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Authors: Smith, David, Punt, Andre, Dowling, Natalie, Smith, Anthony, Tuck, Geoff, et al.

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Reconciling Approaches to the Assessment and Management of Data-Poor Species and Fisheries with Australia's Harvest Strategy Policy

DAVID SMITH*

Commonwealth Scientific and Industrial Research Organization, Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, General Post Office Box 1538, Hobart, Tasmania 7001, Australia

ANDRE PUNT

Commonwealth Scientific and Industrial Research Organization, Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, General Post Office Box 1538, Hobart, Tasmania 7001, Australia; and School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, Washington 98195, USA

NATALIE DOWLING, ANTHONY SMITH, AND GEOFF TUCK

Commonwealth Scientific and Industrial Research Organization, Wealth from Oceans National Research Flagship, Marine and Atmospheric Research, General Post Office Box 1538, Hobart, Tasmania 7001, Australia

IAN KNUCKEY

Fishwell Consulting, 22 Bridge Street, Queenscliff, Victoria 3225, Australia

Abstract.—There is an increasing expectation for decision makers to use robust scientific advice on the status of exploited fish stocks. For example, Australia has recently implemented a harvest strategy policy for federally managed fisheries based on limit and target biomass reference points. In common with most fisheries jurisdictions, however, Australia has many data-poor species and fisheries for which biomass estimates are unavailable. Consequently, the challenge for those tasked with providing management advice for Australian fisheries has been reconciling the need to achieve specific risk-related sustainability objectives with the reality of the available data and assessments for data-poor species and fisheries. Some general recommendations regarding how to achieve this balance are drawn using case studies from two multispecies trawl fisheries. The lack of data on which to base quantitative stock assessments using population dynamics models does not preclude the development of objective harvest control rules. Evaluation of harvest control rules using technical procedures (e.g., the management strategy evaluation approach) is ideal, but implementation before rigorous testing is sometimes a necessary reality. Information from data-rich species and fisheries can be used to inform "assessments" for data-poor species and thereby develop appropriate control rules. This can be done through formal methods, such as the "Robin Hood" approach (in which assessments from data-rich species are used to inform assessments of data-poor species), or less formally by grouping species into "baskets" and basing management decisions on one appropriate member of the group. Stakeholder knowledge and buy-in to the process of developing appropriate harvest strategies are essential when species or fisheries are data poor. Use of this information, however, needs to be constrained by policy decisions, such as prespecified performance standards. There will always be a trade-off between the cost of data collection and the value of a fishery; in this article, we highlight that this trade-off does not have to be a major impediment to the development of realistic and sufficiently precautionary control rules for the management of data-poor species and fisheries.

Recently, a number of high-profile publications (Pauly et al. 1998; Myers and Worm 2003; Worm et al. 2006) have painted a bleak picture of the status of the world's fisheries. The veracity of these arguments can be questioned (e.g., Hilborn 2007a, 2007b), but nonetheless there is increasing public scrutiny of fisheries management. Consequently, there is an increasing expectation for (1) decision makers in jurisdictions such as Australia, New Zealand, South Africa, and the United States to use robust scientific advice on the status of exploited fish stocks, which for key species is based on quantitative stock assessments,

Subject editor: Anthony Charles, Saint Mary's University, Nova Scotia, Canada

* Corresponding author: david.c.smith@csiro.au

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and (2) management decisions to follow the guidelines established by the Food and Agriculture Organization of the United Nations (FAO 1996).

In common with most fisheries jurisdictions, however, Australia has many data-poor species and fisheries. Here, we define "data poor" as meaning that there is a lack of data to permit application of quantitative stock assessment methods, such as statistical catch-at-age analysis and virtual population analysis, which involve fitting time-series of abundance compositional data to estimate changes in population size over time. Many small fisheries have low gross values of production (GVPs), are in exploratory or developmental phases, or are only fished opportunistically given sporadic stock availability. There are often only a few active operators in the fishery, although there may also be a substantial amount of latent effort. Finally, for many fisheries, there will be species taken that have relatively low value and/or are not the main target species, even in valuable, mature multispecies fisheries. Consequently, these fisheries or species are usually data poor, with no assessment or only basic assessments, because the costs of the research and monitoring that are necessary for quantitative stock assessments cannot be met or because the collection of such data has not been considered important in the past.

Australia introduced a harvest strategy policy (HSP) for all Commonwealth (federal) fisheries in 2007 as part of the response to a Ministerial Direction to the Australian Fisheries Management Authority (AFMA) to cease overfishing and rebuild overfished stocks (Australian Government 2007). A key management objective of the HSP is to ensure that harvest strategies meet specified risk thresholds regardless of the level of uncertainty in assessments. This is an explicit recognition of the need for precaution by reducing exploitation rates in the face of increased uncertainty.

