North West Shelf Joint Environmental Management Study

Interim Report

June 2002

CSIRO
MARINE RESEARCH

Department of
Environmental Protection

North West Shelf Joint Environmental Study interim report.

ISBN 1 876996 16 1.

1. Ecosystem management - Western Australia - North West Shelf. 2. Marine ecology - Western Australia - North West Shelf. 3. Sustainable development - Western Australia - North West Shelf Region. 4. North West Shelf (W.A.) - Environmental aspects. I. Western Australia. Dept. of Environmental Protection. II. CSIRO. Marine Research. III. Title.

577.709941

Front cover

Photos courtesy of:

Centre coral reef ecosystem	Clay Bryce WA Museum
Aquaculture pearls	Department of Fisheries WA
Recreational Fishing Jirri Lockman	Department of Fisheries WA
Offshore petroleum platform	Woodside Energy Ltd
Commercial Fishing	Department of Fisheries WA
Tourism	CSIRO
Coastal development aerial photo	Hamersley Iron Pty Ltd

CONTENTS

Executive summary

Rational for the Study

Western Australia's North West Shelf (NWS) contributes $6 billion to the national economy and is an economically significant land and sea region in Australia. It produces the majority of Australia's domestic and exported oil and gas. Other major industries operating on the shelf include commercial fisheries, aquaculture (especially pearl farming), salt production, iron ore processing, shipping (associated with the transport of oil, gas, salt and iron ore), and a rapidly expanding tourism industry. The rapid growth of marine industries in and around the NWS has led to complex and somewhat fragmented, management and regulatory structures. Also the NWS ecosystem, and the interacting ecological impacts of human use, is not well understood. Much of the existing information is scattered and difficult to access and integrate.

The Western Australian Government recognises that a collaborative and informed approach is essential to balancing and managing multiple-uses of the NWS ecosystem, and for achieving ecological sustainable development. As a result the North West Shelf Joint Environmental Management Study (NWSJEMS) was established to support ESD of the NWS region. NWSJEMS commenced in July 2000 and will be completed in June 2003.

This Interim Report of the North West Shelf Joint Environmental Management Study outlines the Study and provides an update on progress to date. It demonstrates that all aspects of the Study are on track and progressing well.

Study Objectives and Benefits

The NWSJEMS is a $6m marine environmental study of the NWS. It is jointly funded by the Western Australian Government, through the Department of Environmental Protection, and the CSIRO, through the Division of Marine Research.

The general objective of NWSJEMS is to develop and demonstrate practical and science-based methods that support, under existing statutory arrangements, integrated regional planning and management of the NWS marine ecosystems. The two key objectives are to:

- Compile, extend and integrate the scientific information and understanding of the marine and coastal ecosystems of the NWS; and

- Develop and demonstrate practical, science-based methods that support integrated regional planning and multiple-use management for ecologically sustainable development of marine ecosystems.

Two kinds of benefits are expected from the Study.

Firstly, it will provide managers with information, models and evaluation of management options specific to the NWS. The new scientific information will be used to predict the likely range of outcomes from existing and proposed sectoral management strategies. The predictions will be in terms of environmental and economic management objectives. The study will make the results available to the institutions responsible for management of the various development and conservation sectors on the NWS, and to other stakeholders.

Secondly, the Study will provide generic methods of data management, modelling and management strategy evaluation for multiple-use management of the NWS and other parts of WA and Australia. Management Strategy Evaluation (MSE) is an approach that provides a practical framework for evaluating the effectiveness of prospective management strategies in achieving defined objectives. The MSE approach does not seek to specify an optimal strategy or decision. Rather it provides decision-makers with information and predictions of the range of consequences from prospective management actions. From this they can make a decision, given their own objectives, preferences and attitudes towards risk. It deals explicitly with multiple and potentially conflicting objectives and with scientific uncertainty (by use of the precautionary approach).

Summary of Progress
Progress is described for each of the main components of the study. These are:

- Biophysical and Management Setting;
- Community Consultation;
- Information Access and Inquiry;
- Ecosystem and Inventory of Human Activities;
- Dynamics of the Ecosystems and Human Impacts; and
- Development Scenarios and Management Strategy Evaluation.

The main achievements of the study are then described and the forward plan outlined.

Biophysical and Management Setting
This provides a general overview and compilation of knowledge about the NWS system prior to the study. It includes the results of reviews conducted by NWSJEMS covering three aspects: the natural system; human activities; and the existing management and legislative arrangements.

The major factors controlling the NWS ecosystem are natural ones. They include climate, ocean currents and waves, sediment processes, nutrient cycling, productivity and benthic communities. The human activities are principally in the industry sectors of petroleum, fishing and aquaculture, salt production, iron ore, shipping and tourism. The natural factors operate on time-scales ranging from the breaking of internal waves (minutes) to long term climate variability (decades). This causes a high degree of natural variability, which is not well understood because of the absence of any systematic, long term monitoring across many parts of the ecosystem. Because of this, our ability to properly understand and predict impacts of the human activities is at present limited.

The existing management arrangements on the NWS cover mainly four areas; petroleum, fishing, conservation and environmental protection. Whilst environmental management responsibilities are shared by the Commonwealth and State government and local authorities, the State is responsible for managing most of the activities. The key State authorities are the Departments of Environmental Protection, Department of Conservation and Land Management, Department of Fisheries and Department of Minerals and Petroleum Resources.

Community Consultation

This describes the mechanisms for information exchange between the Study and the broader stakeholder and community groups. Information exchange between the Study team and the broader stakeholder and community groups has been critical for the success of the Study. This communication process allows mutual understanding between the scientists, regulators, stakeholders and community, about the preferred outcomes and options in environmental and sectoral management of the NWS.

Methods used include workshops and forums held in Perth, Dampier and Karratha, newsletters and media releases, and ongoing consultation. A survey of NWS residents was conducted to determine important uses and values, as well as perceived threats to the NWS marine environment. They were also asked to comment on important issues that should be considered by the Study, and future management of the region.

The survey strongly indicated that water quality, the natural environment, and ecosystems were the most important qualities of the region. The major threats to the region were seen to arise from two major environmental events, cyclones and global warming. Threats from human activities were associated with coastal development, industrial and population growth, impacts of coastal effluents, resource extraction such as fishing, oil and gas, dredging and shipping. The survey found that the preferred outcomes for the region are protection of marine plants and animals, unpolluted waters and accessible beaches for swimming, diving, and boating.

Information Access and Inquiry

This describes the data management framework that has been developed by the study to identify relevant information, and to enable access to this information. For the first time, the data sets compiled through NWSJEMS consolidate existing information about the NWS from a wide range of sources. Two products have been developed - a Geographic Information System (GIS) and a Web-based tool Data Trawler.

The GIS allows spatial data to be viewed, analysed and mapped. An effective GIS approach to facilitate the gathering of ‘expert opinion’ has been developed and applied to make this knowledge available electronically. The GIS contains data on marine and coastal habitats; infrastructure types and locations; bathymetric data; contaminant sources; types and loads; maritime boundaries and zones; boundary data for marine parks; petroleum tenure; fishing and aquaculture licences; aerial photography and satellite imagery. Different data types can be overlain to determine, for example, spatial correlations, or areas of potential conflicting uses.

Data Trawler is a Web based tool that allows data access, review and transfer across different computers and programs. This provides for ‘distributed’ access, transfer and use of information, while maintaining data confidentiality requirements. Data Trawler allows web access to the GIS data, as well as to NWS data held by the CSIRO. Together these data are extensive and cover fisheries, benthic habitats, hydrology, nutrients and physical oceanography. While much of the data is publicly available on the web, some research and industry-provided data are available only to authorised users.

Ecosystem Characterisation and Inventory of Human Activities
This provides a comprehensive description of the NWS ecosystem, and describes human activities and potential interactions with the marine environment. This new information provides a basis for improved understanding and management of the region. It provides a new description of the physical, chemical, and ecological environment of the NWS. An inventory and interpretation of contaminant inputs on the NWS is presented. A categorisation of the NWS ecosystem has been developed and some potential interactions between human uses and NWS ecosystem are also outlined.

A comprehensive description of the physical and chemical environment is now available that allows users to access detailed information on winds, ocean water, properties, and chlorophyll concentration.

Data on anthropogenic sources, types and loadings of nutrients and toxicants are presented. Anthropogenic nutrient inputs are from wastewater treatment plants and are very small by comparison with estimated natural groundwater inputs. The major toxicant inputs are oil and produced formation water from petroleum facilities. Other toxicants include heavy metals and tributyltin, but most of these are at levels well below the (ANZECC and ARMCANZ 2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.

A consistent characterisation of the main habitats and bioregions of the NWS ecosystem has been provided that is based on the available biophysical data and combined knowledge of many experts. A hierarchical classification of NWS coastal and benthic habitats has been developed with 7 levels (level 1 being the most aggregated and level 7 the finest considered here). The key habitat attributes include coastal mangroves, mudflats, coral reefs, sub-tidal vegetation, sessile faunal gardens, water bodies, sediments and nutrients. The available data from all sources cover at least four hierarchical levels (1 to 4) over the study region, and these have been mapped. Some data exists to describe the finer structure near the coast (levels 5 to 6), but these are of variable quality.

