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Conceptual models for Ecosystem Based Fisheries Management (EBFM) in Western Australia

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Fish for the future

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Executive Summary

The Department of Fisheries, Western Australia is currently developing a framework to assess the most appropriate methodologies for the implementation of Ecosystem Based Fisheries Management (EBFM) in Western Australia. The implementation of EBFM can be considered as an operational extension of Ecologically Sustainable Development (ESD), the principles of which were adopted by Western Australia for application in the management of fisheries in 2002. EBFM aims to assess and manage ecological impacts as well as social and economic outcomes related to fish and fisheries at a regional level. The degree to which EBFM will be implemented in terms of activities or processes, additional to those fishery management processes currently in place for the Department, has yet to be ascertained. This report forms part of a project designed to address the question as to what benefits EBFM could generate if applied in Western Australia.

Fisheries management in WA has traditionally focused on maintaining the sustainability of targeted stocks and, as such, has comprehensive data sets on the catches, biology and ecology of many exploited stocks. There are limited quantitative data regarding the ecosystem, social and economic impacts of fisheries and limited formal consideration of the roles of external drivers and governance. Beyond these limitations there is also the challenge to identify linkages and important relationships both within ecosystems (including exploited stocks), and across social, economic and governance facets of fisheries management.

Qualitative modelling (also known as loop analysis) uses feedbacks to investigate the impacts of perturbation on system stability and produce predictions of change in ecological, social and economic aspects of systems. This technique may be used when quantitative data is lacking, as it requires only the signs of interactions between model variables (i.e. positive, negative or zero). For example, there may be qualitative information based on expert opinion suggesting that an increase (perturbation) in the number of iconic fish in an area has a positive effect on the general community through the maintenance of cultural and heritage values. Qualitative modelling can also be used to identify the critical thresholds for change in a system and may be useful to highlight data gaps and identify important relationships. Such information, along with the capacity to investigate system stability, can allow the examination of the efficacy of alternative management strategies and be used to indicate likely methods of aiding species recovery following perturbation.

Qualitative modelling was used to investigate five separate systems within the West Coast Bioregion. Ecosystem dynamics and the importance of social and economic links were examined using different scenarios for each of the five systems. The systems included: the role of direct stakeholders in influencing government decisions; management needs in Cockburn Sound; the impacts of the market on the western rock lobster fishery; and alterations to recreational fisher behaviour following hypothetical changes in management. Investigations involved the examination of system stability and the inclusion/removal of links between particular variables of interest to compare predictions between alternative models. In addition, model predictions following a positive perturbation (i.e. positive disturbance or increase) to specific variables were also used to examine various scenarios.

Collaboration between the government and direct stakeholders, such as commercial fishers, was found to increase the stability of the West Coast Bioregion model. In addition, the relationship between fish, the fishery and fisheries management was identified as an important driver in the Cockburn Sound ecosystem. Strong management, as well as additional management external to

the Department, was shown to be able to counteract the negative effects of coastal development or industry on fish populations and sediment in the water column.

The western rock lobster model reinforced the importance of management and the regulation of rock lobster fisheries in Western Australia to ensure the fishery remains sustainable and is not driven solely by profit. The role of price, demand and illegal fishing in the abalone fishery were also investigated and the analysis identified the need for continued strict regulation of illegal harvest. In addition, if the fishery is to remain economically viable, the need for management to take market impacts into account is necessary, particularly if changes to the management of the abalone fishery occur in the future.

A model of recreational fisher behaviour was produced to investigate the impact of a hypothetical seasonal closure to recreational fishing for a suite of demersal fish species in the metropolitan zone. A seasonal closure was predicted to have positive impacts on protected demersal fish populations but negative impacts on the abundance of all other fish species. The response of these populations depends on the strength of effort reductions by management versus an effort-shift towards targeting alternative species. This model also highlighted the potential impact of a ‘spike’ in fishing pressure outside of the closed season. It is recommended that quantitative data collection regarding the likely changes in fisher behaviour be undertaken.

Recreational fishing and the management of recreational fisheries were found to be important in a number of the qualitative modelling scenarios. Further data collection on the impacts of recreational fishing and the socio-economic drivers behind recreational fishing are essential. In addition, quantitative information on economic factors such as demand, the influence of the international market and the Australian dollar on fisheries exports should be undertaken. This would allow more comprehensive models of the fishery economy to be produced. In addition, quantitative estimates of the existence of illegal fishing and the influence of lobby groups could assist in the development of new management strategies.

Additional management strategies were found to be necessary in the recreational fishing models. Furthermore, social assessments, including the assessment of fisher behaviour, will be an important source of information for the production of future models. To improve the outcomes generated by qualitative models, the social and economic data should be structured to provide relevant data to management and to update the models.

Contents

1.0 Introduction

The Department of Fisheries, Western Australia is currently developing a framework for the implementation of Ecosystem Based Fisheries Management (EBFM) in Western Australia. EBFM is an extension of Ecologically Sustainable Development (ESD) and has the aim of providing a practical means for the implementation of ESD in fisheries. Specifically, EBFM aims to assess and manage ecological, social and economic impacts or outcomes related to fishing within specified ecosystems (Fletcher 2006). All fishing sectors, as well as their individual and cumulative impacts, can be assessed through EBFM, including commercial, recreational, charter and indigenous fisheries.

The need to include holistic ecosystem analyses into fisheries management is becoming widely accepted (Arkema et al. 2006); however, the actual application of EBFM has been slow worldwide. The breadth of species and impacts that may occur in ecosystems has determined that the creation of a general method for the implementation of EBFM has been unable to be put into practice (Fletcher 2005). Furthermore, the complexity of ecosystems determines that quantitative information, such as species abundances or the magnitude of environmental impacts, may be unavailable (e.g. Dambacher et al. 2009, Rochet and Rice 2009). In particular, quantitative information for the impact of change in social and economic factors related to fisheries is often unavailable.

Investigations into the social and economic impacts of change in fisheries management and the fishing industry have recently been undertaken in Australia (Aslin and Byron 2003, Schirmer and Pickworth 2005, Schirmer and Casey 2005, Vieira et al. 2009). These reports indicate that local data is required for the analysis of local issues. However, local social and economic information at a local level is generally not available and the relationships between social, economic and ecological variables may therefore be unknown. For instance, it may be unclear how a group of commercial fishers impact fisheries management. A positive impact may occur if fishers acknowledge the need for management restrictions and abide by the set regulations. Similarly, fishers may negatively impact the fisheries management by opposing new regulations.

Qualitative modelling can be a useful technique in these data-limited situations to provide an understanding of ecosystem structure and dynamics. This technique requires only the signs of interactions (positive, negative or no effect) between species or variables in an ecosystem (Levins 1974, 1975) and can incorporate non-quantitative information, such as trends. Qualitative models may be used as an alternative or complement to traditional quantitative analyses (Hayes et al. 2008, Metcalf et al. 2008) and can be used to:

- Focus research on a core problem or dynamic of interest;
- Identify data gaps and important relationships;
- Investigate system stability;
- Aid discussion with non-scientists through the stylised depiction of an ecosystem and its dynamics;
- Aid the development of EBFM through greater participation of stakeholders and the public;
- Investigate the impacts of structural uncertainty in the behaviour of a system (e.g. when fishers could positively or negatively impact fisheries management);
- Highlight the likely scenarios for change.

Starting in 2007, the Department of Fisheries, Government of Western Australia, facilitated and attended a series of meetings with stakeholders (e.g. Marine Policy Stakeholder Group; CSIRO workshop on developing marine indicators, see Hayes et al., 2008), to begin scoping methods for the implementation of EBFM and decisions as to what extent EBFM might be implemented in WA. These investigations have used the West Coast Bioregion as a case study (Shaw et al., in preparation).

Qualitative modelling was identified as a method that would be able to aid the development of a framework for EBFM, given that there were many data gaps particularly with regard to social and economic factors. In addition, qualitative models can be used as a means of compiling current knowledge, which can aid communication between scientists, managers, fishers, policy-makers and other stakeholders. Such communication tools may aid the overall understanding of ecosystem processes and the holistic impacts of perturbations (impacts) to the system.

1.1 Study region and ecosystem components

This investigation has used the Department of Fisheries' West Coast Bioregion (WCB) as a case study for the implementation of EBFM in Western Australia (Fig. 1). The bioregion supports a number of important commercial fisheries including fisheries for western rock lobster (*Panulirus cygnus*), demersal scalefish (numerous species) and abalone (*Haliotis* spp.). In addition, this bioregion also supports large recreational fisheries. The mainland coastal region adjacent to the WCB contains approximately 81% of the population of Western Australia (1.98 million people) and, according to a 2006 survey, an estimated 457,300 people in this region participate in recreational fishing at least once a year (Barharthah 2008).

As part of the development of a framework for EBFM, 'components' of the West Coast Bioregion, such as different ecosystems, fisheries and habitats, were identified (Shaw et al., in preparation, Fig. 2). The bioregion was delineated further to include important, or high risk ecosystems such as the Peel Harvey and Swan Canning estuaries, Rottnest Island and Cockburn Sound. Ecosystems were defined based on expert opinion, including significant input from stakeholders. Components were placed into trees according to their function, such as retained species or external impacts (e.g. pollution, coastal development).

Social and economic values related to fisheries and marine systems were also identified during the delineation of components (Shaw et al. in preparation). The broadest classification in the component trees included groups such as direct stakeholders, dependent communities and indirect stakeholders. Similarly to ecosystem definition, social and economic values were classified into increasingly specific groups.

A risk assessment was undertaken using available data and the perceptions of stakeholders to determine the level of risk associated with each component (e.g. ecosystem, social value). These components and risks were used to determine the focus of the qualitative ecosystem models. Qualitative models were produced at different scales (i.e. whole West Coast Bioregion, Cockburn Sound ecosystem) depending on the scale of the issue under investigation, such as seagrass beds in Cockburn Sound or larger-scale impacts such as the role of the governance in fisheries management.

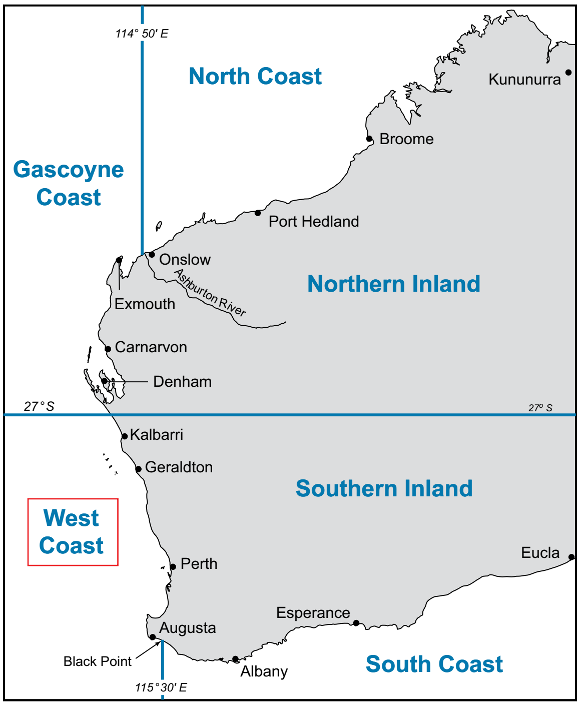


Figure 1. Map of Western Australia showing the Department of Fisheries' bioregional boundaries (WA Department of Fisheries 2008).

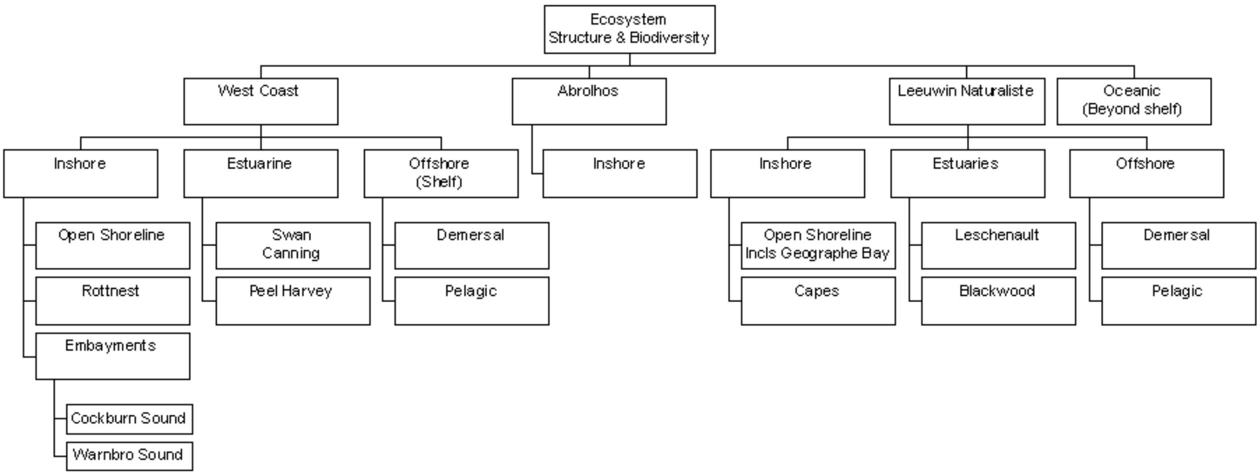


Figure 2. Draft ecosystem structure and biodiversity component tree. The Department of Fisheries West Coast Bioregion is split into the IMCRA bioregions (e.g. West Coast) and then further into various ecosystems based on expert opinion.

