such that the average cost equals the marginal cost. Costs in the model are economic costs and represent full opportunity cost of all inputs in the production process (including unpriced labor and a normal return to capital). Given this, the level of economic profits in the fishery can be given by

$$\pi = pC - cE$$

where c is the average cost per unit of effort and p is the average price. The level of fishing effort that maximizes profits is thus given by

$$\frac{d\pi}{dE} = p\frac{dC}{dE} - c = p\left[qK - 2\frac{q^2K}{r}E\right] - c = 0, \tag{8}$$

from which E_{MEY} is obtained as

$$E_{MEY} = (qK - c/p)/\left(2\frac{q^2K}{r}\right). \tag{9}$$

Given $E_{MSY} = r/2q$, then

$$E_{MEY} = \left(qK - \frac{c}{p}\right)/\frac{qK}{E_{MSY}}, \tag{10}$$

and hence

$$\frac{E_{MEY}}{E_{MSY}} = [1 - c/(pqK)] \tag{11}$$

Given that fishing mortality is given by $F = qE$, then

$$\frac{F_{MEY}}{F_{MSY}} = \frac{qE_{MEY}}{qE_{MSY}} = [1 - c/(pqK)]. \tag{12}$$

That is, the ratio of fishing mortality at MEY to fishing mortality at MSY is a function of prices, costs, catchability, and the carrying capacity of the stock. This value will always be less than 1 for any value of $c > 0$. By definition, the proportional target reference point expressed in terms of fishing mortality is the same as that expressed in terms of fishing effort.

Similarly, the biomass at MEY is given by

$$B_{MEY} = (K/2)(1 + c/(pqK)) = B_{MSY}(1 + c/(pqK)), \tag{13}$$

and hence

$$\frac{B_{MEY}}{B_{MSY}} = [1 + c/(pqK)]. \quad (14)$$

As with the ratio of fishing effort and fishing mortality at MEY and MSY, the ratio of biomass at MEY and MSY is a function of prices, costs, catchability, and the carrying capacity of the stock. This value will always be greater than 1 for any value of $c > 0$.

Introducing dynamics.—The basic model presented above indicates the optimum level of fishing effort and biomass assuming it can be attained instantaneously. Usually, the process of reaching MEY will involve adjustment delays for stock biomass as well as fishing capacity. In particular, in cases where excess fishing effort is being applied to the stock, adjusting to MEY may involve short-term costs in terms of effort reduction (Martinet et al. 2007; Dichmont et al. 2010), against which long-term benefits need to be balanced. Accounting for this, the functional definition of MEY in the Australian fisheries management context is the level of biomass and fishing effort that maximizes the net present value of economic profits over time (DAFF 2007). The dynamic version of MEY incorporates a discount rate to allow the trade-off between future benefits and short-term costs to be factored into the analysis. Following Clark (1990), the level of biomass that produces the dynamic MEY (B_{DMEY}) is given by

$$B_{DMEY} = \frac{K}{4}\left[\left(\frac{c}{pqK} + 1 - \frac{d}{r}\right) + \sqrt{\left(\frac{c}{pqK} + 1 - \frac{d}{r}\right)^2 + \frac{8cd}{pqKr}}\right], \quad (15)$$

where d is the discount rate. When $d = 0$, the value of B_{DMEY} is equivalent to that given in equation (12).

Where the discount rate is positive, estimating the sustainable level of fishing effort that produces the dynamic MEY (E_{DMEY}) is less straightforward than in the case where the discount rate was zero. Instead, E_{DMEY} needs to be estimated from the value of B_{DMEY} and the sustainable level of catch at B_{DMEY}. The associated level of catch at MEY is given by $C_{DMEY} = rB_{DMEY}(1 - B_{DMEY}/K)$ and the level of fishing effort by $E_{DMEY} = C_{DMEY}/qB_{DMEY}$. Consequently, the relationship between E_{DMEY} and E_{MSY} needs to be determined numerically rather than algebraically.

The target reference point, however, is an end point, and the standard models do not indicate how this end point is to be achieved. In practice, the pathway to building the biomass to the target level is often subject to a number of constraints (Martinet et al. 2007; Dichmont et al. 2010). For example, closing a fishery to allow faster stock recovery is not a practical option, nor are pathways that may impose industry losses in several years even if the future gains exceed these (Dichmont et al. 2010). These constraints affect the speed of recovery and, depending on the extent of the constraints, may also influence the target reference point also (Dichmont et al. 2010). For data-poor fisheries, factoring these considerations into the definition of dynamic target reference points is not possible due to the lack of the detailed dynamic models needed to estimate these reference points, taking into account the constraints.

