Fisheries management procedures: a potential decision making tool for fisheries management in California

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TROPHIA

Preface

This report examines the potential of management procedures as a decision making tool for fisheries management in California. It was commissioned by the California Ocean Protection Council and the California Department of Fish and Game under a contract awarded to Quantitative Resource Assessment LLC.

The report is broken into two parts. The first part, "Fisheries management procedures: an introduction" describes fisheries management procedures, their benefits and potential pitfalls. The second part, "Meta-evaluation: application to the California nearshore fishery" applies a newly developed approach to evaluating management procedures. This approach ("meta-evaluation") has been developed as a means of more rapidly and efficiently evaluating management procedures. We applied meta-evaluation to the 19 species belonging to the California nearshore fishery.

Acknowledgements

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Fisheries management procedures: an introduction

Nokome Bentley & Kevin Stokes

1 Executive summary

The quality of decision making is central to the success of fisheries management. Fisheries management procedures are an approach to fisheries management decision making that is more strategic, less subjective, more transparent and more inclusive. The approach actively addresses the key features of fisheries which make their management so challenging: their high levels of uncertainty and their multiple, often conflicting, management objectives. Fisheries management procedures provide a tool for implementing many of the policies defined within the California Marine Life Management Act.

A fisheries management procedure is a formal definition of what, and when, management actions are to be made in response to changes in a fishery. It is a collection of specifications, formula and rules which maps the pathway from fisheries data to fisheries management actions. This document provides a broad overview of the concepts and processes involved in applying a management procedure to a fishery.

Management procedures can take numerous and varied forms. However, the key feature of management procedures that separates them from other fisheries decision making policies is that their performance can be evaluated through simulation. This feature arises because management procedures are formulaic: they set out an exact description of the tactical decision making process. Management procedures can form a core part of a broader fisheries management plan but their role should be limited to those aspects of the fishery which can be realistically simulated. We describe the various components of a management procedure. These components can be combined in different ways to achieve different management objectives for different fisheries.

We provide an overview of the processes involved in developing and implementing a management procedure to a fishery: formulation, design, evaluation, selection and operation. For each of these processes we describe the roles that various participants in the management of a fishery will play.

Stakeholder and political understanding and buy-in are important if the advantages of the management procedures approach are to be gained. To be effective, the approach requires a commitment from both stakeholders and decision makers that the outcomes of the management procedure will be adhered to. However, the approach does allow for “meta-rules” which can define such aspects as exceptional circumstances under which a review, and possibly a change, of the management procedure is warranted.

While the management procedure approach provides several significant advantages over more *ad hoc* fisheries management decision making, it also has pitfalls which participants should be vigilant of. These include over and under precision in simulation models, a lack of attention to the selection process, and over-expectation of the short term performance of management procedures.

2 Introduction

> *"Just as fishing is a human activity, so must fisheries management concern itself with people. Under the MLMA, people are not simply to be controlled or manipulated, but are to be involved in determining how our fisheries can be sustainable. This requires expanding traditional government approaches to public involvement and opening up the decision making process so that the rationale for decisions is clear once decisions are made. This challenge is as formidable as relying upon the best available science."*[1]

Fisheries management, like other forms of management, involves deciding what actions to take in order to achieve pre-specified management objectives. The decision making process is paramount: good management systems that deliver efficient execution of decisions are worthless if the decisions themselves are poor. Fisheries management has two important characteristics which pose significant challenges to its decision making process. First, fisheries management has to deal with a very high level of uncertainty in the current state, and the future dynamics, of the system it attempts to manage. Few, if any, other forms of management have so little certainty in the outcomes associated with alternative management actions. Second, fisheries management usually involves multiple stakeholders with multiple, and often conflicting, objectives.

This document is an introduction to management procedures, a relatively new, more formal approach to fisheries management decision making; one which takes a proactive approach to both the high uncertainty and the multiple objectives that fisheries management must face. A fisheries management procedure is a formal definition of what, and when, management actions are to be made in response to changes in a fishery. It is a collection of specifications, formulae and rules which maps the pathway from fisheries data to fisheries management actions. In essence, a management procedure is simply a "standard operating procedure" for fisheries management decision making. It is analogous to the procedures commonly used in business, medicine, military and other fields, for defining specific responses to specific events. A management procedure could be called a "management strategy" or a "management policy". However, the term management procedure better emphasizes the formality and exactness that is inherent in the approach. As we describe later, this is important because it allows decision makers to evaluate which management procedure is most likely to achieve the management objectives of a fishery.

2.1 Strategy and tactics in fisheries decision making

In any form of management, the decision making process can be divided into strategic and tactical phases. Strategic decision making is deciding on a plan (the strategy) to achieve objectives. Tactical decision making is deciding on actions (the tactics) to achieve the plan. We have introduced the concept of two phases of decision making because they are fundamental to understanding the difference between the conventional approach and the management procedure approach to fisheries management decision making.

The conventional approach to fisheries management decision making is illustrated in Figure 1. This simple schematic represents the pathway between management objectives and data (top), and management actions (bottom). Under the conventional approach there tends to be little strategic decision making. Often strategy is limited to choosing reference points which reflect a limited set of management objectives such as sustainability and yield. Other management objectives, such as economic efficiency or the enjoyment of recreational fishing, are often not formally incorporated into explicit management strategies. The tactical decision making phase consists of estimating the status of the stock by fitting stock assessment models to data from the fishery and then using the

1 Mike Chrisman & Robert C. Hight. Forward to the MLMA.

model to estimate the status of the stock relative to the reference points. This process is usually resource intensive and thus costly, and often disputes can arise over the data used and assumptions made. Decisions are then made regarding appropriate management actions by considering these estimates, and perhaps other aspects of the fishery, in relation to management objectives. We label this phase "consideration" because it is usually a relatively subjective, less formal, and often opaque, weighing up of alternative management objectives. Sometimes, the management decisions that are made are more a reflection of the political environment at the time than a reflection of either stock status or management objectives. This tactical decision making process is repeated, sometimes annually, usually more sporadically, and often reactively in response to perceived problems with the fishery.

The management procedure approach to fisheries management decision making is illustrated in Figure 2. Once again, this figure illustrates the decision making pathway between objectives and data, and actions. Under this decision making approach, management objectives are formulated into a set of performance statistics. Alternative candidate management procedures are designed and evaluated with respect to those performance statistics. This evaluation is done using a computer simulation model, or several models, which are conditioned using the available data to reflect the knowledge currently available for the fishery. Based on the performance statistics arising from the evaluation a single management procedure is selected from amongst the candidates. The tactical phase of decision making is simply the operation of the chosen management procedure. The rules and formulae in the management procedure will define exactly what management actions should be made in response to data from the fishery.

A direct comparison of Figure 1 and Figure 2 is useful for highlighting some of the fundamental differences between the management procedure approach and the conventional approach to fisheries decision making:

- **Clear separation between strategic and tactical decisions**. Under the conventional approach, management objectives are considered during tactical decision making. In the management procedure approach there is a much clearer separation between strategic and tactical phases of decision making: management objectives are only considered in the choice of management procedure and not when operating that procedure.
- **Greater emphasis on strategic decision making**. Under the conventional approach, most of the decision making capacity is invested in the tactical phase. In contrast, under the management procedure approach, the chosen management procedure effectively takes over the tactical decision making. This allows for decision makers and stakeholders to focus on the strategic phase; that is, on the choice of management procedure.
- **Less subjective, more transparent, decisions**. Because a management procedure specifies exactly what, and when, management actions are to be taken, all tactical decisions are completely objective and transparent. This substantially reduces the amount of effort expended on arguing over management actions. Some amount of arguing and subjectivity will occur during the choice of management procedure but this is entirely appropriate during the strategic phase. As we shall describe, the management procedure approach provides a framework in which the potentially conflicting objectives of different stakeholders can be made explicit and thus potentially more easily resolved.

Figure 1. Processes and elements in conventional fisheries management decision making. The infrequent, strategic and frequent, tactical phases of decision making are indicated by the dotted boxes.

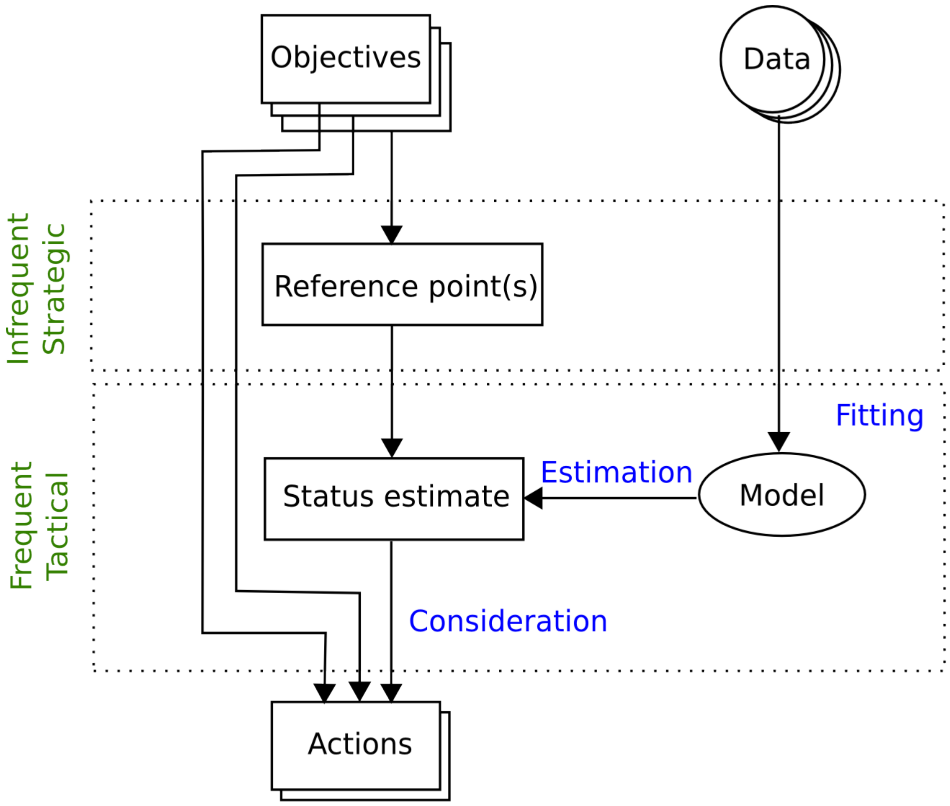
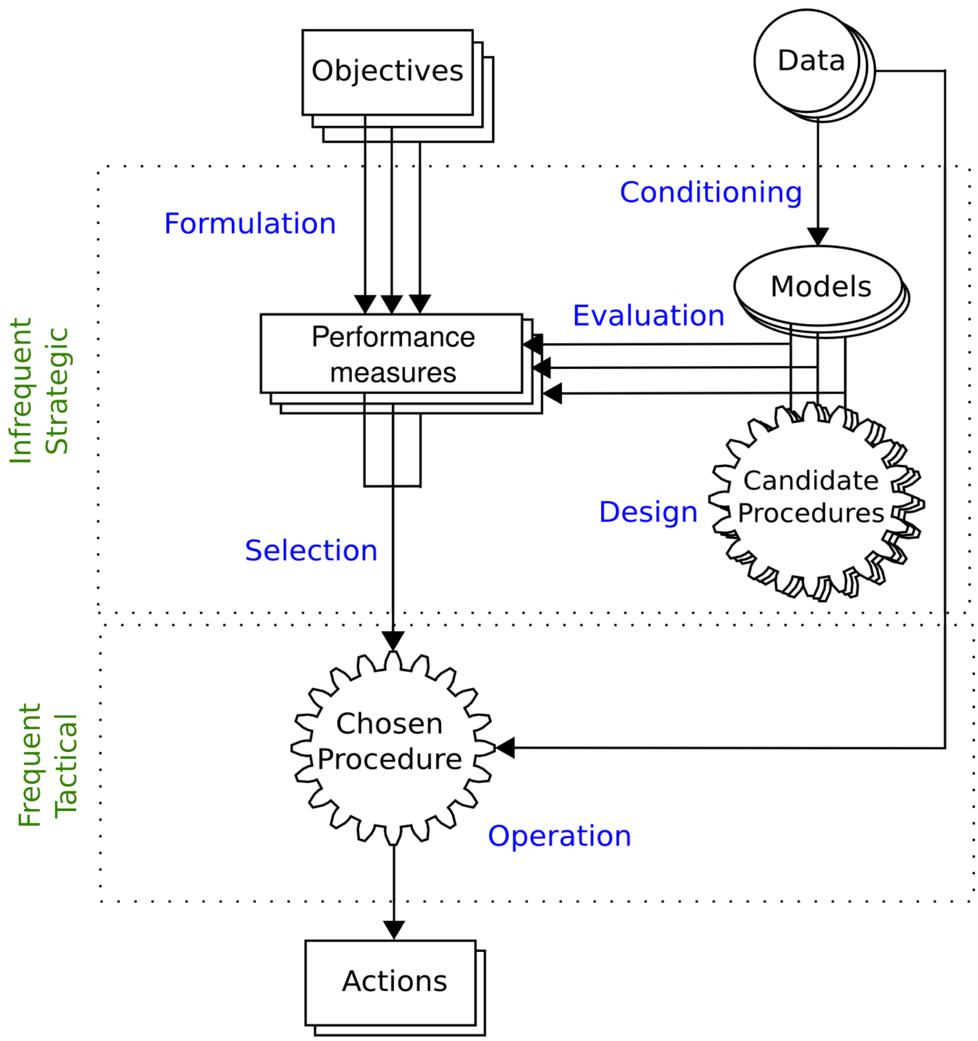


Figure 2. Processes and elements in conventional fisheries management decision making. The infrequent, strategic and frequent, tactical phases of decision making are indicated by the dotted boxes.



2.2 Management procedures and the MLMA

This document was commissioned by the California Department of Fish and Game (CDFG) as a background document on fisheries management procedures. The California Marine Life Management Act (MLMA) became law in 1999. Whilst providing an ecosystem context, the MLMA primarily focuses on marine fisheries and sets out policies to ensure all fisheries are managed to provide long-term benefits. Whilst attending to the wide range of benefits that fisheries can provide, the MLMA especially focuses on ensuring sustainability – the ability of fish stocks to replenish themselves. Sustainability is the necessary building block that enables other benefits both in the long and the short-term. Sustainability is at the heart of international fisheries agreements[2] and Federal legislation[3] and the MLMA provides a simple but important definition of sustainability that places it as the dominant goal that should not be compromised for short-term economic, social or other benefit.

The MLMA provides for a strong fishery management planning framework with an emphasis on involvement of constituents, consideration of multiple objectives, adaptive responses and use of science. In this document we hope to illustrate how fisheries management procedures are not only consistent with the policies of the MLMA, they are sympathetic.

2.3 This document

There are already several reviews of the management procedure approach[4]. This document attempts to present a general and less technical overview. Our intention is to give the reader a broad understanding of the concepts and processes involved in applying a management procedure to a fishery. There are many details of the management procedure approach that we do not discuss but where possible we provide the reader with guides to further reading.

The processes that we describe in this document are often referred together as "management strategy evaluation (MSE)". We avoid using this as an umbrella term for the processes involved because, as we will describe below, evaluation is only one element of the development and implementation of management procedures.

3 Characteristics, roles and components of management procedures

> *We now have powerful new scientific tools to use in developing methods for the management of marine living resources. It is essential that we use these tools if we are to have scientifically based management which will achieve ecologically sustainable utilization and conservation of marine living resources. … Attempting to reach such goals by trial and error on managing real fisheries will be both a trial and an error. Making our mistakes quickly by simulation can spare us from making them in reality.*[5]

Management procedures can take numerous and varied forms. This section begins with a description of the necessary characteristics that all management procedures must have. Next, we describe what role management procedures play inside a complete fisheries management policy. Finally, we discuss in more detail the component parts of a management procedure and how these parts can be put together in different ways to suit the particular management objectives for, and

2 United Nations 1995a, 1995b

3 The primary federal marine fisheries law is the Magnuson-Stevens Fishery Conservation and Management Act which is available via http://www.nmfs.noaa.gov/msa2007/index.html

4 For examples see Smith et al (1999), Butterworth and Punt (1999), Punt and Donovan (2007)

5 From de la Mare (1996).

characteristics of, a fishery. We provide some simple examples of management procedures.

3.1 Characteristics

As we have already described, a fisheries management procedure is simply a specification of what, and when, management actions are to be made. So, what makes a management procedure unique? How does it differ from a "management plan" or "management policy"? After all, these other management constructs also include a specification of what and when management actions are to be made.

The key feature of management procedures that separates them from other fisheries decision making policies is that their performance can be prospectively evaluated. This feature arises because management procedures are formulaic: they set out an exact description of the tactical decision making process. While this exactness may sometimes seem restrictive, it is a very valuable characteristic of management procedures because it allows for them to be repeated. Repeatability is an important part of the scientific method, one that allows for evaluation of alternatives. In contrast, the operation of management policies that are inexact, those that allow interpretation and subjectivity, are very difficult to repeat.