2.0 Qualitative modelling methods

A number of fishery management issues were identified as priorities for the application of qualitative modelling, of which five are investigated in this report. The results of the study will aid the development of a framework for the implementation of EBFM in Western Australia by increasing our understanding of links/interactions between specific variables of interest and in the overall efficacy of our conceptual depiction of these systems.

Using qualitative modelling, ecosystems can be represented by signed digraphs (Puccia and Levins 1985), which are constructed using the signs (+, –, 0) of the interactions between variables. For instance, in Figure 3, the fishery benefits from the target species through harvesting and therefore receives a positive link (arrow) from this variable. In contrast, the target species are removed from the system by the fishery and therefore receive a negative link (filled circle) from that variable. The fishery in this system also gains a benefit from the capture of non-target invertebrate species. As a result, a positive link from invertebrate species to the fishery and a negative link from the fishery to invertebrates was also included. Similar positive and negative links were used between the target and invertebrate species to represent a trophic relationship, for instance, if the target species was a predator of the invertebrate species. Negative links connecting the variable to itself represent density-dependence or a reliance on resources external to the model.

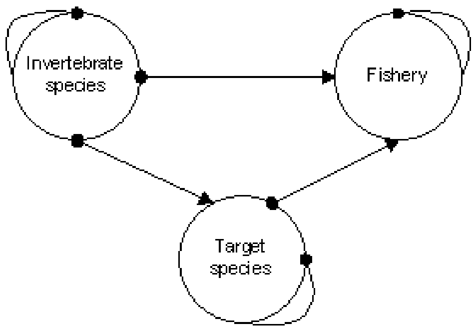


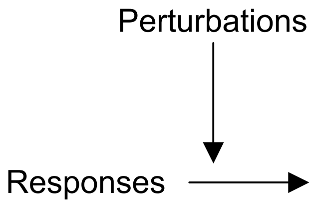
Figure 3. Qualitative model of a *Fishery*, its *Target species*, and a prey resource *(Invertebrate species)* of that stock. Negative effects are filled circles and positive effects are arrows. The fishery also gains a benefit from the removal of incidentally captured invertebrates for sale (i.e. squid). Negative self-effects represent density-dependence or the reliance on external resource. Variables names are shown in italics in the text.

2.1 The Community Matrix

Interactions between variables (+, –, 0) in a signed digraph can be detailed in a matrix, named a 'community matrix' to reflect that this methodology was developed to deal with the ecological interactions within natural communities. As the underlying mathematics used in qualitative modelling is well established in the field of community ecology, we will retain the use of the term 'community matrix'. Also, to improve readability, we refer to the community matrix as **A**.

The community matrix (**A**) for Figure 3 is shown in Equation 1 where the matrix elements (+, -, 0) represent the direct impacts of interactions between variables. In qualitative analyses, perturbations or disturbances are generally included in the calculations as increases in the abundance of the particular variable of interest. For instance, a perturbation to the system in Figure 3 may be shown as an increase to the target species. Perturbations (increases) occur down columns while responses (predictions) to perturbations are read across rows (Dambacher et al. 2002). The numbers at the top of each column refer to the number associated with each variable name shown for the rows. For example, the fishery (row 3) receives a benefit (+) from perturbation to the target species* (column 2, Eq. 1). Similarly, target species (row 2) receive a benefit (+) from a perturbation to their prey, invertebrates^ (column 1, Eq. 1), while invertebrates (row 1) are negatively (-) impacted by an increase in predators, the target species~ (column 2, Eq. 1).

$$\mathbf{A} = \begin{matrix} \text{Invertebrate species} & 1. \\ \text{Target species} & 2. \\ \text{Fishery} & 3. \end{matrix} \overset{\begin{matrix} 1. & 2. & 3. \end{matrix}}{\begin{bmatrix} - & -^{\sim} & - \\ +^{\wedge} & - & - \\ + & +^{*} & - \end{bmatrix}} \qquad (1)$$



2.2 The Prediction Matrix

The community matrix details the direct interactions that occur within a system; however, the complexity of linkages within a system and their indirect effects may determine that non-intuitive responses to change are predicted. For instance, as the fishery in Figure 3 captures invertebrates as a byproduct, the predicted response of invertebrates to a perturbation (increase) to the fishery may be expected to be negative. Yet, because the fishery also captures the target species that prey on invertebrates, there are two possible paths through which invertebrates can be impacted (Fig. 4). The fishery has an indirect positive impact on invertebrates as a result of a reduction in predation through the capture of the target species (Fig. 4a). In addition, the fishery has a direct negative impact on invertebrate species as they are retained for sale following incidental capture (Fig. 4b).

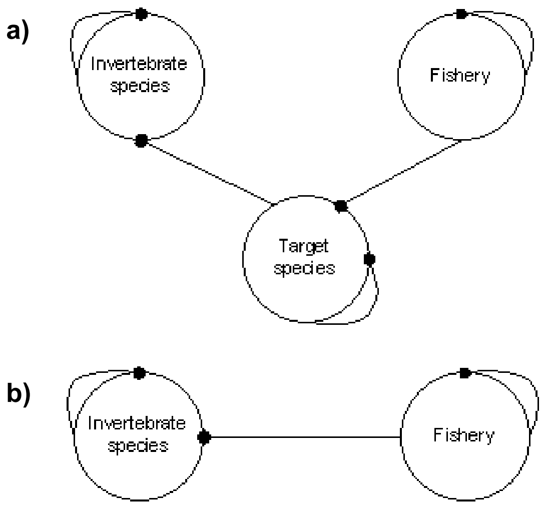


Figure 4. Indirect positive (a) and direct negative (b) paths from the fishery to the invertebrate species.

Predictions of response to perturbation are calculated using both the direct and indirect effects of change in community members. As a result, predictions may be reliant on interactions between all variables in the system, not simply the direct interaction between the perturbed variable and the variable for which the response is being investigated. This may be explained through the use of the previous example in Figure 4 where the response of the invertebrate species to an increase in the fishery also relies on the relationship between the fishery and the target species.

Predictions of response to change are presented in a prediction matrix. The community matrix differs from the prediction matrix in that the former shows only the direct interactions between variables (not the indirect) and does not include information on the predicted change in abundance after a perturbation. Following the established mathematical protocols, the prediction matrix has been designated as 'adj (-**A**)' (Eq. 2) (Dambacher et al. 2002). As in the community matrix, the predicted response is read across the matrix rows while the perturbed variable (variable that increased) is read down the matrix columns (sensu Dambacher et al. 2002). For example, a perturbation to the target species was predicted to have a negative impact on invertebrate species* (Eq. 2). In addition, an ambiguous response was predicted for invertebrates following a perturbation to the fishery# (Eq. 2). Ambiguity occurs when responses with opposing signs contribute to the prediction (i.e. both positive and negative responses exist), as with the response of invertebrates to an increase in the fishery. This situation can also be described using Figure 4 where the fishery in example a) has a positive impact on invertebrate species (as a negative x negative = positive) and in example b) the fishery has a negative impact on invertebrates (single negative link).

Ambiguity is important to consider because the magnitude of interactions may determine that an unexpected response is observed in the field. For instance, if there were four negative responses and one positive response (a total of five responses) as a result of a perturbation, a very strong positive response may determine that an increase in the variable is observed in reality rather than the predicted negative response.

$$\text{Prediction matrix} = \text{adj.}(-\mathbf{A}) = \begin{matrix} \text{Invertebrate species} & 1. \\ \text{Target species} & 2. \\ \text{Fishery} & 3. \end{matrix} \overset{\begin{matrix} 1. & 2. & 3. \end{matrix}}{\begin{bmatrix} + & -^{*} & +,-^{\#} \\ +,- & + & - \\ + & +,- & + \end{bmatrix}} \qquad (2)$$

2.3 Feedback, structural uncertainty and stability

Feedback is a term used to describe the process through which an activity or change in one variable produces change in others and then returns to impact the initial variable (Puccia and Levins 1985). For instance, an increase (or decrease) in fisheries catches, which results in a further increase (or decrease) in catch, is a positive feedback cycle. This could occur in an emerging fishery where catch initially increases and if demand for the product exists, can result in additional effort (e.g. bigger boats, longer sea time, additional gear) being used within the fishery. In contrast, negative feedback could occur when a decrease (or increase) in fishing allows target stocks to increase and eventually result in an increase (or decrease) in fishing. Negative feedback contributes to stability in the system while positive feedback is destabilising. As an analogy for positive feedback, if entry to a football stadium was not limited through ticket sales and security, the size of the crowd could continue to increase to unsafe levels and chaos would likely ensue. On the other hand, negative feedback always opposes the initial change and is therefore stabilising. Stability may be assessed using the methods of Dambacher et al. (2003) where stability values close to 1 are considered more stable than those close to zero.

Alternative models may be necessary if there is uncertainty in how models should be structured, i.e. if there is disagreement or potential errors in the conceptualization of the system in question. For instance, there may be uncertainty about whether the target species consumes the invertebrates in Figure 5. Due to the lack of knowledge regarding the diet of the target species, two models may be used to represent the system. Firstly, a negative link from the target species to the invertebrate species may be used (Fig. 5a) and, secondly, the predatory link may be removed to show that there is no relationship between the target and invertebrate species (Fig. 5b). In this case, the invertebrates could be removed from the model because they do not interact with any other variable in the system. Comparisons of the two (or more) different model structures allow aspects of the structural uncertainty to be investigated. Predictions that are consistent regardless of structural uncertainty suggest the prediction is reliable in comparison to predictions that differ between models. The consistency of predictions between alternative models was examined to assess the impacts of alternative management strategies for a number of the different ecosystems models in this study.

Figure 5. Alternative models that may occur if there is structural uncertainty regarding the relationship between fish and invertebrate species. The relationship is trophic in model a) and invertebrate species receive a negative link from fish while in b) the target species feed on other species in the ecosystem that are not included in the model. In model b), the invertebrate species may be removed from the model because they are not linked to any other variable in the system.

3.0 Ecosystem models

Qualitative models were produced to investigate a number of management systems and perturbations that were highlighted as important during a risk assessment undertaken by the Department of Fisheries in collaboration with stakeholders and other government agencies. Models were produced to investigate:

1. The West Coast Bioregion and the impact of structural uncertainty with regard to the role of direct stakeholders in influencing government decisions;
2. The impacts of eutrophication and fishing in Cockburn Sound, as well as the role of fisheries management in managing ecosystem impacts (i.e. fishing, coastal development, pollution);
3. The impacts of recreational, commercial and illegal fishing on Western Australia's abalone (*Haliotis* spp.) fisheries;
4. The western rock lobster fishery and the impacts of fisheries management, the market, the value of the Australian dollar and the Leeuwin Current;
5. Alterations to fisher behaviour after management changes to recreational line fishing in the West Coast Bioregion.

The model-building methods, investigations undertaken and results for each model will be presented sequentially.

3.1 West Coast Bioregion

Model building and investigation

A model was produced to identify the links between "high-level" components within the West Coast Bioregion (see Fig. 6) and to highlight data gaps. Direct and indirect stakeholders, dependent communities, benthic habitats, non-retained fish species, retained fish species and fisheries administration were included in the model. Ecosystem structure and biodiversity, as in the component tree, was assumed to be represented by *Benthic habitats*, *Retained fish* and *Non-retained species* and was not included as a separate variable. State/National impacts were included in the model within *Government*. The components: "General environmental impacts" and "External drivers" were not included, as these were deemed too general at this time. To clarify this point, alterations to the Leeuwin Current or pollution are specific impacts and may be included in qualitative models. However, a 'General environmental impact' could be any number of perturbations and impact the system in any number of ways. Definitions for each variable (or component) in this modelling exercise can be seen in Table 1.