The AFMA adopts a partnership approach to fisheries management and science (Smith et al. 1999, 2001) that includes a wide variety of stakeholders (fishers, scientists, managers, and nongovernmental conservation organizations). Resource assessment groups (RAGs) provide advice on stock status and management settings. For large fisheries, the RAGs were charged with developing fishery-specific harvest strategies. In addition, a project team was established to develop harvest strategies for low-value and data-poor fisheries (Dowling and Smith 2007; Dowling et al. 2007, 2008).

The HSP does not specify how to develop harvest strategies for data-poor species or fisheries. This information is provided in the associated technical guidance document (Australian Government 2007), which encourages a tiered approach to control rules that caters to different levels of certainty (or knowledge) about a stock (e.g., Goodman et al. 2002; Smith et al. 2007). Such an approach provides an increased level of precaution with increasing levels of uncertainty about stock status, such that the level of risk is approximately constant across the tiers. Dowling et al. (2008) developed general principles for fisheries where the lack of information even precluded adoption of tier rules.

In this article, we briefly outline the HSP and describe empirical methods for data-poor situations that are consistent with the HSP by using case studies from two multispecies trawl fisheries. Finally, we consider model-based approaches for enhancing stock assessment advice for data-poor species or stocks by using intra- and interspecies information.

Australia's HSP

The Australian Government Minister for Fisheries, Forestry, and Conservation issued a Ministerial Direction to the AFMA under Section 91 of the Fisheries Administration Act 1991 in December 2005. This Direction included a requirement for the development of a HSP for relevant Commonwealth fisheries and the implementation of harvest strategies consistent with that policy in all Commonwealth fisheries.

A harvest strategy is a plan that sets out the management actions necessary to achieve prespecified (and agreed) objectives in a given fishery. A harvest strategy should specify the following: (1) a process for monitoring and conducting "assessments" (not to be confused with formal stock assessments) of the biological and economic conditions of the fishery; and (2) rules that control the intensity of fishing activity according to the biological and economic conditions of the fishery (as defined by the assessment). These rules are referred to in the HSP as control rules (sometimes also known as harvest control rules or decision rules).

The Australian HSP is underpinned by target and limit biomass reference points (B_{TARG} and B_{LIM}, respectively). The B_{TARG} is B_{MEY}, the biomass corresponding to maximum economic yield (MEY); the B_{LIM} is half of B_{MSY}, the biomass corresponding to the maximum sustainable yield (MSY; Australian Government 2007). The policy allows for the use of proxies for both B_{MEY} ($1.2B_{\mathrm{MSY}}$) and B_{LIM} ($0.5B_{\mathrm{MSY}}$ or 20% of the average unexploited biomass). Harvest strategies consistent with the HSP needed to be implemented for all fisheries managed by the Australian Commonwealth government by 1 January 2008.

An example of a control rule that is consistent with the HSP is given in Figure 1. The HSP refers to limit