Data inputs into the analysis.—A numerical version of the simple model was developed to assess the relationship between E_{MEY} and E_{MSY}, and to derive a simple framework for determining appropriate target reference points in the case where data are limited. Values of the key parameters were varied stochastically and a range of possible relative target reference points (i.e., E_{DMEY}/E_{MSY} and B_{DMEY}/B_{MSY}) were estimated.

The values used in the stochastic analysis and the distributions of the final "acceptable" values are given in Table 1. Ten thousand random values were generated for each of the parameters assuming a normal distribution and the mean and SD values are given in Table 1. However, a set of criteria was established to ensure that the set used for the analysis was relatively realistic. First, any set of parameters containing a negative value was discarded (removing approximately 250 sets). Second, any set of observations that would have resulted in negative economic profits at MSY was removed. While it is

TABLE 1. Key parameters used in the stochastic analysis to develop the regression tree. See text for definition of abbreviations.

	Values used in stochastic analysis		Distribution of "acceptable" values					
Parameter	Mean	SD	Minimum	First quartile	Median	Mean	Third quartile	Maximum
r	1.4	0.4	0.065	1.140	1.396	1.400	1.661	3.122
q	0.004	0.001	0.001	0.004	0.004	0.004	0.005	0.008
K	1,000	400	138.8	901.0	1,126.0	1,142.0	1,365.0	2,639.0
c	15	6	0.021	9.517	13.150	13.320	17.030	33.640
p	10	4	0.575	9.017	11.400	11.510	13.860	25.460
d	0.1	0.04	0.000	0.074	0.101	0.101	0.128	0.251

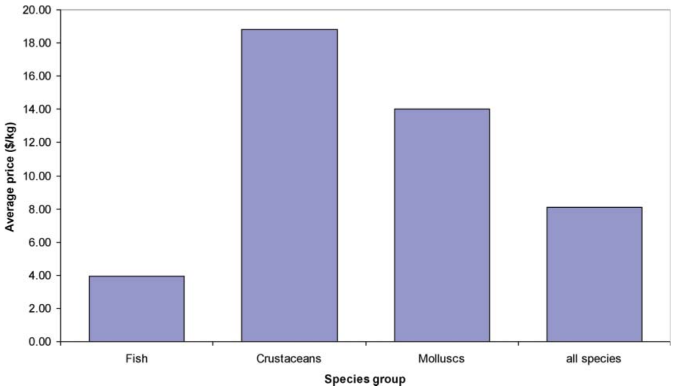

FIGURE 2. Average prices (A$) for species groups targeted in Australian fisheries, 2008–2009 (source: ABARES 2010).

theoretically possible that MSY is not economically feasible, it is rarely observed. This filtering resulted in only 5,897 of the 10,000 random sets of parameter values being used in the analysis.

The choice of the initial mean values of the parameters and their SDs was aimed at producing parameter sets of widely varying values that were representative of a wide range of fisheries. The instantaneous growth rate (r) ranges from relatively slow-growing species (such as sharks: Cortés 1998) to fast-growing species (such as prawns). The mean price of all wild caught Australian produce in 2008–2009 was A$8.10 (Figure 2), although prices varied widely between (and within) different types of species groups (ABARES 2010). A mean of $10/kg was chosen as the basis for the model. This is higher than the current average but, with an SD of $4/kg, the distribution largely captured the range of prices observed for species targeted in Australian wild-caught fisheries. Catchability and the carrying capacity for a species are inversely related in terms of scale, as the derivation of the target reference points relies on the value of their product (qK). Values of these parameters were chosen along with the mean value for costs in order to give an estimated cost per unit catch at MSY of approximately $7.50/kg (i.e., 75% of the average price). This implies that economic profits are assumed to be, on average, at approximately 25% of the revenue at MSY. (Studies elsewhere suggest that economic profits at MEY may be a substantially higher proportion of revenue than the baseline included in this analysis [Dupont 1990; Eggert and Tveteras 2007; Asche et al. 2008; Munro 2010]. However, empirical analyses of Australian fisheries suggest that a more conservative assumption may be appropriate [Kompas et al. 2009, 2010a; Punt et al. 2011]). Cost per unit catch at MSY is given by $c/(0.5qK)$. The model was also run with the discount rate fixed at various levels (0, 5, 10 and 50%) to test the sensitivity of the relationships to the discount rate.