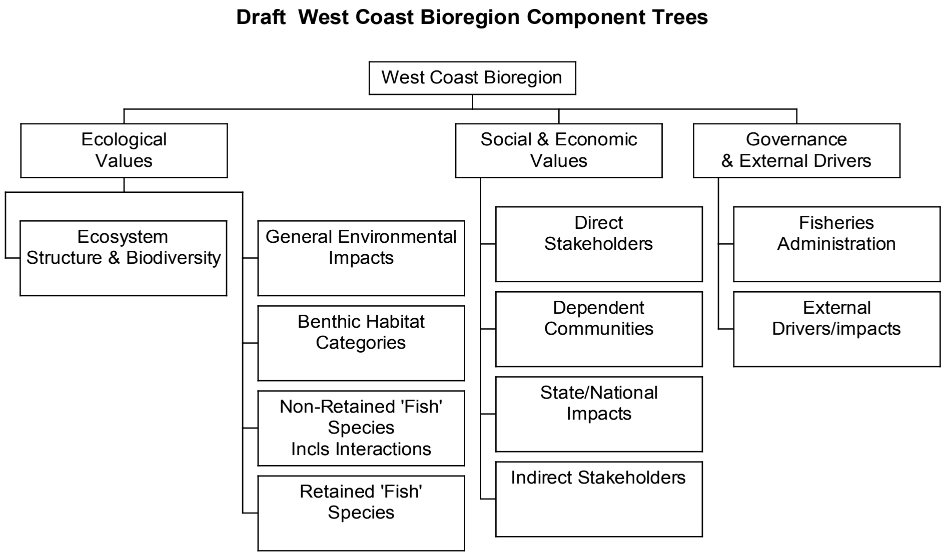


Figure 6. Draft component tree showing the values and assets identified for the West Coast Bioregion (Shaw et al., in prep.).

Table 1. Definitions of variables included in the general fishery model. Variables were sourced from the West Coast Bioregion component tree in Figure 6.

Variable	Definition
Direct stakeholders	All people that are directly impacted by fish resources, such as commercial and recreational fishers.
Indirect stakeholders (i.e. dive companies and processors)	People that are impacted by ecosystems and marine resources but do not benefit directly from harvesting fish. This component was split into two variables in the model. Firstly, people who profit from harvesting (fish processors, bait sales, fish suppliers) and, secondly, those who benefit from marine resources in the natural environment (e.g. dive companies, divers, snorkellers, conservation groups).
Dependent communities	Human communities that directly benefit from the harvest of marine resources (e.g. Geraldton, Jurien Bay).
Benthic habitats	Assemblages of biotic and abiotic components that live on the sea floor and provide habitat for other species to live. For example, seagrass beds, sponge gardens, sand, silt and rocky reef.
Non-retained fish species	Fish that are not kept by commercial and recreational fishers even if they are captured.
Retained fish species	Fish that are targeted and kept by commercial and recreational fishers.
Fisheries administration	Fisheries management, including the enforcement of fishing restrictions.
Government	Jurisdictional minister responsible for fisheries management decisions.

NB: All links in the model building sections represent direct interactions between variables and are not predictions of response to perturbation. Predictions of response are reported in the results.

In this model, *Fisheries administration* takes species abundance as well as fishing catch and effort into account when determining management decisions. A decrease in *Retained species* would be expected to cause *Fisheries administration* to increase their efforts or expenditure on enforcement or monitoring as represented by the negative link between these two variables (Fig. 7). *Fisheries administration* has a negative link to *Direct stakeholders*, which includes commercial fishers, because an increase in management regulations will decrease effort used by the *Direct stakeholders* – fishers view this as a negative impact. In addition, *Fisheries administration* was shown to have a positive link to *Non-retained species* and *Benthic habitats* as it is part of the role of the Department of Fisheries to aid the preservation of these non-target species.

Non-retained and *Retained species* in the West Coast Bioregion interact with each other through reciprocal positive links (◄──►) (Fig. 7). These positive links represent the reliance of these species on each other through trophic and non-trophic interactions, such as the provision of shelter and food. In addition, *Benthic habitats* had a positive link to both *Retained* and *Non-retained species* through the provision of necessary habitat.

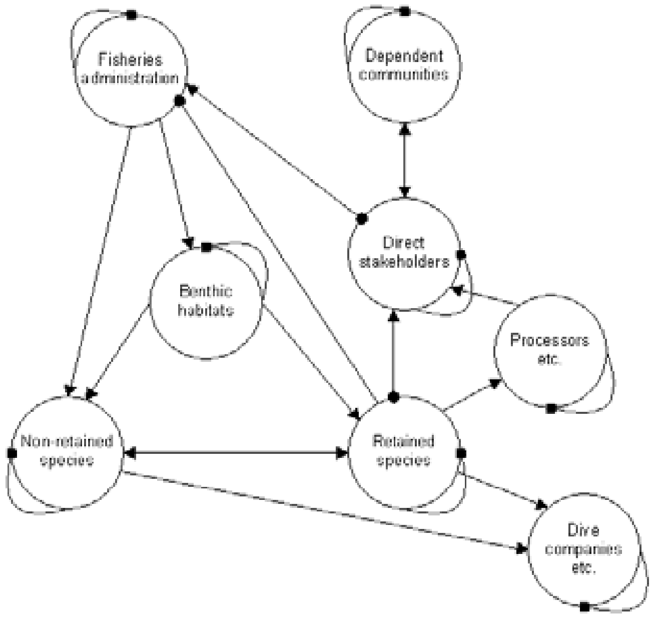
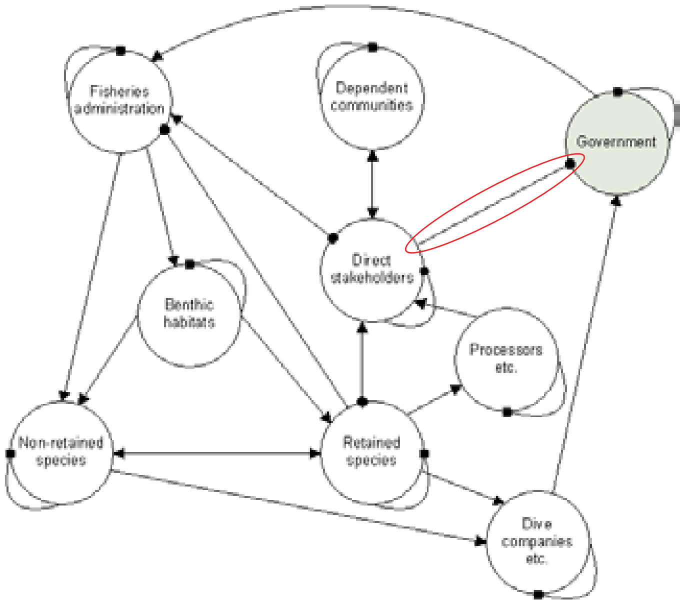


Figure 7. Qualitative model showing the links between components in the West Coast Bioregion.

Dependent (human) communities and *Direct stakeholders* rely on each other for both social and economic reasons (Fig. 7). These two variables were therefore linked by reciprocal positive interactions. In addition, *Direct stakeholders*, such as fishers, had a negative link to *Retained species* while these species had a positive link to *Direct stakeholders* through the provision of catch.

Fisheries administration alone was not able to account for all aspects of management and decision-making. Therefore, *Government* was added as a separate variable (Fig. 8). The role of *Government* (as a decision-maker) in this model was to ensure the appropriate management of fisheries occurred. This was achieved by increasing the efforts and funding of *Fisheries* *administration* through a positive link from the *Government*. *Government* also received a positive link from indirect stakeholders (*Processors* and *Dive companies*) through the opinions of non-fishing voters, as well as conservation and community groups.

a)



b)

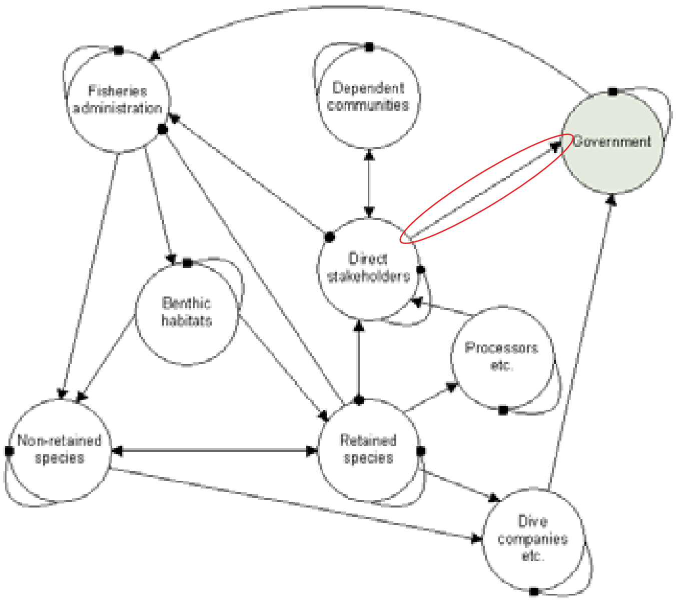


Figure 8. West Coast Bioregion including the government. Model a)represents the system when Direct *stakeholders* influence *Government* to reduce fishing restrictions, while model b) represents the system where Direct *stakeholders* work together with *Government* to create further restrictions.

However, *Direct stakeholders* may impact the *Government* in two ways. Figure 8 has therefore been split into two alternative models to represent the structural uncertainty in the link between these two variables. This uncertainty can affect model predictions and consistent predictions between models are assumed to reflect robustness to structural uncertainty in the model. Inconsistent predictions suggest further research into model structure and/or additional data collection is necessary. Alternative models were used to investigate the likelihood of the predictions regardless of this structural uncertainty.

In Figure 8a, a negative link from *Direct stakeholders* to the *Government* may occur if commercial and recreational lobby groups encourage fewer restrictions on catch. This link is important because fishing groups have been shown to have a significant influence on politics and government decisions (Okey 2003).

The influence of *Direct stakeholders* on the *Government* in different situations may, in fact, be positive (Fig. 8b). Such a link may occur if these stakeholders encourage a management review or create further restrictions on fishing. A comparison of predictions between alternative models and investigations into the stability of the models was undertaken.

Results

The stability of the model in figure 8a, with a negative link between *Direct stakeholders* and *Government*, was found to be 0.064 (on a scale of 0 – 1) and was relatively unstable. In contrast, the stability of the alternative model (Fig. 8b), where *Direct stakeholders* and *Government* work together when a resource sustainability issue is identified, was much higher at 0.32. The greater instability of Figure 8a can be seen when comparing the prediction matrices for Figures 8a and b, with a higher proportion (0.16) of ambiguous predictions in Figure 8a than 8b (0.04) (Equation 3 and 4).

Predictions of response to perturbation (increases) in *Direct stakeholders* (Column 3) and *Dependent communities* (Column 4) (Eq. 3-4) differed between the two models. In figure 8a, these perturbations were predicted to negatively impact *Non-retained species* while in figure 8b perturbations positively impacted *Non-retained species*. These different predictions are a result of the change in the relationship between *Direct stakeholders* and *Government*. When *Direct stakeholders* (i.e. fishers) work against *Government*, they were predicted to negatively impact the abundance of *Non-retained species* (negative link, Fig. 8a, Eq. 3 green circle). In contrast, when Direct stakeholders work with *Government* to ensure appropriate measures are taken to aid sustainability, they were predicted to positively impact *Non-retained species* (positive link, Fig. 8b, Eq. 4 green circle).

Negative link (fig. 8a)

adj. (-**A**)=

		1.	2.	3.	4.	5.	6.	7.	8.	9.
Retained spp.	1.	+,–	+	+	+	+	+	+	+	+
Non-retained spp.	2.	+,–	+	–	+	–	+	+	+	–
Direct stakehold.	3.	–	+	–	+,–	–	+	+	+	–
Benthic habitats	4.	+,–	+	–	–	–	+	+	+	–
Depend. comm.	5.	–	+	–	+,–	–	+	+	+	–
Fisheries admin.	6.	+,–	+	–	+	–	+	+	+	–
Dive companies	7.	+,–	+	+,–	+	+,–	+	+	+	+,–
Government	8.	+	+	+	+	+	+,–	–	–	+
Processors	9.	+,–	+,–	+	+	+	+	+	+	–

(3)

Positive link (fig. 8b)

$$\text{adj. }(-\mathbf{A}) = \begin{array}{lr} & \begin{array}{ccccccccc} 1. & 2. & 3. & 4. & 5. & 6. & 7. & 8. & 9. \end{array} \\ \text{Retained spp.} & 1. \\ \text{Non-retained spp.} & 2. \\ \text{Direct stakehold.} & 3. \\ \text{Benthic habitats} & 4. \\ \text{Depend. comm.} & 5. \\ \text{Fisheries admin.} & 6. \\ \text{Dive companies} & 7. \\ \text{Government} & 8. \\ \text{Processors} & 9. \end{array} \begin{bmatrix} + & + & + & + & + & + & + & + & + \\ + & +,- & + & + & + & + & + & + & + \\ - & + & - & +,- & - & + & + & + & - \\ + & + & - & - & - & + & + & + & - \\ - & + & - & +,- & - & + & + & + & - \\ + & + & - & + & - & + & + & + & - \\ + & + & + & + & + & + & - & + & + \\ + & + & + & + & + & + & - & - & + \\ + & + & + & + & + & + & + & + & - \end{bmatrix} \quad (4)$$

3.2 Cockburn Sound

Model building and investigation

A relatively detailed model of interactions in Cockburn Sound regarding fish stocks and finfish fisheries was produced. This model was then simplified in order to analyse specific relationships and feedbacks within the system. Such simplification is often necessary to allow the identification of relationships and paths of interest.