The evaluation of management procedures is a form of experiment, or test. One way of testing alternative management procedures would be to successively implement them in a fishery and see which one performs best. There are several reasons why such an experiment is inappropriate, and indeed, invalid:

- **Long-time scales**. To perform a single evaluation of a single management procedure in a real life fishery would take several years (at least as long as the generation time of the species being fished). To evaluate and compare several alternative management procedures to determine which was most appropriate would take far too long.
- **Important consequences**. It would be inappropriate to experiment with alternative management procedures in a real fishery because the potential economic, social and environmental consequences are too important.
- **Lack of repeatability**. A requirement of controlled scientific experiments is repeatability. To properly compare the performance statistics arising from several management procedures it would be necessary to implement each one under the same set of conditions. Clearly, this is not possible for a real fishery.

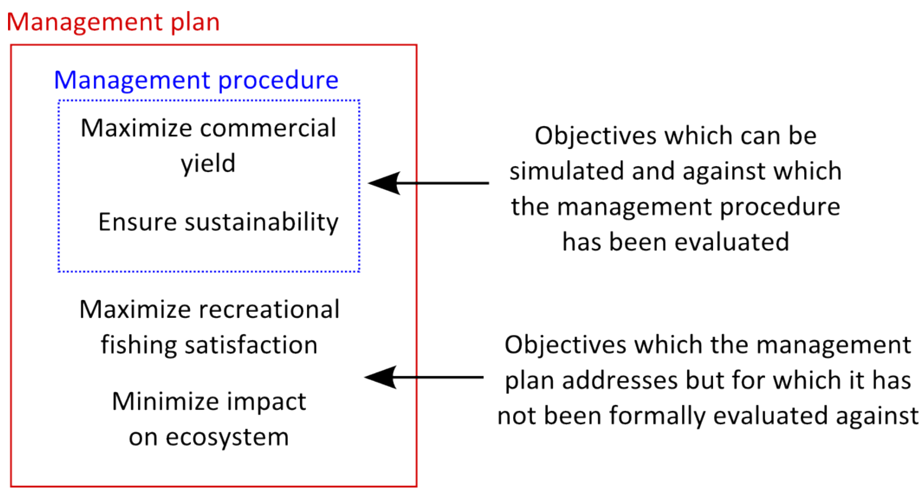
Given that we are unable to test management procedures on real fisheries how can we evaluate them? The answer is to use computer simulation model of the fishery as a test bed. That is, we create a "virtual" fishery based on what we know about the fishery, or similar fisheries, and use this as a "guinea pig" to experiment with alternative management procedures. Computer simulation models allow us to avoid the problems associated with real world experiments: they are very quick to perform, there are no immediate consequences for the fishery, and they are controllable, and thus, repeatable.

3.2 Role and relationships

The ability of management procedures to be simulated is a key characteristic that provides much of their strength. But it is also a limitation: management procedures are restricted in their scope to aspects of the fishery that can be simulated. For instance, if a simulation model for a fishery does not include linkages between the fishery and the wider ecosystem, then it is impossible to evaluate the performance of management procedures with respect to management objectives that address the impact of the fishery on the wider ecosystem. Thus, management procedures are not a "cure all". Attempting to treat them as such may diminish their value. Instead, management procedures should be treated as a core component within a broader fisheries management plan. The role of management procedures should be restricted to those things that can be realistically simulated.

Figure 3 illustrates the potentially changing role of management procedure within a broader fisheries management plan. The management procedure is constrained to addressing those objectives which can be simulated in a computer model. Those objectives which lie outside of the scope of the management procedure may be addressed in a less formulaic manner in the wider management plan. The key point here is to explicitly distinguish between those parts of the management plan which have been evaluated (everything contained within the management procedure) and those that have not. As the knowledge of the fishery grows, and the sophistication of the simulation model of the fishery increases, the management procedure can be evaluated against more of the management objectives.

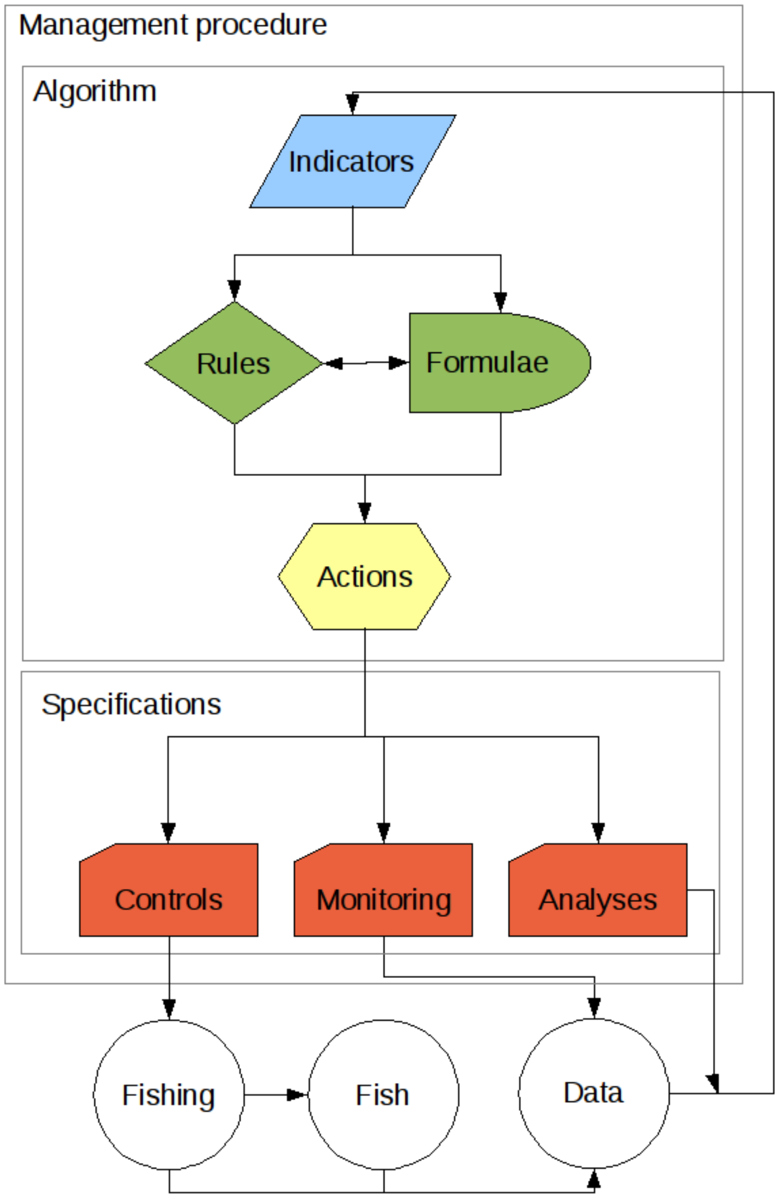
Figure 3. An illustration of the role of a management procedure within a fisheries management plan. Within the management plan there is a distinction between those objectives against which alternative policies have been evaluated (those that lie within the management procedure) and those that have not (which may be addressed in an equally formulaic manner but based on prior experience). As the knowledge and sophistication of modeling for a fishery grow, so too may the role of the management procedure with the management plan.



3.3 Components

Figure 4 is a schematic representation of a generalized fisheries management procedure. It illustrates the components within a management procedure, the connections among them and their consequences for the management of the fishery. In this simplified representation, fisheries management is condensed into a management procedure which defines and potentially changes three management processes: control of fishing activity, data collection and data analysis. We distinguish between two parts of a management procedure: specifications which define how these management processes are to be conducted and an algorithm which defines how specifications are to be altered in response to changes in the fishery.

Figure 4. Components of a fisheries management procedure and their interaction. See text for a description of each type of component.



3.3.1 Specifications

All fisheries management procedures must include at least some specification of how the core processes of fisheries management are to be carried out. In order to be responsive to changes in the fishery, a management procedure will usually alter at least some of these specifications over time. Other specifications may remain fixed over time but are nonetheless necessary, intrinsic, parts of a definition of a management procedure.

3.3.1.1 Controls

We use the term "controls" to describe those specifications that affect fishing activities. They include input controls such as minimum legal size and total allowable effort (TAE) and output controls such as total allowable catch (TAC). Management procedures will almost always involve changes to controls.

3.3.1.2 Monitoring & Analyses

Management procedures react to changes in a fishery. To do this they are dependent on some sort of data collection, or monitoring, and the analyses that condense these data into a set of indicators. Since a management procedure depends upon the method used for data collection and data analysis, these need to be defined in its specifications. Often, management procedures do not change monitoring or analyses over time; that is, they are static specifications of how monitoring and analyses are to be performed. However, it is possible that both these aspects are altered in response to changes in a fishery. This may be particularly important in attempting to maintain cost efficient management. For example, fishery independent surveys are often costly compared to fishery dependent data such as catch-per-unit-effort (CPUE). A management procedure which switches between CPUE and survey indices of abundance depending upon the status of the stock may thus provide more cost effective management[6].

The analyses used in a management procedure may be quite complex. For example, they may even include age-structured modeling of the population. However, it is important that whatever analyses are performed that they are not too complicated, or involved to many subjective decisions, to be simulated. As already stated a fundamental advantage of management procedures is their ability to be evaluated in simulation and this can be lost if they involve overly complex analyses.

3.3.2 Algorithm

Management procedures define an algorithm which defines how specifications will be altered in response to changes in the fishery. This algorithm represents the adaptive part of a management procedure.

3.3.2.1 Indicators

To be effective, management procedures need to respond to changes in the fishery. That is, they require inputs that reflect the current, and potentially the future state, of the fishery. We use the term "indicators" to describe these inputs. Indicators are generated by the analyses that the management procedure specifies. These analyses are in turn dependent upon monitoring to generate the necessary data.

3.3.2.2 Actions

Actions are the end product of a management procedure algorithm. Actions describe the changes to

6 See Bentley & Stokes (2009b) for an example of this type of management procedure

be made to one of the procedure's specifications. For example, "decrease total allowable catch by x %", "undertake fishery independent survey", and "switch to annual analysis of catch and effort data" are actions that could be included in a management procedure to alter the specification of controls, monitoring and analyses respectively.

3.3.2.3 Rules & Formulae

At the heart of the management procedure algorithm are rules and formulae. These define how indicators are used to generate management actions that alter management specifications. A management procedure may combine several rules and formulae.

Formulae are mathematical expressions of the relationship between two variables within a management procedure. Examples of formulae used in management procedures are simple ratios between indicators and their long term average or target values.

Rules are a form of formula that involves an "if x then y" construct. Rules are often used to introduce thresholds for indicators beyond which management actions are made. For example, a management procedure which uses the trend in CPUE over the last 5 years as an indicator might include a rule such as "if the trend in CPUE is greater than 20% per year then increase total allowable catch (TAC) by 20%". Another example of the use of rules in management procedures is to act as a filter by restricting actions to an operationally appropriate range e.g. "if the TAC change from formula B is less than 3% then do not change TAC".

3.4 Examples

In this section we attempt to clarify some of these potentially abstract concepts and illustrate those using examples of management procedures. We show how, specifications, indicators, rules and formulae can be composed in alternative ways to produce management procedures suited to the characteristics of different fisheries. These examples are purely illustrative and are not necessarily recommended for any fishery in particular. They merely serve to display the wide variety of forms that management procedures can take.

3.4.1 A simple management procedure

The most simple management procedures use a single indicator to make changes to a single management control. Other aspects of the procedure, such as monitoring and analyses to be conducted, are represented in static specifications.

Figure 5 shows an example of such a procedure. It specifies that each year, 300 fish are sampled from the catch and total mortality estimated from this sample using the Chapman-Robson method. The specifications for both of these processes should be far more detailed than this simple description: they should include details about the sampling, aging and analysis methodologies. Including these details improves the likelihood that the operation of the procedure is not inadvertently altered by subtle changes in scientific methods.

In this example management procedure, the estimate of total mortality (Z) derived from the age frequency sample is used in a very simple way. A target range of Z values is used as the basis for adjusting TAC up or down in fixed percentage jumps. If Z falls above the target range, for example, because the current catches are high relative to the biomass of the stock, the TAC is reduced by 10%. Conversely, if Z falls below the target range, for example, due to increased abundance of the fish population, then Z is increased by 10%.

Given the complexity that we have become accustomed to in modern stock assessments it may be difficult to see how such a simple management procedure could provide appropriate management responses. The key to understanding this apparent paradox is to recognize that management procedures have attributes that can be varied to suit the particular characteristics of the fishery. For example, even in this very simple management procedure there are three main attributes that can be adjusted : the upper and lower bounds of the target Z range and the magnitude of the percentage change in TAC. Even though the management procedure itself is very simple, the simulation model that is used to evaluate it, and thus which forms the basis for selecting the values of those attributes, can be very complex and incorporate all of the available information for the fishery. For example, for a shorter lived species the optimum values for the target range of Z values and the percentage change in TAC are likely to be higher.

3.4.2 A more complex management procedure

More complex management procedures involve multiple indicators and involve management actions that alter more than one specification. Figure 6 is an example of such a procedure. It involves an annual sample of 1000 fish lengths from the catch and a fishery independent survey which is conducted every 3 years, or as otherwise triggered by the procedure. The mean length of fish and survey biomass index (the survey estimate of total biomass divided by it own long-term mean) are calculated from these two forms of monitoring and used as indicators by the procedure. Each time the management procedure is operated it uses the current value of mean length and the last biomass index that was obtained.

If the mean length is below 35cm then the management procedure changes the TAC by 10%: upwards if the biomass index is above one (i.e. above the long term average) since this suggests increased recruitment, or downwards if the biomass index is below one since this suggests overfishing. In addition to these rules, if the biomass index is ever below 0.7 then the management procedure reduces TAC by 10% *and* triggers a fishery independent survey the following year.

This example illustrates that management procedures can change aspects of fisheries management other total allowable catches. They can also invoke management actions which alter the frequency or intensity of both monitoring and analyses. Doing so may provide significant cost advantages while still providing for robust performance. In this case, the management procedure only requires a survey to be conducted once every three years but is precautionary in that it triggers additional surveys in every year that biomass falls below a threshold. As for the other attributes of the procedure, the attributes which control the frequency (e.g. number of years between surveys) and intensity (e.g. size of the length sample taken) of monitoring can be tuned according to evaluations using the simulation for the fishery.

Figure 5. An example of simple fisheries management procedure. The shapes and colors of components follows Figure 4. Note that in this management procedure only one indicator is used and only one control specification, the value of total allowable catch, is changed. Other specifications, such as the setting of minimum legal size limits, and the monitoring and analyses to be done are static. See text for further description.