Estimating cost shares.—From equations (11) and (14), both B_{DMEY}/B_{MSY} and E_{DMEY}/E_{MSY} are dependent upon the ratio $c/(pqK)$, where $c/(pqK)$ effectively represents the cost per unit catch given an (unknown) unexploited biomass. However, given that the CPUE at MSY is given by $0.5qK$ (as $B_{MSY} = 0.5K$), then the cost per unit of catch at MSY is equivalent to $c/(0.5qK)$, which is directly proportional to the cost per unit catch given an unexploited biomass. (The value $0.5qK$ is equivalent to the CPUE at MSY. Given these relationships, the cost per unit catch at MSY is twice that at the unexploited biomass.) Consequently, the cost share of revenue at MSY is a feasible proxy measure by which the optimal ratio of biomass and effort can be derived in a comparative statics context. [Total fishery costs are given by cE, while total fishery revenue is given by pC (where C is the catch). Given $C = qBE$ (where B is the level of biomass), then the cost share of revenue is defined as $cE/(pqBE)$, or $c/(pqB)$. At MSY, $B = 0.5K$, so the cost share of revenue is equivalent to $c/(pq.5K)$ or $0.5\times c/(pqK)$]. By multiplying both numerator and denominator by the catch at MSY, the cost share is determined to be the ratio of the total fishing cost to the total revenue.

Cost and revenue information is currently available at the individual vessel level for a limited number of Australian fisheries at the commonwealth (e.g., Australian Bureau of Agricultural and Resource Economics and Sciences) and state levels (e.g., South Australia), although within this set of fisheries a substantial panel of data were developed. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, formerly ABARE) has been conducting economic surveys of commonwealth fisheries since the early 1980s and has maintained a regular survey program for selected fisheries since 1992. The aggregated financial and economic performance results generated from each survey are made publicly available through the annual Australian Fisheries Surveys Report series (Perks and Vieira 2010). For South Australian commercial fisheries, EconSearch has been undertaking similar surveys since 1999 (EconSearch 2010a, 2010b, 2010c, 2010d), using consistent definitions as those used by ABARES. Data from the two surveys over the period 1998–2010 were pooled, giving a total of 1,961 observations across 14 different fishing methods. (Ideally, the subsequent analyses would have been run as panel data models to capture any vessel-specific characteristic not captured by the general characteristics considered. However, vessel identifiers had been removed for the South Australian data, and it was not possible to track individual vessels over time. As a result, all observations are considered to be independently distributed.)

Over most of the period the data covered, the management target for most fisheries was MSY, although several commonwealth fisheries were transitioning to a target of MEY from 2008. About 20% of stocks in commonwealth fisheries were considered overfished in 1999 (Caton and McLoughlin 2000), although this declined to less than 10% in 2010 (Woodhams et al. 2012). For South Australian fisheries, around 20% of stocks were considered overfished during the middle period of the data (2002–2005) (PIRSA 2007). Given this, it can be assumed that most fisheries considered in the analysis were at or around MSY for most of the period of the data; hence, the empirical cost shares of revenue are representative of the theoretical shares required for the analysis.

RESULTS

Relationships between Target Reference Points and Cost Shares

The distributions of the target reference points for 5% and 10% discount rates are illustrated in Figure 3. In most cases, $B_{DMEY}/B_{MSY} > 1$ and ranges between 0.95 and 1.5, while $E_{DMEY}/E_{MSY} < 1$ and ranges between 0.5 and 1.05, given a 5% discount rate. At higher discount rates, the distribution of B_{DMEY}/B_{DMSY} shifts to the left while E_{DMEY}/E_{MSY} moves to the right.

A regression tree analysis was undertaken with cost share and the ratio of the discount rate to the stock growth as the explanatory variables, based on equations (12), (14), and (15). These were undertaken for a given discount rate as this is generally determined exogenously for most fisheries (and public policy) analyses. For all levels of standard discount rates tested (0, 5, 10, and 50%), the tree was split only in terms of the cost share component. This is illustrated for the 5% discount rate case in Figure 4, where branches to

