Development of an R&D response to Ecosystem Based Management: spatial management of fisheries and the role of MPAs (2003/073)

A discussion paper for FRDC and AFMF

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Executive Summary

The governance arrangements for fisheries management are based on the use of spatial structures and management measures, such as jurisdictional boundaries, management plans and zoning of fishing type and intensity. These spatially-based arrangements are manifest at various scales and so there is a growing interest in assessing the relative roles of different spatial components in achieving desired outcomes for marine systems as a whole. This includes the use of Marine Protected Areas (MPAs) in the management of fisheries and the ecosystem more generally. Despite this, key uncertainties remain about the use of spatial management approaches and these are a significant constraint on decision-making to achieve Ecologically Sustainable Development (ESD) objectives.

In recent years the Fisheries Research and Development Corporation (FRDC) has received a number of applications concerning the use of spatial management in fisheries, particularly the impact of MPAs. However, the FRDC Board recognised that it lacked clear strategic direction with respect to the R&D needed to support spatially-based management and the way that R&D investment could reduce the risks and improve the benefits of management. In order to facilitate a discussion of this topic with the Australian Fisheries Managers Forum in July 2003, the FRDC board funded the development of this paper to outline the options for fisheries R&D investment in spatial management (including MPAs).

The objectives of the paper were to consider two main issues:

- The effectiveness of spatial based management for fisheries
- The implications for fisheries of closures initiated by other sectors

The paper begins with a description of the policy context and concepts. The current and past R&D relevant to the spatial management of fisheries were considered, and a gap analysis was undertaken and used to develop an R&D framework. Finally the potential management issues/response are outlined.

The overall aim of any R&D investment by FRDC is to reduce the risks and improve the benefits of fisheries management. In order to achieve this aim an R&D framework has been developed that takes into consideration the gap analysis of the

R&D status in Australia. The framework has four main elements:

1. Understanding the spatial dimension of marine systems and their management
2. Predicting the impacts and benefits of spatial management.
3. Measuring the impacts and benefits of spatial management
4. Adaptive or 'continuous improvement' strategies for spatial management

Within this framework several R&D activities will need to commence in the short-term.

- Desk-top review of Ecosystem Based Management approaches in Australian fisheries, including those in the Great Barrier Reef, and especially the reasons for use of spatial zoning, assessment methods for prospective spatial management strategies, and monitoring and performance assessment methods once spatial management is established.
- Use of existing models to test the likely utility of various indicators and performance measures of the system-wide benefits of spatial management. This would include socioeconomic as well as ecological indicators and performance measures.
- Develop and test cost-effective methods for key observations required for design, theoretical testing and field assessment of spatial management – particularly potential new technologies to measure movements of marine organisms among areas with different management arrangements, to determine the source of recruits, to test rapid assessment methods, to test the adequacy of the use of surrogates for ecological properties (eg habitats and biodiversity).
- Identify 2-3 demonstration fishery systems for development and application of concepts. Recommended fishery systems are within the SE Fishery and temperate reef fisheries in SA/Victoria (including Maria Is in Tasmania) and the Western Australian coast. Within these demonstration systems the four elements of the R&D framework above would be addressed, recognising that some activities should be addressed by common approaches across the demonstration systems (eg some of the modelling, indicators and

performance assessment methods) while other activities will be more system or location specific (eg the monitoring and field observation methods).

The proposed R&D framework recognises a fishery management context in which there is likely to be increased use of spatial management and fishery closures as a result of decisions by other marine sector managers – including MPAs - as well as continued scrutiny of the sustainability of fisheries with respect to target species, by-catch species, habitats and biodiversity generally. Against a background of increasing pressure for areas, the benefits of the investment in the types of R&D outlined in this document are clear. Such investment will allow fishery managers to take a proactive approach to spatial management and provide a basis for reducing the risks and improving the benefits from fisheries management by:

- better and more explicit prediction of the likely outcomes of spatial management measures;
- improved and more robust management strategies that have greater 'certainty of outcome';
- more targeted monitoring that is part of an explicit adaptive or 'continuous improvement' design;
- Improved and verifiable performance assessment to demonstrate that fisheries are meeting broader ecosystem objectives.

The proposed R&D will provide a new suite of 'technical' tools and information to support effective spatially based management and the development of proactive and demonstrable strategies for continuous improvement.

Introduction

Background

Effective governance arrangements for fisheries management, and ocean resource management more generally, must ensure that the scientific uncertainties underpinning those governance arrangements are well understood and explicitly accounted for in management decisions and strategies. The governance arrangements for fisheries management are strongly based on the use of spatial structures and management measures, such as the boundaries of jurisdictions, management plans, and zoning of the kind and intensity of fishing. The governance arrangements for management of other marine uses, which can impinge on fisheries, similarly use spatially based governance and management arrangements. As Garcia and Hayashi (2000) point out the spatial aspects of fishing activities, the impacts of fishing, and the events and actions that affect fisheries, are seen as increasingly critical elements of the governance and management of fisheries.

Spatially based arrangements are manifest at various spatial scales. Consequently there is growing interest in managing marine systems at various spatial scales, and in assessing the relative roles of different spatial components in achieving desired outcomes for large marine systems as a whole. This includes the use of Marine Protected Areas (MPAs) in the management of marine ecosystems. In the international arena, for example, this is exemplified by the zoning provision in the recently reauthorised Magnuson-Stevens Fishery Conservation and Management Act. Within Australia, the declaration of MPAs as part of the NRSMPA (ANZECC 1998) is at different stages of development and implementation throughout Australia, but is already in place in several States (eg Victoria) and is a formal requirement under Oceans Policy at Commonwealth level. Zoning is a key arrangement for the management of barrier reef system, including fisheries and MPAs, within the world heritage area off north eastern Australia. MPAs are being identified in the South East Regional Marine Plan that is being established under Oceans Policy to achieve sustainable Ecosystem Based Management. Fisheries managers have used spatial management to various degrees for many years, and virtually all management plans implicitly use some form of spatial management for a variety of purposes. Explicit spatial management has also become a key requirement for a number of Australian fisheries arising from strategic assessments under the EPBC Act. In addition, in response to a perceived failure of traditional fisheries management, there are increasingly frequent calls for widespread use of MPAs (primarily no-take zones) as fisheries management tools (eg Roberts and Hawkins 2000, Gell and Roberts 2002, Pauly et al. 2002). This paper has used, for convenience, the term MPA in which the entire area, or parts, thereof, is fully protected.

Despite these governance arrangements, policy objectives, and management practice, the scientific basis for the spatial management of marine systems and the potential contribution of a given area of marine-space (eg an MPA) is limited. Outcome oriented assessment of the performance has been rare and superficial even for spatial management measures that have had widespread use in fisheries for many years, and there is limited assessment of this for more recently introduced measures such as no-take MPAs (eg, Ward et al. 2001, Sainsbury and Sumalia 2001). Where performance assessment has been undertaken it is usually focuses on examining the consequences in the immediate area of the spatial management zone (eg what accumulates in a closed area) rather than examining the system-wide effects and benefits that were the aim of the spatial management measure (eg protection of the breeding stock or maintaining ecosystem biodiversity). In many instances key uncertainties remain about spatial management approaches and these are a significant constraint on decision making to achieve ESD objectives.

Consequently, in recent years the Fisheries Research and Development Corporation (FRDC) has received a number of applications concerning the use of spatial management in fisheries, particularly the impact of MPAs. However, the FRDC Board recognised that it lacked clear strategic direction with respect to the R&D needed to support spatially-based management, including the development of marine protected areas, and the way that R&D investment could reduce the risks and improve the benefits of management. The Aquatic Protected Areas conference and the related R&D workshop in Cairns in 2002, for example, provided very little direction to the Board or other R&D investors. In part this reflected the lack of clear operational objectives for MPAs, an issue that was highlighted at the conference (Beumer et al 2003). However, as discussed by Adriaenssens et al (2004) operational objectives for ecosystem management may be inherently fuzzy as a result of both epistemic and linguistic uncertainty. Given this need, the FRDC Board agreed with the Australian

Fisheries Managers Forum (AFMF, Fisheries Directors from each jurisdiction) that this topic should be discussed at the meeting with AFMF in July 2003. To facilitate this discussion, the FRDC Board funded the development of this paper outlining the options for fisheries R&D investment in spatial management and MPAs.