Dynamics of the Ecosystems and Human Impacts
This describes a set of models and interpretations to represent and predict the dynamics of the key physical and ecological processes on the NWS. These include models for currents, sediment and particle transport, waves, nutrient cycling and primary

productivity, sea-bed epibenthic communities, and a qualitative model for the food web that supports fisheries. The models provide the necessary tools to explore a broad range of human impacts, ranging from the dispersion of contaminants to the effects of trawling on benthic habitats.

The hydrodynamic models have been used in dispersion and connectivity studies to assess the contamination risk associated with coastal and offshore developments, and to investigate larval dispersion and recruitment. The sediment transport model has been used to confirm the data on sediment bed texture across the NWS. High concentrations of the sand fraction exist in the high-energy environment of the shelf, and there is a high suspended sediment load in coastal waters. Conditions are less energetic beyond the shelf break where there is a transition through silts to fine muds.

A model of the biogeochemical and ecological processes is coupled to the circulation and sediment transport models to investigate primary productivity and nutrient dynamics. Preliminary results indicate that the model reproduces the observed subsurface chlorophyll maximum at the base of the mixed layer at about 50m depth. Many aspects of the biogeochemical cycling, including the impacts of nutrient and contaminants inputs, remain to be investigated.

Models of fish communities and benthic communities have been developed to investigate the influences of natural and human induced events, such as cyclones and trawling. Results to date suggest that fishing effort, depth and sediment type significantly influence epibenthos distributions, while cyclones and bottom stress associated with bottom currents have a weaker effect.

Individually these models provide an ability to examine and make predictions or interpolations about specific features on the NWS. In many cases these models are prototypes that are still under development, but already they provide a comprehensive suite of tools for the prediction, and interpretation of natural and human impacts on the NWS. The factor differentiating this Study from others is its focus on integrating the physical, biological and management models.

Development Scenarios and Management Strategy Evaluation
The Management Strategy Evaluation (MSE) framework has been used in the study to develop a computer-based system for evaluating prospective multiple-use management strategies for the NWS. The MSE approach has been applied in many management situations elsewhere, but this is the first time an attempt has been made to develop and apply it to multiple use management of a whole regional ecosystem. The system developed through the study provides a model that links the ecosystem and human impacts, and predicts both the cumulative impacts of multiple-use of the NWS and the responses of the ecosystem to management measures. The model is presently a prototype, with the main processes represented by simple models at this stage.

The MSE is applied to four sectors: oil and gas; conservation; fisheries; and coastal development. For each sector a selection of development scenarios, provided by the relevant interest group, is represented. These scenarios include predictions of future sectoral activities and their impacts, and the sectoral response to management policy and strategies.

An illustrative example of the application for MSE in the fisheries sector is provided to demonstrate the tradeoffs that can be recognised and quantified using the MSE framework. The example explores the implications of a simple change in zoning strategy for the NWS commercial trawl fishery. This change not only has an impact on the fishery itself, through a redistribution of fishing effort and a change in economic performance, but also affects conservation values through impacts on the habitats and fish populations in the different areas. The example is very simple, but it illustrates the importance of the ecological connections between two sectors of management (fisheries and conservation), and the interaction between the decision processes of the fishing operators and regulators in determining the outcomes of a management measure. Even in this simple example a comprehensive model is required to allow realistic examination of multiple use management and the cumulative impacts of human uses on the ecosystem.

Achievements and Forward Plan

The MSE models and information inputs required for comprehensive and science-based support for multiple use management of regional ecosystems are challengingly complex, but NWSJEMS is demonstrating that they are achievable. While there is still work required, especially in refining the MSE model, we have demonstrated that the approach is technically feasible. This is a first step towards achieving the ecologically sustainable development of the NWS region.

The key achievements of the study to date can be summarised under the two main study objectives.

Objective: To compile, extend and integrate the scientific information and understanding of the marine and coastal ecosystems of the NWS.
Achievements:

- compiled and reviewed the previous scientific studies in the region;
- developed a data-base of information and observations from numerous previous studies and surveys, including from government sources, industry sources and the ‘expert knowledge’ of people very familiar with the NWS;
- compiled an inventory of important pollutants and contaminants, including their sources, and quantities;
- developed user-friendly tools to access and view the data that has been assembled, including tools that are based on world wide web technologies, which are functional across different computers and locations;
- provided a hierarchical classification and mapping of the main ecosystems and habitats that comprise the NWS regional ecosystem;
- developed models of some of the key oceanographic and ecological processes, including water currents and dispersal of particles (e.g. pollutants or larvae), the cycling of key nutrients, primary productivity, the dynamics of seabed and coastal

habitats, food webs, the dynamics of key species, and broad patterns of biodiversity; and
- developed models of the impacts of some of the main human uses of the NWS regional ecosystem.

Objective: To develop and demonstrate practical, science-based methods that support integrated regional planning and multiple-use management for ecologically sustainable development of marine ecosystems.
Achievements:
- identified with stakeholders initial sets of industry development scenarios, objectives and performance measures for comparison of multiple-use management strategies;
- developed a functional although simplified model of the ecosystem, the ecological impacts of the main human uses, and the economic returns generated from those uses;
- developed a functional although highly simplified model of the management strategies currently being used to regulate some industry users of the ecosystem, and of the industry response to these management measures;
- combined the ecosystem model, impacts model and management models to demonstrate their combined use in exploring the effect of a changed sectoral management strategy on that sector, other sectors and the ecosystem as a whole; and
- demonstrated the approach at a stakeholder workshop.

The workplan from this point on will refine the models and the data they are based on, and will further engage users in their application.

The remaining time of the NWS Joint Environmental Management Study will be used in four main activities. The first two relate to completion of the technical tasks of the study. Specifically these are further compilation of existing scientific information and refinement of the ecosystem models and management strategy evaluation tools. The second two relate to the ongoing application of the capabilities developed by the study. Specifically these are to increase the links to practical management of the NWS and develop an ongoing mechanism for use of the tools developed through NWSJEMS after the study is completed.

ACKNOWLEDGEMENTS

The following people and agencies have contributed significantly to the Study through the provision of technical expertise and advice, and historical data and information. The Study partners gratefully acknowledge their contribution.

W.A. State Agencies
Department of Fisheries
Department of Conservation and Land Management
Department of Minerals Petroleum Resources
Department of Transport
Department of Land Administration
W.A. Land Information Service
W.A. Museum
Department of Resources Development

Commonwealth Agencies
Australian Geological Survey Organisation
Australian Institute of Marine Science

Consultants
Cognito Consulting
DA Lord and Associates
Weather News International (Perth)
David Gordon International Risk Consultants

Industries
Woodside Energy
Apache Energy
Hamersley Iron
BHP Petroleum
Chevron Australia

Individuals
Mike Forde
Ian Le Provost

North West Shelf
Joint Environmental Management Study

Chapter 1

Introduction to the study

1.1 Introduction

The North West Shelf (NWS), in Western Australia, is an economically significant land and sea region in Australia. It is the source of most of Australia's domestic and exported oil and gas products. Major industries operating on the NWS include commercial fisheries, aquaculture (especially pearl farming), salt production, iron ore mining, oil and gas production and processing, shipping and a rapidly expanding tourism industry. With this development comes a larger human population and increasing demand for infrastructure, recreation and services, which occurs mainly along the coastal fringe.

The rapid growth of marine industries, across a range of sectors, increases the potential for conflict between different uses and users of the marine environment. And these major developments are occurring in a region recognised for its rich marine biodiversity. From experience, elsewhere in the world it is clear that the environmental quality and ecological sustainability of industries, with their associated employment and wealth generation, may be compromised. To prevent this, development and management should occur, in an integrated and ecologically-based framework, incorporating an understanding of the ecological impacts of human activities. While there are only a few identified environmental concerns on the NWS today, the potential for unexpected detrimental impacts from present and continued development remains. In addition, there is limited baseline information and knowledge available to characterise the natural system and allow us to understand its natural variability. This means that human impacts, particularly chronic impacts, cannot easily be distinguished from the natural variability.

Recognising the rapidly increasing development pressures on the poorly understood marine environments of the NWS, the Western Australian Government, through the Department of Environmental Protection, initiated the NWS Marine Environmental Management Study (NWSMEMS) in January 1998. NWSMEMS had two components. One provided improved scientific information and support for integrated management of all of the human uses of the NWS. The other ensured that the necessary institutional arrangements were in place to allow integrated decision-making and management of the NWS, and to also make the most effective use of the scientific component of the study.

In February 1999 CSIRO allocated new resources to support this initiative, and so provided the opportunity for the WA government and CSIRO to establish a joint collaborative study. In June 2000 the scientific component of the original NWSMEMS was replaced by the North West Shelf Joint Environmental Management Study (NWSJEMS). This was a joint State-Commonwealth study involving the Western Australia Government (administered through the Department of Environmental Protection), and CSIRO (through the Division of Marine Research). The institutional response component of NWSMEMS remains as originally designed.