Seagrass beds play a crucial role in many ecosystems, including Cockburn Sound, through the provision of both food and shelter. In particular, many species of juvenile fish, including King George whiting (*Sillaginodes punctata*), use seagrass beds in Cockburn Sound to shelter from predators (R. Lenanton, pers. comm.). Environmental degradation is an issue in this ecosystem and has caused an approximate 80% decline in seagrass within the Sound since the 1950s (Cockburn Sound Management Council 2005). Both the harvesting of sediment for limestone (Cockburn Cement Limited 2001) and nutrient enrichment (Cockburn Sound Management Council 2005) have contributed to the loss of seagrasses in Cockburn Sound. Trawling has been banned in seagrass beds in the area; however, commercial finfish and recreational fishing using alternative gear still occur within the ecosystem and have unknown impacts on seagrass beds. Decreased fisheries catches in Cockburn Sound have recently occurred and have been associated with eutrophication and increased phytoplankton (Cockburn Sound Management Council 2005), as well as intervention by fisheries management to reduce fishing effort on some species.

Phytoplankton blooms can occur in Cockburn Sound due to high nutrient levels from industry discharge and groundwater run-off. These blooms have the capacity to shade seagrass, reduce growth and cause seagrass death (Short and Burdick 1996). Two models (detailed and simplified) were produced to conceptualise the relationships between the varied and diverse ‘members’ (i.e. species, groups, fishery, management, impacts) within Cockburn Sound. In addition, this model was produced to investigate the role of fisheries management in the recognition of multiple simultaneous perturbations, including coastal development and eutrophication, within the ecosystem. A model was also produced to investigate the impact of decreasing seagrass abundance, due to eutrophication and phytoplankton blooms, on commercially important fish and commercial fishing.

Shading by phytoplankton was shown in the model as a negative link from *Phytoplankton* to *Seagrass*. In contrast, *Phytoplankton* was linked to filter-feeding invertebrates, such as *Bivalves* and *Polychaetes*, by a positive effect because an increase in phytoplankton would be expected to directly increase the abundance of filter-feeders through the provision of food (Lemmens et al. 1996). *Seagrass* had a positive link to juveniles of the commercially valuable species, *Blue swimmer crabs* and *Decapods* through the provision of habitat (Fig. 9). In addition, small crustaceans, such as amphipods, were linked to seagrass through a predatory relationship. To represent this relationship, a negative link from *Small crustaceans* to *Seagrass* was used as well as a positive link from *Seagrass* to *Small crustaceans*. This predation has been demonstrated on seagrass seeds in WA (Orth et al. 2007). Similarly, small crustaceans were shown as an important prey for juvenile fish, such as King George whiting and Australian herring (*Arripis georganis*) (Jenkins and Hamer 2001, Peng 2003).

Juvenile fish were assumed to have broad feeding habits (Russell 1983) and consume bivalves, decapods and polychaetes (Fig. 9). *Blue swimmer crabs* are important for both commercial and recreational fisheries in Cockburn Sound and were therefore included as a separate variable in the model. The diet of these crabs has been shown to consist largely of bivalves, decapods and polychaetes (de Lestang et al. 2000); these predatory links were included in the model. The iconic species, *bottlenose dolphins* (*Tursiops truncatus*) *and cormorants*, were included as important predators of juvenile fish.

Juvenile and *Retained adult fish* were joined by reciprocal positive links because juveniles mature and become adults, while adults create juveniles through reproduction (Fig. 9). A *Direct stakeholder (Fishery)* variable removes adult fish from the system (Fig. 9). These variables were linked by a predatory interaction where the *Direct stakeholders* received a positive link from *Retained adult fish* and these adult fish received a negative link from the fishery. The *Fisheries admin./management* variable represents the quantity of management (e.g. more research, policy review or compliance) that occurs. Fisheries admin./management restrict the direct stakeholders by limiting the amount of effort able to be used (immediate impact only). In contrast, an increase in fishing effort (or catch) should increase action by management to ensure the fishery remains sustainable (positive link). In addition, *Fisheries admin./management* received a negative link from *Retained adult fish* because a decrease in fish stocks, detected through the monitoring of stock abundance, should spur an increase in management effort. A fishery for blue swimmer crabs was not included in the model as fishing for this species was banned in Cockburn Sound in 2006 due to low stock levels.

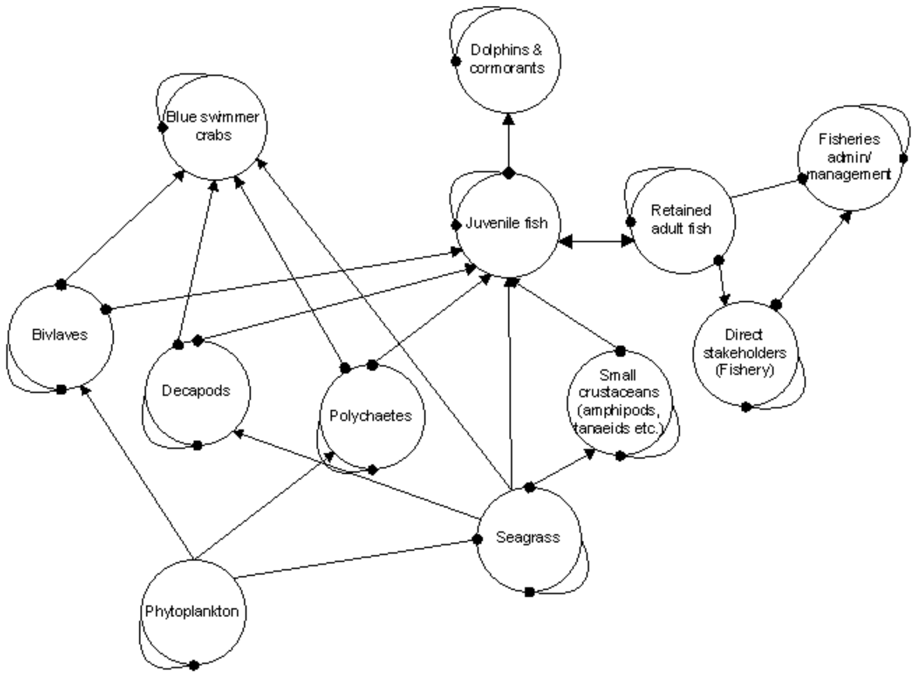


Figure 9. Detailed Cockburn Sound model including *Retained adult fish*, a *Fishery*, *Fisheries admin/management*, and *Dolphins and cormorants*. The *decapod* variable includes mainly prawns and small crabs (excluding *blue swimmer crabs*).

The impact of an increase in fishing was investigated with regard to fish and seagrass abundance, as well as management response. Cockburn Sound is also impacted by phytoplankton blooms, as a result of industry (nutrient) discharge and storm water run-off. A perturbation to phytoplankton was therefore investigated. In addition, development in and around Cockburn Sound is a potential issue for the ecosystem and fisheries. Nearshore development can directly damage seagrass beds as well as create larger loads of suspended sediments that shade and cover seagrasses, reducing their ability to photosynthesise. As development and the population around Cockburn Sound increases, the level of access granted to commercial fishers may decline. Such a relationship exists as negative public opinion regarding fisheries, such as the beach bait fishery (operates from beaches), is communicated to the local government who, in turn, reduce beach access to appease the public. Two additional variables were included in the model to investigate these impacts; *Development* and *Water column sediment* (Fig. 10). The relationship between development, public opinion and beach access was shown in the model through a negative link from *Development* to *Direct stakeholders*. The variable *Development* also encompassed ongoing or intermittent dredging to represent the mining of sediment for limestone as well as dredging to enable new developments (e.g. wharves). *Development* was also shown to have a direct negative link to *Seagrass* and a positive link to *Water column sediment*. *Water column sediment* was also linked to *Seagrass* by a negative effect to represent the effects of shading and smothering.

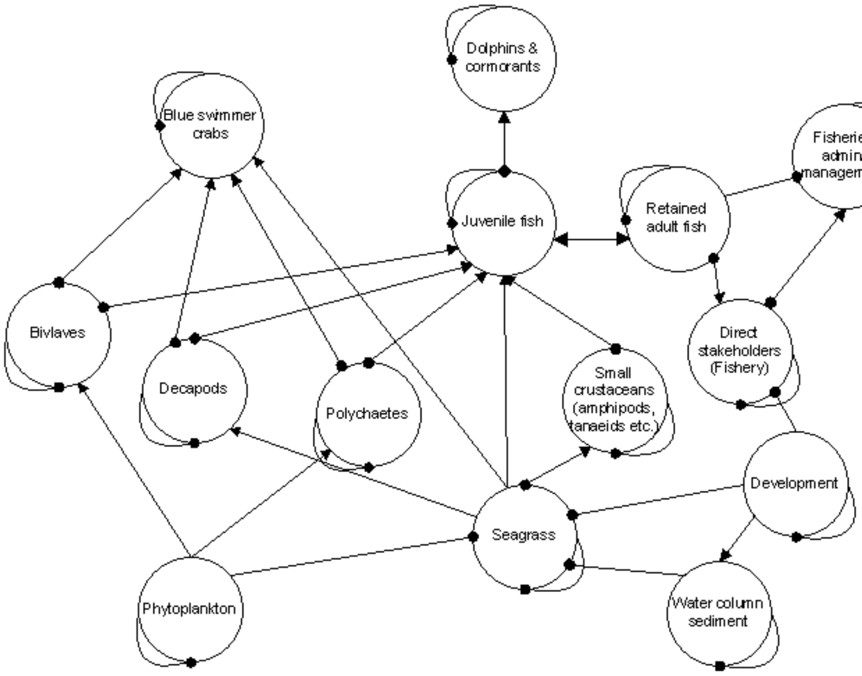


Figure 10. Detailed Cockburn Sound model including the impacts of *Development* and *Water column sediment***.**

The detailed Cockburn Sound model was simplified through the aggregation of 'like' species (Fig. 11). For instance, *Decapods* and S*mall crustaceans* were aggregated into one variable *Crustaceans.* In addition, polychaetes and bivalves were aggregated into a *Filter feeder* variable while *Water column sediment* was subsumed into *Development*. Adult and juvenile fish were aggregated into one variable, *Fish*. *Dolphins and cormorants* were removed from the model as predictions of change in this variable simply mirrors change in the *Fish* variable (i.e. *Fish* abundance increases, *Dolphin and cormorant* abundance increases).

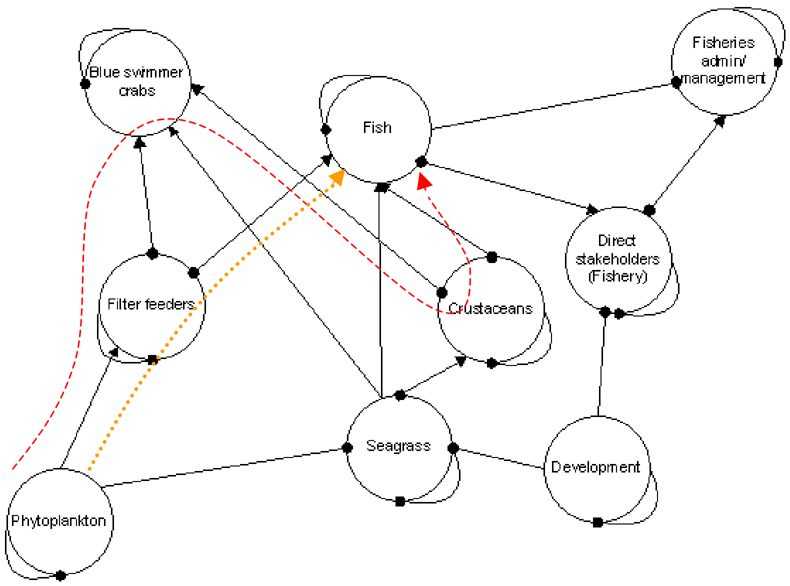


Figure 11. Simplified Cockburn Sound model where *Filter feeders***,** *Fish***,** *Crustaceans* **and** *Development* include aggregated variables from the detailed model. Path a (------) represents a negative path from *Phytoplankton* to *Fish***,** while path b (.........) represents a positive path between these two variables (see *Results*).