In commissioning this document FRDC have recognised that integrated spatial management will continue to be a fundamental tool in fisheries management, that it will grow in importance, and that the options and implications of spatial management initiatives need to be assessed. Because MPAs are only one spatial management tool, this paper considers them within the broader context of spatial management.

The paper was reviewed by a steering committee and Australia's fisheries jurisdictions (Acknowledgments). The terms of reference for the review are shown in Appendix 1.

The objectives of the paper were to consider two main issues:

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The paper begins with a description of the policy context and concepts. The current and past R&D relevant to the spatial management of fisheries were considered, and a gap analysis was undertaken and used to develop an R&D framework. Finally the potential management issues/response are outlined.

Policy Context and Concepts

Fisheries science and management is under increasing scrutiny (Smith and Smith 2001). There are widely held views that fisheries management has been unsuccessful and there is concern for the status of fish stocks worldwide (Mace 1997). Recent FAO figures (State of World Fisheries and Aquaculture 2002) on the status of marine fish stocks (47% fully exploited, 18% over-exploited, and 10% significantly depleted or recovering but far less productive than before) are widely reported. A recent paper by Myers and Worm (2003) paints a bleak picture arguing that the biomass of large predatory fish is about 10% of pre-industrial levels. They argue that this has potentially serious consequences for oceanic ecosystems.

In response to these concerns there has been an increased focus on not only protection of fisheries and fish stocks but also marine ecosystems (eg 1995 FAO Code of

Conduct for Responsible Fisheries, 2001 Reykjavik conference on Responsible Fisheries in the Marine Ecosystem, 2003 FAO Technical Guidelines on the Ecosystem Approach to Fisheries).

Generally, Australia's fish stocks are regarded as well managed by world standards. However, there are several Australian fisheries and fish stocks that are clearly depleted (BRS Status Reports).

During 2000, Australia implemented a new reporting and assessment framework for ESD in fisheries. At the same time the then Environment Australia, under requirements of the EPBC Act, developed new guidelines for export fisheries such that they had to be demonstrably ecologically sustainable. Both approaches have seen a broadening of the focus and scope of fisheries management from the target species to a consideration of the wider ecological issues and impacts. This broader approach has been referred to as Ecosystem Based Fisheries Management (EBFM) (eg Christensen et al. 1996, WWF Australia 2002)).

There has also been a move toward a more integrated approach to multiple use management of marine ecosystems, within which fisheries is one component. Within Australia this is seen as reflecting the principles of ecologically sustainable development at a broader ecosystem, multi-sector, or regional level. In Australia and elsewhere this is termed Ecosystem Based Management (EBM).

This concept of Ecosystem Based Management has arisen in recognition of two main properties: (1) exploited natural resources are highly connected to their surrounding ecosystems and exploitation can therefore impact on productivity, and (2) the exploitation of natural resources can have effects on other resources and aspects of ecosystems (WWF Australia 2002). These two properties are generally agreed to contribute to successful implementation of EBM, recognising the dynamic nature of ecosystems and the importance of spatially based management objectives. The latter includes identifying ecosystem boundaries, connectivity within and between ecosystems and identification of essential fish habitat and sensitive, vulnerable or diverse habitats (Ward et al. 1997, Ecosystem Principles Advisory Panel 1998, WWF Australia 2002). Most definitions of EBM also recognise that human goals and aspirations, including socio-economic and cultural aspects, underpin the very basis of the notion of ‘sustainability’ and what is regarded as acceptable environmental change.

These parallel developments have given rise to a number of terms that can be confusing, yet they can all be interpreted as being consistent with ESD at the sector or ecosystem level. For example Integrated Oceans Management, as used in the present SE Regional Marine Plan under Australia’s Oceans Policy, is effectively the governance and operational management means of implementing multiple-use management to achieve the goals and principles of EBM (see Figure 1). Integrated Oceans Management (or Multiple Use Management) incorporates a number of ecosystem level challenges. One is to coordinate management actions across multiple jurisdictions, recognising that marine ecosystems rarely comply with legislative arrangements. A second is to understand and manage the cumulative effects of all resource use on our oceans. And a third is to consider, and integrate or coordinate, the management of several different users and industry sectors so as to achieve overall sustainability. While the challenges are considerable, spatial management is a key and common element in all of these challenges. Jurisdictional structures in the sea and elsewhere are primarily spatially defined, though at various levels of spatial resolution. The management plans and arrangements for all industry sectors make extensive use of spatial management tools to achieve ecologically sustainable development (Figure 1). For example, spatial components of oil and gas exploration and production include exclusion areas for all other users around drilling platforms and pipelines. Similarly the National Representative System of Marine Protected Areas aims to provide a network of areas around Australia so as to protect and conserve biodiversity. While these spatial management initiatives will be implemented to serve the needs of the different users, in this document we consider such areas only in the context of their potential availability and contribution to fisheries.

Ecosystem Based Fisheries Management is consistent with ESD, in that the principles and elements of each are very similar and achieving one would be effective in achieving the other. The elements of EBFM are contained within Australia’s ESD framework, and so thorough application of that framework would achieve both ecosystem based management and ESD. Spatial management is a key tool in meeting ESD objectives in fisheries.

In terms of fisheries outcomes there are a number of spatially based initiatives available to managers. These include area closures at specific times (eg to protect spawners) or area-specific controls applied to catch (output controls), effort (input controls) or a combination of both realised through other methods such as gear limitations or size limits (technical controls). Permanent area closures (no-take Marine Protected Areas) are only one of a suite of spatial management options, and they may be implemented as a fisheries management tool, or as described above, be implemented by other sectors with concomitant management objectives.

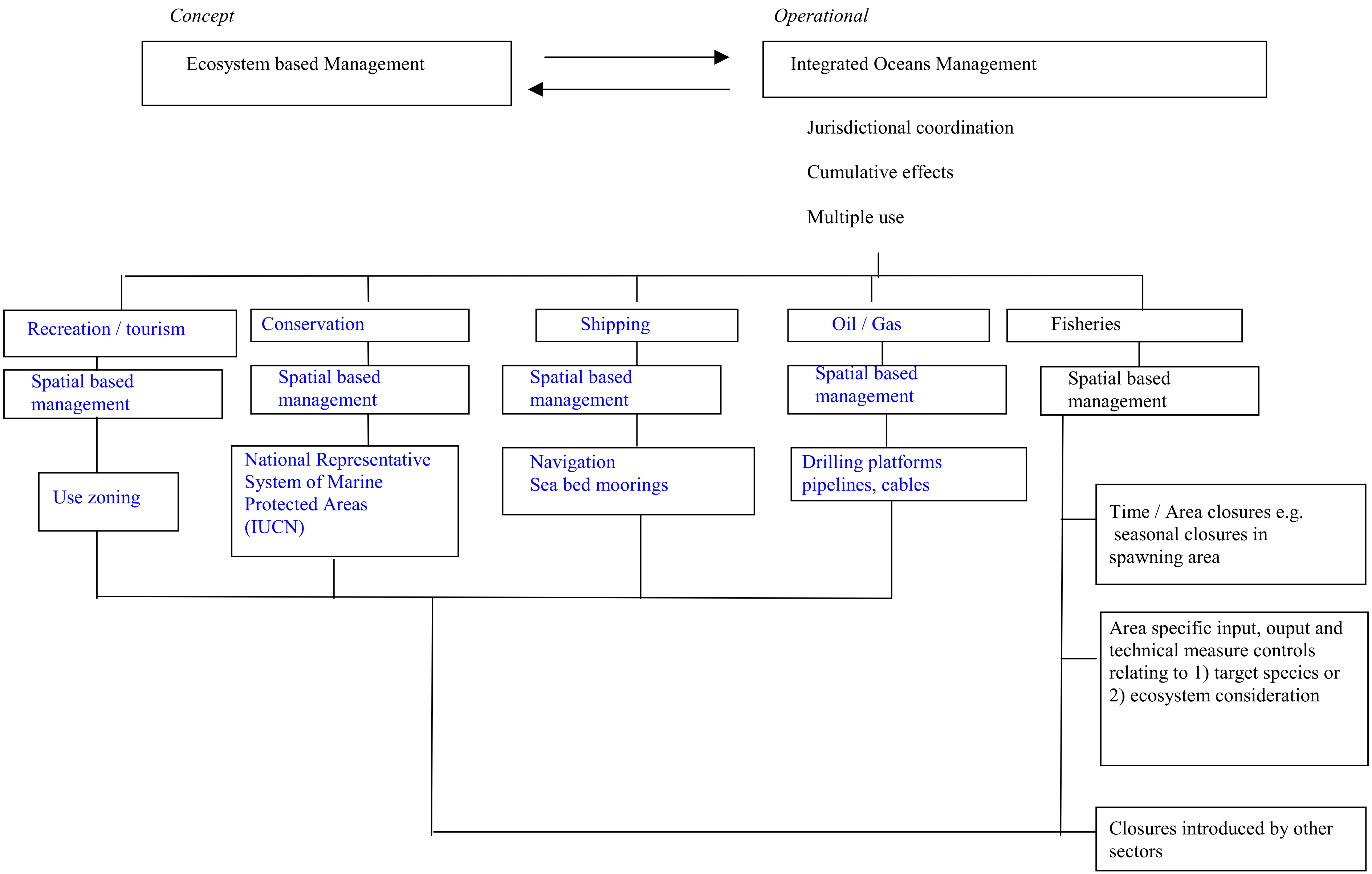

Figure 1. The relationship between the concept of Ecosystem Based Mnagement and the operationalaspects. Text in blue indicates spatial based management initiatives that might be implemented by other sectors but that will have implications for fisheries.