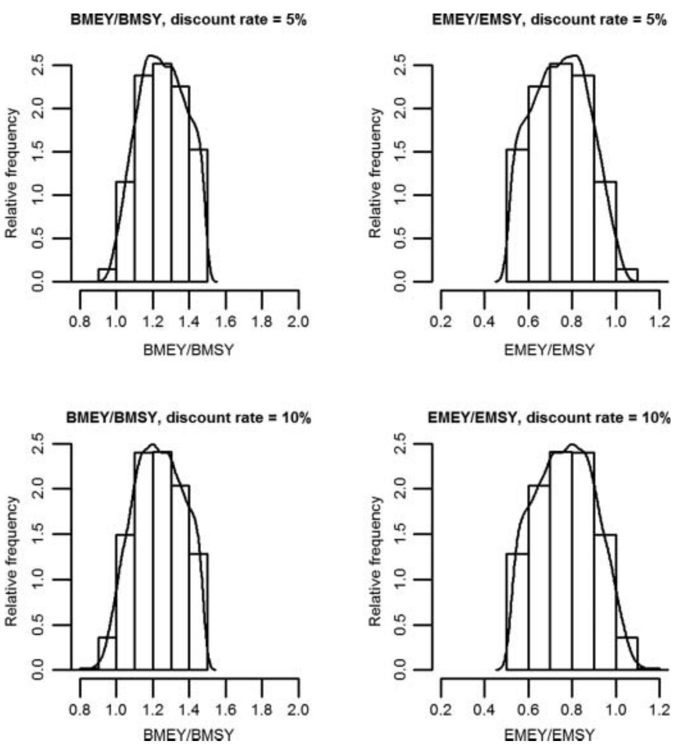

FIGURE 3. Distribution of the dynamic target reference point ratios, B_{MEY}/B_{MSY} and E_{MEY}/E_{MSY}, using discount rates of 5% and 10%.

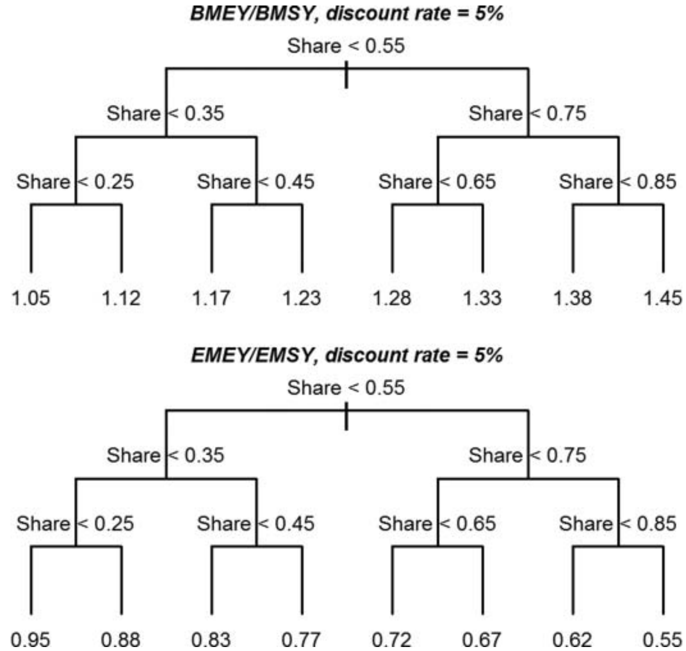

FIGURE 4. Regression trees for B_{MEY}/B_{MSY} and E_{MEY}/E_{MSY} at a 5% discount rate.

the left relate to cases where the inequality is respected. Linear regressions of the tree-predicted values on the actual values suggested that both models captured over 90% of the variation in the ratios, although they tended to slightly underestimate the true ratios (the slope coefficient in both cases was around 0.95).

The current proxy value for B_{MEY}/B_{MSY} adopted in Australian fisheries management is 1.2 (DAFF 2007), and the commonly adopted discount rate for MEY estimation is 5% (Punt et al. 2010). From the tree in Figure 4, this figure is appropriate for fisheries where the cost share is expected to fall roughly between 45% and 55%. That is, expected economic profits at MSY are also between 45% and 55% of revenue.

Relationship between Cost Shares and Fishery Characteristics

The results above from the theoretically derived model require some estimate of the cost share of revenue at MSY in order to derive an appropriate proxy for E_{MEY}/E_{MSY}. While these cost shares are unknown, a reasonable estimate of them may be made based on the economic data used in the previous analysis. The objective of MEY has only been implemented in commonwealth fisheries since 2007, and only one fishery (the Northern Prawn Fishery) has had sufficient information to develop a full bioeconomic model to identify and operationalize MEY (Dichmont et al. 2010). Most other commonwealth fisheries are still transitioning to MEY targets (through the use of the default MEY proxies), many from an overexploited state