Results

A perturbation (i.e. increased catch) to the fishery was predicted to have a negative effect on *Seagrass* (full green line, Eq. 5). This occurred because increased fishing reduces fish abundance, thereby decreasing predation pressure on the predators of seagrass (i.e. allowing small crustaceans to increase in abundance) and reducing seagrass abundance. This result highlights the importance of trophic relationships and knowledge of these relationships for effective fisheries management.

adj. (-**A**)= (5)

		1.	2.	3.	4.	5.	6.	7.	8.	9.
Seagrass	1.	+	−	+	+	+	−	+	−	−
Crustaceans	2.	+	+	−	−	−	−	−	+	−
Fish	3.	+	+,−	+	−	+	+,−	+	−	+,−
BS crabs	4.	+	+,−	−	+	+	+,−	−	+	−
Filter feed.	5.	−	+,−	−	−	+	+	−	+	+
Phytoplank.	6.	0	0	0	0	0	+	0	0	0
Fisheries ad.	7.	+,−	+,−	+,−	+,−	+,−	+,−	+	+	−
Direct stake.	8.	+	+,−	+	−	+	+,−	−	+	−
Development	9.	0	0	0	0	0	0	0	0	+

Fisheries admin./management was shown to have a number of ambiguous responses to change within the Cockburn Sound ecosystem (full blue line, Eq. 5). This occurred as a result of both positive and negative paths existing from *Fish* to *Fisheries admin./management*. One path, from *Fish* to *Fisheries admin.* (Fig. 12, path a), consists of a negative link determining that a decrease to fish as a result of a perturbation to development will increase *Fisheries admin./management*. A second path, from *Fish* to the *Direct stakeholders* to *Fisheries admin./management.* (Fig. 12, path b), consists of a series of positive links. These positive links determine that a decrease in *Fish* (through increased development and/or water column sediment) will decrease the catch by *Direct stakeholders* and allow a relaxation of work by *Fisheries admin./management to mange fishing operations*.

The predicted response of *Fisheries admin./management* to an increase in *Development* and/or *Water column sediment* depends on whether the magnitudes of the negative or positive responses are greater. For example, if the relationship between *Fish* and *Fisheries admin./management* is stronger than the relationship between *Fish*, the *Direct stakeholders (fishery)* and *Fisheries admin./management*, an increase in development and/or sediment (water column) will increase management effort. In this situation *Fisheries admin./management* could increase through the need for monitoring of fish abundance, a review of management regulations or an increase the policing of fishing activities. In contrast, if the relationship between *Fish* and *Fisheries admin./ management* is weaker than the relationship between *Fish*, the *Direct stakeholders (fishery)* and *Fisheries admin./management*, an increase in *Development* and/or *Water column sediment* will reduce management efforts. This reduction may arise through a decline in the abundance of invertebrates and fish that, in turn, results in lower catch in the fishery. This decline in catch and effort may then result in reduced management, such as a reduction in the policing of fishing activities. The relative influence of fisheries and fish stocks will therefore determine whether fisheries management increases or decreases. Thus, while reduced fishing activity may permit a decrease in management, risks to fish stocks posed by other impacts may require an increase in activities by *Fisheries admin./management.*

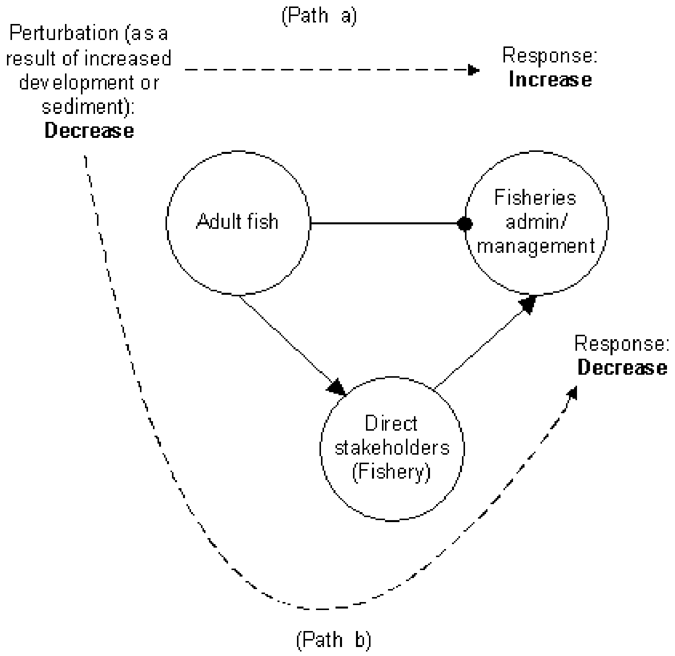


Figure 12. Two paths from *Fish* to *Fisheries* admin.*/management* exist (Paths a and b). These different paths result in ambiguity in the response of management to change, as both an increase and a decrease are possible.

Separate perturbations (increase) to *Phytoplankton* and *Development* were predicted to reduce *Seagrass* and *Crustacean* abundance (dashed red lines, Eq. 5). In contrast, *Fish* and *Blue swimmer crabs* had ambiguous responses to an increased *Phytoplankton* (dashed orange lines, Eq. 5). These ambiguous responses occurred as a result of positive and negative paths from *Phytoplankton* to each variable. For instance, a negative path from *Phytoplankton* to *Fish* can be followed in Figure 11 through these links: an increase *Filter feeder* abundance can increase *Blue swimmer crab* abundance, increased predation on *Crustaceans* by *Blue swimmer crabs* may then reduce prey (crustacean) availability for *Fish*, and result in a reduction (negative path) in fish abundance. In contrast, a positive path from *Phytoplankton* to *Fish* may occur if *Phytoplankton* increases *Filter feeder* abundance and this provides more food for the *Fish* predators (Fig. 11).

One method of combating multiple negative impacts on the ecosystem is to include the regulation of impacts by additional departments or agencies responsible for various impacts on the ecosystem. In order to do so, information sharing from fisheries management (Department of Fisheries) to the relevant departments will be necessary. This was shown in the model through the inclusion of an *Additional management* variable which received a positive link from *Fisheries admin./management*. *Additional management* was also assumed to increase the management of water quality and phytoplankton, as well as water column sediment and other impacts from coastal development (Fig. 13). The predicted responses of seagrass, juvenile and adult fish, and the fishery to this additional management in Cockburn Sound were positive (Eq. 6).

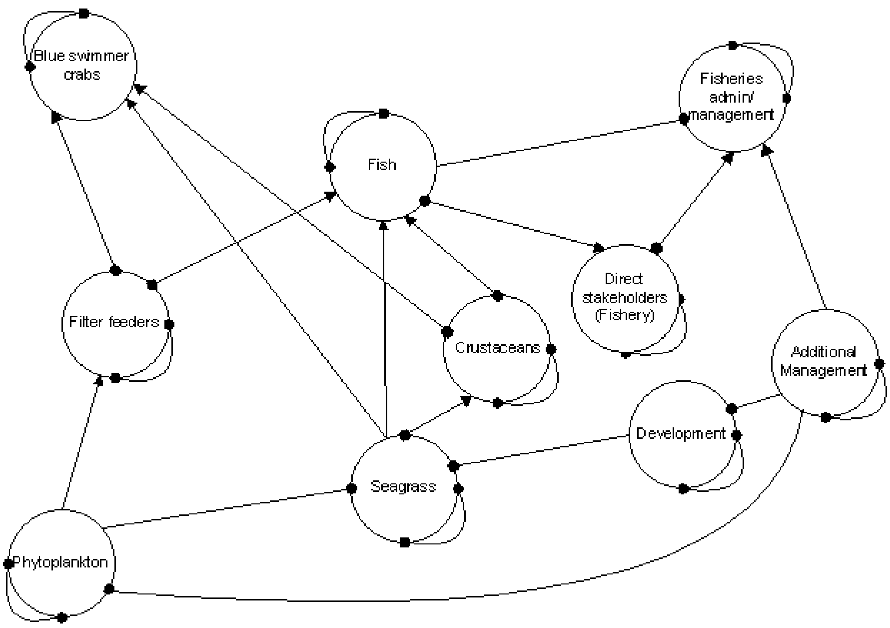


Figure 13. Simplified Cockburn Sound model including management by departments and agencies external to the Department of Fisheries (*Fisheries admin/management*) that are responsible for other impacts on fish and fisheries, such as pollution and the impacts of coastal development.

$$\text{adj. }(-\mathbf{A})= \begin{array}{ll} & \\ \text{Seagrass} & 1. \\ \text{Crustaceans} & 2. \\ \text{Fish} & 3. \\ \text{BS crabs} & 4. \\ \text{Filter feeders} & 5. \\ \text{Phytoplank.} & 6. \\ \text{Fisheries ad.} & 7. \\ \text{Fishery} & 8. \\ \text{Developm.} & 9. \\ \text{Add. mngt.} & 10. \end{array} \begin{array}{c} 10. \\ \left[\begin{array}{c} + \\ + \\ +,- \\ + \\ - \\ - \\ + \\ + \\ - \\ + \end{array}\right] \end{array} \qquad (6)$$

3.3 Abalone

Model building and investigation

Western Australian abalone resources support a world-class fishery: the commercial fishery is of significant value, while the recreational fishery for Roe's abalone (*Haliotis roei*) is one of the most closely regulated fisheries of its type in the world. The vast majority (approx. 98%) of abalone caught in Australia is sold to an international market. This market is highly competitive and includes aquacultured abalone as well as a significant proportion of illegally caught abalone from South Africa, Mexico and Japan as well as other Australian states (Gordon and Cook 2004). The illegal harvest of abalone in the West Coast Bioregion is thought to be relatively small in comparison to illegal fisheries in Victoria and other countries, such as South

Africa. Nonetheless, the illegal fishery in WA has the potential to impact the sustainability of fishery stocks (Regional managers, pers. comm.). A model was produced to represent the harvest of abalone in WA (both legal and illegal) and the impact of fisheries management and the international market.

Abalone stocks were shown to receive a negative link from all types of fishing (*Commercial*, *Recreational* and *Illegal fishing*, Fig. 14) while both the *Recreational* and *Commercial fisheries* received a positive link from *Abalone*. In contrast, the *Illegal fishery* did not receive a link from *Abalone* because this type of fishing is driven by the black market and stays relatively stable regardless of abalone abundance (regional managers, pers.comm.). In this model, the *Recreational fishing* variable represents effort, catch and number of people involved in the recreational fishing of abalone. Similarly, the *Commercial* and *Illegal fishing* variables represent catch, effort and number of fishers involved in those fishing activities.

All fishing sectors (commercial, recreational and illegal) received a negative link from *Fisheries admin./management* through restrictions on fishing and policing of these restrictions. It is important to note that these negative links represent the immediate effect of management restrictions (i.e. reducing catch limits or size limits), not the long-term benefits that management provides to the fisheries. In contrast, *Fisheries admin./management* received a positive link from all sectors because an increase in catch and effort should encourage greater management effort through additional restrictions and/or compliance activities or a review of current management strategies to ensure abalone stocks remain sustainable.

An increase in the productivity of high tonnage fisheries (i.e. South African) would be expected to stem demand on the international market, thereby decreasing the sale price of the product (Abalone Council Australia, pers. comm.). However, the influence of the Western Australian abalone fishery on the *International market* is relatively small due to the lower harvest level (i.e. tonnes). As a result, *Commercial fishing* in WA does not have a direct negative impact on the *International market* but simply continues to drive (positive link) the market through the supply of product. In contrast, changes market-related variables can have a substantial impact on the fishery economy in WA. *International demand* was shown to have a positive link to *International price*, as such an impact is seen during periods of high demand, such as Chinese New Year (Gordon and Cook 2004, Abalone Council Australia, pers. comm.). In contrast, *International price* has a negative link to *International market* as it has been shown that an increase in the price of Australian caught abalone decreases their international sales (Abalone Council Australia, pers. comm.). *Profits* received a positive effect from *International price* as an increase in sales price would increase profits received by the fishers. *Illegal fishing* in WA is thought to be relatively small and therefore did not have a negative link to *International price*. However, if illegal fishing increased substantially this link would need to be included in the model.