R&D relevant to spatial management of fisheries

In this section examples of current or past R&D in Australia are provided that are relevant to spatial management of fisheries. It is beyond the scope of this review to provide an exhaustive account of all relevant Australian R&D projects but a framework is provided that will allow FRDC to compile this list and we consider that this should be a priority action for the future. Appendix 2 provides more specific examples using abalone and rock lobster fisheries.

The concept of spatial management is not new to Australia and there are numerous examples of spatially based fisheries management initiatives that are already in place. For example, the rock lobster fishery in Victoria is split into two zones for management purposes, but this split was related to historical patterns of the way in which fishing was conducted rather than linked to knowledge of the stocks. The abalone fishery in Tasmania is managed with zonal Total Allowable Catches (TAC) based on an understanding of the species biology and the associated ecosystems. The Great Barrier Reef Marine Park is also zoned for management purposes with fishing allowed in certain areas and precluded in others.

R&D on spatial management to achieve target species objectives and ecosystem related objectives

Tables 1 and 2 provide examples of the types of research programs that potentially or already have, led to spatial management initiatives for fisheries. This research is considered in terms of the types of fisheries management actions that can result. These actions have been divided into input (effort) controls, output (catch) controls and technical controls (gear restrictions, mesh size) with relevant research considered under these divisions. Management actions are further split between those with a target species focus and those with an ecosystem focus. So for example, spatial management actions that protect a particular area important to a commercial species are included in the 'target species' section whilst management actions aimed at protecting an area due to services that area provides to the ecosystem in general, are considered under the 'ecosystem focus' section. Examples of the latter include management actions that are implemented to protect by-catch species in particular areas.

Table 1. R&D for spatial management of fisheries with a target species focus.

Spatial management options	**Relevant R&D that has potential for spatial management outcome**
Spatial input controls	- habitat mapping - fish-habitat links - habitat suitability modelling - spawning and larval recruitment processes - hydrodynamic modelling - tagging studies - genetics - otolith microchemistry - catch and effort analysis - spatially explicit population modelling and management strategy evaluation
Spatial output controls	- tagging studies - genetics - otolith microchemistry - basic biology (growth, size at maturity) - catch and effort analysis - spatially explicit population modelling and management strategy evaluation
Spatial application of technical controls	- basic biology (growth, size at maturity) - reproductive biology - gear selectivity studies - spatially explicit population modelling and management strategy evaluation

Much of the relevant R&D undertaken in Australia that relates to input controls is habitat based and, in order to extrapolate this research spatially, relevant habitat mapping is required. The identification of essential or critical fish habitat can be considered an extension of research into fish-habitat links. Mostly this research has a life history focus, often with the aim of identifying spawning areas, nursery areas or habitat that are critical to certain life history stages. Cappo et al. (1998) provide a review and synthesis of Australian fish-habitat research and no attempt is made to reproduce that here. Instead the focus is on R&D examples that have a clear spatial management objectives. For instance, research in Victoria in the 1980s (Jessop 1988) led, along with other considerations, to an area of Port Phillip Bay being declared a protected area due to the importance of the seagrass beds as a nursery habitat for several commercially important species of fish. A combination of fish-habitat research, investigations into larval biology of King George whiting, and hydrodynamic modelling has led to the spatially explicit identification of seagrass beds important for recruitment of juveniles of this species within Port Phillip Bay, Victoria (Jenkins et al. 1996, Jenkins et al. 2000, Neira et al. 2000). In another example model simulations were used to examine the efficacy of closed areas (or seasons) during the spawning aggregations of the coral trout on the Great Barrier Reef (Fulton et al. 1999). They concluded that closures need to be on a scale that ensures migrations to and from the spawning aggregation are also protected. In these examples, the potential spatial management action is an input control – fishing effort is restricted to protect nursery or spawning areas of target species. The purpose of the R&D is to identify the particular areas where such special protection could be important, and to evaluate management options in terms of the risks and benefits of the fishery.

Although many forms of spatial data management and analysis are used, Geographic Information Systems (GIS) has not been widely recognised as a fisheries problem-solving tool in Australia as yet and can be considered in its infancy internationally (Meaden 2001). Habitat suitability modelling, using GIS, combines fish-habitat links research with an interactive and visual modelling tool with a clear spatially based management focus. A current FRDC project in Victoria uses this approach (FRDC 2000/157). GIS has also been used as a spatial management tool in the analysis of catch and effort data within a spatial framework in both Queensland (FRDC 95/167) and Victoria (Ball and Coots 2001). GIS has been used extensively by the National Oceans Office to support regional marine planning in SE Australia, and in examining interacting uses on the North West Shelf. These R&D programs are designed to support exploration and use of both spatial input and spatial output controls.

Other relevant Australian research that has implications for area based input and output controls concentrates mainly on techniques to identify different stocks and migration of adult fish. Examples of this type of research include fish tagging studies, genetic studies and otolith microchemistry (Farrington et al. 2000, Gillanders and Kingsford 2000, Gillanders et al. 2001, Hamer et al. In Review). Identification of different stocks and the spatial extent of the fishery can result in input controls in terms of restricting effort differentially depending on the size of respective stocks or output/technical controls based on differences in growth or reproductive biology. In Victoria the rock lobster fishery is managed as two zones. Although this zonation is a historical implementation, current research shows that due to differences in habitat, growth rates and size at maturity between lobsters in the two areas, different size limits for each zone would be appropriate as spatial-based management actions (Hobday pers. comm.). Similarly, population modelling has considered spatially explicit effort and catches for school sharks (SharkFag papers) and catches for blue grenadier (Punt et al 2001). A recent study of by-catch reduction in the South East Fishery (Knuckey 2003) may well lead to different mesh sizes being used in different areas reflecting different species assemblages by depth, and east and west of Bass Strait.

Table 2. R&D for spatial management of fisheries with an ecosystem related focus.

Spatial management options	**Relevant R&D that has potential for spatial management outcome**
Spatial input controls	- effects of fishing on marine ecosystems - fishery impacts and risk management of bycatch, including protected species - characterisation, fishery impacts and risk management of seabed and coastal habitats - characterisation, fishery impacts and risk management of food chain dependencies - characterisation, fishery impacts and risk management of ecological community structure and function - spatially explicit ecological modelling and management strategy evaluation
Spatial output controls	- as above
Spatial application of technical controls	- as above

Cappo et al (1998) provide a review of other Australian research into the ecosystem effects of fishing, however there is no specific spatial component to this review. The types of research detailed in Table 2, which can be considered under the broad heading of research into the effects of fishing on the ecosystem, is R&D with an ecosystem focus likely to result in an input, output or technical control measure being implemented. Restrictions relating to the ecosystem effects of fishing generally seem to be implemented through technical controls (gear restrictions, technical advances to reduce impacts), although there are cases where input and output controls have been used. For example, research on the North-West Shelf culminated in the conclusion that trawling was having an impact on the habitat and identified spatial management approaches that both reduced the risk to fisheries and the environment but also increased the benefits from fishing (Sainsbury et al. 1997). This and other considerations lead to trawling being precluded in certain zones while trap fishing was permitted throughout the region. Similarly the use of Tori Poles, in combination with other measures, has been introduced to mitigate seabird mortality south of 30ºS in the long line fishery. Seabirds in this area are prolific, as they are on migratory routes towards the breeding grounds, hence the spatial differentiation in mitigating measures. An example of fishery input controls being used to manage ecological impacts is the requirement on fisheries operating under CCAMLR conservation measures to vacate a local area for a certain period if certain bycatch levels are exceeded.