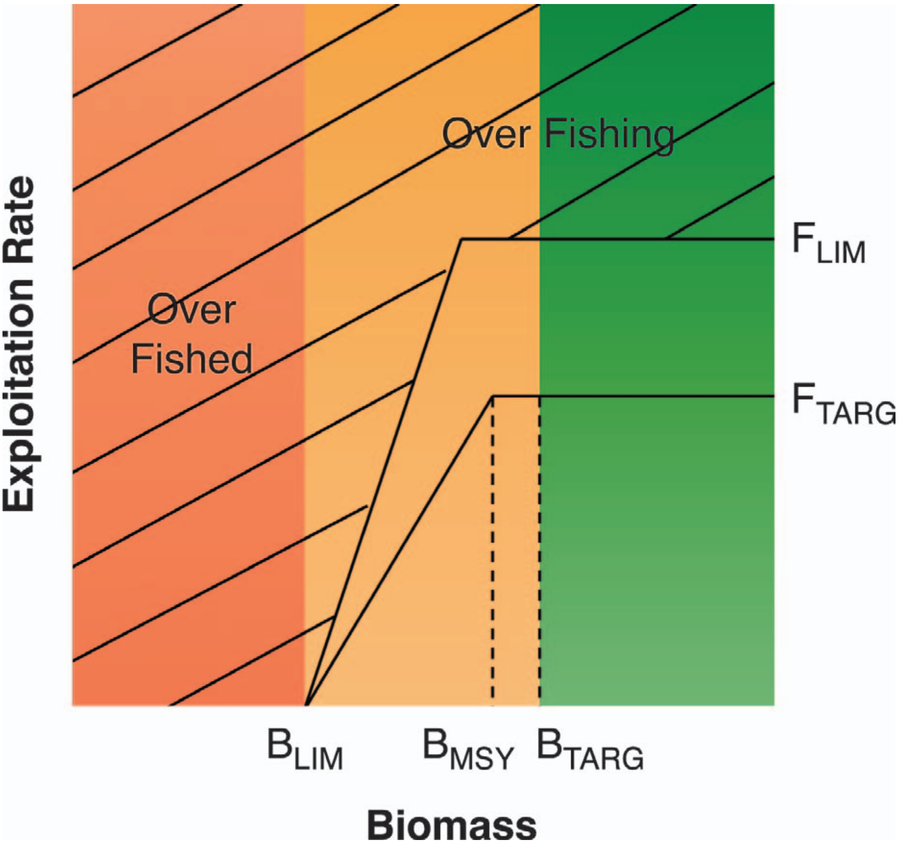

FIGURE 1.—Example of a harvest control rule that is consistent with Australia's harvest strategy policy (HSP; B_{LIM} = limit biomass reference point; B_{MSY} = biomass that corresponds to maximum sustainable yield; B_{TARG} = target biomass reference point; F_{LIM} = limit fishing mortality rate; F_{TARG} = target fishing mortality rate). The HSP specifies B_{TARG} as B_{MEY}, the biomass that corresponds to the maximum economic yield. The control rule specifies that as the biomass reduces below B_{MSY}, F_{TARG} is progressively reduced to zero at B_{LIM}.

and target fishing mortalities, but they are not included in the core elements of the policy (Australian Government 2007). However, for species managed by using control rules such as that depicted in Figure 1, it is necessary to specify appropriate fishing mortality rates (F) that achieve the target biomass levels on average, while avoiding the B_{LIM} with acceptable probability (the policy states that the risk of dropping below the limit should be less than 10%) in the harvest strategy.

The information needed to apply control rules like that shown in Figure 1 is often derived from quantitative stock assessment models. It is recognized in the guidelines, however, that information about many stocks is limited or uncertain and that it may not be possible to make direct use of the B_{TARG} and B_{LIM} described in the HSP (Australian Government 2007). The guidelines state that scientifically defensible proxies for reference points and corresponding control rules need to be specified to achieve the intent of the HSP where only moderate or poor information is available. Moreover, a precautionary approach to fishery management (i.e., leading to lower exploitation rates) must be taken to account for the uncertainty when information for quantifying risk levels is unavailable (Australian Government 2007).

Consequently, rather than expecting a full quantitative assessment for each species in each fishery, the HSP advocates a risk management approach whereby exploitation levels decrease as uncertainty around stock status increases. Consequently, in low-value fisheries for which there is limited research, catches may remain low, better aligning the management costs to the business environment for that fishery.

Therefore, the challenge for those tasked with providing scientific management advice for Australian fisheries has been in reconciling the need to achieve specific risk-related harvest strategies given the reality

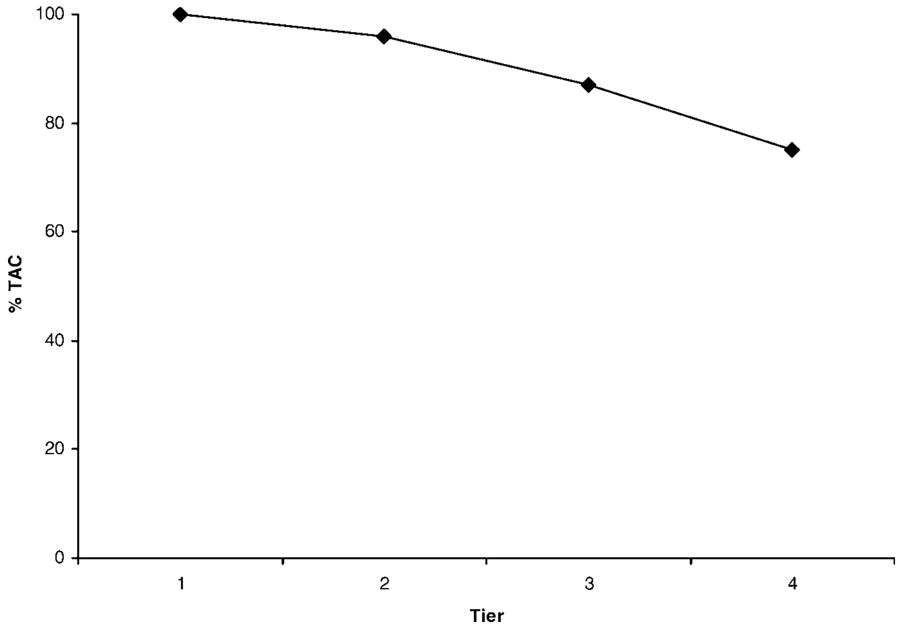

FIGURE 2.—Discount factors applied between tiers 1–4 to achieve comparable levels of risk in the harvest strategy framework for the Southern and Eastern Scalefish and Shark Fishery (Australian Government 2007; TAC = total allowable catch).

of the available data or assessments (both at present and in the future) for low-priority species and the limited likelihood of obtaining additional information for many small fisheries because of their low GVPs.

Southern and Eastern Scalefish and Shark Fishery

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a complex, multispecies, multigear fishery managed by AFMA (Smith and Smith 2001). Now under a single management plan, the fishery includes otter trawl, Danish seine, shark gill-net, and line sectors. It extends from subtropical Queensland to temperate southern waters off the southwest coast of Western Australia, including Tasmania, in depths from 20 m to over 1,200 m.