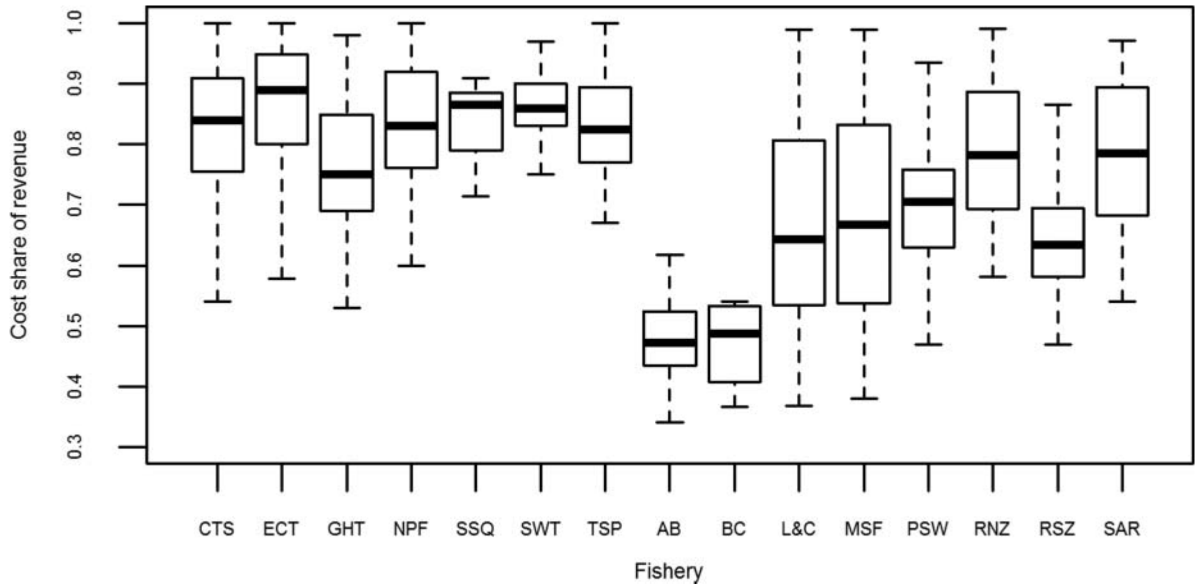

FIGURE 5. Distribution of cost share of revenue in Australian fisheries with economic survey data. Abbreviations are as follows: CTS = commonwealth trawl sector, ECT = eastern tuna and billfish, GHT = gillnet hook and trap, NPF = northern prawn fishery, SSQ = southern squid, SWT = south west tuna, TSP = Torres Strait prawn, AB = abalone, BC = blue crab *Portunus pelagicus*, L&C = Lakes and Coorong, MSF = marine scalefish, PSW = prawns (Spencer Gulf and west coast), RNZ = rock lobster (northern zone), RSZ = rock lobster (southern zone), and SAR = sardines. The upper and lower boundaries of the boxes represent the 25th and 75th percentiles, and the line within the box represents the median. The error bars above and below the box represent the 95 percent confidence interval.

(Woodhams et al. 2012), while state fisheries mostly maintain a target of MSY. While stock status is still improving in commonwealth fisheries (Woodhams et al. 2012), on balance it could be assumed that the observed cost share of revenue was roughly equivalent to the cost shares at or near MSY for most of the period of the data.

The distribution of cost share of revenue in each of the fisheries for which economic data were available is shown in Figure 5. Median cost shares for the South Australian fisheries appeared lower than those of the commonwealth fisheries, although they were subject to considerably greater variability.

The relationship between cost share of revenue and fishery characteristics was examined through simple regression analysis. A priori, it was expected that boat size, fishing method (expressed as dummy variables with trawl as the base), management method (i.e., individual transfer quotas [ITQ] or effort controls), and potentially average price would affect the cost share of revenue. A log-linear form of the model was assumed.

The results of the initial model are shown in Table 2. The explanatory power was relatively low (33%), although this is as expected given the considerable variability between individuals in the data. However, most of the signs on the coefficients were as expected: fisheries with higher prices are likely to have a lower cost share (as revenues are higher, all other things being equal), larger boats are likely to have a higher cost than smaller boats relative to revenue, and cost share differs by main fishing method. The coefficient on the effort control was negative, although this was not significantly different from zero suggesting that effort control fisheries do not have a significantly higher cost share than output control fisheries (consistent with the distribution in Figure 6). While a priori there is an expectation that cost shares in ITQ fisheries would be lower than those in input control fisheries due to the different incentives faced (Asche et al. 2008), a clear significant difference between the cost shares solely on the basis of management type was not observed (Figure 6).

The coefficients on dropline, gill nets, pots, and Danish seine were not significantly different from each other. While Danish seine is a trawl-based method, it is very different from other trawl methods, so a cost share similar to other static gears is not surprising. For the subsequent analyses, these four gear types were amalgamated into an "other static gear" variable. Prawn trawl was not significantly different than other fish trawls.