R&D relating to Marine Protected Areas

The following section considers research relating to Marine Protected Areas both within (Table 3) and outside (Table 4) the boundaries of the MPA that has a fisheries and ecosystem focus. The research issues are considered to be different for these two situations and consequently are considered separately.

Within Marine Protected Areas

Table 3. Relevant R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status within, or in the immediate environs of a Marine Protected Area.

Target Species focus	**Relevant R&D with implications for fisheries**
Genetics	- none known
Population Dynamics	- abundance - age / size structures - reproductive biology - life history characteristics
Ecosystem focus	
Species interactions	- effects of fishing on diets of piscivorous fish
By-catch species	- fate of discards - gear selectivity studies
Key Habitats	- effects of release from fishing pressure on habitat - importance of habitat type to recruitment
Ecological processes	- effects of release from fishing on biodiversity

It is now widely accepted that genetic diversity should be protected because losses are irreplaceable. It is has been suggested that fishing can lead to the loss of genetic diversity through a number of mechanisms (Ward 2002). Marine Protected Areas are seen, by some, as a tool to provide protection to the gene pool by creating a refuge that will rarely, if ever, go through low population bottlenecks (Ward et al. 2001). Genetic analysis is also one tool used to assess population structures and can be used to investigate sources of recruitment and the potential for populations within Marine Protected Areas to self-replenish (Largier 2003, Palumbi 2003). We are not aware of any current or recent relevant research programs in Australia tackling these kinds of research questions.

It is generally accepted that fishing reduces the abundance of target species, change the size and age structure of the population through selective removal of larger, older individuals, affects the spawning biomass and, with over-fishing, recruitment to the population (e.g. Botsford et al. 1997, Pitcher et al. 2000, Pauly et al. 2002, Polunin 2002). As a consequence Marine Protected Areas are predicted to have potential implications for the population dynamics of target species within the protected area (e.g. Ward et al. 2001, Polunin 2002, Halpern 2003). To date, much of the research within Australia has concentrated on this aspect of Marine Protected Areas (Ward et al. 2001). The majority of this research has been undertaken on the Great Barrier Reef and Tasmania and a recent review by Ward et al. (2001) provides a summary of much of this work. Baseline studies have also been undertaken in Victoria for some of these population parameters and will be further investigated following the recent inception of Victoria's network of Marine National Parks (Ferns and Hough 2000).

The principal, direct impact of fishing is to reduce the abundance of the target species (Pauly et al. 2002), but the indirect impacts can involve species interactions, mortality of non-target species, habitat and ecosystem processes (Hall 1999, Kaiser and de Groot 2000, Kaiser and Jennings 2002). Fishery target species may be predators, prey, grazers, competitors or habitat forming species and so the impacts of fishing on species interactions may take a variety of forms (Kaiser and Jennings 2002). The potential effects of fishing on predator/prey interactions has received the most attention in the international literature due to the potential effects of removing a top predator to cascade down the food web, changing community structure and trophic dynamics (e.g. Hall 1999, Garrison and Link 2000, Murawski 2000, Pitcher et al. 2000, Pauly et al. 2002, Myers and Worm 2003). A proposed benefit of Marine Protected Areas is to provide a release from these types of effects of fishing and allow us to increase our understanding of the effects of fishing pressure on species interactions (Conover et al. 2000). A study of this type has been undertaken on the Great Barrier Reef, where diets of the piscivorous coral trout were compared on reefs open and closed to fishing (St John and Russ 2001). In general though, research relating to species interactions in Marine Protected Areas, that has implications for species and spatial scales relevant to fisheries, is limited in Australia.

Marine Protected Areas potentially provide a refuge for by-catch species in the same way that they provide a refuge for target species. This means that many of the predictions relating to the effects of Marine Protected Areas on target species also relate to by-catch species. However, MPAs are not the only mechanism to protect by-catch species. Precluding specific fishing gears may well protect by-catch species without the need to preclude all methods. Research into changes in by-catch populations in many cases could mimic those of target species, however this type of research is not currently been undertaken in Australia to our knowledge. In the Great Barrier Reef researchers have taken advantage of the closed areas to carry out scientific prawn trawling to investigate the by-catch of this fishing method and in particular the fate of the discards (Hill and Wassenberg 2000). As yet, as far as we are aware, this approach has not been extended to consider the population-level implications for the common by-catch species either in the Great Barrier Reef or elsewhere in Australia.

Dependent on the methods used, intensive fishing effort is likely to impact on key habitats through damage caused by the fishing gear (e.g. Hall 1999). A cessation of fishing effort should allow a restoration of habitat complexity and habitat diversity with potential benefits for target species and general ecosystem function (Ward et al. 2001). In Victoria, baseline information regarding habitat parameters and fish/invertebrate assemblages is available and monitoring of these parameters continues following the inception of a network of Marine National Parks (Ferns and Hough 2000). However baseline and performance monitoring is not well established for most Australian MPAs.

The reasons for successful settlement and recruitment to marine populations are complex and differ between species but Australasian research has found habitat complexity to be important for some species (e.g. Connell and Jones 1991, Tupper and Boutilier 1997, Beukers and Jones 1998, Rooker et al. 1998, Lindholm et al. 2001). This is consistent with international data (e.g. Tupper and Boutilier 1997, Rooker et al. 1998, Lindholm et al. 2001) however, these studies did not focus on commercial species. One current research project in Australia is investigating the relationship between habitat complexity and recruitment of reef fishes in a Marine Protected Area in New South Wales (Swearer pers.comm.). Other relevant research investigated the impacts of trawling on seamounts south of Tasmania and the efficacy of a Marine Protected Area to protect this unique deep-sea environment (Koslow et al. 2001).

Ecological processes can be considered at a wide range of spatial and temporal scales and incorporate the mechanisms that underlie the patterns that we observe in an ecosystem (Christensen et al. 1996). Examples of ecological processes include the maintenance of biodiversity, biological productivity, food web dynamics as well as processes we have already included in other sections such as recruitment and population dynamics. The role of Marine Protected Areas in maintaining or restoring biodiversity has received the most attention in the international literature (Bohnsack and Ault 1996, Murawski 2000, Hastings and Botsford 2003). The maintenance of biodiversity is seen as vital to ecosystem functioning and so has implications for fisheries as well as conservation objectives. While the measurement of diversity has been the subject of much discussion in the literature (see Jennings and Reynolds 2000 for overview), it is still relatively straightforward in comparison to measuring the underlying process that resulted in that particular pattern of diversity. While the importance of Marine Protected Areas in maintaining biodiversity is often cited, the majority of the research focuses on measurement of pattern rather than process. This is true for Australia as well and there have been a number of studies investigating species diversity (invertebrates/fish/algae) in Marine Protected Areas (Edgar and Barrett 1999, Ferns and Hough 2000, Koslow et al. 2001). The creation of Marine Protected Areas provides an ideal opportunity to investigate the effects of a release from fishing pressure on ecological processes and increase our understanding and ability to measure process rather than pattern.

Outside Marine Protected Areas

Much of the research relating to Marine Protected Areas, both internationally and within Australia, has concentrated on the areas within the boundary of the protected area. However many of the justifications for MPAs, including the fishery justifications, relate to the effects of the MPAs on the ecological conditions and human activities outside the MPA. These issues relate to the impacts of Marine Protected Areas on the fishery as a whole, and so by necessity involve consideration of effects on a far wider spatial scale than that of the Marine Protected Area.

Table 4. Relevant R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status outside of a Marine Protected Area.