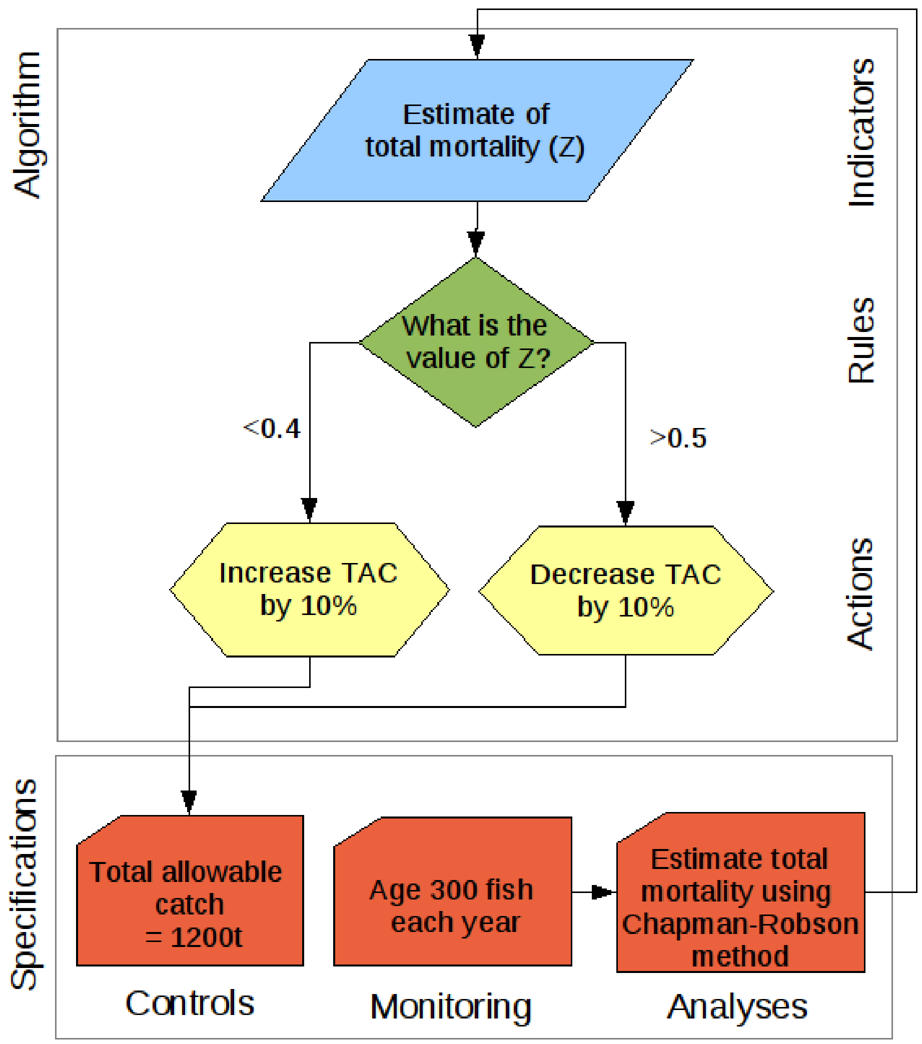
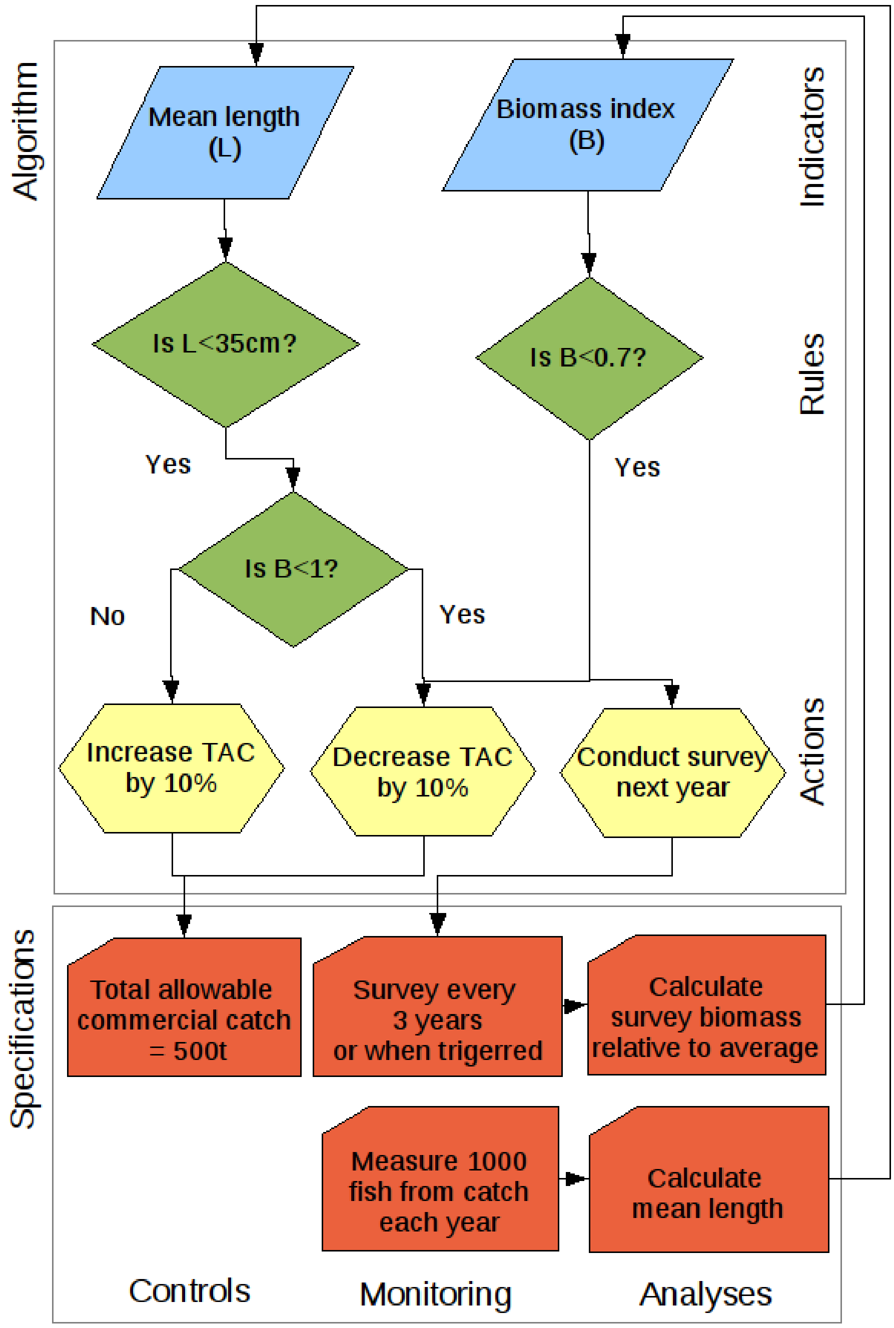


Figure 6. An example of a more complex fisheries management procedure. The shapes and colors of components follows Figure 4. Note that in this management procedure two indicators are used in a series of rules which alter the specifications for total allowable catch (TAC) and for when a fishery independent survey will be done. See text for further description.



4 Applying a management procedure to a fishery

"when people become involved in management decisions, their stake in the stewardship of marine life grows"[7]

In this section we provide an overview of the elements and processes involved in applying a management procedure to a fishery. These parts of the approach are represented in Figure 2 and the following sections describe each process in more detail.

Each of the processes that we outline is a necessary part of applying a management procedure to a fishery. As we describe later, these processes need not be performed in the order that we describe. Often there will be an iterative progression in which some of these processes are revisited.

4.1 Participation

A key advantage of the management procedure approach is that it provides a framework for broad participation in decision making. As described already, this participation is not at the level of tactical decision making, the management procedure takes care of that. Rather, it is at the level of strategic decision making. Thus, repeated haggling over management actions is avoided in favor of balancing multiple objectives during the process of selecting a management procedure to apply to the fishery.

Since participation, particularly stakeholder participation, is an important feature of the approach, for each process we outline the roles of various actors in the management of a fishery. We have grouped people usually involved in a fishery and its management into three broad categories:

- **Stakeholders**: interested parties; any individual or group that is affected by the management of the fishery (e.g., commercial fishers, recreational fishers, environmentalists, government representing interest of public at large).
- **Managers**: policy makers; any individual or group involved in generating and implementing policy for management of the fishery (usually government officials but also including those from commercial fishing, recreational fishing and environmental groups).
- **Scientists**: providers of knowledge and technical expertise; often from government but also scientists employed by stakeholders, and stakeholders themselves.

Obviously, these are broad definitions of the people involved in the management of a fishery[8]. A particular person will often fall into two or more of these categories. For example, within a management framework that is participatory, stakeholders will often also be managers. Stakeholders, particularly those who are actively involved in the fishery, will often provide knowledge that is valuable in the scientific interpretation of data.

4.2 Formulation

Formulating a set of management objectives and associated performance measures is a critical process in applying a management procedure to a fishery. In order to know which management procedure is most appropriate for a fishery, alternative candidate management procedures need to be quantitatively evaluated using some measure of the performance of the fishery, we call these

7 Introduction to MLMA http://www.fgc.ca.gov/mlma/introduction.html

8 See Mikalsen and Jentoft (2001) for a discussion on definitions of fisheries stakeholders and managers

performance statistics. The primary responsibility for defining management objectives and associated performance statistics will usually lie with fisheries managers and stakeholders. Scientists will play an important role in advising on whether or not performance statistics can be feasibly simulated.

4.2.1 Management objectives

Objectives are the "whys" of fishery management. If there were no objectives then there would be no need to manage. As such, management objectives should be a focus of any management approach. Often there are a variety of fisheries management objectives reflecting a variety of stakeholders[9]. However, there are several fisheries management objectives which are common in fisheries around the world. These include:

- maximizing profitability of commercial fishing,
- maximizing satisfaction of recreational fishing,
- minimizing the risk of stock collapse (i.e. maximizing the probability of sustainability)
- minimizing the impact of fishing on the ecosystem,
- maximizing the cost efficiency of management.

Management objectives for a fishery are often already defined. In this case, the process of formulating performance statistics can nonetheless help to remind managers and stakeholders of these management objectives and/or clarify their meaning. Often management objectives are broad. For example, legislated management objectives usually apply to all the fisheries within a jurisdiction. The formulation phase allows for a redefinition of such objectives in terms that are relevant to the specific fishery.

A potentially useful technique for defining management objectives is to express them as a hierarchical tree. In such a tree, broad, generic management objectives are successively split into sub-objectives specific to the particular fishery[10]. In developing a management objective hierarchy it is important not to confuse management objectives, the "whys" of management, with the "hows" of management. A list of management objectives should be about what stakeholders ultimately desire from their fishery and its supporting ecosystem, not the steps required to achieve those desires (that comes later). Table 1 uses a hypothetical California fishery to illustrate how some of the management objectives in the MLMA could be made more specific for a particular fishery.

4.2.2 Performance statistics

The achievement of management objectives is measured by performance statistics[11]. Performance statistics represent qualitative management objectives in quantitative terms. This translation is necessary so that alternative management procedures can be evaluated and their relative performance compared. In this sense, performance statistics represent the link between scientific predictions of management outcomes and stakeholder expectations.

Performance statistics will normally be specified for each of the lowest level management sub-

9 See Leung (2006) and Mardle et al (2002) for descriptions of management objectives commonly found in fisheries.

10 See for example Mardle et al (2004)

11 In using the term "performance statistics" we are following the glossary developed by Rademeyer et al (2007). The term "performance measure" is often used to mean the same thing e.g. Bentley and Stokes (2009b).

objectives defined in the objective hierarchy. To be useful, performance statistics should be[12]:

- **Comprehensive**: completely describe the extent to which a management objective has been achieved; and
- **Simulate-able**: able to be simulated so that the performance of alternative management procedures with respect to the management objective can be estimated.

To a large extent these two properties ask contrasting questions of the appropriateness of performance statistics. Comprehensiveness asks the question: "Does the performance statistic provide the measure we need?" Managers and stakeholders will usually be able to answer this for themselves. Simulate-ability asks the question: "Is it possible to estimate the value of the performance statistic given a particular management procedure?" This will require guidance from scientists; there is little use in managers and stakeholders specifying a performance statistic that can not be simulated.

Unfortunately, there will be some performance statistics that cannot be simulated given the knowledge and models available for the fishery system. For example, performance statistics reflecting the impact of the fishery on the ecosystem will often be very difficult to simulate. Since evaluation through simulation is a fundamental feature of the management procedure approach, management objectives which cannot be represented by simulate-able performance statistics, cannot be properly addressed by the approach. As knowledge on a fishery grows, the scope of performance statistics, and thus the potential scope of management procedures for that fishery, is likely to grow.

In addition to these properties, performance statistics should ideally be able to be easily measured in the real world[13]. This allows a "reality check" to be done between the values of performance statistics arising from simulations and their values actually achieved in the fishery.

Once performance statistics have been has been agreed upon there a number of properties that the set as a whole should ideally have[14],

- **Complete**: as far as possible addresses all management objectives;
- **Decomposable**: allow for aspects of the overall management objective to be analyzed separately;
- **Non-redundant**: avoid double counting of management sub-objectives; and
- **Minimal**: notwithstanding (a), (b) and (c), keep the set as small as possible to ease analysis of trade-offs and final selection.

12 Based on Keeney and Raiffa (1976) who use the term "attributes" for what we call "performance statistics"

13 See Butterworth (2007) and Bentley & Stokes (2009a) for a discussion on preferring performance statistics that can be measured to those that can not.

14 Again, this set of properties is based upon Keeney and Raiffa (1976) with modification where appropriate for fisheries management procedures. See more discussion there.

Table 1: A hypothetical example of a management objectives hierarchy with associated performance statistics. The main management objectives are based on those in the MLMA.

Management objective	**Performance statistic**
1. Sustainability: "Sustainable so that long-term health is not sacrificed for short-term benefits"	Minimize the proportion of years below which spawning biomass falls below 10% of unfished levels.
2. Restoration: "Depressed fisheries are to be rebuilt within a specified time"	Maximize the proportion of years in which biomass increases when biomass is below target level.
3. Fishing communities: "Recognize the long-term interests of people dependent on fishing"	
3.1. Maximize yield	Maximize the average annual catch
3.2. Minimize uncertainty	Minimize the frequency of TAC changes
3.3. Minimize cost of fishing	Maximize the abundance of fish above 30cm length
4. Non-Consumptive Values: "Aesthetic and recreational enjoyment"	
4.1 Maximize the size of fish	Maximize the mean length of fish
4.2. Maximize the abundance of fish	Maximize the abundance of fish
5. Bycatch: "The bycatch of marine living resources in fisheries is to be limited to acceptable types and amounts"	Addressed elsewhere in fisheries management plan
6. Habitat Conservation: "The habitat of marine wildlife is to be maintained, restored or enhanced, and any damage from fishing practices is to be minimized"	Addressed elsewhere in fisheries management plan
7. Conserve entire systems: "It is not simply exploited populations of marine life that are to be conserved, but the species and habitats that make up the ecosystem of which they are a part"	Addressed elsewhere in fisheries management plan

4.3 Design

Having defined a hierarchy of management objectives and an associated set of performance statistics it is necessary to design some candidate management procedures. This set of candidates will be evaluated so that the most appropriate management procedure can be selected for implementation in the fishery.

The development of fisheries management procedures is still very much in its infancy. Practitioners are still learning how to match the attributes of management procedures with the characteristics of a fishery. At this time, there is no catalog of management procedures from which practitioners can select the most appropriate forms. Even if such a catalog existed, the wide diversity of fisheries necessitates a wide variety of management procedures. Management procedures will always need to be customized to the types of data available for a fishery.

Scientists will usually lead the development of management procedures with stakeholders and managers primarily providing input on the feasibility of implementing various designs.

Often the design of candidate management procedures will begin with a review of the literature to ascertain which types of management procedures have previously been used in similar fisheries. There is a growing literature on the development of management procedures including reviews of lessons learned. An appreciation for what has not worked well in the past for management procedure design will often be as important as knowing what has worked well.

The design of a management procedure for a particular fishery will be dependent upon what data have, or are able to be, collected for that fishery. For example, is their a reliable index of relative abundance available from catch-per-unit-effort data or surveys? Have length and/or age frequency data been collected on a regular basis and, if so, for how long? Knowing what data are available, or are potentially available, is important because it determines what indicators can be used to drive the management procedure algorithm.

Similarly, determining what management actions are possible for a fishery is an important step in management procedures design. The legislative framework may restrict fishery controls to a certain subset. Likewise, management actions involving changes to both monitoring and analyses may be constrained by logistical considerations. For example, although it might make sense to design a management procedure which triggers occasional fisheries independent surveys based on indicator values, this may not be logistically feasible.

4.4 Evaluation

Evaluation is a core phase of the management procedure approach. Without it there is no clear, objective basis for saying that management procedure A is better for a particular fishery than management procedure B. Such statements are difficult to make based on the design of management procedures alone; we can not rely on prior judgments. Even with a very well thought out design process, trying to predict the relative performance of management procedures over a range of possible dynamics for the fishery is close to impossible. A management procedure that is grounded in the scientific theory of fish stock dynamics may actually perform less well than a more *ad hoc* design, if the particular assumptions that it makes are not met. The dynamics of fisheries are complicated and the feedback between management procedure actions and subsequent performance statistics are not easy to predict. For these reasons, the implementation of management procedures that have not been evaluated should be avoided.

The development and testing of simulation models and their subsequent use for evaluating candidate management procedures will primarily be done by fisheries scientists. Managers and stakeholders may be involved in advising on plausible assumptions for parts of the model associated with fishing activities and the possible implementation error associated with various management controls.

4.4.1.1 Simulation model uncertainty

Computer simulation models have widespread use in fisheries. They form the basis of stock assessments where they are used to infer knowledge about the fishery based on observed data. Often a model used for stock assessment will be used as a basis for management procedure evaluation since it represents the best available knowledge for the particular fishery.

Fisheries models never attempt to capture the full complexities of a real fishery. Instead they attempt to replicate the most important aspects of the fishery’s dynamics in an attempt to interpret the data that have been observed in the past and to predict the consequences of alternative management actions. As such, fisheries models represent approximations of reality. As with most approximations there is uncertainty in the degree to which fisheries models reflect the true dynamics of the fishery.

Accurately representing the uncertainty in the simulation model[15] is perhaps the most important aspect of using a simulation-based approach to evaluation. Rather than attempting to capture all details of a fishery's dynamics, it is more important that, for the aspects that are modeled, uncertainty is properly incorporated. It is more important that a management procedure is robust to uncertainty than it be finely tuned to potentially incorrect assumptions.

4.4.1.2 Application to data-poor stocks

Most of the management procedures that have been developed around the world are for valuable, data-rich fisheries. These fisheries usually already have sophisticated stock assessment models and often these have been used as the basis for management procedure evaluations. How can management procedures be evaluated for less valuable, data-poor fisheries for which there is insufficient data for a stock assessment? Although management procedures for data-poor fisheries are likely to be simpler than those for data-rich fisheries, they can still be evaluated using the same, often sophisticated, simulation approach. However, rather than using stock assessment as the source for parameter estimates and their associated uncertainty, these values can based on prior knowledge. Basic biological knowledge, such as the value of growth parameters, are often available for the species, either within the fishery, or for elsewhere. The simulated ranges for these and other parameters can then be based on "educated guesses" [16]. Although this will involve a degree of subjectivity, as long as there is an honest appraisal of the uncertainty around parameters, this can be preferable to relying solely upon the estimates of uncertainty from a stock assessment which, depending upon how that model was fit, may be unrealistically narrow.

4.4.1.3 Multi-species and ecosystem considerations

To date, the vast majority of fisheries management procedures have been implemented for single species. That is, indicators for a single species are used in a management procedure which alters management controls for that species.

Often, however, a single fishing activity catches several species, in which case it is described as a multi-species fishery. This has important ramifications for management because a management action that is taken in response to indicators for one species can have consequences for the other species. For example, if indicators suggest that species A is increasing and total allowable catches are thus increased for species A, this could cause inappropriate declines in the abundance of species B,C & D.