The principal objective of NWSJEMS is to develop and demonstrate practical and science-based methods that support, integrated regional planning and management of the NWS marine ecosystems, under existing statutory arrangements. The study will provide the basis for ecologically sustainable development of marine industries and for the conservation of representative marine ecosystems. A detailed Study Plan comprising 24 research tasks was finalised in June 2000. The research tasks cover data compilation and management, contaminants inventory, ecosystem characterisation, ecological modelling and prediction, and management strategy evaluation. They are designed to consolidate and increase our basic understanding of the NWS marine ecosystem, and to produce a range of predictive tools. This includes tools to predict the cumulative impacts of multiple human uses on the ecosystems and also to support management decision-making.

This is an Interim Report of the North West Shelf Joint Environmental Management Study. The aims of the report are to provide an update on progress to date and some preliminary results. The final report is due on 30 June 2003.

1.2 Reasons, Objectives, and Benefits of the Study

Reasons for the Study
This environmental study of the NWS was established because:

1. The W.A. Government has the goal of achieving Ecologically Sustainable Development (ESD) of the NWS region and ecosystem. This is described as, ‘using, conserving and enhancing the community’s resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased’. It was recognised that this goal requires the understanding, and managing of the ecological impacts of the individual human uses on the ecosystem, as well as the combined impacts of all uses.
2. There has been rapid growth of the marine industries, and other human uses of the NWS ecosystem, and this growth is expected to continue.
3. The rapid growth of marine industries in and around the NWS, has led to complex, and somewhat fragmented, management and regulatory structures. The Western Australian Government recognised that a collaborative approach to integrated management was essential in balancing and managing multiple-uses of the NWS ecosystem so as to achieve ESD.
4. The NWS ecosystem, and the interacting ecological impacts of human use, is not well understood. Much of the existing information is scattered and difficult to access and integrate.
5. The scientific and technical methods and tools to support integrated decision-making in multiple-use management are poorly developed.

6. The Western Australian Government recognised the need for improved scientific understanding, information and tools to provide the basis for an ecosystem-based, integrated approach to managing multiple-uses on the NWS.

Objectives of the Study

The key objectives are to:

1. Compile, extend and integrate the scientific information and understanding of the marine and coastal ecosystems of the NWS so as to:
   - improve the quality, quantity and accessibility of data and understanding about the ecosystems and human uses of it;
   - describe the ecosystems; and
   - predict the impacts of natural events and human use.

2. Develop and demonstrate practical, science-based methods that support integrated regional planning and multiple-use management for ecologically sustainable development of marine ecosystems.

3. Provide improved scientific understanding and methods for multiple-use planning and management of the resources and environment of the NWS, under existing statutory arrangements.

Benefits from the Study

The Study will provide two kinds of benefit:

1. Information, models and evaluation of management options specific to the NWS. In keeping with the motivation and focus of the NWSMEMS, the study will provide new knowledge and understanding of marine conditions and processes on the NWS. It will interpret and integrate these data, including the development of models of key ecological processes and interactions with human uses. The new scientific information will be used to predict the likely range of outcomes from existing and proposed sectoral management strategies. The predictions will be in terms of environmental and economic management objectives. The study will make the results available to the institutions responsible for management of the various development and conservation sectors on the NWS, and to other stakeholders. The ultimate benefit will be enhanced capacity for sustainable development and multiple-use management of the NWS ecosystem.

2. Generic methods of data management, modelling and management strategy evaluation for multiple-use management of regional marine ecosystems. There is increasing recognition in Australia, and many regions of the world, that integrated multiple-use management within an ecosystem-based management framework is necessary for sustainable development and wealth generation. However, the scientific basis and technical tools to reliably support decision-making aimed at achieving this goal are weakly developed. A benefit of the study will be the development of the data management, modelling and decision support tools that can be transported and used for the multiple-use management of other regional marine ecosystems.

1.3 Multiple-use Management and the Approach taken by this Study

The Study was created due to a recognition of the need to establish an integrated mechanism for the multiple-use management on the NWS, so as to achieve Ecologically Sustainable Development. Four fundamental principles have been identified for multiple-use management in this context:

- maintenance of ecosystem integrity;
- wealth generation and resource use;
- equity among users and between generations; and
- a participatory framework for decision making.

The first two principles, and part of the third, relate to the objectives of natural resource use and management. A key scientific role is to help formulate management objectives, in operational and measurable form, so that they are amenable to scientific observation and analysis, while still reflecting management intent. The main scientific task is to predict and assess the range of likely outcomes of proposed resource use, monitoring and management arrangements. The predictions and assessments would be in terms of the operational objectives.

The fourth principle, and part of the third, relates to the process of management decision-making. Participatory decision making recognises sector-specific or user-specific objectives, management plans and strategies. It also recognises that information and understanding must be accessible to all participants in the decision-making process. The key State and Commonwealth departments and regulators, as part of NWSMEMS, have taken responsibility for developing or refining the institutional arrangements (as necessary) to facilitate integrated decision making and implementation of multiple-use management on the NWS. A key scientific task is to ensure that the scientific input, both information and assessment, is broadly accessible and useable in the decision-making forums.

Such scientific input is commonly provided to support natural resource management of single industry sectors and single types of resource, and the scientific methods for this are well developed. There is no established methodology to provide this scientific support, for management of the multiple-uses, of a whole regional ecosystem. This raises many challenges including, for example, the difficulty of accessing and assembling the background data about the ecosystems, and the human uses of it, from a wide range of sources and institutions. The major challenge comes from the complexity of ecosystems themselves and the limited human understanding of how ecosystems, anywhere, really work.

There is good reason to expect that accurate and detailed predictions about ecosystems could not be made even if there was good understanding of ecosystem processes and detailed data about the present state of the ecosystem – for much the same reasons that limit weather forecasting. And for ecosystems there is neither a good understanding of the ecological processes at work nor detailed data about the ecosystem’s present state. Therefore ecosystems, and the impacts of multiple human uses on them, and predictions of outcomes will inevitably be highly uncertain. The major challenge for NWSJEMS is, to provide a method, to scientifically assess the likely outcomes of management options that is scientifically defendable, despite this uncertainty.

The Scientific Framework for Evaluation and Providing Management Advice for Multiple-use Management

Environmental management is characterised by multiple and conflicting objectives, multiple stakeholders with divergent interests, and high levels of uncertainty about the dynamics of the resources being managed. This conjunction of issues can result in high levels of contention and difficulties in the management process. The approach taken here is that scientific assessment, in support of multiple-use management is best focused on comparing the performance of management strategies. This includes the comparison of how different strategies perform under different interpretations of how the ecosystem works. A management strategy in this context includes monitoring and a determination of how future management decisions will be made in light of the information from that monitoring. So by detecting and correcting departures from intended outcomes, a successful strategy could achieve the intended outcomes across a wide range of alternative interpretations of how the ecosystem might work. This would be valid despite highly uncertain predictions about how the ecosystem might respond to a given human activity. This allows a scientifically rigorous analysis and comparison of the management options and strategies, despite high levels of uncertainty about how the ecosystem works.

Comprehensive science based support for the multiple use management must be able to scientifically compare the performance of different prospective management strategies. Different management strategies may involve different management measures. For example, the zoning and levels of use permitted for the various industries, different monitoring programs, and different ways to alter the management measures in future in response to the results from monitoring (if, for example, monitoring showed than an objective was not being met under the current measures). The comparison may be required across different scenarios of industry growth or across different ways that it is thought that the ecosystem might behave (because there will always be scientific uncertainty in this).

The emphasis in this approach is on the robustness, risks and trade-offs, with respect to the operational objectives, of different management strategies across an identified range of uncertainties about how the ecosystem works. The Study also places considerable emphasis on developing tools to make the background information and management strategy comparisons available to non-specialist users.

Management Strategy Evaluation (MSE)

Management Strategy Evaluation (MSE) is an approach that provides a practical framework for evaluating the effectiveness of prospective management strategies in achieving defined objectives. The approach is participatory and requires close collaboration between management agencies, stakeholders, and technical experts.

At a technical level, the MSE and risk assessment framework facilitates dealing with multiple objectives and uncertainties in prediction. At the implementation level, it fails if it cannot accommodate effective stakeholder participation and acceptance. MSE can be used to develop adaptive monitoring and management strategies and to develop management procedures.

The MSE approach involves assessing the consequences of a range of management strategies or options, and presenting the results in a way that makes explicit the trade-offs in performance across different management objectives. The approach does not seek to specify an optimal strategy or decision. Instead it aims to provide decision-makers with the information on which to base a rational decision, given their own objectives, preferences, and attitudes to risk. It deals explicitly with multiple and potentially conflicting objectives, and with scientific uncertainty. In dealing explicitly with sources of uncertainty and in predicting the consequences of alternative management actions it directly supports operational use of the precautionary approach. The MSE framework has been used in the NWSJEMS to develop a computer-based tool for evaluating prospective multiple-use management strategies for the NWS.