Target Species focus	**Relevant R&D that has resulted in spatial management outcome**
Recruitment (source/sink)	- otolith microchemistry – sources of recruitment. - Genetic markers and identification
Yield (spillover/migration)	- Incorporation of MPAs into spatially explicit stock assessment models - Movement studies using marking, tagging (conventional, data logging etc) and ultrasonic telemetry
Effort Displacement	- Incorporation of MPAs into spatially explicit stock assessment models
Risk Management	- Incorporation of MPAs into spatially explicit stock assessment models
Ecosystem focus	
Species interactions	- none known
By-catch species	- none known
Ecological processes	- none known

An area of research that has received considerable attention in the international literature in recent years and, in particular in relation to the design of networks of Marine Protected Areas, is the potential for larval export/import and the connectivity of Marine Protected Areas (e.g. Roberts 1997, Warner et al. 2000, Botsford et al. 2001, Gaines et al. 2003, Palumbi 2003, Shanks et al. 2003). Most marine fish and invertebrates have a planktonic larval dispersal stage with ocean currents potentially dispersing gametes, fertilised eggs and/or larvae considerable distances. Ecologists often use the terms source and sink to separate areas that contribute greatly to population replenishment by supplying large numbers of offspring (source) from areas that supply few recruits but receive large numbers of offspring (sinks) (Dayton et al. 2000, Ward et al. 2001). Marine Protected Areas that effectively act as sink areas may eventually become source areas or alternatively contribute to population biomass through migration of juveniles or adults to the fishery.

There are a number of research techniques available to increase our understanding of the connectivity between Marine Protected Areas and the supply of larvae and adults in and out of reserves. Larvae produced inside a protected area may recruit back into the area or alternatively recruitment within a protected area may be dependent on areas elsewhere within the species range (Palumbi 2003). Most measures of larval dispersal are indirect because in general making direct observations is impractical. Larval dispersal distances are often inferred from known life-history parameters and oceanographic data (e.g. Gaines et al. 2003, Grantham et al. 2003, Largier 2003, Shanks et al. 2003). Other more recently developed methods for measuring larval dispersal and connectivity of different areas include genetic studies (Palumbi 2003) and otolith microchemistry (Swearer et al. 1999, Gillanders and Kingsford 2000, Hamer et al. In Review). While these techniques have been used in Australia (e.g. (Jenkins et al. 1996, Farrington et al. 2000, Gillanders and Kingsford 2000, Jenkins et al. 2000, Hamer et al. In Review), there has been little of this type of research undertaken that directly relates to Marine Protected Areas. An exception is an existing research program being undertaken in New South Wales that is investigating sources of recruitment in reef fish to the protected area of Lord Howe Island that integrates oceanographic data with otolith microchemistry (Swearer pers.comm.).

A related issue to larval export is that of 'spillover' which is a term that reflects the potential of a Marine Protected Area to contribute to the overall production of the fishery and so increase yield. Fish may leave protected areas for a number of reasons; random movements, density dependent movements, directed movements for functions such as spawning, feeding or visiting cleaning stations, and ontogenetic shifts (Ward et al 2001, Gell and Roberts 2002). Once outside the boundary of the Marine Protected Area adult fish are available to the fishery and, if such migrations are maintained, then increases in yield or catch per unit effort should be observed. In Australia relevant research includes the incorporation of Marine Protected Areas in predictive stock assessment models and more general modelling studies (eg Tuck and Possingham 2000, FRDC 1999/162, Victorian rock lobster fishery assessment). These studies provide some information on the implications for fisheries in terms of yields for certain species. The movement of coral trout across boundaries of areas open and closed to fishing at Lizard Island on the Great Barrier Reef has also been investigated using branding with mark-release-recapture techniques as well as ultrasonic telemetry (Zeller and Russ 1998).

One effect of Marine Protected Areas on the fishing community is that fishing effort is preferentially concentrated along the boundaries of the protected area, sometimes referred to as 'fishing the line'. This behavioural response, enables fishers to remove any fish that cross the boundary and to reduce the effects of spillover. It may also, of course, reduce the efficacy of the Marine Protected Areas to contribute to overall production of populations (see Ward et al 2001 for review of these issues). Again, there is some international research investigating the effects of these changes in fisher behaviour (Ward et al 2001, Gell and Roberts 2002). Apart from some anecdotal evidence of 'fishing the line' in a trawl fishery on the Great Barrier Reef reported by Gell and Roberts (2002), we are not aware of Australian research into this issue. There is rarely enough fine-scale effort data to allow a spatial analysis of fishing activity along boundaries to be undertaken (Hall 1999). In some countries there is a move towards satellite tracking of fishing vessels for monitoring and fisheries enforcement or installation of automated position-recording systems on vessels (Hall 1999) and these approaches allow for a much finer spatial resolution for analysing effort and fisher behaviour. The wide use of VMS in Australia should provide the basis for assessing whether 'fishing the line' occurs.

Another proposed benefit of the creation of Marine Protected Areas is their role in reducing uncertainty including fisheries, in the system they form part of. It has been suggested that the building of stock biomass will reduce variation in certain fish populations (Polunin 2003) which in turn will reduce variability in recruitment. These factors are considered to reduce the probability of recruitment failure and lower the chance of stock collapse – a bet-hedging strategy (Lauck et al. 1998, Ward et al. 2001). Assemblages within a Marine Protected Area may be less stressed due to the reduction in fishing mortality and therefore be more resilient to other impacts (Dayton et al. 2000). There have been a number of modelling studies that incorporate the idea of bet-hedging overseas (e.g. (Lauck et al. 1998, Hannesson 2000), but there has been no research in Australia that we are aware of that address the hypotheses regarding the role of Marine Protected Areas in reducing uncertainty.

The final section in Table 4 deals with research on the effects of Marine Protected Areas that has an ecosystem focus and that is concentrated outside the protected area. There is very little research either internationally or within Australia that addresses these questions. Species interactions that are affected by a release from fishing pressure within the Marine Protected Area may have a knock-on effect through larval export or migration of juveniles and adults to adjacent areas. Similarly population dynamics of by-catch species effected by the release from fishing pressure may also mimic target populations in the potential effects on populations outside the protected area. In terms of ecological processes, again there is the possibility that changes in a protected area will impact on areas outside the boundary. With biodiversity for example, genetic and species diversity may be preserved by protected areas acting as a reservoir for some of the species that are impacted by fishing. Community structure therefore, may be maintained to some degree outside of protected areas through this process (Ward et al. 2001).

Gap Analysis

In this section we have undertaken a subjective 'gap analysis' where we score the current understanding and state of R&D out of five under a number of headings that attempt to provide a consistent framework for considering R&D in Australia (where 1 represents limited use or R&D). This framework is fairly broad but the text will provide examples of the types of R&D that we consider could be undertaken where scores are low. Consideration of relevant research and development has been split into the two main objectives of the paper 1) the effectiveness of spatial management for fisheries and 2) implications for fisheries of closures introduced by other sectors, eg NRSMPA. Within these sections we further split the analysis into R&D that focuses on target species and R&D that focuses on ecosystem related spatial management initiatives.

Within this broader framework, R&D status is assessed by considering area based input controls, area based output controls and area based technical measures. The R&D status is considered under a number of headings that allow us to judge whether or not the appropriate R&D has been done, whether we have a good conceptual understanding of the problem and the best way to address the questions posed by the problem, and whether we have a good understanding of the broad principles relating to the problem.

1) **Use**. This relates to how commonly we perceive that a particular management strategy is used in fisheries management.

2) **Design theory**. This heading aims to reflect our general understanding of the research and development required to address the need for a particular management strategy.

3) **Application**. This column scores the application of the R&D required to address the needs for a particular management strategy. In other words we may have a good understanding of the R&D required to address a particular management strategy (design theory scores highly) but that R&D may have been applied very infrequently (application scores low).

4) **Evaluation**. This column relates to R&D undertaken to evaluate the effects, or performance, of particular management strategies. Within this single score two concepts are incorporated; the use or effectiveness, which relates to how effective is the implementation, and the appropriateness, which considers how appropriate the design of the spatial based management strategy is to achieve the desired objectives. In other words an R&D program might be undertaken to evaluate the performance of an area-based Total Allowable Catch control. But it may also consider the performance of the stock overall and whether that particular management strategy was a good design and appropriate to achieve the stated objectives.

Again Appendix 2 provides fishery-specific information using abalone and rock lobster fisheries as examples.

The effectiveness of spatial management for fisheries

The following table (Table 5) considers the R&D status for spatial based management that has been undertaken with a target species focus. In Australia, spatial input controls are used frequently, for example controls on fishing effort to protect nursery or spawning grounds. The type of R&D programs that might lead to this type of input control would include habitat mapping and classification, habitat suitability modelling, fish-habitat links that detail a critical chain of habitats throughout a species life-history. The design theory of R&D that relates to this type of input control is also relatively well understood. In other words we have a good idea of how to address the problem of identifying nursery areas for target species. The question of how to allocate effort or input controls on migratory species is less well understood and although we have some understanding of the design of R&D required to obtain movement data, we currently have a poor understanding of how to apply and evaluate spatial based input controls to protect migratory target species.