Similarly, there are ecosystem effects of all fisheries[17]. Even single species fisheries have an impact on the trophic relationships within an ecosystem. For example, reducing the abundance of a species through fishing will affect to some degree the abundance of both its prey and its predators.

Both multi-species and ecosystem considerations for fisheries management can be addressed

15 Traditionally the term "operating model" has been used to describe the simulation model used to test management procedures. This probably arose to differentiate it from an "assessment model". Generally we prefer the term "simulation model" since it better describes the purpose and approach particularly for an audience that may be unfamiliar with these terms.

16 See Dichmont and Brown (2010) and Bentley and Stokes (2009b) and for examples of how management procedures can be applied to relatively data-poor fisheries.

17 See Pikitch et al (2004) for a brief synopsis of ecosystem considerations for fisheries management.

through the management procedure approach[18]. However, this requires that the simulation model used to evaluate management procedures include assumptions about the functional relationships between species. These relationships can be complex and are usually poorly understood. This can lead to a significant increase in the complexity and time required to develop a simulation model of the fishery. While multi-species and ecosystem consequences are important considerations, rather than investing considerable resources in this area, it may be beneficial to instead focus on properly establishing all the processes required for successful implementation of management procedures, including effective stakeholder participation and buy-in. Once such processes have been fully established and stakeholders have become familiar with the management procedure approach, the scope of the simulation model can be broadened to allow evaluation with respect to ecosystem related management objectives.

4.5 Selection

The selection phase is at the core of the strategic decision making phase of the management procedure approach. Its purpose is to select a long term strategy, a management procedure, with which to manage the fishery. This decision is made in relation to the management objectives and associated performance statistics arising from the “Formulation” phase and their relative values arising from the “Evaluation” phase. The purpose of the “Selection” phase is to choose a single management procedure, from amongst many candidates, which will be implemented for the fishery.

Stakeholders should be the primary decision makers during this phase. (Remember that we include government employees in our definition of stakeholders when they are representing the interests of the wider public in the fishery.) Managers and scientists will primarily provide facilitation and guidance particularly on any minimum legislative requirements for the performance of management procedures (e.g., meeting sustainability risk criteria).

Usually, the candidate set of management procedures that are evaluated for a fishery will be large. Even for a simple class of management procedure that has a small number of variable attributes there can be a very large number of combinations of those attributes. There will also often be several performance statistics that management procedures are evaluated against. In addition, to incorporate uncertainty, numerous evaluation trials are done over a wide range of possible values for model parameters and possibly over alternative models. For each evaluation trial, each performance statistic is generated for each candidate management procedure. This can lead to the generation of a very large set of numbers. For example with 1000 trials, 200 candidates and 5 performance statistics, one million individual values will be produced. Summarizing these values so that decision makers can make a choice between candidates is not trivial.

Usually, tables and plots summarizing the outcomes of performance statistics over all evaluation trials are presented to managers and stakeholders. But such presentation tools can become unwieldy when there are a very large number of candidate management procedures. One solution for this is to summarize performance statistics according to each level of management procedure attribute. For example, say a class of management procedure had two attributes, one describing a threshold change in CPUE that triggers a change in total allowable catch (TAC) and another specifying the magnitude of the TAC change that is triggered. Each performance statistic could be summarized in a two-way table with the rows for each level of one attribute and the columns for each level of the other.

A key aspect in the selection phase is the trade-off between performance statistics. For example, for

18 For example, Sainsbury et al (2000) for a discussion of the design of management procedures for achieving fishery ecosystem objectives.

a particular fishery, stakeholders may have high yield and high abundance as performance statistics. But trade-offs are common between such performance statistics. That is, one management procedure may provide high yield but low average abundance, and another procedure may provide the converse. Illustrating these trade-offs so that stakeholders can make an informed choice is a fundamental challenge of the selection phase.

4.6 Operation

A management procedure is a definition of how management actions are to be made in response to indicators from the fishery. Superficially, operation is thus simply a matter of following the formulae and rules in a procedure. But in their specifications management procedures may require that certain analyses of data be performed to produce the indicators upon which they are based. Depending upon the complexity of these analyses, this may require significant scientific resources.

Management procedures are chosen from amongst numerous alternatives on the basis that they most robustly provide the performance desired by stakeholders. It is thus important to ensure that any management procedure that is implemented in the fishery be exactly the same as that which was evaluated; if not, then the performance outcomes may be different to expected.

4.7 Order of processes

We have described the processes involved in applying a management procedure in their most logical order: formulation, design, evaluation, selection, operation. But these processes should not necessarily conform to such a simple progression. In particular, it will often be appropriate for there to be some iteration in the design, evaluation and selection phases. As stakeholders, managers and scientists work through each of these processes there is potential for substantial collective learning about which management procedures work best and how management objectives need to be traded off against one another. Ideally, there should be enough flexibility in the overall process to allow for this learning to be used in an iterative manner. Allowing for this type of iteration will hopefully foster a sense of involvement and ownership of stakeholders in the final management procedure.

4.8 Management procedure development and implementation in New Zealand

The application of management procedures to New Zealand rock lobster fisheries provides an example of the processes involved as well as their iterative refinement. Fisheries in New Zealand are managed under the Fisheries act (1996). The primary management objective is to ensure stocks remain at or above a level capable of producing the maximum sustainable yield and the primary management tool is the setting of Total Allowable Catches (TAC). Currently there are 629 fishstocks (a combination of species and area) managed under The Act. For each fishstock, commercial shares in the Total Allowable Commercial Catch (TACC) are determined by Individual Transferable Quotas (ITQ) which are freely tradeable, though subject to some aggregation conditions. Catches have to be covered by the purchase of Annual Catch Entitlement (ACE), in effect the leased form of ITQ generated by multiplying ITQ and TACC. The vast majority of stocks are managed using a traditional, assessment approach. However, with so many stocks and limited capacity to support TAC and TACC decisions, most stocks are subject to infrequent review, constraining utilization and possibly jeopardizing sustainability.

Unlike other fishstocks, management procedures and decision rules have been used to manage a number of rock lobster (*Jasus edwardii*) stocks in New Zealand since the mid 1990s. The primary benefits of the different approach are laid out in annual reports of the National Rock Lobster Management group (NRLMG; see http://www.nzrocklobster.co.nz/rl-mandocs), a co-management group responsible for providing management advice to the Minister of Fisheries (the final decision maker). The NRLMG-stated benefits of management procedures include the ability for stakeholders to plan rationally, requirement to define management goals explicitly, requirement to agree on data and rules to be used in TAC/TACC setting, objective and consistent incorporation of uncertainty into decision making, and increased acceptance and understanding of decisions.

Decision rules based on CPUE to guide when assessments are conducted have been used since 1993 for a range of rock lobster stocks. Fully evaluated management procedures have been used since 1996 to guide TAC setting for two stocks (CRA 7 and CRA 8) and since 2008 to guide TACC setting on one more (CRA 4). All of these stocks are predominantly commercial fisheries with limited recreational and customary take. A management procedure for an important shared fishery (commercial, recreational and customary), CRA 3, is currently being developed.

Taking CRA 8 as an example, a sequence of management procedures have been developed and implemented, reflecting changing management goals from rebuilding to maintenance. In all cases, working closely with stakeholders and scientists, the NRLMG oversaw the development and choice of procedures and formally recommended their adoption to the Minister of Fisheries of the time as a basis for guiding subsequent TAC setting. The NRLMG has also managed implementation of the rules, making TAC recommendations based on their use. For stocks managed using an assessment approach, TAC/TACC recommendations always include multiple options because legally the minister cannot be fettered. For recommendations based on management procedures, however, including for CRA 8, the NRLMG has only ever recommended TAC/TACCs based on the minister-adopted procedure; this is legally secure as the choice in decision making is recognized at the point of selection of the management procedure to guide future decisions. In all cases, having made strategic decisions to adopt management procedures, and in the face of multi-stakeholder acceptance of the outputs, ministers have adopted the NRLMG TAC recommendations.

The first CRA 8 management procedure was developed in 1996 at a time when the stock was assessed to be at a low level. The procedure was intended to rebuild the stock and resulted in two TAC decreases, both of 20%. At the time of the first decrease industry would have supported a larger cut to effect a faster rebuild but the NRLMG recommended, and the minister adopted, decreases guided by the already adopted procedure. Rebuild of CRA 8 was rapid, exceeding expectations, and in 2002 a new procedure was developed and implemented to maintain the rebuild. As for the 1996 procedure, the 2002 one was based on CPUE but used a more complex harvest control rule accounting not just for stock size relative to targets but also stock trends. Implementation of the rule resulted in a 5% and then a 25% TAC increase with no disagreement. By the time the procedure was reviewed in 2007, CRA 8 was well above its target reference point and a revised management procedure was developed that reflected changed goals. Commercial stakeholders asked for a procedure that would maintain a stable but high catch and catch rate, would only give small increases at very high biomass, would respond quickly to reducing biomass, and would guide annual TAC changes (the previous rules were implemented biannually). A new procedure with these attributes was recommended and adopted in 2007, leading to TAC increases in 2008 and 2009. Interestingly, commercial stakeholders volunteered some of the 2009 TAC increase to the recreational allowance.

The CRA 8 management procedure story relies on thorough scientific analysis to support development and implementation, but also on a strong multi-stakeholder management context (the NRLMG). Described simply, as above, it appears that everything has been straightforward. This is generally the case but along the way there have been numerous discussions on goals, on data interpretation and on checking that the conditions of evaluation remain unchanged. Problems have arisen along the way. In 2003 following the SARS epidemic in Asia and subsequent effects in the rock lobster market, CPUE data interpretation and analysis (as used for management procedure inputs) had to be reviewed following a change in fishing behavior. In 2008 a major issue arose following legal action (in other fisheries) that affected interpretation of reference points used in the management procedures. Dealing with these unforeseen issues required a strong management process and good management and scientific dialogue.

5 Requirements and meta-rules for management procedures

Having outlined the processes involved in applying a management procedure to a fishery, including the roles of different participants, it is worthwhile to review the requirements of the approach.

5.1 Commitment

As we have described, one of the key strengths of the management procedure approach is that through simulation testing it is possible to prospectively evaluate the performance of alternative forms of management. But for evaluations to hold as true reflections of the future, the chosen management procedure must be allowed to run its course. That is, decision-makers must trust the management procedure to run as an "autopilot" for the fishery. If participants attempt to tinker with the management procedure by ignoring or altering its outputs then the simulated evaluations become invalid since they are no longer a true reflection of actual management.

Stakeholder and political understanding and buy-in are important if the advantages of the management procedures approach are to be gained. Only with understanding and buy-in is there the possibility that a management procedure intended to run like an autopilot will actually be implemented. As has been described, the management procedure approach provides substantial opportunity for stakeholder involvement that should result in greater trust in the management procedure that is implemented. Such buy-in must be reciprocated by politicians. All parties must be willing to accept the management actions resulting from the operation of the management procedure, even if, as will often be the case, those actions are contrary to short term expectations. Without such a commitment, the processes of formulation, design, evaluation and selection outlined above, risk being academic exercises. In contrast, with this commitment, these process contribute to a robust and strategic decision making process.

5.2 Meta-rules

Whilst the success of the approach relies on a commitment to the chosen management procedure this does not necessitate a permanent "lock-in". There are at least two situations under which it is appropriate to either change a management procedure in favor of another, or to adjust the management actions which the procedure outputs. First, there may be "exceptional circumstances", in which the state or the dynamics of the fishery are outside of the boundaries under which evaluation simulations were done. That is, the trajectory of the fishery has moved it into an unanticipated condition, one for which the operated management procedure has not been tested to run as an autopilot. Second, there may be an improvement in knowledge of the fishery which invalidates the evaluations upon which a management procedure was selected. Given the new science an alternative management procedure may be more appropriate. Under both of these circumstances it may be appropriate to adjust the recommendations of, or review and possibly change, the management procedure.

Although under these circumstances there is a clear and justifiable rationale for adjusting or changing the management procedure, there is a risk that allowing for such change will introduce the type of tinkering that the approach attempts to avoid in the first place. It is thus essential that any reviews be conducted under strict protocols, or meta-rules (i.e. the rules about the rules), that define exactly the circumstances under which reviews will take place. The simplest form of meta-rule is that a review be conducted once every *x* years. Meta-rules for defining "exceptional circumstances" can be based on whether indicators, such as CPUE, fall into the upper or lower percentiles of those predicted under evaluation for the given management procedure[19].

6 Potential pitfalls in the management procedure approach

> *Without question, these tools improve practice compared with ignoring uncertainty and applying ad hoc decision-making. Unfortunately, they also create a new and subtle class of challenges. ... The methods need to be looked at critically with regard to both the opportunities they present for advances in practice and the new pitfalls against which practitioners must be vigilant*[20]

Management procedures are not a silver bullet for all fisheries management issues. Nor are they without their pitfalls. In this section we outline some of the issues that managers need to be aware of when evaluating and applying management procedures for a fishery.

6.1 Over and under precision

Fisheries management is often bedeviled by little data and poor knowledge. The conventional approach to fisheries management decision making essentially takes a passive stance to this uncertainty by focusing on quantifying its magnitude and subsequently altering the degree to which it errs on the side of caution. In contrast, the management procedure approach takes a more active stance by attempting to design procedures that are robust to the particular uncertainties in a fishery. But in attempting to achieve robustness, the management procedure approach is still heavily reliant upon a realistic quantification of uncertainties.

Precision is the term used to describe the degree of uncertainty that is built in to the simulation model, or models, that are used to evaluate management procedures. A more precise model has less uncertainty built into it and implies a greater confidence that the model is a true reflection of reality. If the model is overly-precise, that is if it under-states uncertainty, there is a risk that the true state and/or dynamics of the fishery will not lie within the bounds of what is simulated during evaluation. If that situation arises, the management procedure that is chosen for the fishery on the basis of its simulated performance will actually under-perform in the real-life fishery. In essence, being too precise creates a risk that the management procedure will be too finely tuned to the wrong assumptions.

Conversely, if the simulation model over-states uncertainty, it creates the risk that the chosen management procedure is not finely tuned enough. That is, because the simulation model incorporates a wide range of uncertainty, the best performing management procedure over that range will probably be one which performs moderately well under a wide variety of assumptions but not particularly well under any one assumption. In other words, under-precision, risks the selection of a management procedure which is a "jack of all trades, but master of none". Usually, when uncertainty is very high, the choice of management procedure will be dominated by risk criteria and thus the best management procedure may be overly-conservative.

Clearly, specifying the correct degree of uncertainty in simulation testing of management procedures is important. However, this is not a trivial exercise. Although there are formal statistical methods for quantifying uncertainty in the parameters of fisheries models it is less clear how to express the broad scale uncertainty in the structural assumptions used in those models. Often a large degree of subjectivity will enter into the process of defining uncertainties. However, it is probably

19 See Butterworth (2008) for a fuller discussion with examples of the use of 'exceptional circumstances' meta-rules

20 Rochet & Rice (2009)

far preferable to subjectively incorporate uncertainty than it is to ignore it completely[21].

6.2 Under-selection

The selection process is the core strategic element of the management procedure approach: it is where a long-term strategy is chosen. It is also the phase of implementation that offers the most for stakeholder involvement, sense of ownership and thus buy-in. Given the importance of the selection process, there is a risk that it is under-emphasized. This risk is exacerbated by the fact that those that have traditionally led the application of the management procedure approach are fisheries scientists who have strong quantitative skills. Their focus is usually on the evaluation process which can produce huge volumes of numeric output. The communication of evaluation results in a way that allows for stakeholders and managers to make a well informed strategic choice, whilst frequently acknowledged as important, is often not given as much attention. There will probably always be a trade-off between maintaining transparency and confusing participants with too much technical detail. Improving this situation is also non-trivial, although there are methods developed in the field of multi-criteria-decision-making may usefully be applied.

6.3 Over-expectation

Management procedures are selected based on their *long-term, relative* performance. This is often forgotten and expectations may arise amongst stakeholders and managers that the management procedure will automatically lead to better achievement of management objectives. But a management procedure is not magical; it can not influence things such as environmental conditions. Particularly in the short-term, these can often have more influence on the outcomes of performance statistics than management actions. For example, after implementing a management procedure in a fishery there could be several years of environmental conditions that cause poor recruitment to the fishery. No management procedure could change that. But, based on the simulations done, the management procedure that was chosen is expected to adapt to such an event better than any of the other management procedures that were tested.

Care needs to be taken that participants understand the long-term and relative nature of the evaluations done. When in operation a management procedure may appear, particularly in hindsight, to have made the “wrong” management action. But that does not mean the management procedure is not the best means for achieving the specified management objectives over the long term.

21 See Kolody et al (2008) and Butterworth (2008) for further discussion on the issue of how to express uncertainty when evaluating management procedures.

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Meta-evaluation : application to the California nearshore fishery

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1 Executive summary

Fisheries management procedures are a potentially useful tool for decision making in the California nearshore fishery. However, the design and evaluation of management procedures can be a resource intensive process and has traditionally relied on a stock assessment to provide a simulation model with associated parameter estimates upon which evaluations can be based. To ameliorate these issues, an approach dubbed meta-evaluation and partition analysis has been developed .This approach allows for the rapid evaluation of a range of management procedures, even for fisheries with little information, and the subsequent analysis of results to ascertain the potential benefits of alternative forms of research. Meta-evaluation uses a generalized simulation model to evaluate generic management procedures across a broad, but plausible, range of parameters values. The results from the meta-evaluation are then partitioned, or in other words, 'filtered', to provide results for individuals species. This approach has the advantage that it is quicker to evaluate several management procedures for a range of species and can be performed for species that do not have recent assessments. This approach does not necessarily replace species-specific management procedure evaluation but rather provides an alternative in lieu of such work.