The primary management tool is a quota management system with total allowable catches (TACs) allocated as individual transferable quotas to 34 species or stocks. Other measures include input (vessel numbers) and gear (e.g., mesh size) controls and, in recent times, extensive spatial management, including spatial closures.

The SESSF has a history of monitoring and assessment programs, but there is a number of data-poor species, including some quota species. Until recently, however, there were no control rules linking the outcomes of assessments to management decisions. Consequently, TAC setting was often protracted and controversial. Although the quota management system was introduced in 1992, 12 species were identified as overfished or subject to overfishing in 2005 (McLoughlin 2006) when the HSP was announced.

A harvest strategy framework with tiered control rules was introduced into the SESSF in 2005 (e.g., Smith and Smith 2005; Smith et al. 2007). In this approach, each species or stock is assigned to one of four tier levels depending on the amount and type of information available to assess stock status: tier 1 represents the highest quality of information available—a robust quantitative stock assessment; tier 2 represents a preliminary quantitative assessment; tier 3 represents estimates of F from catch curves (age–length data); and tier 4 represents the least information available, for which targets and limits are based on historical standardized catch rates (catch per unit effort [CPUE]).

The RAGs advise on which species belong in which tier level. Each tier has its own means of determining relative stock status and a control rule that is used to determine a recommended biological catch (RBC). The RBCs provide the best scientific advice on what the total kill (landings plus discards) should be for each species or stock and are used in determining TACs.

The harvest control rules use similar targets and limits but have a discount factor applied to the outcomes of higher tier levels to that from tier 1 so that similar levels of risk operate across all tiers (Figure 2).

This approach deals effectively with data-rich and data-poor species. There are currently eight species for which RBCs are based on the tier 1 control rule, whereas management advice is provided for 12 species based on the tier 4 control rule (the tier that corresponds to the species or stocks with the most limited data).

Western Deepwater Trawl Fishery

The Western Deepwater Trawl Fishery (WDTF) operates off the Western Australian coast from subtropical to temperate waters. It began in 1987 as an extension of the North West Slope Trawl Fishery, as operators extended their exploratory fishing for scampi *Metanephrops* spp. and deepwater prawns (mainly royal red prawns *Haliporoides sibogae*). In response to poor crustacean catches, the fishery evolved into a finfish trawl fishery with considerable species diversity (>50 species; Moore et al. 2007). In recent years, bugs (fan lobsters) *Ibacus* spp. have been targeted and now form the majority of the catch. According to logbooks, between one-third and one-half of the total catch is discarded. Of the discards, about one-quarter is unidentified to species. The fishery is developmental and largely opportunistic, and species composition has been temporally variable. The GVP peaked at AU$2.5 million in 2002–2003 but has since declined dramatically, largely as a result of high fuel costs and low market prices (McLoughlin 2006). From 2004 to 2005, the GVP was AU$829,000.

It is impossible to characterize vessels, trawl types, or fishing methods given the diverse range of vessels that have operated in the fishery. There has never been a formal management plan. Rather, the WDTF was managed informally via limited entry (11 permits of 5 years' duration, although only seven vessels have operated in recent years). There were no output controls prior to the harvest strategy implementation.

There is limited information regarding the resources exploited by the WDTF. Consequently, the status of the fishery is classified as uncertain (McLoughlin 2006), although it is assumed that the current low effort levels are sustainable. However, many of the exploited demersal species, such as oreos (Oreosomatidae) and eteline snappers (Lutjanidae), are thought to be long lived, slow growing, late to mature, and vulnerable to overfishing because they aggregate to spawn (Wayte et al. 2007).

Unlike the SESSF, there is very little information for the WDTF and consequently it is impossible even to apply control rules such as the tier 4 rule outlined above. Consequently, the harvest strategy for this fishery focuses on detecting impacts of increases or changes in effort. Dowling et al. (2008) identified four broad principles for a harvest strategy that could be applied in this case: (1) trigger levels as reference point proxies; (2) identifying data-gathering protocols and subsequent simple analyses to better assess the fishery; (3) archiving biological data for possible future analysis; and (4) spatial management.

It is clearly not possible to set meaningful triggers for every species captured in this fishery. Therefore, the harvest strategy for the WDTF is focused on key commercial species as well as high-risk species identified by an ecological risk assessment (Smith et al. 2007; Wayte et al. 2007). This approach was considered adequate to control the overall level of fishing pressure. It was assumed that the subset of main species included in the harvest strategy would indirectly control the level of fishing pressure on low-value byproduct and bycatch species. Within the harvest strategy, regular reviews of the catch composition from the fisheries will be undertaken to check this assumption.

Existing monitoring of the fishery, including detailed logbooks and opportunistic observer coverage, was extended to a collection of baseline biological data (e.g., otoliths, length, and sex) on key species as a high-priority, ongoing requirement. Should a more thorough assessment for a particular species be triggered in the future, the cost of analyzing the samples is only accrued at this time. There may be no need to analyze these data until exploitation levels increase such that higher trigger levels are reached, so the costs associated with monitoring are minimal. However, a time series of critical information on the population biology of key commercial species can be established by collecting this information from the outset and simply archiving it.