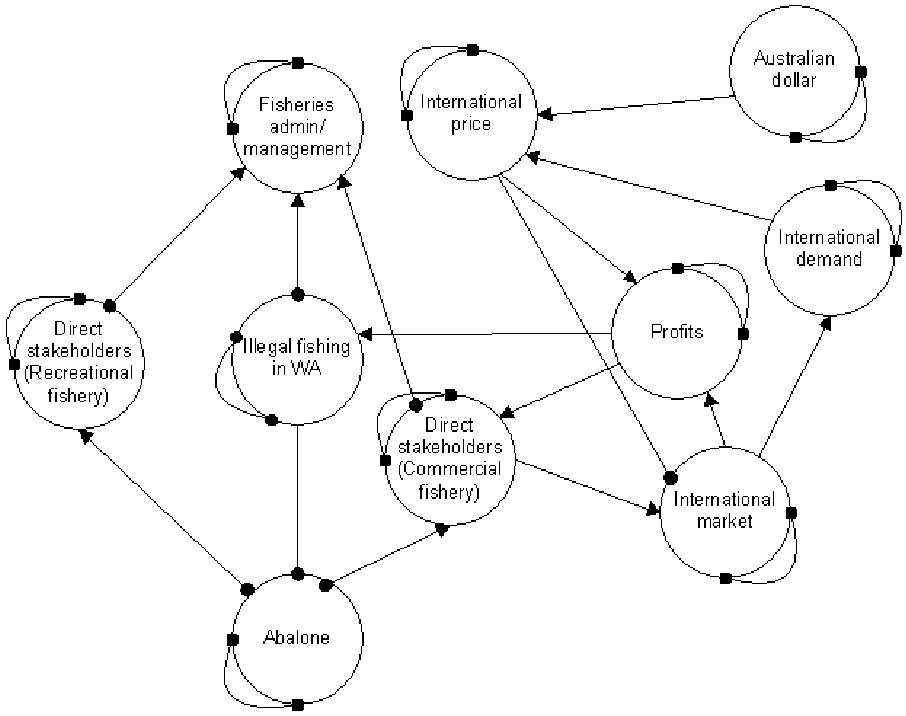


Figure 14. Roe's abalone models showing the relationships between different fishing sectors and the international market (through price, demand and the Australian dollar).

The impact of perturbations to *Commercial*, *Recreational* and *Illegal fishing* on other variables in the system was investigated. In addition, the impact of fluctuations in *International demand* on fishing sectors, *Fisheries admin./management* and the *International market* were examined. As the abalone fishery is managed through output controls, specifically TACCs in the form of Individual Transferable Quotas (ITQs), the impact of a halt to the production of Australian abalone on the international market was also investigated. This halt in the fishery was shown by removing the commercial fishery from the model.

Results

As would be expected following the harvest of any resource, a perturbation (increases) to the commercial fishing sector was predicted to negatively impact abalone abundance through the removal of individuals (Eq. 7, dashed red lines). *Fisheries admin./management* was predicted to have both positive and negative impacts (ambiguous prediction) on the *Recreational* and *Commercial fisheries* (dashed green line, Eq. 7). This ambiguity was a result of the direct limitation of catch in the model by *Fisheries admin./management* (a negative impact on catch in the model) as well as the indirect positive impact to each sector via the abalone stocks. In other words, if catches are reduced abalone stocks should recover and allow higher catches in the future. The actual response observed will depend on whether the increase in stock abundance due to management has a stronger impact on commercial and recreational catches than the short-term limitations through bag and size limits.

adj. (-**A**)= (7)

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Fisheries admin.	1.	+	+,−	+	+,−	+	+,−	+,−	+,−	+	+
Recreational fishing	2.	+,−	+	−	+,−	+,−	+,−	+,−	+,−	−	−
Commercial fishing	3.	+,−	−	+	−	+	+,−	+,−	+,−	+	+
Illegal fishing	4.	−	−	+	+	+,−	+,−	+,−	+,−	+	+
Abalone	5.	+	+,−	−	+,−	+	+,−	+,−	+,−	−	−
International price	6.	+,−	−	+	−	+	+	+	+	+	+
Int. demand	7.	+,−	−	+	−	+	+	+	−	+	+
Australian dollar	8.	0	0	0	0	0	0	0	+	0	0
Profits	9.	+,−	−	+	−	+	+,−	+,−	+,−	+	+
Int. market	10.	+,−	−	+	−	+	−	−	−	+	+

The extent of Illegal fishing for abalone in WA is thought to be relatively small (A. Hart, pers. comm.), however, if illegal fishing were to increase, the commercial fishery and consumer demand would decline (Eq. 7, column 4). If a higher level of illegal fishing continued over a long period, this reduction in demand may then negatively impact price by increasing the availability of abalone in the market. This reduction in price could then have negative implications for the economics of the commercial fishery.

Competition with abalone production (both legal and illegal) in other countries has a similar impact to illegal fishing on the West Australian commercial sector. An increase in world abalone production would reduce demand for Australian products and therefore reduce the price available for Australian exporters. This result may be intuitive, however, it remains useful to aid the understanding of the relationships between the fishing sectors and the international market.

The commercial abalone fishery in WA operates under an Individual Transferable Quote (ITQ) and when the quota has been reached the legal harvest of abalone is not allowed until the following year. During the period of nil supply (when the quota has been reached), abalone production in other regions of the world would be expected to take the place of Western Australian produced abalone in the market (if demand is steady throughout the year). According to the model, if this overseas production reduced demand (negative perturbation, signs must be flipped in Eq.7), the international price would also decline (dashed yellow line, Eq. 7). As a result, when Western Australian produce becomes available again its value will be reduced. This situation has been observed in the WA commercial abalone fishery (Abalone Council of Australia, pers. comm.).

3.4 Western rock lobster fishery

Model building and investigation

A model of the western rock lobster fishery was produced in order to investigate the impact of the market and beach price received by commercial fishers on rock lobster stocks and fisheries. The Western Rock lobster fishery is the most valuable of Western Australia's fisheries and the majority of the catch is exported and sold internationally. The role of the market in the rock lobster fishery is therefore very important and has been investigated using qualitative modelling.

Rock lobster were linked to the *Commercial* and *Recreational fisheries* by a predatory interaction whereby the stock received a negative link from the fisheries and visa versa (Fig. 15).

The *Commercial fishery* and the *International market* had reciprocal positive links, as may occur due to the demand for the resource and the provision of rock lobster to the market. The *International market* was the sole determinant of *Beach price* and was therefore positively linked to this variable. The *Beach price*, in turn, had a negative link to the *Australian market* because people would be unable to afford lobster if the beach price was high. In addition, as *Beach price* was set by the *International market*, a rise in the value of the *Australian dollar* would determine that the *Beach price* was worth less (in Australian dollars). This relationship was shown by a negative link from the *Australian dollar* to *Beach price*. *Beach price* was then linked back to the *Commercial fishery* by a positive effect because eventually price becomes profit.

Fisheries management had negative links to each fishery as a result of restrictions on catch (Fig. 15). *Commercial* and *Recreational fishing* had a positive link to *Fisheries management* as an increase in fishing effort or catch should encourage additional regulations or research and monitoring. In addition, *Rock lobster* stock was shown to have a negative link to *Fisheries management*, as a decrease in rock lobster abundance should increase management regulations.

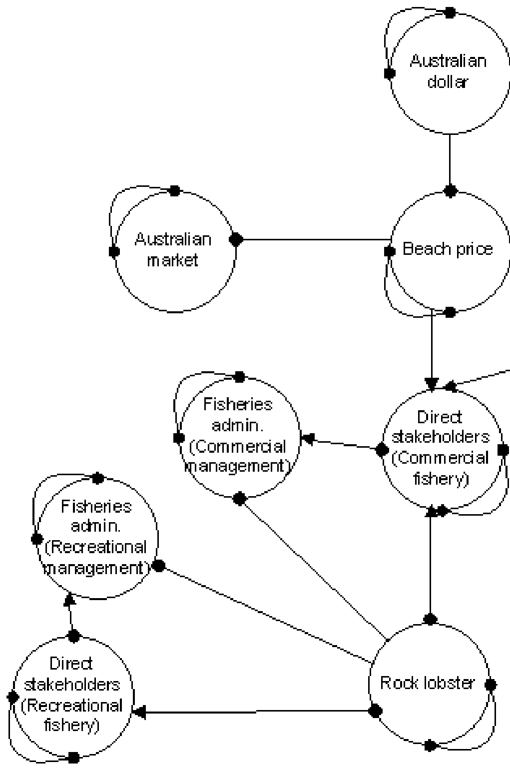


Figure 15. Western rock lobster fishery including the relationship between *Rock lobster*, the *International market* and the *Beach price*.

Results

This model was found to be unstable as a consequence of ambiguity in the response of variables to management (dashed red lines, Eq. 8). For example, *Fisheries management* may positively or negatively impact *Rock lobster*. The response was found to depend on whether the regulation of *Commercial* and *Recreational fisheries* by *Fisheries management* is stronger than the drive for profits between the *Commercial fishery*, *International market* and the *Beach price*. If management is not stronger than the drive for profits, the fishery and rock lobster stocks would be expected to collapse. This result shows the importance of management and regulation of the rock lobster fishery (both recreational and commercial).

$$
\text{adj.}(-\mathbf{A}) = \begin{array}{lr} & \\ \text{Rock lobster} & 1. \\ \text{Comm. fishery} & 2. \\ \text{Aust. market} & 3. \\ \text{Int. market} & 4. \\ \text{Beach price} & 5. \\ \text{Aust. dollar} & 6. \\ \text{Fisheries mngt.} & 7. \\ \text{Rec. fishery} & 8. \end{array}
\begin{array}{c}
\begin{array}{cccccccc} 1. & 2. & 3. & 4. & 5. & 6. & 7. & 8. \end{array} \\
\left[\begin{array}{cccccccc}
- & - & 0 & - & - & + & +,- & + \\
+ & + & 0 & + & + & - & +,- & - \\
- & - & +,- & - & - & + & +,- & + \\
+ & + & 0 & + & + & - & +,- & - \\
+ & + & 0 & + & + & - & +,- & - \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
+ & + & 0 & + & + & - & +,- & - \\
- & - & 0 & - & - & + & +,- & +
\end{array}\right]
\end{array}
\qquad (8)
$$

3.5 Recreational management changes

Recreational fishing pressure for demersal fish species including dhufish (*Glaucosoma herbraicum*), baldchin groper (*Choerodon rubescens*), breaksea cod (*Epinephelides armatus*) and pink snapper (*Pagrus auratus*) is high in the metropolitan zone of the West Coast Bioregion. In addition, dhufish and pink snapper breeding stock levels have been identified as declining and low, respectively (Western Australian Department of Fisheries 2008). Additional management regulations may be needed to ensure the sustainability of these stocks. A seasonal closure on recreational fishing for a suite of demersal fish species in the metropolitan zone (within the West Coast Bioregion) is one potential method of reducing effort to ensure stock sustainability. Such a closure would be expected to reduce the capture of demersal fish during the closed period. However, a seasonal closure may also alter fisher behaviour, for instance, encouraging fishers to target alternative species. As a result of the potential for change in fisher behaviour, the overall impact of a seasonal closure on fish species in the West Coast Bioregion is unknown. The closure represented in these models was assumed to occur for a few months over summer in the metropolitan zone. This seasonal closure was assumed to occur during the peak period for recreational fishing and would prohibit the capture of a suite of demersal fish species, including dhufish and baldchin groper.

Increasing restrictions on recreational fishing through the use of a seasonal closure may alter fisher behaviour in a number of ways. For instance, management changes may increase the number of people who:

- Stop fishing altogether;
- Travel to areas in which the closure is not in place (e.g. elsewhere in the West Coast Bioregion);
- Increase shore-based fishing effort for other species (e.g. herring, *Arripis georgianus*, and King George whiting, *Sillaginoides punctata*);
- Increase boat-based fishing effort for other species (e.g. non-protected demersal species as well as pelagic fish etc.).

One or all of these changes may occur as a result of a seasonal closure for a suite of demersal fish species. These behavioural changes are important to investigate because they may determine whether the proposed management strategy would be effective. For instance, if management restricts fishing in a particular area but fishers simply increase their effort on the boundary of the protected area, the management strategy may not actually protect the species.

A 'core' model was produced to investigate the relationships that may drive the overall impact of the seasonal closure on fish populations in the West Coast Bioregion. Following the production of this model, a detailed model including all potential changes in fisher behaviour in the metropolitan zone was produced.