Table 5. Knowledge Gap Analysis for Australian R&D considering the effectiveness of spatial management for fisheries with a target species focus. Scores are out of five.

Spatial management options	Use	Design Theory	Application	Evaluation
Spatial input controls	4/5	3	3	3
Spatial output controls	2	1	3	2
Spatial application of technical controls	5	3	4	3

Spatial output controls are used to some extent in Australia. In most cases, the existing management strategies that use this approach have primarily been introduced for historical reasons rather than resulting from an R&D based approach. For example, Total Allowable Catch in the Tasmanian abalone fishery is divided into zones so that the catch is more evenly distributed across the State. This strategy was developed out of an understanding of historical catch and effort distribution, but the application is still not at an appropriate scale and is currently the topic of an FRDC-funded study. Similarly, in Victoria, there is increasing interest in the introduction of sub-zonal TACs in the abalone fishery. Overall, the design theory needed to address the spatial allocation of catch needs further study.

The spatial application of technical measures includes controls on gear such as mesh size limitations, gear restrictions and also size limit restrictions. These types of management strategies are very commonly used in Australia, and while they are not always implemented on a spatial basis, often gear restrictions apply to particular areas only. There is a reasonably good understanding of the R&D required to investigate the use of such spatial based technical control measures that might be used to protect target species.

The second phase of the gap analysis considers R&D addressing the effectiveness of spatial management for fisheries that has an ecosystem focus (Table 6). Spatial input controls might involve the restriction of effort in particular areas to protect sensitive habitat (e.g. Sainsbury et al. 1997) or vulnerable by-catch species. In Western Australia, most areas are closed to trawling and these closures are designed to limit this type of impact on the environment (W Fletcher pers comm). R&D programs that might contribute to this type of spatial input control could include habitat mapping, values assessment, assessment of non-fishery impacts such as aquaculture, pollution, climate change variability, exotic species etc. to identify sensitive habitats or ecological communities.

Table 6. Gap Analysis for Australian R&D considering the effectiveness of spatial management for fisheries with an ecosystem related focus. Scores are out of five.

Spatial management options	Use	Design Theory	Application	Evaluation
Spatial input controls	2	2	1	1
Spatial output controls	1	2	1	1
Spatial application of technical controls	1	1	0.5	0

Spatial based output controls with an ecosystem focus might include by-catch catch controls. In other words in certain areas the allowable amount of by-catch might differ to other areas. This type of approach is currently little used in Australia and the general understanding and knowledge base of the R&D that would address such spatial management strategies is considered poor.

The spatial application of technical controls undertaken with an ecosystem focus is also relatively unusual in Australia. Previously we described an example where Tori poles in combination with other methods, (a spatial-based technical control) are used to mitigate against seabird mortality. In general, this type of approach is uncommon and the R&D knowledge base is considered poor.

The implications for fisheries of closures introduced by other sectors

In this section we consider the implications to fisheries of closures introduced by other sectors, although we use the National Representative System of Marine Protected Areas as a case study. These types of area-based management regimes have attracted the most attention in recent years and have been highlighted by FRDC in the Terms of Reference for this paper as a focus area.

We again take the approach of considering the status of R&D within Australia that has a focus on, firstly target species and secondly the ecosystem. We also consider the R&D that relates to issues that are relevant within a Marine Protected Area separately to R&D that relates to issues outside a Marine Protected Area. This was considered a particularly important consideration by the authors because the majority of research relating to MPAs has focused on the immediate area in and around Marine Protected Areas whilst implications for fisheries need to be considered on a larger scale.

Within Marine Protected Areas

The important R&D issues for target species inside an area were considered to be gaining an understanding of genetics (genetic diversity and population genetics) and population dynamics (abundance and age/size structures). The important R&D issues relating to the ecosystem within an area were considered to be gaining an understanding of species interactions, by-catch species population dynamics, key habitats and ecological processes with an emphasis on the implications of the absence of fishing on these factors (Table 7).

Table 7. Gap Analysis for Australian R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status within, or in the immediate environs of a Marine Protected Area. Scores are out of five. Scores given a 0* are considered very low, with only one or two examples in Australia that the authors are aware of.

Target Species focus	Design Theory	Application	Evaluation
Genetics	0	0	0
Population Dynamics	4	1	0.5
Ecosystem focus			
Species interactions	1	0*	0
By-catch species	4	0*	0
Key Habitats	3	2	0*
Ecological processes	2	1	0

The general understanding, application and evaluation of R&D focused on the genetics of target species is considered to be poor in Australia. Ward (2002) and Palumbi (2003) both provide good overviews of the variety and application of a range of genetic analysis techniques and while they have been used in Australia to address more general stock management questions, they have not been used in Marine Protected Area research.

While we have a good understanding of the design theory of R&D aimed at assessing population dynamics in terms of comparative abundance and age/size structures inside and outside, the majority of this type of work has been undertaken in Tasmania or the Great Barrier Reef. This type of R&D has not been applied widely in other parts of Australia and the implications for fisheries are only recently being considered.

Although the majority of research focused on Marine Protected Areas has concentrated on the immediate environs of the area, in terms of implications for fisheries, our understanding of the benefits or impacts on fisheries is still limited. Little information exists regarding the potential changes in species interactions in the absence of fishing and the implications of these potential changes to fisheries. Similarly, while we have a good understanding of how to approach the question of effects on by-catch population dynamics within Marine Protected Areas, such approaches have yet to be widely used and the implications for fisheries evaluated. There have been slightly more application of R&D in regards to key habitats. While there have been a number of programs that map habitat in Marine Protected Areas, there has been less application of research that identifies fish-habitat links within Marine Protected Areas. The implications of the responses of key habitats to Marine Protected Areas for fisheries have received very little evaluation in Australia so far.

There may also be the potential difficulty of undertaking R&D within MPAs as some sampling techniques may not be consistent with the management objectives of the area. This requires further discussion by ocean managers.

Outside Marine Protected Areas

There has been very little research effort focused on the implications for fisheries of Marine Protected Areas on the scale of the whole fishery either in Australia or overseas (Table 8). The presence of Marine Protected Areas has been incorporated in predictive stock assessment models, which provides some information on the implications for fisheries in terms of yields for certain species (eg the Victorian rock lobster fishery). In general however, our conceptual understanding and methods for assessing and evaluating the implications for fisheries of area closures introduced by other sectors is limited.

Table 8. Knowledge Gap Analysis for Australian R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status outside of a Marine Protected Area. Scores are out of five. Scores given a 0* are considered very low, with only one or two examples in Australia that the authors are aware of.

Target Species focus	Design Theory	Application	Evaluation
Recruitment (source / sink)	1	0*	0*
Yield (spillover / migration)	1	0*	0*
Effort Displacement	2/3	0*	0*
Risk Management	1	0	0
Ecosystem focus			
Species interactions	1	0	0
By-catch species	1	0	0
Ecological processes	0*	0	0

R&D Framework

Implicitly, or explicitly, spatial management is already a well-established management tool in the management of fisheries, as well as in the management of other marine industries and activities. For example the great majority of marine management plans and arrangements include a spatial aspect – from the water quality zones identified in coastal zone planning through to fishing effort and catch zones within various fishery management plans. As a result there is already some basis for understanding the R&D needs of spatial management. The overall aim of the R&D investment is to reduce the risks and improve the benefits of fishery management. Based on the previous gap analysis, an R&D framework has been developed that has 4 main elements:

1. Understanding the spatial dimension of marine systems and their management.

This is to improve the basic understanding of spatial processes in the ocean and its use by humans, so as to better identify the scale and location of zones used in spatial management for various purposes. For example this includes:

- habitat mapping and classification;
- reliability of using surrogates (eg acoustic backscatter) for habitats and biodiversity;
- development of rapid-assessment and cost-effective methods to measure changes in species, habitats and biodiversity;
- ‘Chain of habitat’ usage by key species through their lives
- movement of individuals of key species at key life history stages, and especially movement between areas with different management arrangements;
- development of cost-effective methods, potentially including application of new genetic methods and new technologies for tagging and moored instrumentation, to measure movements of marine organisms among areas with different management arrangements;
- dispersal of particles (eg biological and pollutants) by currents and seabed sediments;
- rapid and cost-effective methods to identify the source spawners that contribute to recruitment in a particular area;
- modification and recovery of key habitats under different conditions of fishing intensity and fishing gears.