Three trigger levels were set for key commercial species at generally 0.5, 1.0, and 2.0× the highest recorded catches, and these are associated with actions as follows: level 1 (catch exceeds half of the highest recorded catch) will lead to an exploratory analysis of catch and effort data; level 2 (catch exceeds the highest recorded catch) will lead to an assessment (along the lines of tier 3 or tier 4 of the SESSF) based on archived biological data together with an analysis of standardized catch rates; and level 3 (catch exceeds double the highest recorded catch) acts as a limit reference point in that targeted fishing will cease until a stock assessment demonstrates that any increased catch is sustainable. The inclusion of three trigger levels limits the expansion of the fishery by assigning progressively higher data and analysis requirements with higher trigger values. As such, the risk associated with further expansion is managed.

The harvest strategy also introduces strict catch controls for high-risk species, dividing the fishery into smaller management units and implementing spatial closures to protect benthic habitats. Full details of the harvest strategy can be found in Dowling et al. (2008).

The harvest strategy described above was developed during a series of workshops with broad stakeholder representation. Given the sporadic nature of the fishery and the paucity of data, anecdotal information from industry was particularly crucial when identifying the key species and developing potential trigger levels. Fishers' knowledge also assisted with the identification of appropriate spatial management boundaries.

Enhancing Stock Assessment Advice for Data-Poor Species by Using Intra- and Interspecies Knowledge

The previous sections have focused on the use of control rules designed specifically for data-poor species as a way to achieve fishery management goals. Another way to overcome the dilemma of providing advice for management of data-poor stocks is to make use of information for other stocks of the same species or for different species altogether.

Intraspecies Comparisons

It is possible to set the values for some of the parameters in assessments of data-poor stocks equal to those based on assessments of data-rich stocks when a species consists of multiple stocks, some of which are data rich and others are data poor. This approach has been applied for gummy sharks *Mustelus antarcticus* off Southern Australia. This species has been divided into three stocks; the Bass Strait stock has been fished and monitored extensively since the early 1970s, whereas the stocks off Tasmania and South Australia were not fished (or monitored) extensively until the late 1990s. The data for Bass Strait are sufficient to estimate two of the parameters that determine the underlying productivity of the population (MSYR: the ratio of MSY to the biomass at which MSY is achieved; M_{2+}: the rate of natural mortality for age-2 and older fish). However, this is not the case for the stocks off South Australia and Tasmania.

Early assessments (e.g., Pribac et al. 2005) set M_{2+} and MSYR for Tasmania and South Australia gummy shark stocks to those estimated for the Bass Strait stock, reflecting a simple way to use information from data-rich stocks to improve stock assessments of data-poor stocks. This approach led to a way to set MSYR and M_{2+} for gummy sharks off Tasmania and South Australia. However, because the values for these highly influential parameters were set rather than being estimated, it led to the paradoxical situation in which the uncertainty associated with biomass estimates for gummy sharks in Bass Strait was estimated to be higher than that for gummy shark stocks off Tasmania and South Australia (Pribac et al. 2005). Recent assessments of gummy sharks (e.g., Punt et al. 2008) have assessed all three stocks simultaneously and shared parameters (in particular M_{2+} and MSYR) among stocks. This has the advantages that data for all stocks inform the estimates of these parameters (although obviously the data-rich stock has the greatest influence on the estimates) and that the uncertainty associated with the estimates of these parameters is propagated through to all stocks.

Although the assessment of gummy sharks is based on a purpose-built software package, the more recent versions of Stock Synthesis II (SS2; Methot 2005, 2007) can model multiple stocks simultaneously using the "area" and "growth morph" options. However, to date, no assessments for species off Australia have been based on SS2 applications in which stocks in multiple areas are assessed simultaneously.

Interspecies Comparisons

The approach of the previous section is predicated on the assumption that at least one stock of the species being assessed is data rich. Unfortunately, it is more common that all stocks of assessed species will be either data rich or, more frequently, data poor. In this situation, it is necessary to use information for species other than that being assessed to inform data-poor assessments. This can be achieved by using Bayesian or quasi-Bayesian approaches. The 2007 round of assessments for groundfish species off the U.S. West Coast provides an example of the latter approach; the value for the steepness of the stock–recruitment relationship (a key parameter determining stock productivity) was set to the mean of a posterior distribution for this parameter constructed from rockfish and flatfish stock assessments conducted during 2005, implicitly recognizing that the ability of data for West Coast groundfish to estimate steepness is generally low. While this approach allowed the value for a poorly known parameter to be specified and hence allowed assessments to be conducted, there was no ability to propagate the uncertainty associated with the estimate of steepness through to the measures of uncertainty reported to decision makers.