MSE Components and Model for the NWS

The key components of the MSE approach are:

- a clearly defined set of management objectives;
- a set of performance measures related to the objectives;
- a set of management strategies or options to be considered;
- a means of calculating the performance measures for each strategy;
- use of the performance criteria to compare and evaluate the strategies; and
- communication of the results, highlighting the trade offs.

Within this a management strategy consists of specifications for:

- the monitoring program;
- how the monitoring results will be analysed and used in assessment;
- how the results of assessment will be used in management decision making, often through specification of a ‘decision rule’ in relation to acceptable limits and targets; and
- how the management decisions will be implemented.

A computer-based model is used to calculate the performance measures for each strategy. This model consists of several sub-models:

- a model of the natural system;
- a model of the activities and consequences (wealth generation and ecological impacts) for each of the important sectors of human activity;
- a model of the observational or monitoring program;
- a model of how decisions are made and implemented; and
- calculation of the performance measures.

These models are used together to predict how the natural system might respond to both natural and human activity, including management measures introduced on the basis of ongoing monitoring and assessment. Where there is uncertainty about the way processes or interactions occur, for example in the natural system or the impacts of a human use, then more than one model may be used so as to reflect the range of possibilities. The computer program used for MSE traces the impact of a particular management strategy on the actions of sector firms or agencies, and then the affect that these actions have on the natural environment. In so doing, the program keeps track of details about the sectoral response to management actions, sector performance, the way the natural systems respond to sector-specific actions and important natural events (such as cyclones), and any strategy-mandated adjustments by managers. Central to the program's output is the choice of environmental and sector performance indicators.

The model of the natural system on the NWS requires a description, or characterisation, of ‘what is where’ at various levels of aggregation. For example at species, habitat or ecosystem levels (e.g. coral reefs, mangroves, sponge beds and seagrass beds). It also requires representations of the main processes forcing or mediating the dynamics of the ecosystem, such as wind, waves, circulation, sediment transport, nutrients and productivity, fish and habitat dynamics.

1.4 This Report

This Interim Report of the NWS Joint Environmental Management Study provides an update on the main activities and progress to date. Because the study is not complete, different aspects of the study are at different stages of development. For example, the initial data acquisition and data management projects are near completion, some individual sub-models for components of the ecosystem are completed, while the integrated model of the ecosystem, impacts of use and management is as yet rudimentary. However, at this stage in the study, the approach has been to develop the full ecosystem and management model in skeletal, but still functional, form so that a ‘thin’ version of the final management tools can be examined and refined.

The body of this report is provided under the following chapters:

Chapter 1: Introduction to the Study
This chapter introduces the Study and outlines the reasons for and benefits from the Study. It also introduces the concepts of multiple-use management and Management Strategy Evaluation, which is the approach used in this Study.

Chapter 2: Biophysical and Management Setting
This chapter provides a general overview and compilation of knowledge about the NWS system prior to NWSJEMS. It includes the results of reviews conducted by NWSJEMS covering three aspects the natural system, human activities, and the existing management and legislative arrangements.

Chapter 3: Community Consultation
This chapter describes the mechanisms for information exchange between the Study and the broader stakeholder and community groups. Information exchange between the Study team and the broader stakeholder and community groups has been critical for the

success of the Study. This communication process allows mutual understanding between the scientists, regulators, stakeholders and community, and preferred outcomes and options in environmental and sectoral management of the NWS.

Chapter 4: Information Access and Inquiry
This describes the data management framework that has been developed for the NWSJEMS, to identify relevant information and enable access to this information. For the first time the data sets compiled through NWSJEMS consolidates existing information about the NWS from a wide range of sources. Two products have been developed a Geographic Information System and a Web-based tool Data Trawler.

Chapter 5: Inventory of Ecosystem Characterisation and Human Activities
This chapter describes the key characteristics of the NWS ecosystem. It provides a new description of the physical, chemical, and ecological environment of the NWS. An inventory and interpretation of contaminant inputs on the NWS is presented. A categorisation of the NWS ecosystem has been developed, and some potential interactions between human uses and NWS ecosystem is also outlined.

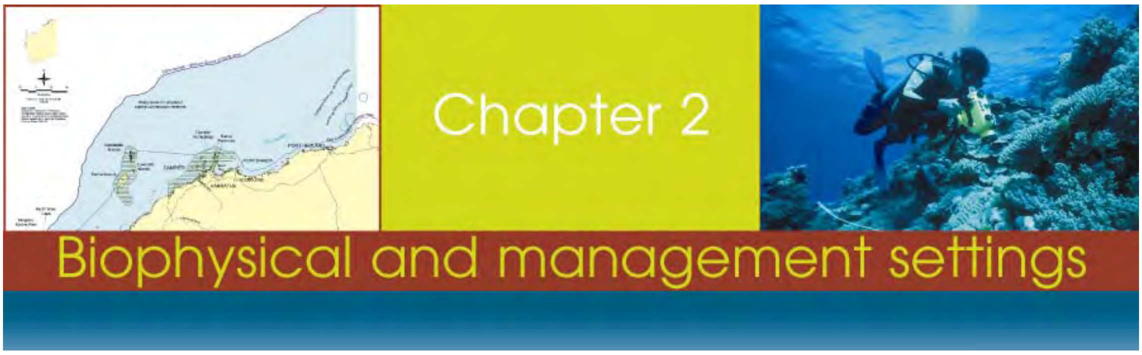
Chapter 6: Dynamics of the Ecosystems and Human Impacts
This chapter describes a set of models and interpretations to represent and predict the dynamics of some physical and ecological processes on the NWS. These include models for currents, sediment and particle transport, waves, nutrient cycling and primary productivity, sea-bed epibenthic communities, and an exploratory qualitative model for the food web that supports fisheries. The models provide the necessary tools to explore a broad range of human impacts, ranging from the dispersion of contaminants to the effects of trawling on benthic habitats.

Chapter 7: Development scenarios and Management Strategy Evaluation
Management Strategy Evaluation (MSE) is an approach that provides a practical framework for evaluating the effectiveness of prospective management strategies in achieving defined objectives. The MSE approach does not seek to specify an optimal strategy or decision. Rather it provides decision-makers with the information and predictions of the range of consequences from prospective management actions from which to base a decision, given their own objectives, preferences and attitudes towards risk. It deals explicitly with multiple and potentially conflicting objectives, and with scientific uncertainty (by use of the precautionary approach).

The MSE framework has been used in the NWSJEMS to develop a computer-based system for evaluating prospective multiple-use management strategies for the NWS. The system provides a linked ecosystem and human impacts model of the NWS for prediction of the cumulative impacts of multiple-use and the responses to management measures. The model is a quantitative prototype, with the main processes represented by very simple models at this stage. This is used to demonstrate how the combination of biophysical models and sectoral management models will be combined to predict the consequences of the present legislative arrangements for management.

This chapter describes the overall MSE model being developed for the NWS regional ecosystem and the major uses of it. These uses are oil and gas, conservation, fisheries and coastal development. The MSE model is still being finalised and tested, but an application of the MSE approach is illustrated. This illustration examines the consequences to production and conservation of a change in the zoning of commercial trawl fishing. The illustrative example is relatively simple but demonstrates the approach and the trade-offs that can be explored and quantified using the MSE framework.

Chapter 8: Conclusions and Forward Plan
This chapter summarises the results and progress to date, and outlines the plans for the remainder of the study.



2.1 Introduction

This chapter provides a general overview of our knowledge of the NWS system prior to NWSJEMS. It includes understanding of the natural system, human activities, and existing management arrangements.

The Study Area

The Study area extends 1500km along the Pilbara coast from North West Cape to Port Hedland, and out from the coast to the 200 metre depth contour, encompassing an area of 110,000 square kilometres (figure 2.1.1). Of this area, 32,000 square kilometres are in water depths less than 25m and 25,000 square kilometres are in W.A. State waters.