2. *Predicting the impacts and benefits of spatial management.*

This is to improve the ability to develop and evaluate spatial management options for fishery management. For example this includes:

- development of spatial models of marine populations, ecological processes and fishery impacts, including the observation program required to meet ongoing information needs;
- socioeconomic dependence and resilience assessment;
- prediction of the response by fishers to changed spatial management arrangements (including introduction of MPAs);
- risk assessment and management scenario prediction;

- conceptual framework and modelling methods for spatially nesting physical and ecological processes, and linkage to the human socioeconomic system.

3. *Measuring the impacts and benefits of spatial management.*

This is to enhance the ability to measure the performance of spatial management, so as to enable identification of outcomes and to demonstrate management effectiveness to third parties. For example this includes:

- cost effective ecological monitoring methods;
- socioeconomic impact assessment;
- methods to allow use of spatial zoning (including MPAs) as reference areas to measure impacts and benefits of spatial management;
- development of a suite of tested indicators and performance measures for spatial management;
- spatial interpretations of target and limit reference points for fisheries management;
- planned 'before and after' or 'similar system' comparisons of fisheries with and without various forms of spatial management (including MPAs).

4. *Adaptive or 'continuous improvement' strategies for spatial management.*

This is to support pro-active identification of management strategies and responses that have a high chance of achieving management goals. A management strategy in this context is the combination of monitoring, assessment of information from the monitoring, and options for management decision based on the results of that assessment. For example this includes:

- Spatial fishery management strategies for optimising harvest of target species, including the setting of target species TACs, that account for areas that are protected in various ways by other sectoral management arrangements (including MPAs, shipping and petroleum closed areas);
- Spatial management strategies for control of by-catch (including by-catch of protected species to meet the requirements of Threat Abatement Plans), habitats and biodiversity;

- Use of spatial zones (including MPAs) as reference areas to assess fishery impacts and sustainability;
- Spatially based strategies for managing developing/expanding fisheries..

Implementation of this R&D framework would be most effectively pursued by:

(i) a coordinated set of projects to develop methods, and

(ii) identification of a small number of demonstration systems in which the system-wide methods and performance assessment is developed and applied.

The small number of demonstration systems should be of contrasting types that have well-developed plans for the use of spatial management by fisheries and conservation managers. Some obvious contenders are within the SE Regional Marine Planning area of the National Oceans Office, the coastal reef systems of South Australia and Victoria in general and the Maria Island system in particular, the Western Australian coast and the Great Barrier Reef – in each case significant MPAs have already been identified and spatially-based management is used in fisheries management.

This framework provides a basis for R&D investment in fisheries spatial management and assessing the impact on fisheries of spatial management decisions by other sectors. MPAs will have a significant role in the latter and, most likely, the former. We have identified a number of R&D activities that should commence within the short-term:

- Desk-top review of EBM approaches in Australian fisheries, including those in the GBR, and especially the reasons for use of spatial zoning, assessment methods for prospective spatial management strategies, and monitoring and performance assessment methods once spatial management is established.
- Use of existing models to test the likely utility of various indicators and performance measures of the system-wide benefits of spatial management. This would include socioeconomic as well as ecological indicators and performance measures.
- Develop and test cost-effective methods for key observations required for design, theoretical testing and field assessment of spatial management – particularly potential new technologies to measure movements of marine organisms among areas with different management arrangement, to

determine the source of recruits, to test rapid assessment methods, to test the adequacy of the use of surrogates for ecological properties (eg habitats and biodiversity).

- Identify 2-3 demonstration fishery systems for development and application of concepts. Recommended fishery systems are within the SE Fishery and temperate reef fisheries in SA/Victoria (including Maria Is in Tasmania) and the Western Australian coast. Within these demonstration systems the four elements of the R&D framework above would be addressed, recognising that some activities should be addressed by common approaches across the demonstration systems (eg some of the modelling, indicators and performance assessment methods) while other activities will be more system specific (eg the monitoring and field observation methods).

Management Implications

As noted above, spatial management is a well-established tool in the management of fisheries, as well as other marine industries and activities, and is an increasingly key consideration in development of effective governance arrangements. While managers of marine uses are often well used to using spatially based management tools, existing spatial management arrangements in fisheries have often been ad hoc responses to perceived fishery and ecological needs, and have been applied without regard to the spatial management arrangements of other sectoral managers. In addition, they have not been subsequently evaluated for their effectiveness – a key governance issue given the uncertainties and associated risks.

The main contemporary challenges are to manage fisheries effectively in the context of the spatial management of other sectors, to influence the spatial management decisions of other sectors, to achieve a wider range of fishery management objectives (especially in relation to fishery EBM), and to clearly demonstrate sustainability to third party interests in a way that can be objectively verified.

Several reviewers of this paper stressed that one of the challenges is for more clearly defined objectives for proposed spatial management initiatives, in particular to differentiate between conservation and fishery management objectives. There is no doubt that a cause of much of the controversy surrounding the introduction of MPAs reflects the diverse and fuzzily defined operational objectives.

The four elements of the R&D framework provide comprehensive and interconnected R&D mechanisms to support development and application of spatially based management in fisheries. The framework recognises a fishery management context in which there is likely to be increased use of spatial management and fishery closures as a result of decisions by other marine sector managers (eg the NRSMPA), as well as continued scrutiny of the sustainability of fisheries with respect to target species, by-catch species, habitats and biodiversity generally. Examples include:

- managing target species to meet sustainability requirements (Fishery Acts and EPBC Strategic Assessment criteria),
- managing bycatch – ecological risk assessment (EPBC criteria), endangered species (EPBC and endangered species Acts), competing/conflicting fisheries (eg SBT bycatch in ECT fishery, trawl and line fisheries in SEF, commercial/recreational resource sharing),
- managing habitats and biodiversity, and
- precaution and insurance in fisheries management.

It is likely that fishery managers may use closed areas to meet fishery ecosystem objectives, and there are clearly potential benefits identifying areas that provide benefits across a range of sectors. Notwithstanding this, there is a concern that the use of Marine Protected Areas as a fisheries management tool will result in degradation of the areas outside of the MPA if this particular management option is seen as a panacea for all fisheries problems (Pauly et al 2002, WWF Australia 2002). Instead, they should be considered as one of a combination of fisheries management methods that might include other spatial-based controls as well as input, output or technical controls that apply to the whole fishery (eg Sainsbury and Sumalia 2001).

However, to reiterate, the global move to improve oceans governance is increasingly focusing on the explicit use of spatial management measures. As a part of that the focus there is increasing emphasis on the declaration and implementation of MPAs as a necessary tool in spatial marine planning and management. MPAs, as a component of spatial management, are going to happen and in increasing numbers – sometimes for fishery purposes and sometimes for other purposes but almost always having an effect on fisheries and requiring a management response from fisheries. In the FRDC R&D Plan 2000-2005, it is suggested that nations will set targets such as 20% of the coastal zone for high degrees of protection through MPAs. Only recently, the Great Barrier Reef Marine Park Authority announced its intention to fully protect over 30% of the park. In addition, the calls for more closed areas from highly influential lobby groups and international scientists are likely to increase. Against this background, the benefits of investment in the types of R&D we have outlined are clear. It will enable fishery managers to take a proactive approach to spatial management, including a better basis for influencing the decisions of other sectors and for optimising fishery management arrangements in the context of the decisions made by other sectors. It will provide the basis for reducing the risks and improving the benefits from fisheries management by:

- better and more explicit prediction of the likely outcomes of spatial management measures;
- improved and more robust management strategies that have greater 'certainty of outcome';
- more targeted monitoring that is part of an explicit adaptive or 'continuous improvement' design;
- Improved and verifiable performance assessment to demonstrate that fisheries are meeting broader ecosystem objectives.

In recent years, the impacts of MPAs on fisheries, particularly the commercial and recreational sectors have been highly contentious and, without a sounder scientific basis they will continue to be contentious. Similarly the rate of failure of fisheries is being judged as being too high in many national and international arena, and without better and more transparent risk management and performance assessment this assessment is likely to both continue and increase in its vigour.