Punt et al. (2005) extended the idea of constraining the values for uncertain parameters by using a fully Bayesian approach to stock assessment of multiple species. Prior distributions were imposed on all parameters, including the steepness of the stock–recruitment relationship (based on a meta-analysis of the stock–recruitment data assembled by R. A. Myers; e.g., Myers et al. 1995b). However, and of more relevance to data-poor assessments, the approach of Punt et al. (2005) also took account of the a priori information that arises because fishing intensity by one fleet leads to fishing mortality on all species available to that fishery in a multispecies fishery (essentially generalizing multispecies yield-per-recruit analysis [Pikitch 1987] to methods of stock assessment based on nonequilibrium population dynamics models). This involved imposing a prior (implemented as a penalty within a maximum likelihood estimation framework) on the relative trend in fully selected F (i.e., F for each year included in the assessment divided by the average F over the assessment period) on all the stocks fished by each of the fleets represented in the model. The prior was placed on the relative trend in F rather than F itself because catchability differs among species so that while the trends in F by a given fleet may be similar among species, this will not necessarily be the case for the absolute level of F. A similar approach is being proposed for the assessment of bronzespotted rockfish *Sebastes gilli* off the U.S. West Coast (S. Ralston, National Oceanic and Atmospheric Administration Fisheries, Southwest Fisheries Science Center, personal communication).

Priors (penalties) were also imposed on the length at 50% selectivity and the deviations in recruitment about the stock–recruitment relationship among species. This approach allows (1) the assessments for stocks that are data rich to be based on the data for those species almost exclusively and (2) the assessments for data-poor species to be based on their data (to the extent possible) but to be constrained to follow the patterns in F, selectivity, and recruitment variation for the more data-rich species. The approach is therefore effectively a nonlinear mixed-effects model where the estimates for key parameters (such as steepness, selectivity, and deviations in recruitment about its expected value) are "shrunk" to the mean values based on the data for all species.

The approach of Punt et al. (2005) has been applied to a group of species in the SESSF, including some of the most data-rich species (blue grenadier *Macruronus novaezelandiae* and the eastern stock of gemfish *Rexea solandri*), along with some very data-poor species (ocean perch *Helicolenus barathri* and mirror dory *Zenopsis nebulosus*). Currently, tier 4 rules are applied to the latter two species as the data are not adequate to conduct robust formal assessments for management purposes. However, it is recognized that the tier 4 control rule is subject to considerable uncertainty, in particular because it uses proxies for biomass reference points and because it relies on the assumption that catch rate is linearly proportional to biomass, an assumption that is frequently violated.

As expected, accounting for interspecies (and interstock) information tends to stabilize assessments of the data-poor species. For example, the estimated time-trajectory of relative abundance for ocean perch is sharply downward when an age-structured population dynamics model is fitted to (limited) age- and length-composition data (Figure 3B, D; note that the time-trajectories of model output provided as "stand-alone" assessments of the mirror dory and ocean perch in Figure 3 are for illustrative purposes only and are not sufficiently reliable as the basis for management advice). However, allowing for a prior based on trends in relative F indicates a stock sustained well above the conventional target level for SESSF species (Figure 3A, C). This result arises because the rapid increase in F needed to drive a marked reduction in biomass evident in Figure 3 (B, D) is not evident for the more data-rich species. The time-trajectory of relative abundance for the data-rich species (eastern stock of gemfish) is largely insensitive to whether priors are placed on among-species differences; in other words, the results for the data-rich species are not changed by being included in the multispecies analysis. The trends in mirror dory abundance are insensitive to the imposition of priors as there is information on catch rate and catch age composition, but trends are sensitive when the assessment is restricted to length composition data (contrast the upper and lower panels of Figure 3).

Discussion

There is a growing body of literature on formal harvest strategies, including control rules (e.g., see review by Deroba and Bence 2008), but they have been implemented in relatively few jurisdictions (Australia, United States, South Africa, and New Zealand). In most cases, such harvest strategies are based on model-derived estimates of stock status and relatively little attention has been paid to harvest strategies for data-poor fisheries (Smith et al. 2007, 2008; Cadrin and Pastoors 2008; Dowling et al. 2008; Prince et al. 2008).

In Australia, it is likely that there will always be data-poor species and fisheries, but the SESSF harvest strategy framework and the HSP have certainly provided the impetus to consider these species and fisheries more explicitly than was the case in the past. There are considerable sources of uncertainty, including observation, process, and model errors, even in the most sophisticated stock assessment. This uncertainty is magnified in data-poor situations. The key question, then, is how to judge whether the scientific management advice is suitably precautionary and whether the resulting management decisions will ensure sustainability and the satisfaction of the management objectives.