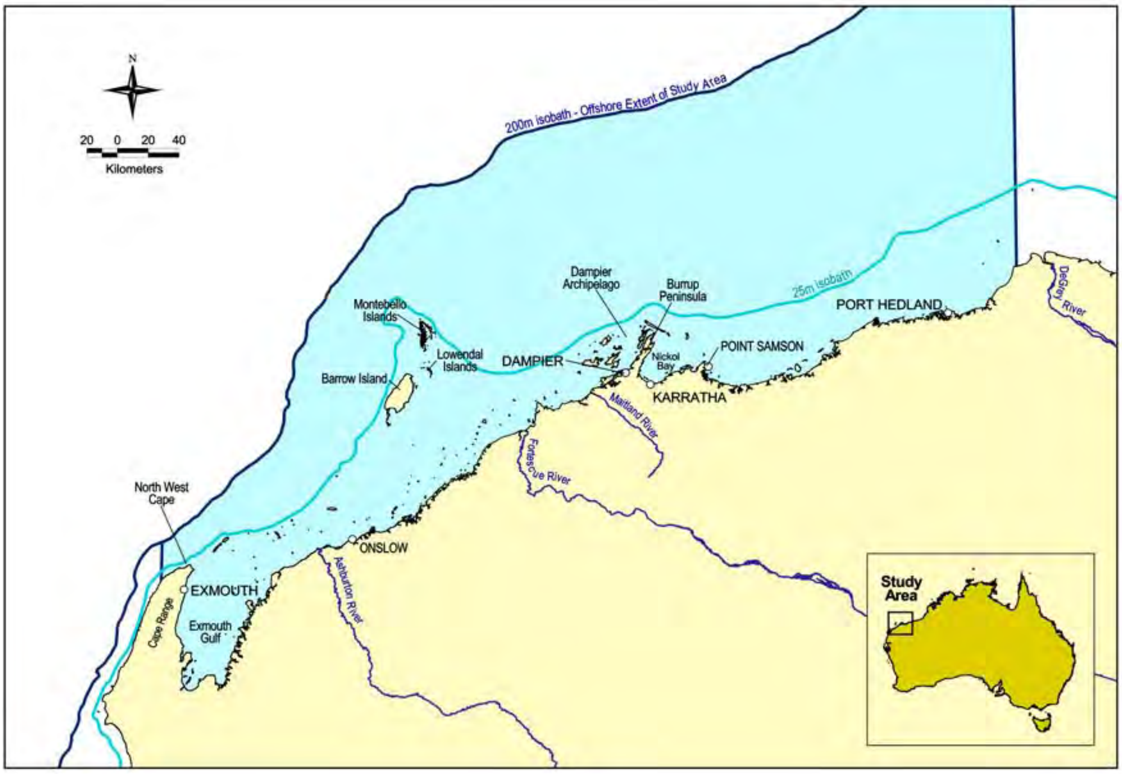


Figure 2.1.1: Map of the study area.

2.2 Characteristics of the Natural System

The natural variability of the NWS marine ecosystem is governed by processes operating on timescales ranging from the breaking of internal waves (minutes) to long term climate variability (decades). Our understanding of this variability has been limited by the absence of any systematic long term monitoring across many parts of the ecosystem. Without basic knowledge of the background natural variability it is difficult to properly assess the potential impact of industrial developments and other human activities on the shelf.

Climate

The NWS is a tropical arid region with maximum daily summertime temperatures around 36°C and minimum daily wintertime temperatures around 13°C. The mean annual rainfall is typically only 250 mm, most of which falls over the summer months. However, extreme downpours can occur under tropical cyclone conditions, which usually impact the study area a few times per year. Terrestrial runoff into the marine environment similarly shows strong peaks during cyclones, but is generally very low. The region is also impacted by El Nino Southern Oscillation (ENSO) cycles, with a lower incidence of cyclones evident under El Nino conditions.

During summer, prevailing winds are from the northwest and southwest, swinging around to dry southeasterlies over winter. However, in coastal areas local seabreezes (generated by the temperature difference between land and sea) often dominate the daily patterns. Under extreme cyclone conditions winds can reach 180 km/hr, with 17m ocean waves and ocean currents exceeding 3m s^{-1}.

Ocean currents

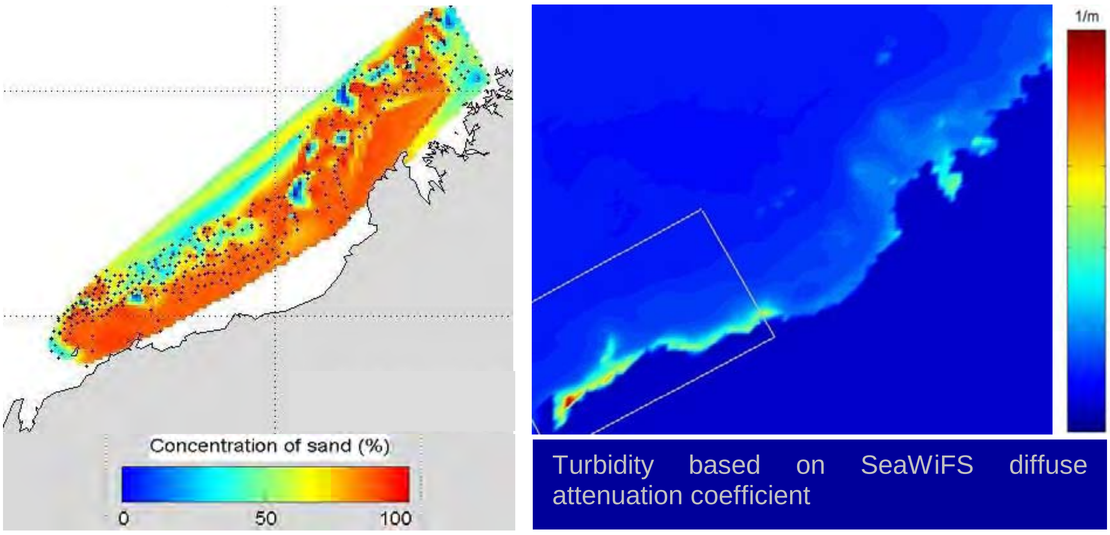
The NWS experiences large tides (6m range at Port Hedland) and currents over the shelf are usually dominated by semidiurnal flows up to 1 m s^{-1} (Holloway 1983). Wind forced currents (Webster 1985, Holloway and Nye 1985) only become dominant around the neap tide. The tidal currents are predominantly in the cross-shelf direction, except around Barrow Island and the Monte Bello Islands where they are orientated closer to the east-west direction. The combination of large tides and strong stratification also generates large internal tides over the upper slope, which propagate onshore and dissipate over the outer shelf (Holloway 1984, 1987). The amplitude of the internal waves can be as large as 100 m near the shelf break and the associated currents comparable to the barotropic tide, with evidence of significant bottom intensification (Holloway 1985, 2001).

Circulation on the NWS is also influenced by the broader scale circulation of the Indonesian Throughflow to the north (Cresswell et al. 1993, Meyers et al. 1995) and Leeuwin Current to the west (Godfrey and Ridgway 1985, Batteen et al. 1992). These flows carry warm low salinity water southwestward along the outer NWS from February to June (Holloway and Nye 1985, Holloway 1995). However, strong winds from the southwest cause intermittent reversals of these currents over the remainder of the year, with occasional weak upwelling of cold deep water onto the shelf. During the summer period tropical cyclones can generate major short-term fluctuations in current patterns and coastal sea levels (Hearn and Holloway 1990, Fandry and Steedman 1994). These events are likely to have significant impacts on sediment distributions and other aspects of the benthic habitat.

The currents on the NWS control the dispersion of contaminants generated by both natural processes and human activities. They also influence biological processes such as recruitment and re-colonisation by controlling larval transport. However, the connectivity patterns on the NWS have only previously been studied in the context of environmental impacts of specific contaminant inputs. The NWSJEMS dispersion modelling addresses this issue more systematically over a regional scale.

Sediment processes

The sediment bed texture changes markedly across the NWS in response to variations in the exposure to ocean currents and waves (figure 2.2.1a). In the relatively high-energy environment of the mid- to outer-shelf winnowing and transportation are dominant. This results in high concentrations of coarse sand, with any active deposition restricted to localised areas (Brunskill et al. 2001). Conditions are less energetic beyond the shelf break, where there is a transition through silts to fine muds on the upper slope (Jones 1973, McLoughlin and Young 1985). The distribution of suspended material is quite different, with maximum concentrations of fine suspended sediments occurring in the coastal zone (figure 2.2.1b). One of the main objectives of the NWSJEMS sediment transport modelling is to understand how these zonations are formed and maintained.



(a) (b)

Figure 2.2.1: (a) Sediment bed texture (percentage sand) on the NWS (Jones 1973). (b) Mean turbidity (1998-2000) based on the SeaWiFS diffuse attenuation coefficient at wavelength 490nm (m^{-1}). Standard SeaWiFS algorithms based mainly on Northern Hemisphere oceanic measurements have been used, so significant errors are likely on the inner shelf (SeaWifs Technical Report 1997). However, values should still correlate with particulate matter concentrations. The box indicates the study area.

Nutrients and Productivity

Existing evidence suggests that the standing crop of phytoplankton on the NWS is nitrogen limited. The only significant source of nitrate is nutrient rich water residing on the continental slope below the surface mixed layer. There exists very little nitrate in surface waters and terrestrial inputs are negligible. Enhanced productivity in the mixed layer has been attributed to deeper fluxes of nitrogen resulting from upwelling and mixing induced by barotropic and internal tides, and the episodic influence of tropical cyclones (Holloway et al. 1985). Net fluxes are fairly constant throughout the year and nitrate rich slope water rarely intrudes onto the shelf further than the 50m isobath.

Primary productivity resulting from the available nitrogen fluxes peaks either at the base of the surface mixed layer or in the bottom mixed layer (Tranter and Leech, 1987). However, shoreward of the 50m isobath, the subsurface phytoplankton maximum is not observed and the depth integrated standing crop is significantly less than offshore. Tidal mixing also allows benthic biota to access this pool of phytoplankton over the shelf region, although their contribution is yet to be quantified.