Four classes of management procedures with a range of monitoring requirements were evaluated in this project. All four classes of management procedure have a single management action: changing the total allowable catch (TAC) but achieve this in differing ways.

1. Proportion of recent average catch (PRAC)

A “static” management procedure which does not require monitoring and instead sets a single, fixed TAC to be used in all years. This class of management procedure is included principally to provide a comparison between static and dynamic management procedures.

2. Proportion of historical exploitation rate (PHER)

A class of management procedure that requires an annual index of abundance both historically and into the future. It seeks to maintain the relationship between the index of abundance and catch at some multiple of the implied average historical exploitation rate. The historical exploitation rate need not be known explicitly, nor does it need to have been appropriate, but rather through evaluation the most appropriate multiple of the historical ratio between catches and the abundance index is determined.

3. Target range for Z/K (TRZK)

A class of management procedure that attempts to maintain the ratio between the total mortality (Z) and the growth coefficient (K) of the fish population within a target range. Instead of using total mortality as an indicator, this class uses the ratio Z/K because it can be estimated directly from estimates of mean weight or mean length as well as from age-frequency data. When Z/K is above the target range, the TAC is reduced by a fixed proportion. When Z/K is below the target range, the TAC is increased by the same, fixed proportion.

4. Matrix of abundance and size trends (MAST)

This class of management procedure attempts to utilize trends in both abundance and size to infer likely changes in the biomass of the fish stock. It does this by calculating the observed trends over a specified time horizon, determining whether each of these trends is significant (from a management perspective, not a statistical perspective) based on thresholds for proportional changes, and then using a decision matrix to change TAC accordingly.

Information dynamics of the nearshore fishery were collated from source such as the Life History

Database maintained by the CDFG and stock assessments. This information was used to develop general prior probability distributions for each simulation model parameter. These general prior distributions were sampled from to generate parameter replicates against which each management procedure was evaluated. For some parameters, species specific priors were developed and these were subsequently used to partition evaluation results into species specific subsets so that the most appropriate management procedure for each species could be determined.

Of the 5215 management procedures evaluated, 1213 (23%) satisfied the risk condition that the spawning biomass at the end of 2060 was greater than 10% of virgin biomass for at least 95% of simulations.

The PHER class performed the best with 47% of instances meeting the risk condition and 16% of instances in the top quartile. This suggests that the PHER class is the most robust to its parameterization. That is, altering the control parameters of this class of management procedure has the least impact on its performance.

In contrast, the MAST appears to be the least robust. For this class of management procedure only 1.3% (22) instances met the risk condition. However, those instances of MAST that met the criteria performed in the top quartile. This suggests that the MAST procedure can perform well for the California nearshore fishery if it's control parameters are set appropriately.

For the general prior and for each of the specific partitions, an instance of the PHER class of management procedure performed the best. The optimal value of its control parameters was very similar across species. However, for the species that have the highest estimated status (relative to virgin biomass), black rockfish, scorpionfish and cabezon the optimal value for the *ratio multipler* control parameter is higher than for the other species.

We discuss some of the limitations of the current study and make recommendations for how these could be remedied in future work.

2 Introduction

This report describes an evaluation of several fisheries management procedures for the California nearshore fishery. The California Nearshore Fishery Management Plan (NFMP) currently includes 19 species (Table 1). The Nearshore Fisheries Management Act, 1999, identified nine species of nearshore fish but noted that nearshore fish "may include other species of finfish found primarily in rocky reef or kelp habitat in nearshore waters". The Act also provided an initial definition of nearshore waters as those waters within 1 nautical mile of land. In 2000, the Fish and Game Commission redefined nearshore waters to mean waters from the shoreline to a depth of 20 fathoms (120 feet). The Commission also increased the list of nearshore fish species to 19. This list was based in on an evaluation of the "need of immediate attention" of 124 species of nearshore fishes. The evaluation was based on a number of life history (e.g. longevity, maturation age, fecundity) and fishery (e.g. importance in fishery, changes in magnitude of landings) related factors (CDFG 2002).

The fishery for the 19 species occurs along the entire California coast. The recreational fishery consists of both land and boat based anglers using hook and line, and divers using spearguns. Commercial fishers use hook and line, traps and gill nets. There have been substantial changes in species and size selectivity particularly for the commercial fishery. For example, the advent of a fishery for live fish in the late 1980s resulted in greater targeting of species such as California scorpionfish (Schaaf-Da Silva and McKnight 2008).

The main species by landings are blue rockfish, black rockfish, cabezon and California sheephead (Table 1). Together these species account for about 56% of landings, and, along with gopher rockfish and kelp greenling, have had relatively recent stock assessments (Table 2). For most species, the recreational sector takes at least 70% of the catch (Table 1). The exceptions to this are cabezon and California sheephead for which about half of the catch is taken commercially.

Most of the fish stocks in the nearshore fishery are considered to be "data poor". Although stock assessments have been done for some of species, some of these assessments have had very high uncertainty, often resulting from a paucity of data. For example, in the 2007 assessment of blue rockfish (Key et al 2008) it was noted that there was evidence of variability in growth over time and between areas along the coast of California but that the lack of sufficient data did not allow for the complex modeling needed to properly asses the stock. Due to the high uncertainty, the stock assessment was only marginally accepted for management purposes by the review panel. The 2005 stock assessment for kelp greenling was not accepted for use in management due to its high uncertainty particularly regarding age, growth and natural mortality (Hoobler 2006).

Fisheries management procedures are a potentially useful tool for decision making in the California nearshore fishery. The usual approach for developing management procedures for a fishery is to use a recent stock assessment model as a simulation model for evaluating specific management procedures for that fishery. One problem with this approach is that it is resource intensive, requiring many hours of time of experienced personnel (Cooke 1999, Kolody et al 2009). This has largely limited the use of management procedures to valuable, data-rich fisheries (Bentley & Stokes 2009a).

In an attempt to circumvent some of these issues, an alternative approach, dubbed meta-evaluation has been developed (Bentley & Stokes in prep a). This approach allows for the rapid evaluation of a range of management procedures, even for fisheries with little information, and the subsequent analysis of results to ascertain the potential benefits of alternative forms of research. Meta-evaluation uses a generalized simulation model to evaluate generic management procedures across a broad, but plausible, range of parameters values. The results from the meta-evaluation are then partitioned, or in other words, 'filtered', to provide results for individuals species. This approach has the advantage that it is quicker to evaluate several management procedures for a range of species and can be performed for species that do not have recent assessments. This approach does not necessarily replace species-specific management procedure evaluation (also known as management strategy evaluation) but rather provides an alternative in lieu of such work. The meta-evaluation approach was developed as part of a New Zealand research project aimed at expanding the use of management procedures to low information fisheries in that country (Bentley & Stokes, in prep).

This report describes the evaluation of several classes of management procedure for the California nearshore fishery using meta-evaluation. The following section provides an overview of meta-evaluation including its key components. Next we describe the methods used to apply the approach to the California nearshore fishery including the management procedures that were evaluated. Results of evaluations are then presented based for both general and species-specific simulation model dynamics. Finally, we discuss some of the limitations of the current study and make recommendations for how these could be remedied in future work.

Table 1: Species of nearshore fishes in the California Nearshore Fishery Management Plan. Landings data from RecFIN and CALCOM (M. Key, CDFG pers. comm.). "Rec. 2001-2009" is the percentage of total landings from 2001 to 2009 that were taken by recreational fishers. The abbreviated codes used for each species in this document are also provided.

Order	Family	Scientific name	Common name	Percentage of landings			Code
				1993-2000	2001-2009	Rec. 2001-2009	
Scorpaeniformes	Sebastidae	*Sebastes mystinus*	Blue rockfish	18%	16%	92%	BLUR
		Sebastes melanops	Black rockfish	16%	27%	74%	BLCK
		Sebastes auriculatus	Brown rockfish	6%	9%	76%	BRWM
		Sebastes carnatus	Gopher rockfish	6%	7%	73%	GPHR
		Sebastes caurinus	Copper rockfish	7%	5%	87%	COPP
		Sebastes serranoides	Olive rockfish	4%	5%	98%	OLVE
		Sebastes rastrelliger	Grass rockfish	3%	2%	38%	GRAS
		Sebastes nebulosus	China rockfish	2%	2%	81%	CHNA
		Sebastes chrysomelas	Black-and-yellow rockfish	2%	1%	38%	BYEL
		Sebastes maliger	Quillback rockfish	1%	1%	58%	QLBK
		Sebastes atrovirens	Kelp rockfish	1%	1%	91%	KLPR
		Sebastes serriceps	Treefish	1%	1%	86%	TREE
		Sebastes dallii	Calico rockfish	<1%	<1%	100%	CLCO
	Scorpaenidae	*Scorpaena guttata*	California scorpionfish	9%	7%	92%	SCOR
	Cottidae	*Scorpaenichthys marmoratus*	Cabezon	10%	7%	53%	CBZN
	Hexagrammidae	*Hexagrammos decagrammus*	Kelp greenling	2%	1%	76%	KLPG
		Hexagrammos lagocephalus	Rock greenling	<1%	<1%	100%	RCKG
Perciformes	Labridae	*Semicossyphus pulcher*	California sheephead	11%	7%	48%	SHPD
	Stichaeidae	*Cebidichthys violaceus*	Monkeyface prickleback	<1%	0%	98%	MFPB

Table 2: Summary of the most recent stock assessments for species in the California nearshore fishery including associated assumptions, estimates, or ranges (shown in square brackets) of key population parameters.

		von Bertalanffy growth equation						
Species	**Natural mortality**	**Asymptotic length**	**Growth rate coefficient**	**Age at zero length**	**Coefficient of variation of length at age**	**Steepness of stock recruitment curve**	**Standard deviation of recruitment deviations**	**Reference**
Blue rockfish	0.12(M)0.1(F) [0.09/0.07-0.15/0.13]				0.11	0.58	?	Key et al (2008)
Black rockfish	0.16(M)/0.16-0.24(F)				0.07	0.6	0.5	Sampson (2008)
Gopher rockfish	0.2 [0.15-0.25]				0.06	0.65	?	Key et al (2006)
California scorpionfish	0.25 [0.2-0.3]				0.05 [0.025-0.1]	0.7 [0.5-1.0]	?	Maunder et al (2006)
Cabezon	0.25(M)/0.3(F) [0.2/0.25-0.3/0.35]	58.97 (F) 41.5 (M)	0.21(F) 0.5(M)	-1.28 (F) -0.75 (M)	from 0.14 (age 1) to 0.09 (age 17)	0.7	0.5	Cope & Key (2010)
Kelp greenling	0.26				0.1-0.09	0.7	1	Cope & MacCall (2006)
California sheephead	0.2 [0.15-0.3]	52.6	0.068		0.11	0.99	0.8	Alonzo et al (2005)[22]

22 Values from 'final' assessment model Table 8.3

3 Meta-evaluation

This section provides a general overview of meta-evaluation approach. In the following section the methods used to apply the approach to the California nearshore fishery are described

The underlying principle behind meta-evaluation is that a management procedure can, and should, be evaluated based on the available information, even if the amount of information is low. The best management procedure for a fishery is the one that performs the most robustly given the available knowledge and its associated uncertainty. Meta-evaluation involves several key components described in the following sections.

3.1 Generalized management procedures

Management procedures have generally been designed around the specifics of particular fisheries. In contrast, generalized management procedures are specified and parameterized in ways that they can be tuned to different fisheries. For instance, a specific management procedure might use an index of abundance obtained from CPUE standardization. A generalization of this management procedure might instead have a control parameter which specifies whether the index of abundance is obtained from unstandardized CPUE (which may be more prone to biases caused by changes in the season and/or location of fishing but which may be all that is available) or from scientific surveys (which are not so prone to changing biases over time but which are more expensive to obtain). This generalization not only allows the management procedure to be quickly applied to different fisheries but also, for an individual fishery, it allows an investigation of the relative performance of the management procedure obtained from using alternative indices of abundance.

An aim of the meta-evaluation approach is to have an expanding “library” of management procedures that can be taken “off the shelf” and easily evaluated for a particular fishery.

3.2 Generalized parameter distributions

Management procedure evaluation typically involves using parameter distributions from stock assessments. But where there is no stock assessment for a fishery alternative source of parameter distributions must be used. This includes general knowledge about the probability distributions of parameters of the fishery (e.g. natural mortality, selectivity) and the relationships between them (e.g natural mortality versus growth rate coefficient). Both are these are useful for “filling in gaps” in knowledge for a particular fishery. For example, when there is no specific knowledge available on natural mortality, a probability distribution can be inferred based on knowledge on the growth coefficient based on known relationships between these parameters (Jensen 1996).

3.3 Generalized simulation model

To evaluate generalized management procedures and make use of generalized parameter distributions it is necessary to use a generalized simulation model. So that a range of management procedures with a range of monitoring requirements can be evaluated such a model needs to be capable of simulating alternative forms of monitoring (e.g. surveys, catch-per-unit-effort, length ampling, age-sampling). A generalized model can be parameterized in such a way that there are natural priors for parameters. This is not to say that a generalized model is necessary for fishery-specific management evaluations. When there is good specific knowledge about a fishery and a limited number of monitoring options an existing simulation model is likely to be preferable. However, for rapid evaluation of a wide range of management procedures for a fishery which is data poor a generalized simulation model is very useful.

4 Methods

This section describes the specific methods used to apply meta-evaluation to the California nearshore fishery. It is divided into four subsections reflecting the four key components of the approach.

4.1 Generalized management procedures

4.1.1 Terminology and notation

Management procedures are algorithms that specify how fisheries monitoring data are translated into fisheries management actions. Management procedures usually have one or more control parameters which allow each management procedure algorithm to be "tuned" to the dynamics of a particular fishery. When describing management procedures we adopt the terminology used in object-oriented programming (Meyer 1997): we use the word "class" to refer to a particular management procedure algorithm and the word "instance" to refer to a particular parameterization of a particular class on management procedure. Since a class of management procedure needs to be designed and translated into a computer programming language there is a finite set of classes of management procedures. However, because each class usually has at least one control parameter, and because these parameters can usually take on a large number of possible values, each class on management procedure has a very large number of possible instances.

To signify a class of management procedure we use capitalized acronyms of their name (e.g. PRAC). To signify an instance of a class we use a parenthesized list of it's control parameter values (e.g. PRAC(5,0.4) is an instance of the PRAC class of management procedure which has its two control parameters set to 5 and 0.4 respectively).

A number of classes of management procedures have already been developed in the literature. In this project we limited evaluations to four classes which provide an illustration of the range of monitoring requirements and algorithm complexity that are possible within management procedures. All four classes of management procedure have a single management action, changing the total allowable catch (TAC), but differ quite markedly in the way that they change TAC from year to year.

4.1.2 Proportion of recent average catch (PRAC)

Proportion of recent average catch (PRAC) is a "static" management procedure which does not require monitoring and instead sets a single, fixed TAC to be used in all years which is based on the recent catch history. This class of management procedure is included in evaluations principally to provide a comparison between static and dynamic management procedures. Also PRAC reflects the de facto form of TAC setting that appears to be common for many, but particularly for data poor, fisheries.

PRAC has two control parameters:

- Horizon (*h*): the number of years over which the historical average catch is calculated
- Multiplier (*m*): the multiple of the historical average that is used to determine the TAC

PRAC is initialized by calculating a constant TAC ($\bar{Q}$) equal to some multiple (*m*) of the mean catch over some number (*h*) of the most recent years:

$$\bar{Q}=m\frac{\sum_{t=0}^{t=h} C_{-t}}{h}$$

PRAC is operated by setting the TAC to the constant TAC ($\bar{Q}$):

$$Q_t=\bar{Q}$$

For instance, PRAC(5,0.5) signifies an instance of this class which sets the TAC at half of the average catch over the five years prior to initialization.

4.1.3 Proportion of historical exploitation rate (PHER)

A class of management procedure that requires an annual index of abundance both historically and into the future. It seeks to maintain the relationship between the index of abundance and catch at some multiple of the implied average historical exploitation rate. The historical exploitation rate need not be known explicitly, nor does it need to have been appropriate, but rather through evaluation the most appropriate multiple of the historical ratio between catches and the abundance index is determined.

PHER has six control parameters:

- Frequency (*f*): the number of years between successive operations of the procedure
- Source (*s*): the source of the abundance index where 1=unstandardized CPUE, 2=standardized CPUE, 3=survey
- Horizon (*h*): the number of years over which the historical catch:abundance ratio and the minimum and maximum annual catches are calculated
- Ratio multiplier (*r*): the multiple of the historical catch:abundance ratio to use
- Lower multiplier (*l*): the multiple of the minimum historical catch to use as the minimum future catch
- Upper multiplier (*u*): the multiple of the maximum historical catch to use as the minimum future catch

PHER is initialized by calculating and adjusted ratio (R) between catch (C_t) and the biomass index (I_t), as well as adjusted minimum (L) and maximum (U) catch over the previous *h* years:

$$R=r\frac{\sum_{t=0}^{t=h} \frac{C_{-t}}{I_{-t}}}{h}$$

$$L=l\,min(C_{-1},\ldots,C_{-h})$$

$$U=u\,max(C_{-1},\ldots,C_{-h})$$

PHER is operated by setting the TAC according to the current value of the biomass index and the values of R, L and U:

$$\dot{Q}_t=R\,I_t$$

$$Q_t=\left\{\begin{matrix} L & \dot{Q}_t\leq L \\ \dot{Q}_t & L<\dot{Q}_t<U \\ U & \hat{Q}\geq U \end{matrix}\right\}$$

That is, PHER sets the TAC at R times the value of the abundance index in the year (I_t) but does not allow TACs of less that L or greater than U .