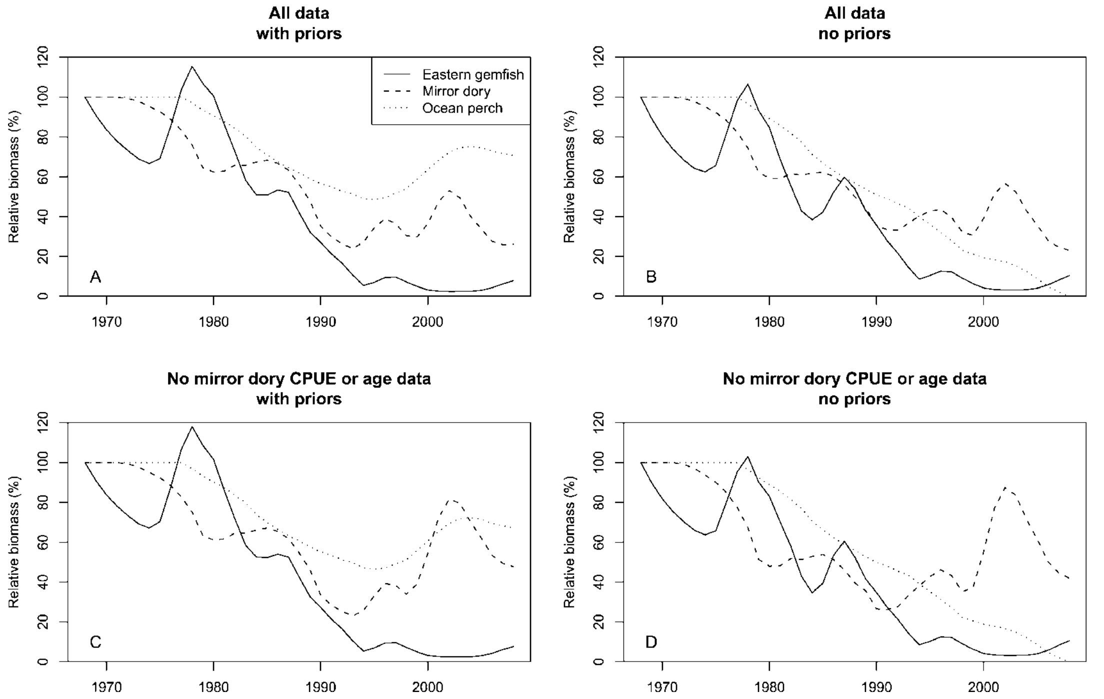

FIGURE 3.—Time-trajectories of spawning biomass relative to the unfished level for three species in Australia's Southern and Eastern Scalefish and Shark Fishery. Results are shown for assessment variants that treat each species independently (right panels) and that include priors on the trends in fishing mortality off eastern Australia (left panels). Results are also shown for two approaches to stock assessment in which the catch per unit effort (CPUE) and age composition data for one of the species (mirror dory) are ignored (lower panels).

There is usually a long time series of catch and effort data and a sound basis for standardizing CPUE to create an index of relative abundance for most stocks in mature fisheries, such as the SESSF. This provides some basis for scientific management advice (albeit dependent on the assumption that catch rates are proportional to abundance). Fisheries such as the WDTF are more problematic because even control rules like the SESSF tier 4 rule cannot be applied. For this fishery, it is assumed that the very low effort and catches are unlikely to significantly impact the stocks. Expert opinion on the same or similar species in other fisheries is also used to inform the harvest strategy for this fishery, and thus the resulting trigger levels are believed to be sufficiently conservative to ensure that future development in the fishery will be sustainable and, more importantly, that there is some basis to stop development if the need arises.

In principle, one way to improve the quality of stock assessment is to collect additional data. While this is to be both lauded and encouraged, additional data collected only over a few years will usually not be sufficient to allow a robust stock assessment to be constructed for a currently data-poor species. This is because methods of stock assessment that involve fitting population dynamics models (and could hence form the basis for the application of rules such as that for SESSF tier 1 species; Figure 1) require "contrast" in both catch and population size to enable key parameters to be estimated. For example, perhaps the most important parameter determining F reference points, such as F_{TARG} (Figure 1), is the parameter that determines the extent of compensation in the stock–recruitment relationship (steepness). However, the ability to estimate the steepness parameter depends critically on having contrast in spawning biomass. Unfortunately, it is not likely that enhanced data collection schemes will produce the amount of contrast needed to estimate steepness reliably over the short term or intermediate term except for species that are highly variable.

Clearly, cost is a very important issue. The HSP (through the guidelines) argues that the cost of collecting additional information must be taken into account (Australian Government 2007). Consequently, control rules are associated with costs: to achieve the same level of risk as control rules for data-rich species, control rules for data-poor species need to be more conservative. There is therefore a desire to "move species up the tier levels" and, in principle at least, achieve higher harvests for the same level of risk. This approach, therefore, puts a premium on collecting additional data. There is a trade-off between the cost of obtaining additional information and the benefit of additional harvest.

Harvest strategies need to be evaluated formally by using technical procedures, such as the management strategy evaluation (MSE) approach (Smith et al. 1999; Punt et al. 2001), to ensure that they meet the core elements of the policy (Australian Government 2007). The HSP highlights the importance of this, particularly in data-poor situations. The preferred approach is, of course, to evaluate harvest strategies before they are implemented. Unfortunately, this was not possible given the short lead time to implement harvest strategies for Commonwealth-managed fisheries in Australia. One consequence of this was that the original formulations of the SESSF tier 3 and tier 4 control rules, while sensible in principle, were shown to have undesirable properties (Smith et al. 2008) and have since been revised. Harvest strategies for fisheries such as the WDTF have yet to be evaluated, although this should be a matter of priority.