Model building and investigation: 'core' model

A variable representing *Fishing*, such as number of fishers and fishing effort, was included in the core model (Fig. 16). In addition, *Primary* (e.g. demersal fish species) and *Alternative* (e.g. herring and whiting) *target* variables were included in the model. The *Fishery* variable had a direct negative link to both the *Primary* and *Alternative target* variables through the removal of individuals following capture. In contrast, *Fishing* is positively impacted by the target variables.

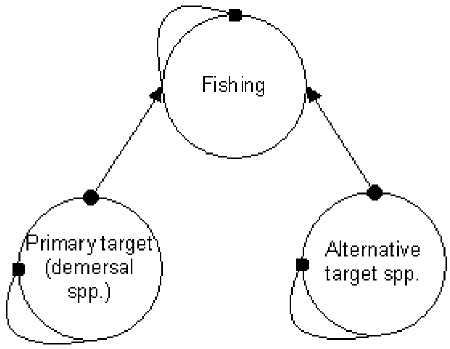


Figure 16. Three variable 'core' model to investigate the impact of the seasonal closure on recreational fisher behaviour and associated fish populations.

The use of a fisheries management variable to represent a seasonal closure incorporated a number of new links into the core model (Fig. 17). A seasonal closure would reduce the capture of the primary target species, thereby essentially interfering with the negative link from the fishery to the primary target variable (Fig. 17a). The 'interference' of this link was expressed in the model through a reversal of the signs linking the fishery to the primary target species (Fig. 17b) and is equivalent to a model with direct links from *Fisheries management* to *Fishing* and the *Primary target species*. Interfering in the links between *Fishing* and the *Primary target species* can force a switching behaviour in the *Fishing* variable. A switch from targeting the primary species to targeting the secondary target species has been suggested as a possibility if a seasonal closure of the Perth metropolitan zone occurs. The switch in preference from the *Primary* to *Alternative target species* essentially strengthens the links between *Fishing* and the *Alternative target* variable and may be shown as positive interference from the *Fisheries management* variable (Fig. 17d). This results in a direct negative link from *Fisheries management* to *Alternative target species* and a direct positive link from *Fisheries management* to *Fishing*. The relative strength of the direct positive link in comparison to the direct negative link from *Fisheries management* to *Fishing*, as occurs through restricting the capture of the *Primary target species*, will determine which link should be included in the model (Fig. 17e). It was assumed that the reduction in fishing during the seasonal closure (negative link) would be stronger than the benefits fishers would gain from switching prey species (positive link). As a result, only the negative link from *Fisheries management* to *Fishing* was included in the model (Fig. 17f).

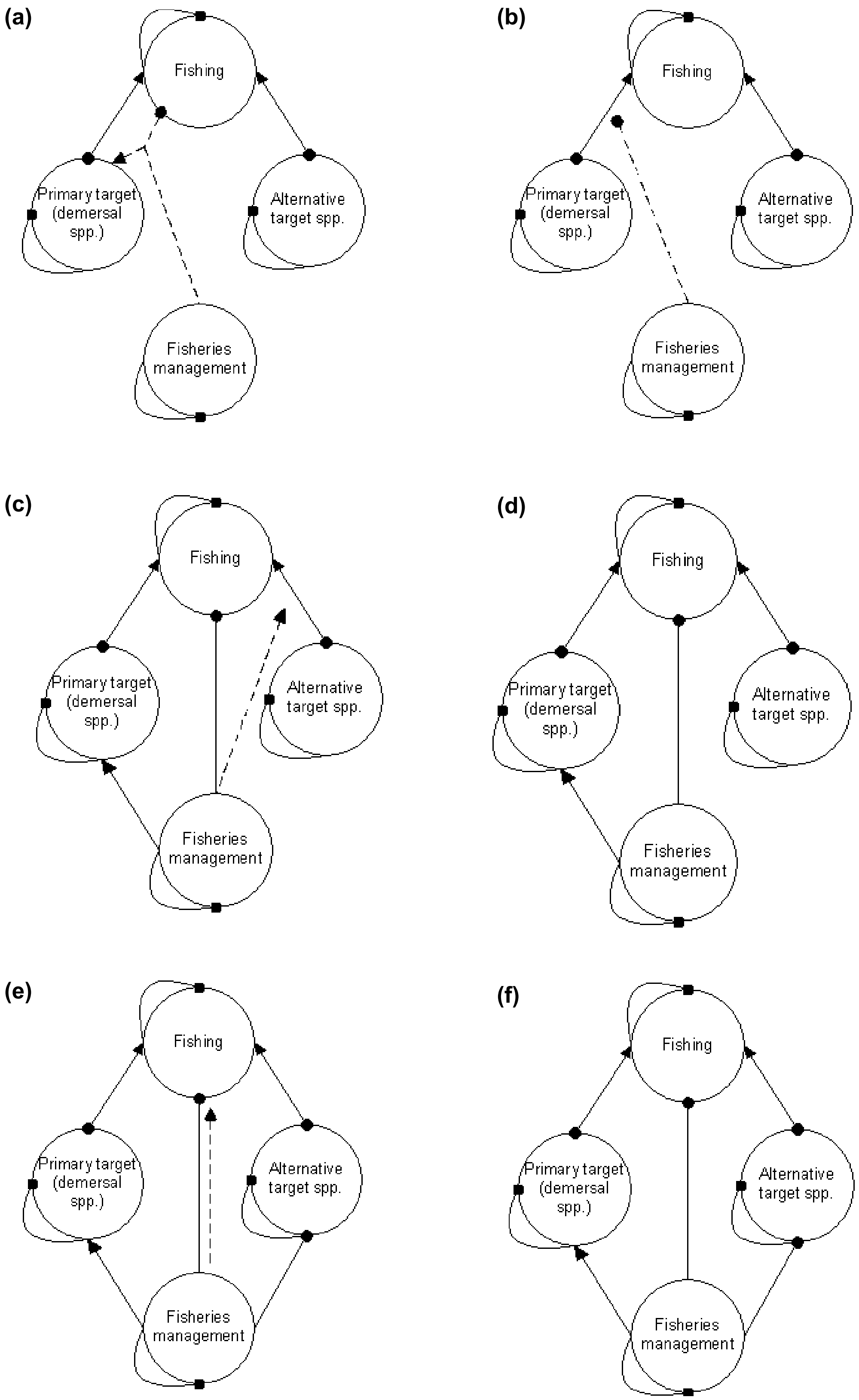


Figure 17. 'Core' recreational fisher behaviour model with a) *Fisheries management* suppressing (dashed line) in the capture of *Primary target species* by instigating a seasonal closure, b) and c) the direct effects associated with negative interference, d) positive interference (enhancement, dashed line) from *Fisheries management* to the *Fishery* as a result of forced behaviour switching among recreational fishers, e) the direct effects associated with positive interference and f) the final core model including all effects of fisher behaviour due to the seasonal closure.

Results: Core model

An increase in fisheries management, as used to represent a seasonal closure, was predicted to negatively impact the fishery, positively impact the primary target species and negatively impact the secondary target species (dashed red line, Eq. 9).

$$\text{adj. } (-\mathbf{A}) = \begin{array}{ll} \text{Fishery} & 1. \\ \text{Prim. target} & 2. \\ \text{Alt. Target} & 3. \\ \text{Fish. mngt.} & 4. \end{array} \overset{\begin{array}{cccc} 1. & 2. & 3. & 4. \end{array}}{\begin{bmatrix} + & + & + & - \\ - & + & - & + \\ - & - & + & - \\ 0 & 0 & 0 & + \end{bmatrix}} \qquad (9)$$

There was some ambiguity in the predictions for the fishery as a result of an increase in management (seasonal closure). This ambiguity occurred as there were three paths included in the calculation of prediction sign; 2 negative paths and 1 positive path. A negative prediction was observed in the adjoint matrix as one negative path cancelled the positive path, leaving a net of one negative path. This ambiguity remains important regardless of the negative prediction because a particularly strong positive path could override the two negative paths in the model. This may result in an increase in the fishery as a result of the seasonal closure. The separation of each of these paths highlights the interactions of interest and can identify the likely responses in the fishery as a result of differing fisher behaviour (Fig. 18).

One path that may determine the response of the fishery is the direct negative path from *Fisheries management* to *Fishing* (Fig. 18a). This path represents the situation where a reduction in fishing effort throughout the year occurs as a result of the seasonal closure. This may occur if some fishers stop fishing altogether due to the new management measures. The second negative path involved in the response of *Fishing* to an increase in *Fisheries management* represents the situation where fishers reduce the abundance of the *Alternative target species* (through switching targets) and thereby negatively impact themselves (Fig. 18b). Finally, the positive path represents the situation where a 'spike' in fishing pressure may occur if the seasonal closure increases the abundance of the *Primary target species*. This increase in abundance, in turn, increases fishing effort during non-closed periods (Fig. 18c). If this spike in fishing effort is stronger than the decline in effort due to a reduction in *Alternative target species* (path b) and an increase in the number of people that give-up fishing (path a), an increase in *Fishing* may be observed as a result of the seasonal closure.

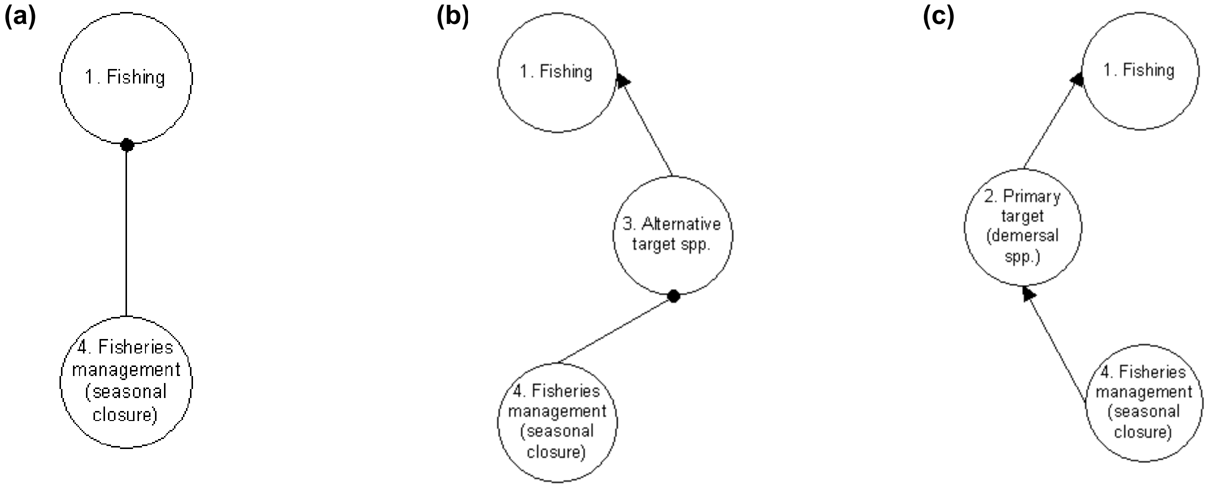


Figure 18. Paths from *Fisheries management* (seasonal closure) to *Fishing*. Paths a) and b) are negative and will result in a decrease in *Fishing*, while path c) represents a 'spike' in fishing effort outside of the closed season and, if stronger than the two negative paths, may result in an increase in *Fishing* due to the seasonal closure.

Model building and investigation: 'Detailed' model

A detailed model was produced to investigate all possible impacts on fish populations as a result of change in fisher behaviour following the instigation of a seasonal closure (Fig. 19). Both nearshore (0-20m depth) and inshore (20-250m depth) fishers in boats may catch demersal fish, such as dhufish and pink snapper. Two variables representing these types of fishing were included in the detailed model in addition to a demersal fish variable. This *Demersal fish* variable was assumed to include all species protected by the seasonal closure. Both *Nearshore* and *Inshore* fishers may capture other species, such as herring and samsonfish (*Seriola hippos*), however the capture of these species is stratified by depth. For instance, samsonfish may be caught by fishers in deeper water (inshore fishers) while fishers will catch herring closer to shore (nearshore fishers). As a result, *Other nearshore species* and *Other inshore species* were included in the detailed model. Separating target fish populations in this way allows fishers to switch their behaviour to target secondary species. *Shore-based fishing* may also target *Other nearshore species*, for example, beach fishers using hook and line. An increase in fishing elsewhere (i.e. outside of the metropolitan zone) during the seasonal closure would be expected, as people may decide to travel further in order to catch the demersal species banned within this zone. A *Fishing elsewhere* variable therefore received a negative link from *Nearshore fishing* and *Inshore fishing*. A *Fish elsewhere* variable was included as the target of these people fishing outside of the metropolitan zone. Similarly to the core model, an increase in *Fisheries management* was used to represent a seasonal closure whereas a decrease in management represents the removal of restrictions outside of the closed period.