For instance, PHER(2,3,15,0.75,0,1) signifies an instance of this class which is operated every 2 years, uses a survey based index of abundance, a 15 year historical horizon and sets TAC at 0.75 of the historical catch:abundance ratio with no minimum TAC and a maximum TAC equal to the maximum historical catch.

4.1.4 Target range for Z/K (TRZK)

A class of management procedure that attempts to maintain the ratio between the total mortality (Z) and the growth coefficient (K) of the fish population within a target range. Instead of using total mortality as an indicator, this class uses the ratio Z/K because it can be estimated directly from estimates of mean weight or mean length as well as from age-frequency data. When Z/K is above the target range, the TAC is reduced by a fixed proportion. When Z/K is below the target range, the TAC is increased by the same, fixed proportion.

TZRK has six control parameters:

- Frequency (*f*): the number of years between successive operations of the procedure
- Source (*s*): the source of Z/K estimates where 1=mean weight, 2=mean length, 3=age-frequency
- Precision (*p*): the coefficient of variation for weight, length and age samples upon which Z/K is estimated
- Midpoint (*m*): the value of Z/K that defines the middle of the target range
- Range (*r*): a multiplier that defines the width of the target range
- Change (*c*): the proportional change in TAC when the estimated Z/K ratio falls outside of the target range.

TRZK does not require initialization. It is operated by calculating Z/K from the data specified by source (*s*). In all cases, the aim is not to obtain an accurate estimate of Z/K, but rather to calculate an indicator of exploitation rate and thus approximations are used.

When using mean length, Z/K (given the symbol O_t in the following equations) is calculated using the equation of Beverton and Holt (1957; cited in Pauly 1984) where knowledge of the growth curve is not assumed and as such asymptotic length is replaced by the current maximum length observed in the catch ($\hat{L}$) :

$$O_t=\frac{\hat{L}-\bar{L}_t}{\bar{L}_t-\acute{L}_t}$$

where $\acute{L}_t$ is the modal length in year *t*, and $\bar{L}_t$ is the mean length in year *t* of fish that are larger than $\acute{L}_t$.

When using mean weight Z/K is calculated using the mean weight of <u>all</u> fish in the catch (Pauly 1984):

$$O_t=\frac{\hat{W}^{1/3}-\bar{W}_t^{1/3}}{\bar{W}_t^{1/3}-\acute{W}^{1/3}}$$

where $\acute{W}$ is the current maximum weight of fish from the catch, $\acute{W}$ is the current 10th percentile of the weight distribution of fish from the catch, and $\bar{W}_t$ is the mean length in year *t*.

When using age frequency data the Chapman-Robson (1960) estimator of total mortality is used. Dunn et al (2002) found this estimator to be more precise and less biased than other catch curve estimators of total mortality. The Chapman-Robson estimator is based on the mean age above the age of full selectivity. The modal age (determined separately for each age sample) plus one year was assumed to be the age of full selectivity, the growth coefficient (κ) is assumed to be known exactly and a sample size of 50 is assumed:

$$O_t = \ln\left(\frac{1+\bar{A}_t - 1/50}{\bar{A}_t}\right)/\kappa$$

Regardless of how it is calculated, the value of Z/K is then compared to the target range and the TAC is reduced by *c* if it falls below the range and increases by *c* if it falls above the range:

$$Q_t = \begin{Bmatrix} (1-c)Q_{t-1} & O_t < m/r \\ Q_{t-1} & m/r \le O_t \le mr \\ (1+c)Q_{t-1} & O_t > mr \end{Bmatrix}$$

For example, TRZK(3,3,0.2,3,1.5,0.2) signifies an instance of this class which is operated every three years, uses the Chapman-Robson method to estimate Z/K based on age-frequency samples with a coefficient of variation of 0.2, which compares the estimated Z/K to target range defined by mid-value of 3, a lower bound of 2 (3 divided by 1.5) and an upper bound of 4.5 (3 multiplied by 1.5), and which increases or decreases TAC by 20%.

4.1.5 Matrix of abundance and size trends (MAST)

This class of management procedure attempts to utilize trends in both abundance and size to infer likely changes in the biomass of the fish stock. It does this by calculating the observed trends over a specified time horizon, determining whether each of these trends is significant (from a management perspective, not a statistical perspective) based on thresholds for proportional changes, and then using a decision matrix to change TAC accordingly (Figure 1).

- Frequency (*f*): the number of years between successive operations of the procedure
- Horizon (*h*): the number of years over which trends in abundance and size are calculated
- Abundance method (*m*): the source of the abundance index, 1=unstandardized CPUE, 2=standardized CPUE, 3=survey
- Abundance threshold (*a*): the threshold applied to define a significant proportional change in abundance
- Size precision (*p*): the coefficient of variation for size samples
- Size threshold (*s*): the threshold applied to define a significant proportional change in size
- Change (*c*): the proportional change in TAC

MAST is operated by calculating the trend in the abundance index (T_t) based on the least-squares slope of the log transformed index:

$$T_t = \exp\left(\frac{n\sum y\ln(I_y) - \sum y \sum \ln(I_y)}{n\sum y^2 - \sum y \sum y}\right) - 1$$

where *n* is the equal to the horizon (*h*) or the number of available years of the abundance index whichever is greater and all summations are over the previous *n* years. For instance, $T_t = 0.1$ indicates that the index of abundance has increased on average by 10% over the time horizon and a value of $T_t = -0.1$ indicates it has decreased by 10%.

The trend in size (S_t) is based on the proportional change in mean length since the last operation of the management procedure (which is determined by the frequency (*f*) control parameter):

$$S_t = \frac{\bar{L}_t - \bar{L}_{t-f}}{\bar{L}_{t-f}} - 1$$

The TAC is then changed according the decision matrix (Figure1) where significant trends in abundance and size are determined by the thresholds *a* and *s* respectively.

For example, MAST(1,5,2,0.25,0.2,0.1,0.3) signifies an instance of this management procedure which is operated every year, and uses a 5 year time horizon to calculate trends in standardized CPUE and mean length from samples collected with a c.v. of 0.2. For this instance, a significant trend in abundance is determined to a trend of a least than 25% increase of decrease, and for size at least 10% increase or decrease.

Figure 1: Decision matrix for the MAST class of management procedure. Columns indicate alternatives for the trend in abundance: significant upward (+), not significant (0), and significant downward (-). Rows are for trends in size. Each cell defines a corresponding change in TAC: increase(+), no change (0), decrease (-).

		Abundance trend		
		+	0	-
Size trend	+	+	+	-
	0	+	0	-
	-	+	-	-

4.1.6 Management procedure instances evaluated

A total of 5215 management procedure instances from the four classes were evaluated (Table 3). Thirty one instances of PHER were evaluated, all used a horizon of 5 years with a range of values for proportion based on a geometric series symmetric around 1.0. For the other management procedures, a range of values for their control parameters were evaluated.

Table 3: The number of instances, and combinations of control parameter evaluated, for each class of management procedure.

PRAC	PHER	TRZK	MAST
Instances: 31	Instances: 1728	Instances: 1728	Instances: 1728
Horizon (*h*): 5	Frequency (*f*): 1,2,3	Frequency (*f*): 1,2,3	Frequency (*f*): 1,2,3
Multiplier (*m*): (0.035,0.044,...,0.8,1,1.25,...,22.73,28.42)	Source (*s*): 1 (unstandardized CPUE), 2 (standardized CPUE), 3 (survey)	Source (*s*): 1 (mean weight), 2 (mean length), 3 (age frequency)	Horizon (*h*): 3,5,10
	Horizon (*h*): 5,10,15	Precision (*p*): 0.1,0.2,0.3	Abundance method (*m*): 1,2,3
	Ratio multiplier (*r*): 0.25,0.5,1,1.5	Midpoint (*m*): 1,2,3,4	Abundance threshold (*a*): 0.05,0.1,0.2,0.4
	Lower multiplier (*l*): 0,0.25,0.5,1	Range (*r*): 1.1,1.25,1.5,2	Size precision (*p*): 0.3
	Upper multiplier (*u*): 0.75,1,1.25,1.5	Change (*c*): 0.05,0.1,0.2,0.4	Size threshold (*s*): 0.05,0.1,0.2,0.4

4.2 Generalized simulation model

We used the generalized simulation model developed by Bentley & Stokes (in prep) as the basis of the management procedure evaluations. The model uses a simple age-structured population dynamics model with a stock-recruitment relationship and recruitment variation and autocorrelation. Whilst the population dynamics are simple compared to many modern stock assessment models (for instance, there is no sex or spatial structure) the simulation model involves considerable flexibility in terms of the monitoring data that it simulates. These include:

- alternative types, precisions and frequencies of monitoring including:
  - CPUE (potentially incorporating hyperstability/hyperdepletion and/or increasing catchability),
  - survey indices of abundance with alternative levels of precision (potentially incorporating negative or positive bias),
  - age, length and weight frequency sampling with alternative levels of precision
- alternative analyses on the data generated by the simulated monitoring including:
  - CPUE standardization (assumed to remove trend in increasing catchability),
  - analyses of time series such as calculation of slope and coefficient of variation,
  - analyses of age, length and weight frequencies to estimate total mortality.
- generation of a wide range of performance statistics and an output file structure that facilitates the analysis of evaluation results.

For example, catch-per-unit-effort can be simulated with alternative degrees of both observation error and hyperstability or hyperdepletion. Age and length samples of alternative effective sample size can also be simulated. This allows the performance of a wide variety of management procedures, for example those that are based on CPUE, age frequency or length sampling, to be evaluated. The model equations in Bentley & Stokes (in prep) use a convention of lower case Greek letters for all model parameters. The same symbols are used in this report although it should be noted that in this causes a departure from the conventional symbols used for some parameters.

4.3 Parameter priors

For meta-evaluation, prior probability distributions need to be defined for each model parameter. For many of the parameters we used the “default” prior developed in Bentley & Stokes (in prep) (Table 4). However, where there was specifies-specific information for the California nearshore fishery two levels of prior are developed: one general prior and several species specific priors (Table 5). The general prior defines the sampling distribution of parameters upon which replicates of the management procedure evaluation simulations are based. The species-specific priors are then used to partition these replicates to obtain evaluation results for each species.

In Bentley & Stokes (in prep), FishBase is used as the primary source of data for meta-analyses on the probability distributions of parameters and their relationships. However, for the California nearshore fishery, the “Life History Database” (LHD) (http://www.dfg.ca.gov/marine/lifehistory.asp) maintained by CDFG provides a useful source of parameter estimates and was used to develop prior distributions for key population parameters. The database contains life history characteristics of 130 Californian nearshore fish species based on the work of Cailliet et al (2000). Data for the 19 species of interest was extracted and where necessary this information was augmented with results from more recent literature. In addition, estimates of parameters arising from stock assessments for several of the nearshore species were incorporated. However, we did not conduct a full literature review, rather we simply used the literature to fill gaps in the the information available in the life history database. For the primary species, we ensured that parameters were consistent with those used in recent assessments (Table 2).

4.3.1 Growth

Estimates of the parameters of the von Bertallanfy growth equation were extracted from the life history database. Where the parameters were for growth in standard length or fork length, the estimate of asymptotic length (often given the symbol L_∞ but given the symbol λ in this report to maintain consistency with the simulation model documentation) was converted to total length using the length conversion equations in the database. The database did not have estimates of growth parameters for treefish, rock greenling, or sheephead. Estimates for sheephead were obtained from Alonzo et al (2008) and treefish from Colton and Larson (2007).

The following notes document some of the issues that were encountered when collating these data.

Length conversion equations:

- The LHD did not have equations for monkeyface prickleback for the conversion of standard length to total length. Instead, the equation of Marshall and Wyllie-Echevarria (1992; SL = 0.931TL + 1.416) was inverted to TL = (SL – 1.416)/0.931.
- The LHD did not have equations for calico rockfish. Instead we used equations for the superficially similar copper rockfish.
- The database did not have equations for California sheephead. The equation of Alonzo et al (2005) based on the RecFIN database FL = -1.4564+1.094 TL implies that for most lengths, FL is actually greater than TL (e.g 50cm TL gives a FL of 53cm). FishBase gives the equation TL=FL/0.951 and so this equation was used instead.

Growth equation estimates:

- The parameters for blue rockfish from McGregor (1983) and for black rockfish from Worton (2000) were not included because their entries in the database were not complete or the related database fields appeared to be inverted.
- The length type (FL,TL etc) were missing for black rockfish from Wallace & Tagart (1994). TL was assumed.
- The estimates of asymptotic length for cabezon and kelp greenling were greater than 300cm whereas their maximum recorded lengths are listed as less than 100cm. Thus, their Linf values were assumed to be in mm and were divided by 10 to convert to cm.
- Some of the estimates for cabezon were excluded. Two estimates from Lauth (1987) did not have length type or t0 so were excluded. The other estimates from Lauth (1987) had much higher k than more recent estimates. Estimates from O'Connel (1953) did not have t0 and also had much higher k than more recent estimates.
- Alonzo et al (2008) provide growth parameter estimates for four locations for sheephead. The estimates for two locations have very high Linf (San Benitos Island and Cabo Thurloe; >130cm, higher than the maximum observed size of 91cm) and low k. These were not used.
- Parameter values for KEG from Moulton (1977) which has k 4 times other estimates were

excluded.

For each species a uniform prior was defined for asymptotic length (λ) based on +/- 40% of mean of the available estimates (Table 3). For rock greenling, for which no growth parameter estimates were available, the species-specific prior for the closely related kelp greenling was used.

Across the nearshore species, there is a relationship between asymptotic length (λ) and the growth rate coefficient (κ) (Figure 2). To develop a joint prior for these two parameters the relationship between log(κ) and log(λ) was modeled using a hierarchical linear model with a separate intercept for each species and a joint slope (estimated at 1.53; Figure 3). For each species, a uniform prior was defined for the intercept at +/- 0.7 of the its estimated value (Table 3). The range of this uniform prior was set so that it captured the range of estimates for each species (Figure 3).

4.3.2 Natural mortality

The Life History Database has few estimates of natural mortality for the nearshore species of interest (Table 6). The available estimates were augmented with estimates from, or assumptions used in, stock assessments (Table 2). In addition, estimates of longevity available from the life history database were used to derive estimates of natural mortality using the method of Hoenig (1983).

The relationship between natural mortality and growth estimates was examined. Whilst the relationship is close to that suggested by Beverton and Holt (1959) it appears that for the Scorpaenids that natural mortality might be a lower multiple of the growth coefficient (Figure 4). Species-specific priors for this relationship were defined accordingly (Table 4).

4.3.3 Stock recruitment steepness

Steepness (h) is the proportion of virgin recruitment that is expected when spawning stock is at 20% of its virgin size (Mace and Doonan 1988). Myers et al. (1999) estimated steepness for many stocks, of various species, including 3 species of *Sebastes (*although none of those listed in the Table 1). The estimates of steepness for the *Sebastes* species (chillipepper, pacific ocean perch and deepwater redfish) ranged from 0.35-0.47, amongst the lowest values for all the species studies, although the authors state they are not sure whether this is related to the low natural mortality rate and oviviparous reproduction of the species, or is an artifact of the data. Dorn (2002) estimated a mean steepness of 0.65 across 6 species and 11 stocks of rockfish.

Following Mangel et al (2010) a prior for steepness was defined using a beta probability distribution for a derived parameter, ω ,

$$pdf(\omega)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\omega^{\alpha-1}(1-\omega)^{\beta-1}$$

$$h=\frac{\omega+0.25}{1.25}$$

where α and β are parameters of the beta distribution and Γ is the gamma function. The beta distribution is defined on the interval of [0,1] whereas steepness is defined on the interval of [0.2,1]. By defining steepness in terms of omega it is possible to define a prior for steepness whose integral is 1 over the range 0.2 to 1. Values of alpha=1.91 and beta=1.28 were chosen so that the 5th,25^{th,} 75th and 95th percentiles of the prior (0.34,0.53,0.69,0.83,0.95) approximated the corresponding values for the estimates of steepness provided in Myers et al (1999).

4.4 Selectivity and minimum legal size limits

Estimates of selectivity ogives are available for some of the nearshore species (Table 8). Although some of the assessment use a domed selectivity the simulation model currently only allows for a sigmoid selectivity ogive parameterized according to fraction of the asymptotic length at which 50% of fish are vulnerable to fishing. Based on the range of ratios of assessment estimates of the length at 50% vulnerability relative to asymptotic length a general prior for this parameter was defined with bounds of 40% and 80% (Table 4).