Clearly, it is not suggested that continued implementation of fisheries spatial management or responses to the implementation by other sectors should be delayed until relevant R&D is completed. Rather the proposed R&D will provide a new suite of 'technical' tools and information to support effective spatially based management, and the development of proactive and demonstrable strategies for continuous improvement.

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Appendix 1

Terms of Reference:

Develop a paper that:

1. Is developed with and circulated to AFMF and FRDC no later than 13 June 2003.
2. Utilises a steering committee comprising: Professor Colin Buxton, Mr Ian Cresswell, Professor Hugh Possingham, Dr Glen Hyndes. Mr Chris Simpson, Mr Richard McLoughlin and Dr Keith Sainsbury.
3. Identifies and discusses the key gaps in knowledge as they relate to the integrated spatial management of fisheries, including the role of aquatic protected areas.
4. Identifies R&D, including specific outputs, that will address these gaps
5. Draws an explicit link between these R&D outputs and the fisheries and/or ecosystem based management responses that would be expected as a result of these R&D outputs.
6. Develops an R&D framework for investment in research on fisheries integrated spatial management including the role of aquatic protected areas. This framework could provide options or examples on where future R&D is required. Further, this framework should clearly identify the various stakeholder involvements.
7. Discusses the relevant benefits and risks in undertaking this R&D.
8. Demonstrates very clearly the link between these needed R&D outputs and existing R&D activities and understanding.

It is important that the main fisheries and MPA management agencies (possibly through the MACC) support the discussion on management responses and outcomes.

Appendix 2

The following tables give more specific examples of relevant research (note this has a Tasmanian and Victorian focus) and gap analysis using abalone and rock lobster fisheries as specific examples. See main body of text for details of table row and column headings.

ABALONE

Relevant R&D considering the effectiveness of spatial management for abalone fisheries.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**
Spatial input controls	Closure in Franklin sound to protect greenlip spawner populations
Spatial output controls	Local and regional limits on catch within fishing Zones to either a) distribute effort to remote areas of the abalone fishery (e.g. blacklips at King Island), and b) to limit over-exploitation of key stocks (e.g. Blacklip in the Acteons, greenlip in the Furneaux Group, NW and NE). Development of zub-zonal TACs in Victoria
Spatial application of technical controls	Size limits set on knowledge of size at reproductive maturity and growth rates. Currently 5 size limits in the Tasmanian blacklip fishery and 3 in the greenlip fishery. Area specific size limits in Victoria.

Relevant R&D considering the effectiveness of spatial management for abalone fisheries with an ecosystem related focus.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**
Spatial input controls	Nil in abalone
Spatial output controls	Nil in abalone
Spatial application of technical controls	Nil in abalone

Relevant R&D relating to implications for fisheries of closures introduced by other sectors.for the abalone fisheries This table considers R&D status within, or in the immediate environs of a Marine Protected Area.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**
Target Species focus	
Genetics	Nil in abalone
Population Dynamics	Nil in abalone

Ecosystem focus	
Species interactions	Nil in abalone
By-catch species	N/a to abalone
Key Habitats	Nil in abalone
Ecological processes	Nil in abalone

Relevant R&D relating to implications for abalone fisheries of closures introduced by other sectors. This table considers R&D status outside of a Marine Protected Area.

SPATIAL MANAGEMENT OPTIONS	RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME
Target Species focus	
Recruitment (source / sink)	Nil in abalone
Yield (spillover / migration)	Edgar and Barrett 1999
Effort Displacement	TAFI MPA models - Haddon et al 2003,
Risk Management	TAFI MPA models - Haddon et al 2003,
Ecosystem focus	
Species interactions	Nil in abalone
By-catch species	N/A
Ecological processes	Nil in abalone

SOUTHERN ROCK LOBSTERS

Relevant R&D considering the effectiveness of spatial management for rock lobster fisheries with a target species focus.

SPATIAL MANAGEMENT OPTIONS	RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME
Spatial input controls	Closed seasons combined with small open areas as part of management of soft shelled lobsters proposed in 1882, introduced in 1926 for 1 year, again in 1947, 1960s and proposed again now. Well developed design theory and associated management objective for spatial management of lobster egg production in regional areas by size limits (eg current emphasis on northern Tasmanian blocks). Current management response is to "penalise" yield in order to increase northern egg production.
Spatial output controls	1. Well developed design theory and associated management objective for spatial management of lobster egg production in regional Tasmanian areas by quota. Quota has been reduced statewide rather than split between regions to produce outcome of increasing egg production in some areas. 2. Spatial restrictions on areas allocated for puerulus harvest operations to exclude areas prioritised for egg production rebuilding.
Spatial application of	1. Restriction on the use of traps in the lobster fishery to

technical controls	northern Tasmanian areas in the early 1900s. 2. Recreational fishing only areas.

Relevant R&D considering the effectiveness of spatial management for rock lobster fisheries with an ecosystem related focus.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**
Spatial input controls	Beached kelp harvest operations restricted to certain beaches
Spatial output controls	Harvest of puerulus restricted to areas of sandy habitat Release of juveniles intended to target areas of lower natural recruitment. Kelp harvest with regional quotas
Spatial application of technical controls	

Relevant R&D relating to implications for rock lobster fisheries of closures introduced by other sectors. This table considers R&D status within, or in the immediate environs of a Marine Protected Area.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**
Target Species focus	
Genetics	
Population Dynamics	Project on use of MPAs as management tool recommended that area closures provide risk to lobster fishery and should not be implemented as broad scale management tool – this recommendation has been adopted.
Ecosystem focus	
Species interactions	
By-catch species	
Key Habitats	
Ecological processes	

Relevant R&D relating to implications for rock lobster fisheries of closures introduced by other sectors. This table considers R&D status outside of a Marine Protected Area.

SPATIAL MANAGEMENT OPTIONS	**RELEVANT R&D THAT HAS RESULTED IN SPATIAL MANAGEMENT OUTCOME**

Target Species focus	
Recruitment (source / sink)	Research on reseeding at TAFI is being applied to the enhancement of lobster population in small coastal areas with exclusive indigenous management. Areas are typically those with low recruitment.
Yield (spillover / migration)	
Effort Displacement	Victorian stock assessment, Hobday et al in review
Risk Management	Victorian stock assessment, Hobday et al in review
Ecosystem focus	
Species interactions	
By-catch species	
Ecological processes	

Gap Analysis of R&D relevant to spatial management of target fisheries. Scores are out of five.

ABALONE FISHERIES (Australia wide)

Spatial management options	Use	Design Theory	Application	Evaluation
Spatial input controls	1	2	1	2
Spatial output controls	3	4	3	4
Spatial application of technical controls	5	4	4	2

ROCK LOBSTER (Australia wide)

Spatial management options	Use	Design Theory	Application	Evaluation
Spatial input controls (life history focus)	3	4	3	2
Spatial output controls	2	3/4	2	2
Spatial application of technical controls	2	3	1/2	2

Gap Analysis for R&D considering spatial management of rock lobster fisheries where there is an ecosystem related objective. Scores are out of five.

ABALONE and ROCK LOBSTER FISHERIES (Australia wide)

Spatial management options	Use	Design Theory	Application	Evaluation
Spatial input controls	0	0	0	0
Spatial output controls	0	0	0	0
Spatial application of technical controls	0	1/2*	0	0

Gap Analysis for R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status within, or in the immediate environs of a Marine Protected Area. Scores are out of five. Scores given a 0* are considered very low, with only one or two examples in Australia that the authors are aware of.

ABALONE and ROCK LOBSTER FISHERIES (Australia wide)

	Design Theory	Application	Evaluation
Target Species focus			
Genetics	0	0	0
Population Dynamics	2	1	0.5
Ecosystem focus			
Species interactions	1	0*	0
By-catch species	n/a	0*	0
Key Habitats	1	0	0*
Ecological processes	1	1	0

Gap Analysis for R&D relating to implications for fisheries of closures introduced by other sectors. This table considers R&D status outside of a Marine Protected Area. Scores are out of five. Scores given a 0* are considered very low, with only one or two examples in Australia that the authors are aware of.

ABALONE and ROCK LOBSTER FISHERIES

	Design Theory	Application	Evaluation
Target Species focus			
Recruitment (source / sink)	2	0*	0*
Yield (spillover / migration)	2	0*	0*
Effort Displacement	2/3	0*	0*
Risk Management	1	0	0
Ecosystem focus			
Species interactions	0	0	0
By-catch species	0	0	0
Ecological processes	0*	0	0