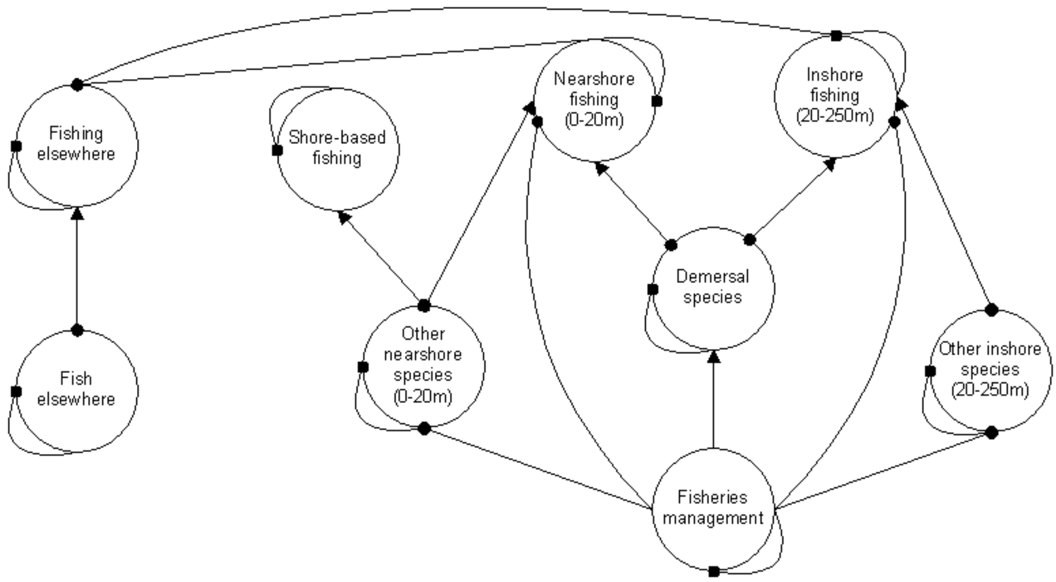


Figure 19. Model representing recreational fishing for demersal fish species in the West Coast Bioregion. Opportunities for changes in fisher behaviour through target or location switching that may occur following the instigation of a seasonal closure as included in links from *Fisheries management* and fishing variables. The *Fisheries management* variable represents the seasonal closure.

The impacts of an increase to *Fisheries management* to represent a seasonal closure were investigated. Similarly to the core model, this perturbation was investigated to identify important impacts on fish variables and highlight changes in fisher behaviour that may reduce the effectiveness of the management strategy.

Results

Similarly to the core model, all fish variables, excluding those protected (demersal species) during the closed period, were predicted to decline in abundance as a result of the seasonal closure (dashed red lines, Eq. 10). In addition, there was some ambiguity involved in the calculation of prediction signs for *Nearshore* and *Inshore fishing*. The actual change in these fishing variables due to a seasonal closure will depend on the strength of the 'spike' in fishing effort following the re-opening of the metropolitan zone to fishing.

There was also ambiguity involved in the predictions of response in *Other inshore species*, *Other nearshore species* and *Fish elsewhere* as a result of increased management. The observed change will be determined by the relative strength of the direct negative link from management to fish variables (through forced behaviour switching) and the overall reduction in fishing effort, allowing fish abundance to increase during the seasonal closure. Quantitative estimates of the magnitude of such impacts may help to determine the effectiveness of the closure as a strategy on the broader fish populations of the West Coast Bioregion.

$$
\text{adj.}\,(-\mathbf{A}) = \begin{array}{ll} & \\ \text{Shore-b. fishing} & 1. \\ \text{Nearsh. fishing} & 2. \\ \text{Inshore fishing} & 3. \\ \text{Fishing elsewh.} & 4. \\ \text{Other insh. spp.} & 5. \\ \text{Demersal spp.} & 6. \\ \text{Other near. spp.} & 7. \\ \text{Fishing elsewh.} & 8. \\ \text{Fisheries mngt.} & 9. \end{array}
\begin{array}{c} \begin{array}{ccccccccc} 1. & 2. & 3. & 4. & 5. & 6. & 7. & 8. & 9. \end{array} \\
\left[\begin{array}{ccccccccc}
+ & - & + & 0 & + & - & + & 0 & - \\
- & + & - & 0 & - & + & + & 0 & - \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & +
\end{array}\right] \end{array}
\qquad (10)
$$

4.0 Discussion

There has been an increasing recognition of the need for knowledge regarding the responses and links between social, economic and ecological factors in relation to ecosystem change (Berkes et al. 2003). Qualitative modelling was therefore used to link various different social and economic variables to ecological variables within the West Coast Bioregion. Important relationships and data gaps were identified and can be used to focus and guide further research regarding the successful management of multiple fish stocks with the context of achieving the principles of ESD. The models also display current knowledge, which can be of particular importance for communication with stakeholders and to aid the understanding of whole system processes and impacts.

The integral role that direct stakeholders (recreational and commercial fishers, industry members) play in fishery management and governance was highlighted in the West Coast Bioregion model. When direct stakeholders worked cooperatively with the government, system stability was greater. In contrast, when cooperation in management of the fishery did not occur, the stability of the West Coast Bioregion model, was substantially lower. Similarly, the importance of illegal fishing was highlighted in the Abalone model, where an increase in illegal fishing has the capacity to make the commercial fishery economically unviable.

The role of fisheries management (Department of Fisheries) in Cockburn Sound was investigated in addition to numerous impacts including fishing, increases in phytoplankton and coastal development. Fisheries management was predicted to positively impact seagrass, fish and the fishery in the Cockburn Sound model. In contrast, increases in the fishery, infrastructure development, phytoplankton and the suspension of sediments were predicted to negatively impact seagrass and fish. The models highlighted the important role of fish stocks and fisheries in determining the level of action by fisheries management in response to perturbations, such as phytoplankton blooms. The relationships between fisheries management, stocks and fisheries may vary between fisheries. For example, a decline in the catch and effort in a high value fishery would stimulate an increase in fisheries management due to the economic value to the State and the number of fishers involved in the fishery. However, a decline in a lower value fishery employing few fishers may not cause a similar increase in fisheries management actions. The Cockburn Sound model illustrated the need for information regarding the relative influence that change in fisheries and fish stocks have on fisheries management. Such information may allow predictions of the effects of change in management to be calculated, thereby aiding the sustainable management of the ecosystem.

The management of fishing impacts must be undertaken in conjunction with the management of impacts from alternative sources, such as agricultural run-off. All impacts within an ecosystem are important as all members (i.e. species, groups) interact and the effects of disturbance may flow-on to impact other parts of the ecosystem. However, the task of managing the impacts of increasing development, sediment suspension and phytoplankton as well as fisheries is likely to be impossible without a fully co-operative approach to managing all impacts, i.e. Ecosystem Based Management is required. In order to effectively manage the impacts of development and water quality (and its impacts on phytoplankton) collaboration with other government departments (Dept. of Water, Dept. Planning and Infrastructure Dept. Environment and Conservation), as well as the Cockburn Sound Management Council, Fremantle Port Authority and other regulatory groups that have the power to influence inputs/impacts is necessary. The Cockburn Sound model illustrated a simple method of collaborative management whereby multiple ecosystem impacts were mediated to enable the reduction of the negative impacts on seagrass beds. Such reductions may occur through the specific management of water discharge that increases phytoplankton abundance and the impacts of development and industry (e.g. dredging), including the suspension of sediment in the water column. With the effective management of fisheries, this collaborative management may, in turn, allow an increase in fish abundance and fisheries catches in the long-term.

The Western rock lobster fishery model identified the need for the regulation of fishing effort by fisheries management to be stronger than the drive for profits in order to ensure rock lobster stocks and the fishery are sustainable. If fisheries management is able to effectively regulate fishing catch and effort at sustainable levels, the Western Australian rock lobster fishers will benefit both economically (through profit and stable markets) and socially (stable source of income promotes social wellbeing). The drive for financial profits was shown to be an important consideration in the Western rock lobster model because the positive feedback between the commercial fishery, the international market and the beach price has the capacity to drive the fishery to collapse. This positive feedback can stimulate the international market, creating additional profits that can be reinvested back into the fishery. Collapse could occur if the fishery continues to profit (driven by the positive feedback cycle) regardless of stock abundance. Similar situations have occurred with whales (Clark 1981) and Newfoundland cod (*Gadus morhua*, Roughgarden and Smith 1996). In addition, there are some examples of market impacts on fisheries from other regions of the world (e.g. Iudicello et al. 1999, Pinnegar et al. 2002, Roheim 2003), yet there is a significant amount of uncertainty with regard to fishery economics in Australia (Smith 2006). To better understand this uncertainty, information on the relationships between price, market demand, changes in the Australian dollar and fishery production should be collected.

In the model of recreational fisheries management changes, data collection regarding likely changes in fisher behaviour due to a seasonal closure would be useful prior its instigation. Such information on behaviour is critical, as broad-scale movements of fishers to alternative behaviours may not actually serve to decrease fishing impacts at a whole-of-stock level (Woodward and Griffin 2003). This possibility was observed in the recreational behaviour models where a spike in effort could actually result in increased fishing in the metropolitan zone rather than the expected reduction. Data on the likelihood of changes in behaviour may help to determine the magnitude of impacts on secondary target populations due to fisher behaviour switching. For instance, an estimate of the number of people likely to switch to targeting herring during the seasonal closure would allow the overall fishing effort on this species to be estimated. This information could then be used to aid decision-making as to whether this level of effort was appropriate for the sustainability of herring populations. Knowledge of changes in fisher behaviour may allow funds to be placed strategically to effectively manage any flow-on impacts of the seasonal closure, such as increased shore-based effort. This may help to avoid the problems associated with a lack of knowledge or foresight into fisher behaviour as have been observed in a number of fisheries worldwide (Clark et al. 2005).

Importantly, the seasonal closure was predicted to positively impact populations of protected demersal fish species within the metropolitan zone, indicating that the primary aim of the management change may be achieved through a seasonal closure. However, the potential for negative impacts to occur in other species within the metropolitan zone and the West Coast Bioregion as a whole could have significant consequences for the overall health of the ecosystem. The seasonal closure may result in sequential serial depletion at an increased number of locations. A management strategy that considers a range of alternative restrictions designed to deliver the required reductions in fishing mortality is necessary.

Investigation into the influence of lobby groups and the prevalence of illegal fishing may also aid the successful implementation of new management strategies in WA. In the abalone fishing model, illegal fishing was found to be able to increase if recreational fishers and their lobby groups had a strong influence on fisheries management thereby reducing fishing regulations and policing. A similar situation occurred in Greece, where the poaching of fish and birds in Lake Kerkini has important social and cultural implications (Bell et al. 2007). Management authorities have protected the lake, yet, there was constant pressure to allow continued fishing and reduce regulations. While the illegal fishery for abalone or other WA fisheries may not be substantial, this example highlighted the capacity for illegal fishing to reduce the economic viability of the abalone fishery. In addition, this model highlighted the importance of data collection to increase understanding of the level of illegal fishing and the role of the market in management decisions in WA. This may enable the development of effective management decisions, including education programs, to combat non-compliance.

5.0 Conclusions

This report has highlighted a number of areas in which data collection and further research would benefit fisheries management in WA. Relationships involving recreational fishing and the management of recreational fisheries were found to be important in a number of the qualitative modelling scenarios. Further data collection on the impacts of recreational fisher behaviour including investigation into the social and economic drivers behind recreational fishing is essential. In addition, quantitative information on economic factors such as consumer demand, the influence of the international market and the Australian dollar on fisheries exports would allow more comprehensive models of the fishery economy to be produced.

Quantitative estimates of the prevalence of illegal fishing and the influence of lobby groups could assist in the development of successful new management strategies to combat non-compliance or the development and implementation of policy that aims to reduce risks to sustainability. The relationship between politics, government, fisheries administration and fishing lobby groups was found to be of particular importance and the collection of qualitative information on these relationships would be useful in the construction of detailed governance models. Such models may engender a holistic understanding of fisheries management and fishery ecosystems and may therefore aid the implementation of EBFM in WA.

Besides qualitative modelling, there are no other techniques available in WA that would allow the rapid modelling of several management systems to be undertaken as occurred in this study. The formal assessment of these management systems is a significant step towards understanding some of the issues to be faced through the implementation of EBFM in WA.

6.0 Acknowledgements

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