The seasonal phytoplankton distributions on the NWS do not reflect the strong variability in the circulation patterns (Tranter and Leech, 1987). The Leeuwin Current acts to damp any seasonal variability by lowering the pycnocline in the winter (when stratification is weak and up slope intrusions would ordinarily be greatest) and thereby inhibits exchange of nutrient rich deep water with the surface.

Benthic Communities

The benthic environments on the NWS exhibit high species diversity associated with habitat diversity and complexity (Marsh and Marshall 1983, Rainer 1991). They support a remarkable array of marine fauna, including tropical fish, turtles, dugongs, whales, hard and soft corals, sponges, and many crustaceans. The food chain is supported by enhanced subsurface productivity and includes a range of commercial species (Sainsbury et al. 1993, Moran et al. 1995). Rainer (1991) has speculated that the high diversity is imposed by predation and physical disturbance. Some benthic species are endemic to the region including sponges and invertebrates such as echinoderms, cnidarians, and polychaetes (Rainer, 1991). Genetic linkages within species are not well understood, although there is evidence of genetic connections over large distances (Johnson et al., 1993; Williams and Benzie, 1996).

The benthic communities include extensive coral reef systems. In addition to the Ningaloo reef system, which is already protected as a marine reserve, the coral reefs around the Montebello Islands and Dampier Archipelago are recognised as high priority for preservation in marine reserves. The most common morphology of these reefs is a fringing formation adjacent to mainland rocky shores or emergent islands. The major coral spawning event occurs between March and April each year (Simpson, 1985). Interannual variations in coral cover are thought to be associated with predation, tropical cyclone activity and El Nino events, although the response of corals to these events are still not well understood.

Mangroves grow in a thin fringe along much of the mainland coast bordering the NWS and around the shores of the Lowendal and Montebello Islands. They are highly unusual by world standards as they grow adjacent to an arid zone, rather than the more typical wet tropics. The biogeography, zonation, structure and physiognomy of NWS mangroves have been studied in detail (e.g. Semeniuk 1983, 1993; Carr et al. 1996a,b,c). However, there is limited data on the role of mangroves in primary production in the shallow coastal waters (Robertson 1993, Paling and McComb 1994) and little is known about their role as nursery grounds and other linkages to coastal foodchains (Blaber et al. 1985).

2.3 Human activities

The NWS region produces the majority of Australia's domestic and exported oil and gas. Other major industries operating on the shelf include commercial fisheries, aquaculture (especially pearl farming), salt production, iron ore processing, shipping (associated with the transport of oil, gas, salt and iron ore) and a rapidly expanding tourism industry. With the rapid growth of marine industries across a range of sectors, the potential for conflict between different uses of the marine environment is increasing.

Petroleum

The Pilbara is Australia's leading petroleum region with annual production valued at over $5 billion. Four main producers access the massive NWS reserves. Woodside Offshore Petroleum deals mainly in natural gas and liquefied natural gas (LNG), while Apache Energy, Chevron Australia, and BHP Petroleum produce crude oil.

Since the first commercial oil development on Barrow Island in 1966, petroleum exploration and development has occurred mainly offshore. Today there are nine major offshore oil and gas production facilities operating in the Study area discharging some 12 million tonnes of produced formation water annually. Last year 63 new wells were spudded in water depths ranging from 8 to 1500m (figure 2.3.1). It is anticipated that the petroleum industry will continue to grow well into the 21st century with Woodside currently planning to double their production and Chevron Australia positioning itself to enter the LNG market with a massive project based on their rich Gorgon field.

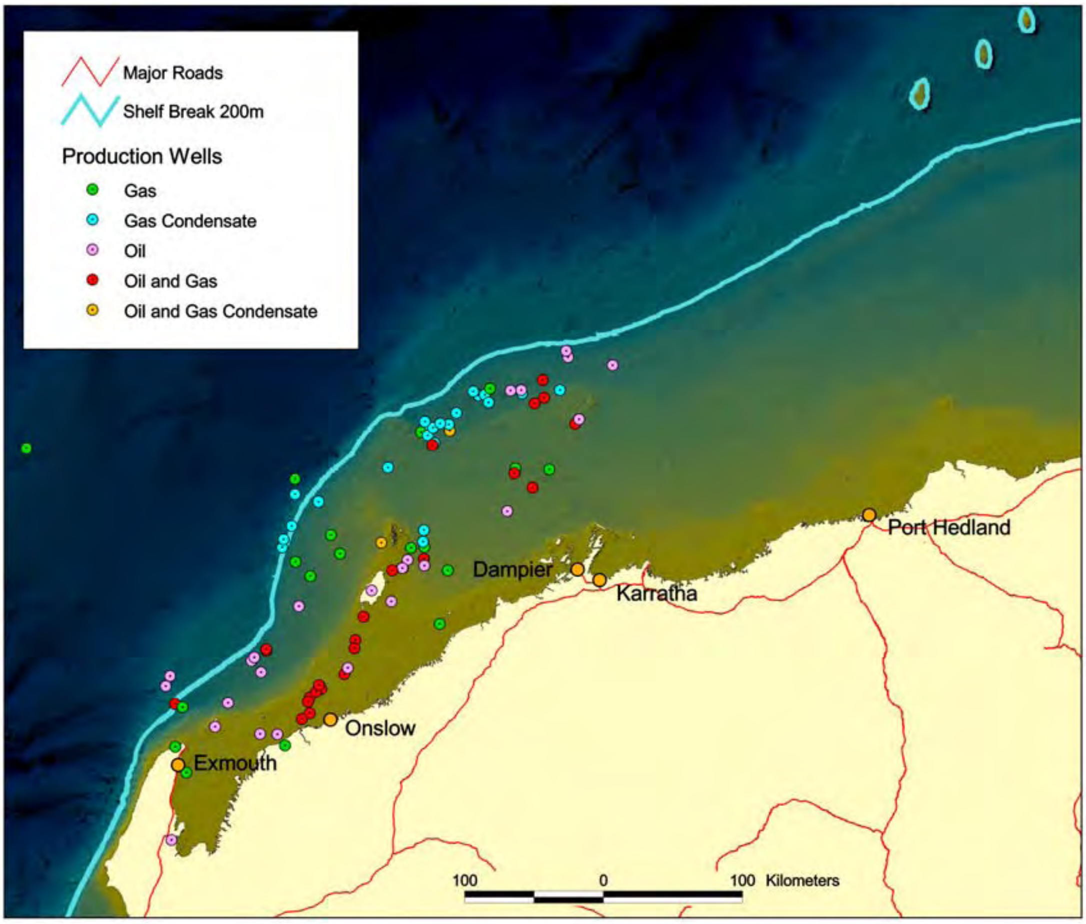


Figure 2.3.1: Oil and gas production wells off the Pilbara coast.

The main potential environmental impact of the petroleum industry on the NWS is associated with the introduction of contaminants. These include oil, produced formation water (containing petroleum compounds), and heavy metals. However, petroleum compounds are also introduced naturally to the marine environment through oil seeps on the sea-bed.

Fishing

There is a range of commercial fishing activities on the NWS valued at around $15 million per year. These include the Exmouth Gulf, Onslow, and Nickol Bay prawn fisheries, the Exmouth Gulf beach seine fishery, and the Pilbara finfish fishery with trawl, trap, and line activities.

Commercial trawling began with foreign fleets on the mid-shelf (50 - 100m) in the early seventies. Effort was sustained at relatively high levels from 1980 to 1985, while catches showed a gradual decline (figure 2.3.2). Foreign fishing effort fell sharply after closures were implemented in 1985 (figure 2.3.3, a and b, Sainsbury 1987) and collapsed entirely after 1989, as a domestic fishery became established on the mid-shelf. Catches by the domestic fishery grew slowly through the nineties, before stabilising at modest levels.

The main potential environmental impacts of fishing on the NWS are reductions in target species, bycatch, and damage to benthic habitat by trawling.

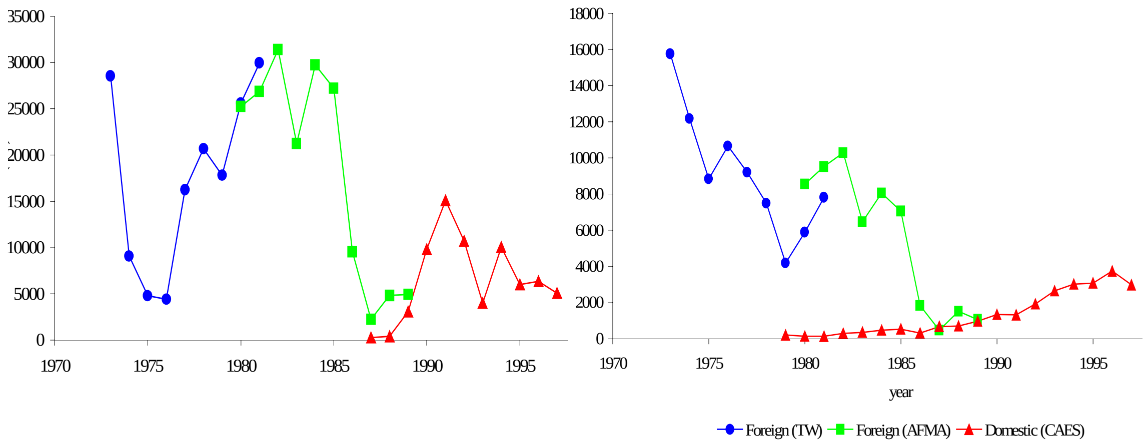


Figure 2.3.2: Time series of trawling effort in hours per year (left) and total catch in tons per year (right) for the foreign trawl fishery (Taiwanese and Australian Fisheries Management Authority (AFMA) data) and for the domestic fishery (catch and effort statistics data).