Minimum size limits (MLS) are in place for half of the nearshore species:

- 10” – black-and-yellow rockfish, California scorpionfish, gopher rockfish, kelp rockfish
- 12” – grass rockfish, China rockfish, rock greenling, kelp greenling
- 13” – California sheephead
- 15” – cabezon

However, to simplify the evaluations we assumed that there is no legal size limit.

4.4.1 Exploitation history and current status

Estimates of current exploitation rates and status relative to unexploited, virgin biomass are available for some species from assessments (Table 9). Species-specific uniform priors were used for those species where theses values are available. For other species, a general prior, based on the overall limits of species-specific priors was used (Table 5).

Table 4: Parameter priors used in the meta-evaluation and partition analysis. Where a single value is given it indicates a fixed values was used for a parameter. Prior distribution types and their parameters are, B: Beta(alpha,beta), U: Uniform(min,max), LU: Log-uniform(min,max), LN: Lognormal(mean,sd), *:Indicates that the 'default' prior defined in Bentley & Stokes (in prep a) was used.

	Symbol	Prior
Biological parameters		
Asymptotic length	λ	See Table 5
Growth rate coefficient	κ	Relationship with λ see Table 5
Age at which length is zero	τ	U(-6,0)
Coefficient of variation of length at age	ϱ	LU(0.05,0.5)*
Instantaneous rate of natural mortality	π	Relationship with κ see Table 6
Intercept of the length weight relationship	α	U(0.01,0.04)
Exponent of the length weight relationship	β	U(2.7,3.3)
Length at 50% maturity (as a fraction of asymptotic length)	γ	U(0.5,0.7)
Steepness of maturity ogive	δ	U(0,1)*
Standard deviation of recruitment deviates	σ	LN(0.6,0.2)*
Autocorrelation of recruitment deviates	ς	LU(0.01,0.7)
Stock recruitment steepness	η	(B(1.91,1.28)+0.25)/1.25
Fishing related parameters		
The fraction of λ at which 50% of fish are vulnerable	ν	U(0.4,0.8)
Steepness of vulnerability ogive	ξ	U(0,1)*
Return mortality proportion	ϖ	Not used because no size limit assumed
Exploitation history	ζ	50 year
Fraction of exploitation rate history when the trend in exploitation rate changed	ϑ	20/ ζ
Exploitation rate at the year when the trend in exploitation rate changed	ι	U(0.1,0.3)
Current exploitation rate	ω	See Table 5
Proportion of asymptotic length at which legal	ρ	0 (i.e. no legal size limit)
Management related parameters		
Quota implementation error	υ	0.1
Quota implementation bias	ϕ	0
Quota Implementation lag	θ	1

Table 5: Overall general prior and species-specific prior distributions for some model parameters. All prior distributions are uniform with the lower and upper bounds tabulated. Only parameters where there is a species-specific prior are given.

	Asymptotic length λ		**Growth rate - asymptotic length relationship** $\ln(\kappa)+1.53\ln(\lambda)$		**Mortality-growth relationship** π/κ		**Status** B_{2010}/B_0		**Exploitation rate** C_{2010}/B_{2010}	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Overall	14	124	2.3	5.43	0.5	3	0.15	0.9	0.01	0.2
BLUR	26	61	3.37	4.77	0.50	2.50	0.15	0.50	0.02	0.07
BLCK	35	83	3.50	4.90	0.50	2.50	0.40	0.90	0.02	0.06
BRWM	27	63	3.00	4.40	0.50	2.50	0.15	0.90	0.01	0.20
GPHR	20	47	3.29	4.69	0.50	2.50	0.20	0.80	0.05	0.15
COPP	33	77	3.24	4.64	0.50	2.50	0.15	0.90	0.01	0.20
OLVE	29	68	3.68	5.08	0.50	2.50	0.15	0.90	0.01	0.20
GRAS	25	57	3.35	4.75	0.50	2.50	0.15	0.90	0.01	0.20
CHNA	23	53	3.19	4.59	0.50	2.50	0.15	0.90	0.01	0.20
BYEL	18	43	3.07	4.47	0.50	2.50	0.15	0.90	0.01	0.20
QLBK	31	72	2.57	3.97	0.50	2.50	0.15	0.90	0.01	0.20
KLPR	22	51	3.46	4.86	0.50	2.50	0.15	0.90	0.01	0.20
TREE	18	43	3.11	4.51	0.50	2.50	0.15	0.90	0.01	0.20
CLCO	14	33	2.30	3.70	0.50	2.50	0.15	0.90	0.01	0.20
SCOR	24	56	2.92	4.32	0.75	3.00	0.50	0.80	0.05	0.15
CBZN	34	79	4.03	5.43	0.75	3.00	0.30	0.80	0.03	0.15
KLPG	29	68	3.73	5.13	0.75	3.00	0.15	0.90	0.01	0.20
RCKG	29	68	3.73	5.13	0.75	3.00	0.15	0.90	0.01	0.20
SHPD	53	124	3.42	4.82	0.75	3.00	0.15	0.90	0.07	0.20
MFPB	43	101	3.64	5.04	0.75	3.00	0.15	0.90	0.01	0.20

Figure 2: Observed relationship between estimates of asymptotic length (λ) and the growth rate coefficient (κ) amongst California nearshore species. Note that both axes are on a log scale.

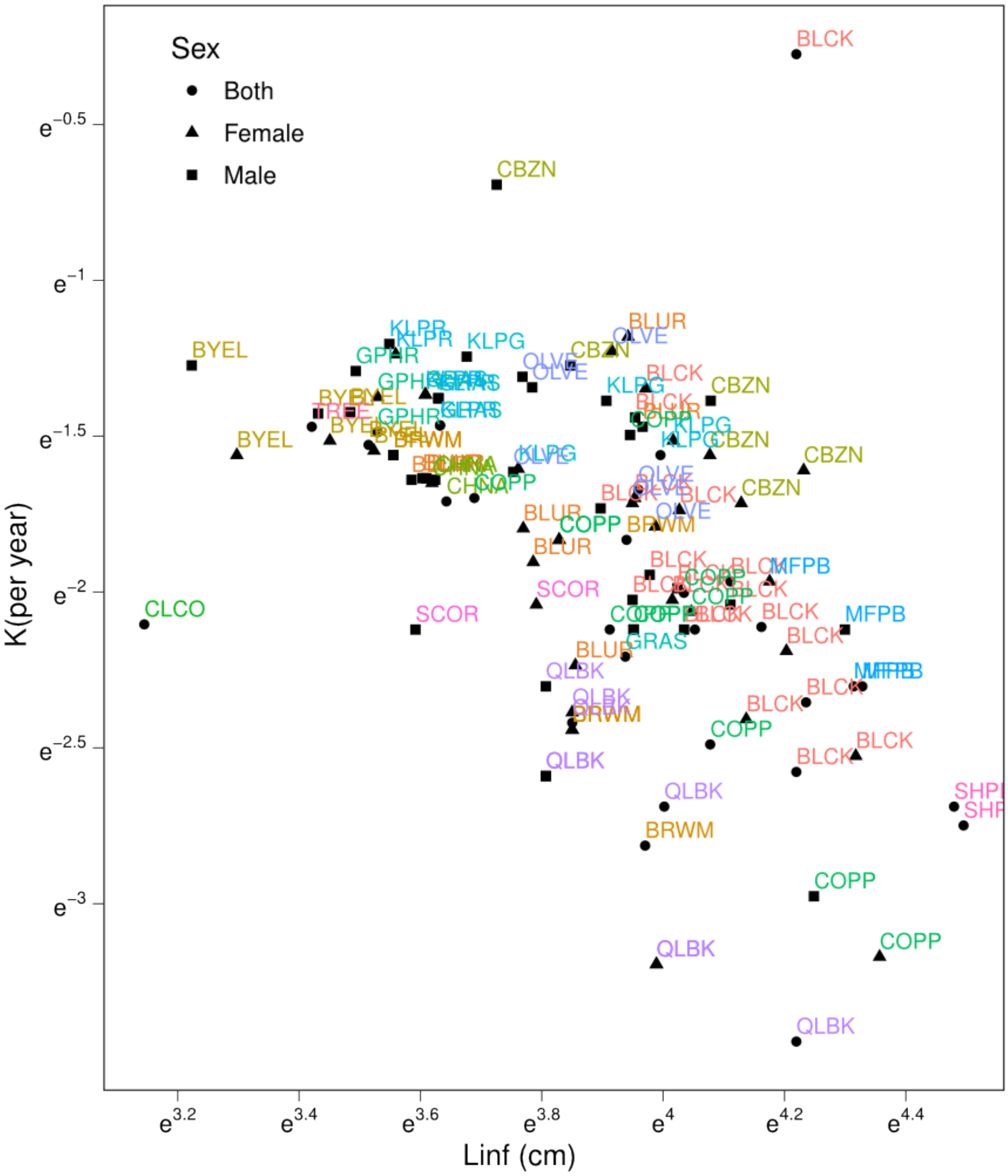


Figure 3: Estimation of the relationship between the von Bertallanfy growth parameters asymptotic length (λ) the growth rate coefficient (κ). Parameter estimates for males, females and sexes combined are shown by points with grey lines connecting estimates that are from the same location within each study. Black vertical lines indicate the uniform prior for asymptotic length for each species. Black diagonal lines indicate the prior for each species for the relationship between asymptotic length ans the growth coefficient.

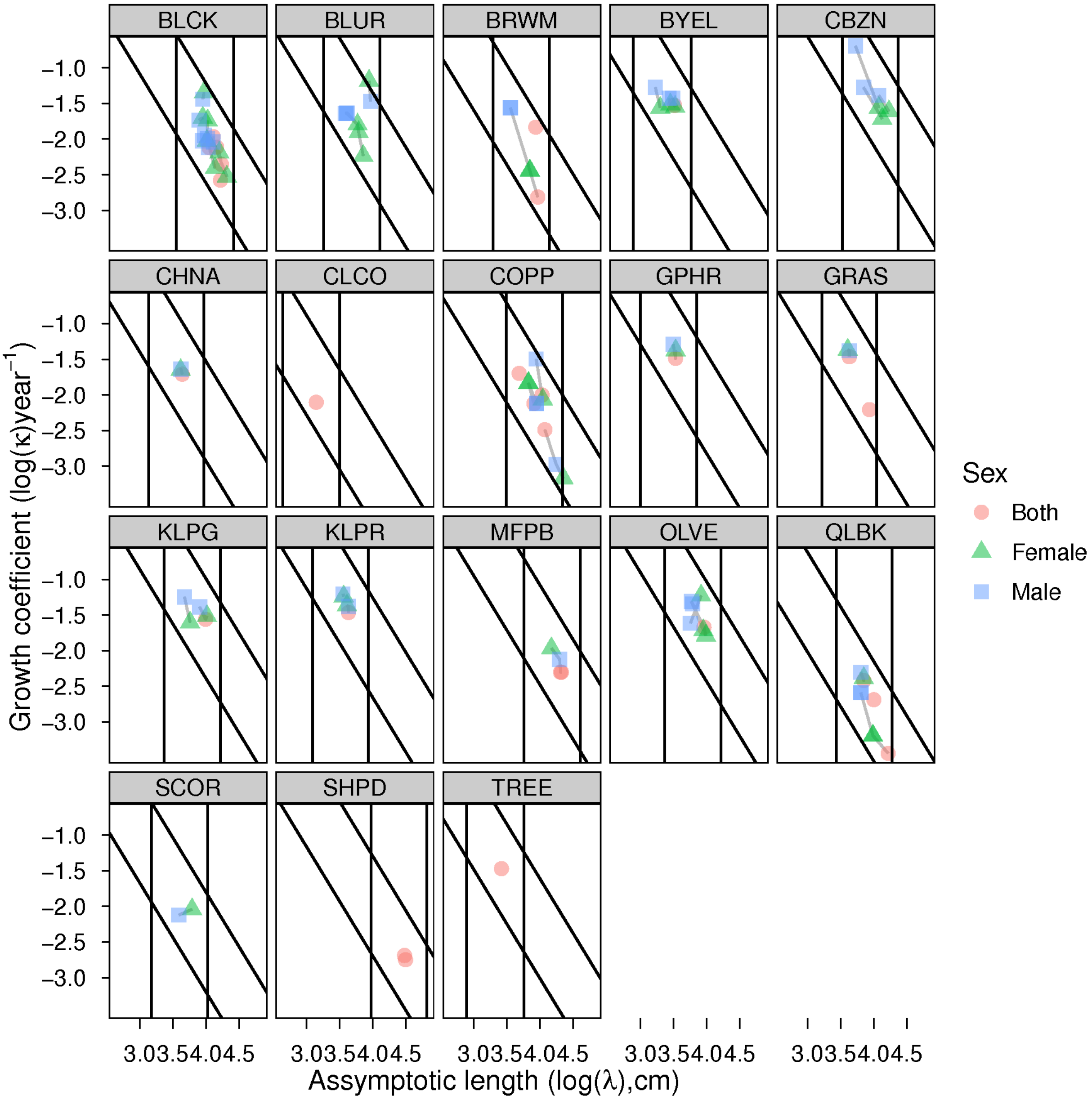


Table 6: Estimates of natural mortality from the CDFG Life History Database. Those estimates that were based on empirical relationships (e.g. Hoenig 1983 method) have not been included. Where are range was given the mid point is used.

Species	Natural mortality	Sex	Range	Method	Reference
Blue rockfish	0.14	B	Juveniles		Tenera (2000)
	0.12	M		Assessment	Key et al (2008)
	0.10	F			
Black rockfish	0.17	M	9 to 16	Catch curve	Wallace & Tagart (1994)
	0.24	F			
	0.30	B		Catch curve	STAR (1999)
	0.25	B	4 to 12	Age frequency	Gowan (1983)
	0.28	B		Re-par. of stock-recr.	Dorn (2000)
	0.31	B	3 to 14	Tag & recapture	Barker (1979)
	0.41	M	6 to 16	Tag & recapture	Wallace et al (1999)
	0.52	F			
	0.16	M		Assessment	Sampson (2008)
	0.20	F			
Brown rockfish	0.11	B	6 to 15	Age frequency	Gowan (1983)
Copper rockfish	0.11	B	5 to 34	Tag & recapture	Barker (1979)
	0.13	B	9 to 18	Age frequency	Gowan (1983)
Quillback rockfish	0.12	B	9 to 16	Age frequency	Gowan (1983)
	0.13	B	6 to 37	Tag & recapture	Barker (1979)
California scorpionfish	0.25	B		Assessment	Maunder et al (2006)
Cabezon	0.25	M		Assessment	Cope & Key (2010)
	0.30	F			
Kelp greenling	0.26	B		Assessment	Cope & MacCall (2006)
California sheephead	0.20	B		Assessment	Alonzo et al (2005)

Figure 4: Relationship between estimates of natural mortality (π) and the growth coefficient (κ). The vertical and horizontal lines for each species represent the range of estimates for natural mortality and growth coefficient respectively. The black lines indicate the lower and upper bounds used for the relationship between the parameters: for scorpaenids $0.5\kappa \le \pi \le 2.5\kappa$, for others $0.75\kappa \le \pi \le 3.0\kappa$. For reference, the relationship $\pi = 1.5\kappa$ (Beverton & Holt 1959, Jensen 1996) is given as the grey line.

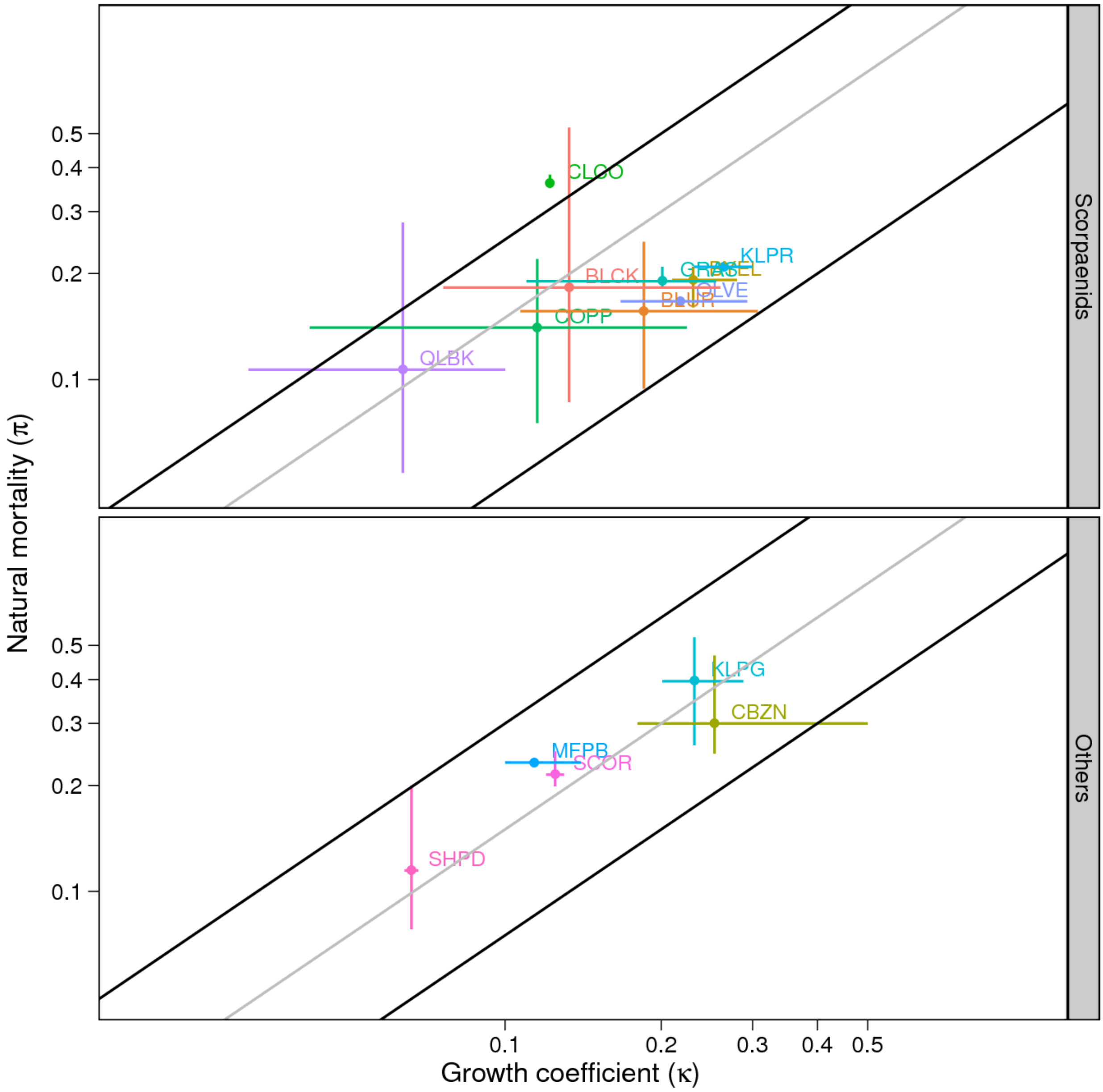


Table 8: Estimates of selectivity ogives from some of the assessments for California nearshore fisheries. Due to the parameterization of the assessment model and/or the information provided in reports many of the estimates in this table are approximate only.