As the aim of the study was to develop proxy estimates of MEY from limited data, a regression tree analysis was run with cost share as the dependent variable and price, length, and gear types (trawl, dive, long line, purse seine, and other static gear) as the explanatory variables. The resultant tree is illustrated in Figure 7.

Combining Figures 7 and 4 allows an estimate of the ratio B_{MEY}/B_{MSY} or E_{MEY}/E_{MSY} to be derived based on limited information on the fisheries—effectively some indication of the average price, average boat size, and the main fishing methods. From Figure 7, larger boats tend to have higher cost shares than smaller boats, although this is not always the case. For example,

TABLE 2. Regression results for ln(CostShare). Significance (P) levels: *** < 0.001; ** < 0.01; * < 0.05.

Parameter	Estimate	SE	t-value	Significance level
Constant	−0.365	0.059	−6.149	***
Ln(Price)	−0.045	0.010	−4.450	***
Ln(Length)	0.078	0.018	4.245	***
Method dummy variables				
Dropline	−0.083	0.027	−3.049	***
Trawl prawn	0.029	0.026	1.122	
Gill net	−0.125	0.023	−5.437	***
Pots	−0.101	0.027	−3.725	***
Dive	−0.369	0.042	−8.824	***
Longline	0.061	0.020	3.067	***
Danish seine	−0.091	0.028	−3.197	***
Purse seine	−0.166	0.043	−3.868	***
Effort control dummy	−0.001	0.017	−0.047	
$-R^2$	0.338			
Nobs	1,961			
F-value	61.38			***

small longline vessels and small vessels targeting low-valued fish species tend to have comparable cost shares to the larger trawl vessels. From the two figures, for example, a trawl vessel targeting relative high-valued species (i.e., >$15.50/kg) would have an average cost share of around 0.77 (Figure 7), which would imply a B_{MEY}/B_{MSY} ratio of around 1.38. A summary of the relationships between fishing gear type, size, and price and the ratio E_{MEY}/E_{MSY} is also presented in Table 3.

DISCUSSION

The focus of this study has been estimating proxy values for target reference points based around MEY. There has recently been substantial debate in the fisheries literature about the appropriateness of MEY as an economic target reference point, namely as it does not take into consideration values generated outside of the fishery per se (e.g., in local communities and/or processing industries) (Bromley 2009; Christensen 2010; Norman-López and Pascoe 2011; Grafton et al. 2012; Wang and Wang 2012a, 2012b; Pascoe et al. 2013). Sumaila and Hannesson (2010) demonstrated that an

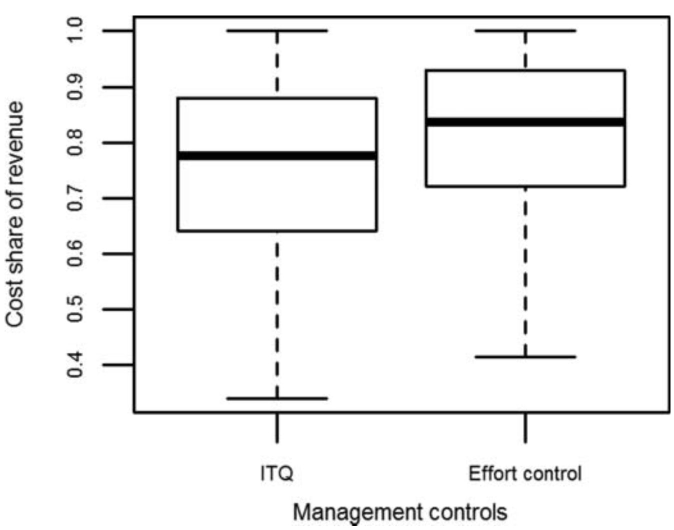

FIGURE 6. Cost share by management type. See Figure 5 for a description of the box plot.