The HSP specifies B_{MEY} as the B_{TARG}. While B_{TARG} values have been estimated by using bioeconomic models for some Australian fisheries (e.g., Australian Government 2007; Dichmont et al. 2008), there is an even greater paucity of economic data than biological data for data-poor fisheries. This does not necessarily mean that substantial expenditure is justified to obtain economic data. The guidelines discuss some potential options for proxies to monitor the economic state of data-poor species and fisheries (Australian Government 2007). For example, monitoring the profitability of operators could be possible through the calculation of net returns, productivity indices, or profit decompositions (Australian Government 2007). However, some assessment of the likely benefits of using such methods relative to the costs of doing so needs to be undertaken. Latent effort may also be used as a simple indicator of profitability. A fishery operating at or near MEY will be generating above-average returns and will be attractive for permit or quota holders to enter. In a quota-managed fishery, sale and lease prices of quota may also provide an indication of the profitability of the fishery because how much a fisher is willing to pay for quota depends on the likely profits that the quota will generate (Australian Government 2007). Such proxies have yet to be formally considered or evaluated as the focus to date has been on biological rather than economic issues.

It is generally acknowledged that stakeholder engagement through processes such as co-management is a central component of modern fisheries management, particularly in Australia (Smith et al. 1999; Mapstone et al. 2008). Stakeholder engagement has been an important component of developing and implementing harvest strategies for Australia's small and data-poor fisheries. This has been through RAGs in some cases, but more generally it has been through consultative arrangements, such as workshops, organized specifically for the harvest strategy development process. Stakeholder buy-in is crucial to the adoption and ongoing success of the harvest strategy process in Australia. Fishers were, in many cases, not familiar with common assessment methods, let alone indicators, reference points, control rules, and the like. Equally important, however, has been the ability to incorporate the industry's knowledge when developing harvest strategies. This knowledge has proved very useful in setting the various triggers and targets given the lack of information available for many of these fisheries. Without this information, for example, developing the harvest strategy for the WDTF would have been extremely difficult.

Using assessments from data-rich species to inform assessments of data-poor species (termed a "Robin Hood" approach in Australia) has exciting possibilities. The multiple-stock Bayesian approach described here "allows" assessments for data-poor stocks to "learn" from assessments for data-rich stocks. However, it has yet to be used to provide formal management advice in Australia. In common with all Bayesian techniques, the approach relies on the assumption that stocks are interchangeable after appropriate covariates are taken into account (Gelman et al. 1995). This means, for example, that the impact of availability is minor compared to that of selection so that the lengths at 50% selectivity for the species taken by a fleet are roughly comparable among species. Similarly, placing a prior on the among-stock deviations about the stock–recruitment relationship assumes that the factors that influence recruitment success are common across stocks or species (Myers et al. 1995a). The approach does require further work, but results to date are encouraging and this approach has potential benefits for multispecies fisheries in which at least some of the species are data rich.

It is too early to assess the effectiveness of Australia's HSP, particularly in relation to sustainability of data-poor species. The HSP is to be reviewed 5 years after its commencement, but it is acknowledged that harvest strategies for specific species or fisheries may need to be amended within this time frame as more information on the performance of these strategies becomes available (Australian Government

2007). There have already been some benefits, however, that are most notable in the greater stakeholder input into the development of explicit harvest strategies with predetermined management outcomes. For example, there are much improved and focused data collection protocols in place for low-value, data-poor fisheries. Smith et al. (2008) described the SESSF harvest strategy as a success because, for example, the TAC setting process is now better defined and characterized by greater certainty and efficiency, even for data-poor species.

In conclusion, we believe that the Australian situation provides some general recommendations related to the provision of management advice for data-poor species as follows:

- The lack of data on which to base quantitative stock assessments that involve fitting population dynamics models does not preclude the development of objective harvest control rules.
- Evaluation of harvest control rules by using technical procedures, such as the MSE approach, is ideal but can be time consuming. In some cases, implementation before testing is a necessary reality.
- Information for data-rich species can be used to inform "assessments" for data-poor species. This can be done through formal methods, such as the Robin Hood approach, or less formally by developing precautionary harvest strategies for key commercial species, which will limit overexploitation of other bycatch and byproduct species in the fishery.
- Stakeholder buy-in and knowledge are essential when species are data poor. Use of this information, however, needs to be constrained by policy decisions, such as prespecified performance standards.
- Control rules for data-poor species should recognize that for some species, sufficient data may never be available to enable quantitative assessments to be conducted. In these cases, there is a trade-off between the cost of data collection and the value of the fishery; adopting a sufficiently precautionary approach may be the only realistic way to manage some low-value, data-poor species.

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