Species	**Method**	Type	**50%**	**95%**
Blue rockfish (Key et al 2008)[23]	Comm. Hook and line	Logistic	32.7	39.57
	Comm. Set net	Logistic	37.91	41.38
	Recr. Hook and line	Logistic	27.11	34.49
Black rockfish (Sampson 2008)[24]	Comm. Hook and line	Bell	~31	~37
	Comm. Trawl	Logistic	~46	~57
	Recr. Hook and line	Bell	~27	~33
Gopher rockfish (Key et al 2005)[25]	Comm. Hook and line	Logistic	26.5	30.3
	Recr. Hook and line	Bell		
California scorpionfish (Maunder et al 2005)[26]	Comm. Hook and line	Logistic	~21	~22
	Comm. Trawl	Logistic	~21	~22
	Recr. Hook and line	Logistic	~23	~25
California sheephead (Alonzo et al 2005)[27]	Recr.	Logistic	~25	~30
	Comm. Trap	Logistic	~27	~30
	Comm. Hook and line	Logistic	~47	~55
	Comm. Set net.	Logistic	~55	~70

23 Parameter estimates from Table 21.

24 Parameter estimates do not seem to be tabulated. See Figure 21 for graphs.

25 Parameter estimates from Table 6.

26 Parameter estimates do not seem to be not tabulated so derived from Figure D5.4. Gillnest and trap selectivities assumed equal to commercial hook and line. Where selectivity separated separately for early and late periods, only late is tabulated.

27 Although estimates are tabulated. So these values have been derived from simply eyeballing Figure 8.2

Table 9: Estimates of current (2010) status and exploitation rate from stock assessments.

Species	Status (percent of virgin biomass)	Exploitation rate
Blue rockfish (Key et al 2008)	30.4% (13.9-50.2%)[28]	2-7%[29]
Black rockfish (Sampson 2008)	67.2% (49.3-88.1%)[30]	2-6%[31]
Gopher rockfish (Key et al 2005)	58.9% (25.5-70.1%)[32]	5-15%[33]
California scorpionfish (Maunder et al 2005)	57-74%[34]	5-15%[35]
Cabezon (Cope & Key 2010)	Northern 48% (37-56%)[36]	3-15%[37]
	Southern 57% (32-83%)	
California sheephead (Alonzo et al 2005)	?	7-20%[38]

28 From Table 26, medium catches.

29 From Table 22 and based on range of exploitation rates estimated since 2001.

30 From Table 37, medium catches.

31 From Table 30.

32 From Table 11, medium catches.

33 Based on Table 10 and from values implied in Table 11.

34 From Table G2, current catches.

35 Based on recent estimates in Figure D5.3.

36 From Table 25, “40-10, F45% ”, “base M catches”.

37 Based on estimates in Table E-9.

38 Based on Figure 6.11

5 Results

Each of the 5215 management procedures were evaluated for each of 5000 replicate draws from the general parameter prior distributions. For each replicate the operation of each management procedure instance was simulated over 50 years.

A simple two part "conditional-utility" was used to assess the performance of management procedures. Performance was judged based on maximizing the simulated average annual catch subject to the condition that the simulated spawning biomass at the end of 2060 was greater than 10% of virgin biomass for at least 95% of simulations. Of the 5215 management procedures evaluated, 1213 (23%) satisfied the risk condition that the spawning biomass at the end of 2060 was greater than 10% of virgin biomass for at least 95% of simulations.

5.1 Comparison of the performance of each management procedure class

The PHER class performed the best with 47% of instances meeting the risk condition and 16% of instances in the top quartile. This suggests that the PHER class is the most robust to its parameterization. That is, altering the control parameters of this class of management procedure has the least impact on its performance (Table 10).

In contrast, the MAST appears to be the least robust. For this class of management procedure only 1.3% (22) instances met the risk condition. However, those instances of MAST that met the criteria performed in the top quartile (Table 10). This suggests that the MAST procedure can perform well for the California nearshore fishery if it's control parameters are set appropriately.

The TRZK class provided intermediate performance with 21% of instances meeting the risk condition. However, no instances of this class were in the top quartile for performance.

Often the best performing instances of PHER and MAST result in similar TAC changes and thus trajectories of biomass and recruitment. In contrast, the TRZK class often appears not to reduce TAC quickly enough when reductions are needed as thus can cause biomass to fall to low levels. Examples of biomass, recruitment and TAC trajectories are shown for three example parameter replicates in Figure 10. In replicate 0, the starting biomass was high and there was little difference in the TAC produced by each procedure and thus little difference in the resultant biomass and recruitment trajectories. Not that for this replicate, TRZK does not change the TAC because the estimate of Z/K remains withing the target range. In replicate 5, biomass also starts high but a high exploitation rate, coupled then a prolonged period of low recruitment causes biomass to fall dramatically. Both the PHER and MAST instances reduce catches by about half over the following 10 years. However TRZK does not reduce the TAC until biomass has already declined substantially. Although PRAC(5,0.64), equivalent to a fixed TAC of 64% of average of the catch from 2006-2010, starts with a more conservative initial catch this is still too high in this replicate eventually causes stock biomass to collapse. In replicate 10, biomass starts at lower levels and under constant catch increases. Both the PHER and MAST classes increase the TAC similarly over time but with fluctuations associated with fluctuations in biomass caused by recruitment variation.

5.2 Best performing management procedure instances

For the general prior and for each of the specific partitions, an instance of the PHER class of management procedure performed the best. The optimal value of its control parameters was very similar across species (Table 11). Unsurprisingly, the optimal source for the biomass index was a survey since in the simulations this is not prone to the trends in catchability and hyperstability/hyperdepletion as is CPUE. For most species, the best value of the *ratio multipler* control parameter (which defines the multiple of the historical catch to abundance index to use) is 1. This suggests that, of the values of this parameter that were evaluated, the average ratio between catch and abundance over the last 15 years is appropriate for setting future catches. However, for the species that have the highest estimated status (relative to virgin biomass), black rockfish, scorpionfish and cabezon the optimal value for *ratio multipler* is 1.5 (i.e. a higher implied exploitation rate than over the historical time horizon).

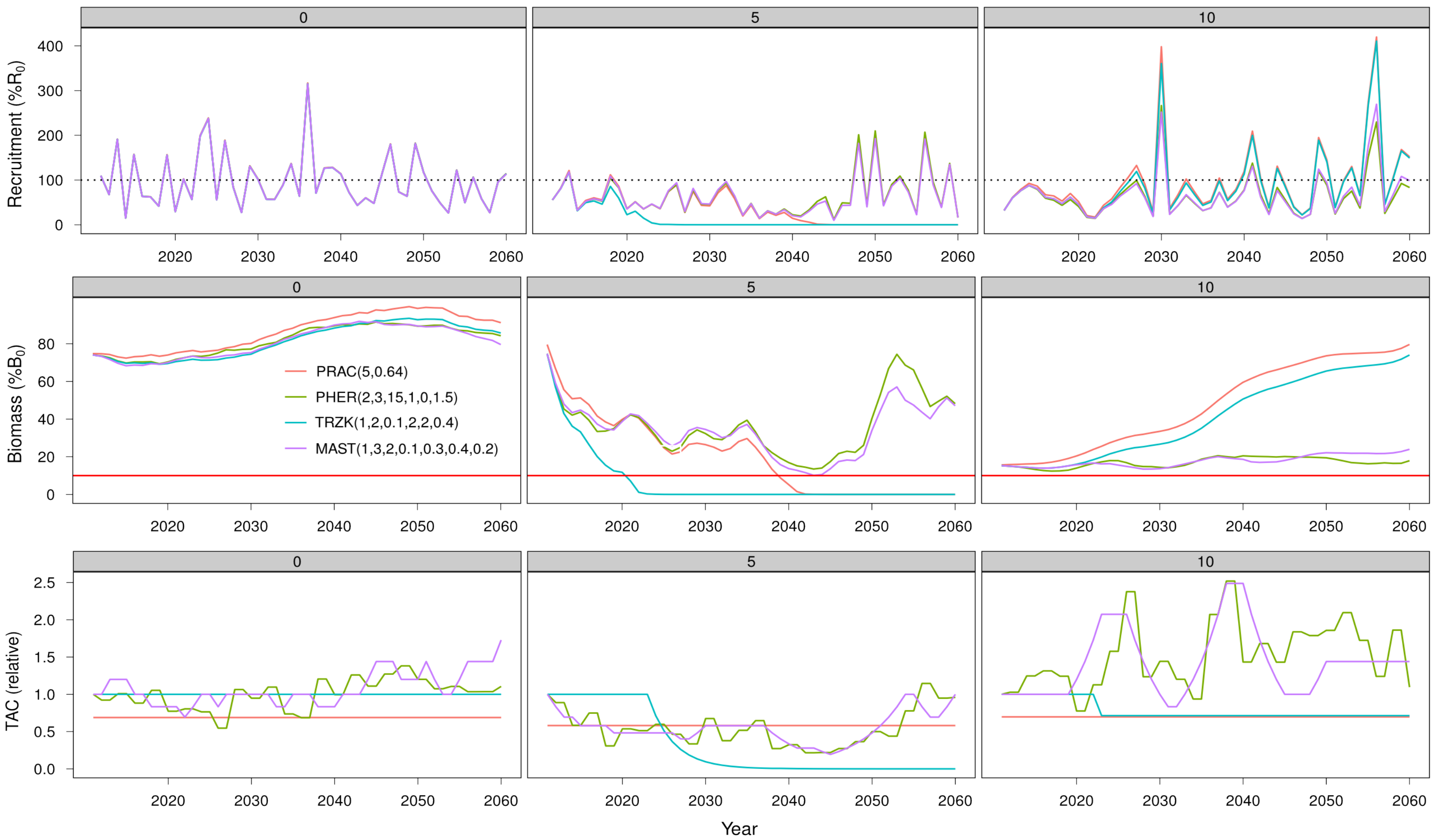
Table 10: The percentage of management procedure instances of each class that fall into each of five groups based on performance. Failed risk criteria: instances that failed to meet risk criterion. Quartiles are the quartiles of ranked conditional utility e.g. 4th quartile is the top 25% of instances that met the risk criterion.

Group	PRAC	PHER	TRZK	MAST
Failed risk criterion	58.1	53.0	78.9	98.7
1st quartile (worst)	32.3	4.2	12.7	0.0
2nd quartile	6.5	11.7	5.7	0.0
3rd quartile	3.2	14.8	2.7	0.0
4th quartile (best)	0.0	16.3	0.0	1.3

Table 11: Control parameter values for the best performing PHER management procedure instances for the general parameter priors and each of the species-specific partitions.

Species	Source (s)	Frequency (f)	Horizon (h)	Ratio multiplier (r)	Minimum multiplier (l)	Maximum multiplier (u)
General	Survey	2	15	1	0	1.5
BLUR	Survey	2	15	1	1	1.5
BLCK	Survey	2	15	1.5	0	1.5
BRWM	Survey	2	15	1	0	1.5
GPHR	Survey	2	15	1	0	1.5
COPP	Survey	2	15	1	0	1.5
OLVE	Survey	2	15	1	0	1.5
GRAS	Survey	2	15	1	0	1.5
CHNA	Survey	2	15	1	0	1.5
BYEL	Survey	2	15	1	0	1.5
QLBK	Survey	2	10	1	0	1.5
KLPR	Survey	2	15	1	0	1.5
TREE	Survey	2	15	1	0	1.5
CLCO	Survey	2	10	1	0	1.5
SCOR	Survey	2	15	1.5	0	1.5
CBZN	Survey	2	15	1.5	0	1.5
KLPG	Survey	2	15	1	0	1.5
RCKG	Survey	2	15	1	0	1.5
SHPD	Survey	1	15	1.5	0.25	1.5
MFPB	Survey	2	15	1	0	1.5

Figure 10: Examples of individual evaluation replicates comparing the performance of the best instance of each class of management procedure. Each column represents a single evaluation replicate. The total allowable catch (TAC) is relative to the catch in 2010.



6 Discussion

This study evaluated several classes of management procedures to the California nearshore fishery. It illustrates how the available knowledge for the fishery, both from biological research and stock assessments, can be used to rapidly evaluate management procedures for a range of species. This work shows how relatively simple management procedures can provide an effective basis for changes in total allowable catches,

However, it would be inappropriate to take the results from this study and directly apply the management procedures evaluated. This study has several limitations which require further work before management procedures can be applied to the California nearshore fishery.

6.1 No stakeholder participation

An important feature of management procedures is that they can foster the participation of stakeholders in strategic decision making. This occurs through stakeholder involvement in the definition of management objectives, performance statistics, risk criteria and utility functions and in the final choice of management procedures. There was no stakeholder participation in this project and instead a very simple utility function was defined based on yield alone. In reality stakeholders are likely to be interested in other management objectives such as maximizing abundance (in order to maximize catch rates) and reducing management variability (i.e. minimizing the frequency of TAC changes to reduce uncertainty). Furthermore, alternative risk criteria may be considered appropriate by stakeholders and managers alike.

Proper stakeholder participation in the selection of management procedures can be a time consuming process usually involving several iterations of evaluation and selection. However, this initial process is important for generating the buy-in that is crucial for the long term success management procedures.

6.2 Limited number of management procedure classes

In this project only four classes of management procedure were evaluated. This was partly to make the work more tractable given the time available. However, it also reflects the fact that the design of generalized management procedures, those that can be "taken off the shelf" and evaluated for almost any fishery, is in its infancy. As the library of generalized management procedures grows it is expected that better performing management procedure will be available for fisheries such as the California nearshore fishery.

It is likely that, based on the lessons learned in projects such as this, new classes of management procedure will be developed that provide superior performance with respect to management objectives. For example, in this study the PHER class of management procedure performed well despite the fact that it only uses an index of abundance. However, it would be wrong to conclude that this implies that other monitoring data is unnecessary. A management procedure class derived from PHER but which augments the abundance index with additional information such as mean length, may well perform better.

In addition, in this project there was only limited consultation with CDFG staff regarding the monitoring data available for the nearshore fishery. Better examination of the data available and its relative strengths and weaknesses may suggest alternative management procedures. Ideally, CDFG staff and other with more experience with the fishery would be able to design management procedures which could then be evaluated against generalized procedures such as those presented here.

6.3 Limited analysis of evaluation results

Given the time available, only a limited set of analyses of evaluation results was done in this study. These were focused on the broad scale questions of which classes of management procedures perform the best given the dynamics of the California nearshore fishery. However, there are far more intensive analyses that could be done to better explain why the observed patterns in performance arise and to better tune management procedures to the particular dynamics associated with each species. This limitation of the current study is related to the limitations above regarding the lack of stakeholder participation and the number of management procedure classes evaluated. In an ideal process, the results from as study such as this would be taken to stakeholders and managers for discussion and input before another round of procedure refinement and evaluations.

The approach taken in this study is intentionally “scattergun”: a very large number of management procedures (5215) were evaluated over a large number of parameter replicates (5000). This allows for broad patterns in the performance of management procedures to be examined before focusing attention of particular classes and instances. However it also creates very large output files of performance statistics with over 26 million rows and over 3Gb in size. The large size of these evaluation data sets poses technical challenges in itself and we are still developing the software used for efficiently interrogating them.

It is not the intention of this work to provide a definitive set of management procedures for the California nearshore fishery. Rather, it is hoped that this study shows the potential to efficiently evaluate and apply management procedures to a diverse fishery whilst making the most of the available knowledge and data.

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