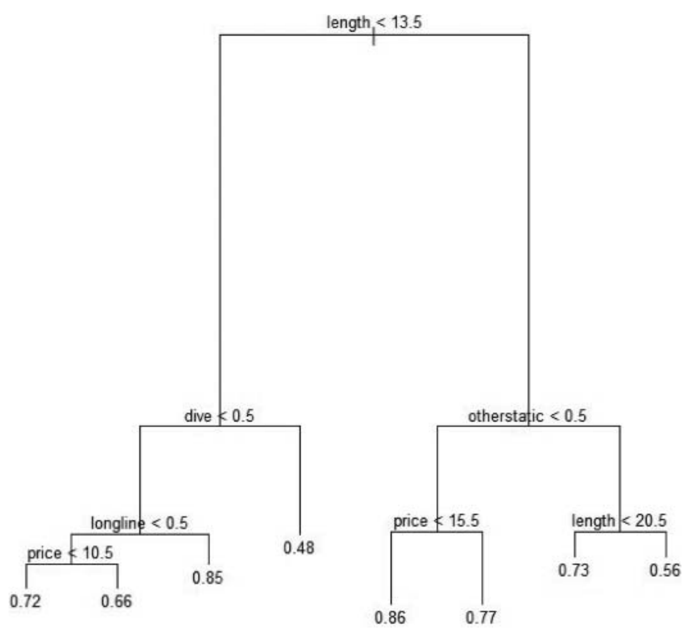

FIGURE 7. Regression tree describing cost share as a proportion of revenue. The length of each branch reflects the degree of variance in the outcome explained by each split.

TABLE 3. Determination of E_{MEY}/E_{MSY} ratio based on empirical results.

Main fishing gear	Vessel length class (m)	Average first sale price of fish landed (A$)	Estimated cost share of revenue at MSY	Cost share class	E_{MEY}/E_{MSY} at 5% discount rate
Longline	<13.5	Any	0.85	>0.85	0.55
Active gear	>13.5	<$15.5	0.86	>0.85	0.55
Active gear	>13.5	>$15.5	0.77	0.75–0.85	0.62
Active gear	<13.5	>$10.5	0.66	0.65–0.75	0.67
Active gear	<13.5	<$10.5	0.72	0.65–0.75	0.67
Other static gear	>20.5	Any	0.73	0.65–0.75	0.67
Other static gear	13.5–20.5	Any	0.56	0.55–0.65	0.72
Dive	<13.5	Any	0.48	0.45–0.55	0.77

optimal outcome for both the fishery and processors and marketers occurs at the level of catch and effort that maximizes economic profits to the fishery, while Norman-López and Pascoe (2011) showed that flow-on effects to local communities may often be greater at MEY than at higher levels of production. Consequently, MEY is considered to be a good target for achieving economic objectives of fisheries management in most cases. (In some countries, consideration of social impacts is also an important component when assessing optimal target reference points, while other objectives may also be important in some cases, e.g., food security. These may result in alternative target reference points and require alternative multi-objective modeling approaches to derive these more appropriate reference points [Charles 1989; Pascoe and Mardle 2001]. However, once derived, a similar process as outlined above could be developed to derive proxy measures for data poor fisheries.) In cases where some market power exists and fishers are able to influence prices, there are good economic grounds to include broader economic considerations such as changes in consumer surplus (Anderson 1986; Hannesson 1993; Grafton et al. 2012). Relatively few fisheries fall into this category, as most have little influence on the price received for their product.

In data-poor fisheries, it is unlikely that the values of the key biological and economic parameters will be known in any detailed quantitative way. Garcia et al. (1989) demonstrated that reasonable estimates of B_{MSY} and E_{MSY} can be made with very limited data, based on a few assumptions about the characteristics of the fishery. More recent studies have developed approaches to estimate reference points related to fishing mortality (Zhou et al. 2012a, 2012b), from which estimates of E_{MSY} may be derived. Depletion-based approaches have also recently been developed for estimating unfished biomass levels from limited data (Dick and MacCall 2011; Zhou et al., in press) from which other biomass based reference points can be derived.

Relatively few studies have attempted to quantify the revenue share of economic profits at MSY although several studies have looked at the potential share of profits in the fishery at MEY. DuPont (1990) found that in the Canadian Pacific salmon fishery, potential economic profits were about 42% of total revenue. Potential economic profits were estimated to be between 20% and 30% of revenue for Denmark, Sweden, and the UK, and even higher for Iceland and Norway (Asche et al. 2008; Pascoe and Mardle 2001).

The broader applicability of the relationship between cost share of revenue and fishery characteristics beyond Australia is uncertain. However, these estimates could be used as a starting point, from which adjustments can be made through discussions with industry or, more preferably, some economic survey estimates. As a test, the approach was applied to economic data from 58 fleets published by the FAO (Tietze et al. 2005). Estimates of the cost share of revenue based on the characteristics of the vessels (gear type, size, and price received) were, on average, only 8% different from the observed values. However, for some artisanal fleets in developing countries (e.g., some of the smaller vessels in India and the Caribbean), the estimates were substantially different and usually higher than those observed from the economic data. Crew costs in these fleets were often lower than would be expected (and excluded an allowance for owner–operator labor) and explain much of the divergence between the tree-derived cost share and that observed. Other fleets also recorded costs greater than revenues, which would be unsustainable in the long term, and suggest that the fleet is closer to the open access equilibrium than is MSY, as assumed in the above analysis. Where the fleets had cost shares of a similar range to those used to develop the regression trees, the derived estimates of the E_{MEY}/E_{MSY} ratios derived from the gear and fishery characteristics were reasonably similar to those based on the reported cost information. (Further details on this analysis can be obtained from the corresponding author.)