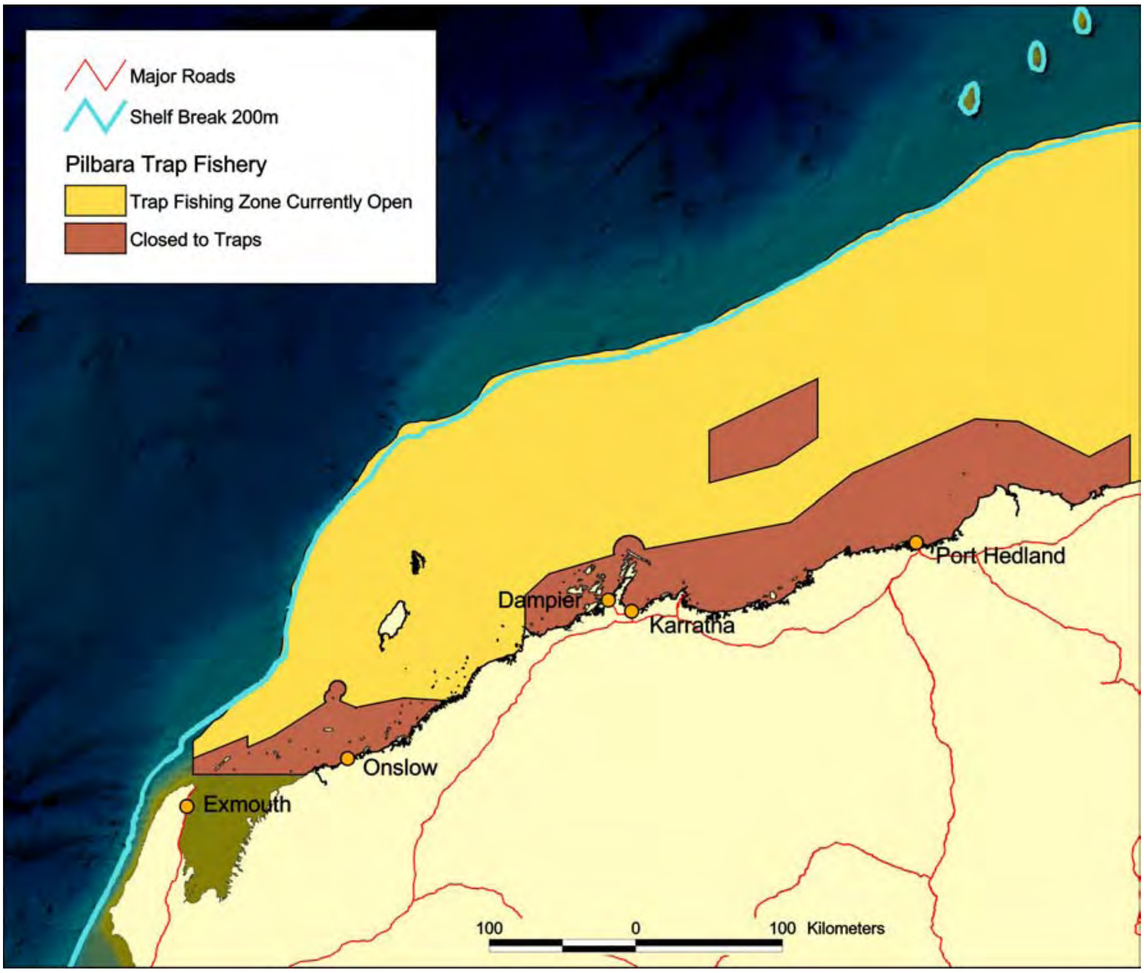


Figure 2.3.3a Management Zone for the Pilbara trap fishery

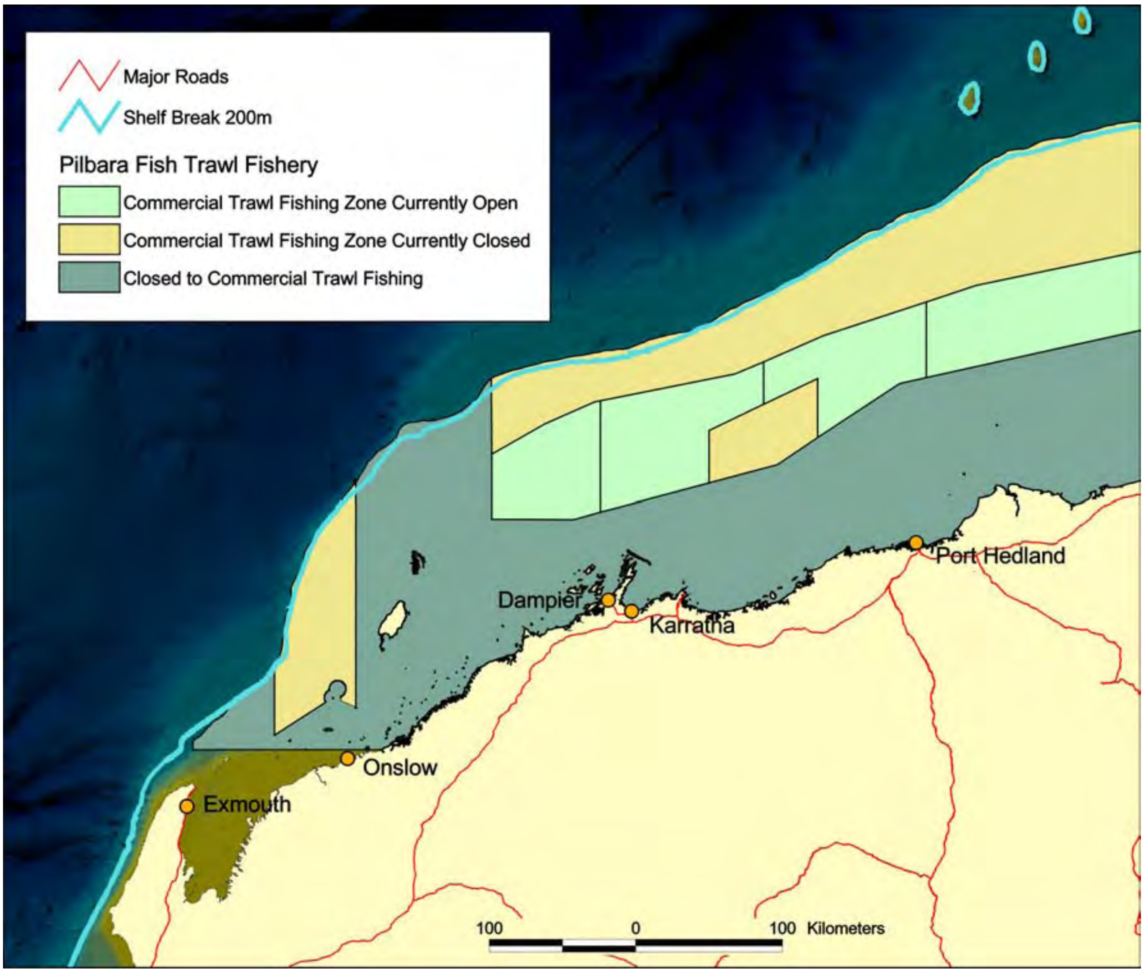


Figure 2.3.3b: Management zones for the Pilbara trawl fishery.

Aquaculture

The aquaculture/mariculture industry, in particular pearling, has been steadily growing in the Pilbara over the last five years. There are now 12 aquaculture leases in the region mainly centered on the sheltered waters of the Dampier Archipelago, Montebello Islands, and Exmouth Gulf (figure 2.3.4). The main potential environmental impact of aquaculture on the NWS is the removal of wild pearl oyster stocks.