This relationship between economic profits at MEY and economic profits at MSY varies substantially depending on the relative costs and prices of fishing across fisheries. For some fisheries, economic profits at MSY may be small relative to those at MEY, whereas in other fisheries the difference in economic profits may be large. Assuming that economic profit at MSY is around one-half that at MEY such that the ratio of economic profits to revenue at MSY ranges between 10% and 20%, then more appropriate "default" proxy values for B_{MEY} may be 1.3–1.4 times B_{MSY}. Similarly, it might be expected that optimal effort levels are most likely to fall between 55% and 65% of those at MSY.

Preliminary bioeconomic model-based estimates of the ratio B_{MEY}/B_{MSY} have also been undertaken for several species in Australia's South East Trawl Fishery (Kompas et al. 2009). While this is a multispecies fishery, several species within the fishery could effectively be considered single-species subfisheries, Orange Roughy *Hoplostethus atlanticus* being a key example. Estimates of the ratio B_{MEY}/B_{MSY} were 1.20 and 1.53 for the two separate stocks of Orange Roughy (Kompas et al. 2009). Published economic survey results for the fishery suggested that in 2009–2010 total costs were roughly 89% of the total revenue for trawlers (George and New 2013). Based on our cost share regression tree model, the optimal ratio of B_{MEY} to B_{MSY} would be 1.45, which is higher than the bioeconomic-based estimates of optimal values for one stock of Orange Roughy and lower for the other Orange Roughy stock. However, the fishery has been going through severe financial stress in recent years (Smith et al. 2008), which may have resulted in increased costs relative to revenue.

The MEY has also been assessed for the Northern Prawn Fishery (Buckworth et al. 2013a). This is a relatively high CPUE fishery, and with a low catch is also a relatively high cost per unit catch fishery. Based on the most recent published economic survey estimates, total costs were roughly 84% of revenue for the fishery as a whole in 2008–2009 (Vieira et al. 2010). Bioeconomic model based estimates of B_{MEY}/B_{MSY} for the three primary species in the fishery in 2013 were 1.57, 1.39 and 1.44 for grooved tiger prawns *Penaeus semisulcatus*, brown tiger prawns *P. esculentus*, and blue endeavor prawns *Metapenaeus endevouri* and red endeavor prawns *M. ensis*, respectively (Buckworth et al. 2013a); the stocks of two of the latter species are believed to be slightly higher than the MSY over the period 2008–2012 and the third is slightly lower than the MSY (Buckworth et al. 2013a). Although the fishery is characterized largely by joint production, there is some ability to target brown tiger prawns (Pascoe et al. 2010), and the stock assessments include this assumption. From the regression tree, a default proxy value of 1.38 would have been selected as appropriate for the fishery, which is consistent with the bioeconomic model estimate for brown tiger prawns.

The models used in this analysis were based on a single-species fishery. In multispecies fisheries, the issue of joint production adds a further complication into the definition of MEY. The optimal yield in a multispecies fishery is rarely the same as the individual optimal yield if it could be perfectly targeted (Anderson 1975). Nevertheless, the proxy values for the relative target reference points based on the single-species model were closer to that estimated using a multispecies bioeconomic model rather than the base assumption of $B_{MEY} = 1.2B_{MSY}$.

The analysis was undertaken using a generic bioeconomic model but with economic data specific to Australian fishing vessels. However, similar approaches could be used with economic data where available in other countries to develop more country-specific proxy measures. Attempts are also underway to develop a global database of economic information (Lam et al. 2011) that will be of further benefit to data-poor fisheries.

CONCLUSION

For many fisheries, the cost of data collection and analysis to estimate MEY targets accurately may be high relative to the economic benefits that may result from an improved definition of target reference points. Potentially, a zero, negative, or, at best, small improvement over their existing profitability may be realized if the costs of obtaining "better' information are taken into account. Scientists are working on data-poor methods for assessing F_{MSY} and other proxy measures in such fisheries (Zhou et al. 2012b). Given this and the "rules of thumb" developed through the regression tree analysis, it is possible to extend this to proxy measures of F_{MEY} (through the relative effort at MEY compared with MSY) and help improve the economic performance of such fisheries even in the absence of robust data. Such information may be useful, even in fisheries where the targets for management are not MEY, as it can provide managers with an evaluation of the trade-offs between economic, ecological, and social implications of alternative management strategies.

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