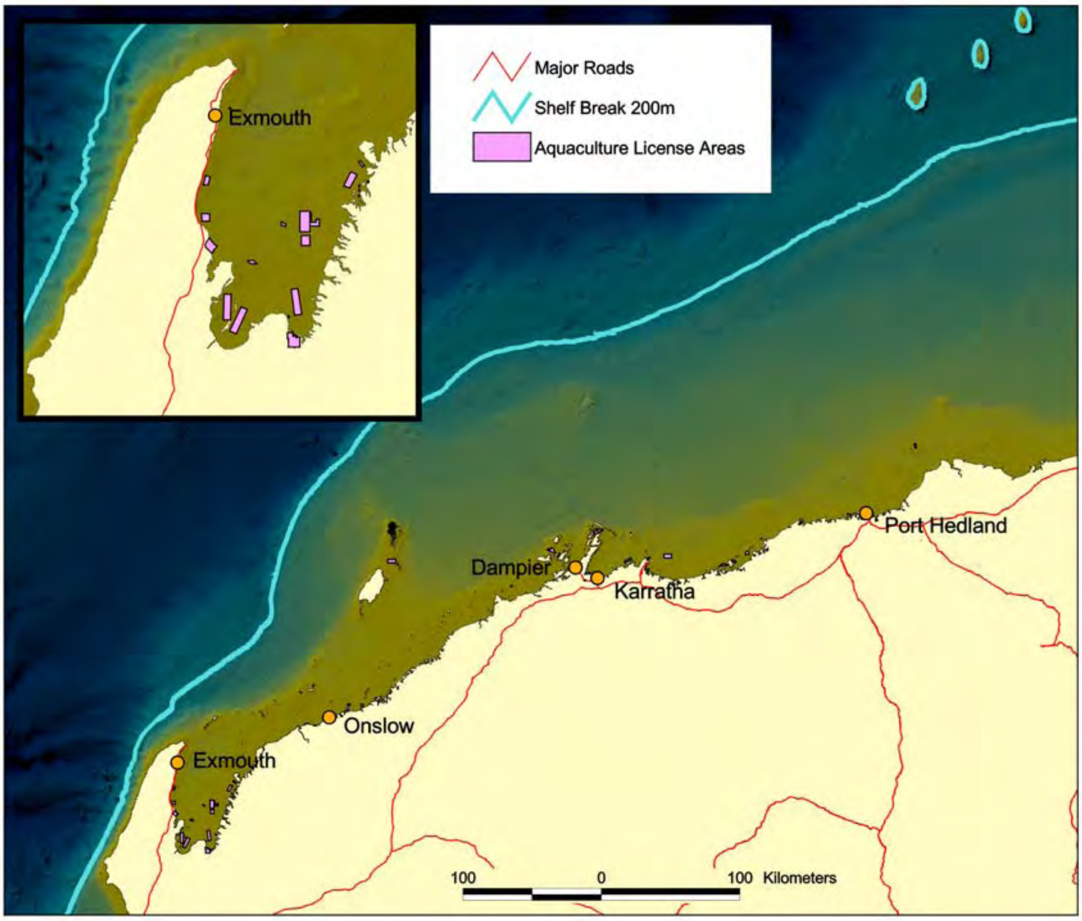


Figure 2.3.4: Aquaculture sites along the Pilbara coastline.

Salt Production

The Pilbara's high temperatures, high evaporation, and low rainfall make it an ideal location to establish solar salt operations. There are two major producers of solar salt in the Pilbara, Dampier Salt (Rio Tinto) and Cargill Salt located in Port Hedland. A third operation has recently been established at Onslow. Their combined production value is in excess of $110 million annually.

The main potential environmental impacts of salt production on the NWS are removal of coastal habitat, such as mangroves, to build evaporation ponds, and inputs of the waste product called bitterns.

Iron Ore

Iron ore production and processing is a major industry on the NWS. Crushed ore is shipped from a number of ports in the region, and processed ore is shipped from Dampier and Port Hedland. The main potential environmental impact of iron ore production is ore dust blowing onto surface nearshore waters and settling in the sediments.

Shipping

On both a global and national scale the NWS ports in particular Dampier and Port Hedland, handle a large tonnage of mineral and gas exports. Other export cargoes include salt, manganese, feldspar, chromite and copper. Dampier is the largest port in Australia by tonnage shipped, with over 2000 arrivals and 83 million tonnes of cargo in 2000. The main potential environmental impacts of shipping on the NWS are associated with spills, tributytlin (TBT) leaching from vessel hulls in the major ports, and the possible introduction of non-native species from ballast water and hull fouling.

Dredging

Dredging is an ongoing activity that is required to maintain ports and for new port and channel projects. Port Hedland undergoes maintenance dredging of its port area and the shipping channel every 3 to 4 years with the dredge spoil containing silt and sand dumped offshore under a Commonwealth permit. Several projects to extend the current shipping berths and deepen the channel are proposed over the next few years with some spoil being dumped on land and some at sea. The Dampier Port requires very little maintenance dredging.

Dredging will be required for several new projects including the construction of a new shipping channel in 2003 which will require some 2 million cubic meters of spoil to be dumped offshore. The dredging of a shallow trench some 100km long is proposed by Woodside for its new trunkline, and Hamersley Iron and Dampier Salt are proposing to deepen their shipping channel by about 0.5m. Both projects will involve spoil being dumped offshore. The main environmental concern with dredging is the disturbance of benthic habitats through the direct effect of the dredging operation and the smothering by dumped spoil.

Tourism

Tourism is an important industry with over 220,000 visitors to the region in 1996, spending an estimated $60 million. Coastal and marine tourism and recreation is substantial and rapidly growing in the region. This growth is expected to continue, if the Montebello Islands and the Dampier Archipelago are declared marine reserves and the areas are promoted as tourist destinations. Recreational fishing is one of the major activities, undertaken by both tourists and locals. Private boat ownership in the major coastal towns is very high by Australian standards. The main potential environmental impact of tourism on the NWS is increased coastal development and loss of habitat.

The challenge for government is how to balance the many and varied demands of small and large tourism-based enterprises while ensuring the long-term environmental health of the marine ecosystem. In tourism it is often unclear what really is acting as the attraction for tourism and related wealth generation. Understanding this will require an integrated and multidisciplinary approach. The ultimate long-term success of the marine tourism industry will no doubt depend on a high quality marine environment.

2.4 Management Regime

Under the United Nations Convention on the Law of the Sea, Australia is obliged to manage its 11-million sq. km Exclusive Economic Zone (EEZ) to conserve living and non-living resources in a sustainable manner. Achieving these goals on the NWS is complicated by the rapid growth of industries and complex management and regulatory structures. Each of these industries is managed under separate arrangements through either State or Commonwealth or combined arrangements. More than 200 separate federal, state and local government legislative requirements govern marine resource allocation, use, conservation and environmental protection on the NWS (Gordon 1999) A collaborative approach to integrated management that identifies the resources, habitat types and conservation values of ecosystems, and involves stakeholders in decision making, is essential to balancing these uses, and avoiding conflict.

There is a management agency primarily responsible for each of the major industry sectors operating on the NWS. The main W.A. government agencies responsible for management of the marine industries on the NWS are; Department of Fisheries, Department ofConservation and Land Management, Department of Minerals and Petroleum Resources, and Department of Environmental Protection.

Department of Fisheries

Key Responsibilities:

- the environmental management of fisheries activities is administered under various Acts and Regulations on behalf of the W.A. government and also on behalf of Commonwealth for some agreed functions;
- The Environmental Protection and Biodiversity Act (1999) gives the Commonwealth regulatory powers for all actions likely to have a negative impact on a matter of "national environmental significance";
- management of Western Australia's fish, marine and aquatic resources and pearling industry, while protecting and conserving the various related ecosystems;
- conservation, development and sharing of fish and other living aquatic resources within Western Australia for the benefit of present and future generations. Specifically this includes management of aquaculture and both commercial and recreational fishing;
- fish habitat protection; and
- surveillance and enforcement in waters adjacent to Western Australia on behalf of the Commonwealth.

Key Management Issues on the NWS:

- growing populations and expanding urban and industrial development, and their effects on marine habitats and increased demand for fish products and recreational fishing access;

- expansion of the planning, establishment and management of marine reserves;
- increased demand for areas suitable for aquaculture production, including in response to the fully-exploited or over-exploited status of most of the world's wild-stock fisheries;
- the impact of increasingly efficient fishing technology;
- the threat of harmful aquatic species or diseases being introduced to WA through shipping or the importation of fish products; and
- the need to develop more cost effective approaches to marine and fisheries management.

Main Management Measures:

- commercial fishing: area zoning of the catch and the amount and types of fishing equipment that can be used. Additional measures are also used to restrict the size of individuals caught and the period of time fishing that fishing is permitted;
- recreational fishing: limits on the species, number and size of fish that can be retained per fisher per day; and
- aquaculture: area zoning of the types and scale of aquaculture facility, and the species cultured. Where aquaculture involves collection of animals from the wild then there are additional restrictions on the catch limits, area and fishing equipment that can be used.

Department of Conservation and Land Management

Key Responsibilities:

- the Department of Conservation and Land Management's (CALM) mission is to, in partnership with the community, conserve Western Australia's biodiversity, and manage the lands and waters entrusted to it, for the appreciation and benefit of present and future generations (CALM, 2000);
- CALM operates under the *Conservation and Land Management Act 1984* and the *Wildlife Conservation Act 1950*;
- CALM has integrated responsibilities, to manage lands and waters for the conservation of biodiversity at ecosystem, species and genetic levels, including management for the renewable resources they provide, and for there creation and visitor services they can sustainably support;
- CALM assists statutory bodies under the *Conservation and Land Management Act 1984* (Conservation Commission, Marine Parks and Reserves Authority, and Marine Parks and Reserves Scientific Advisory Committee) to carry out their statutory functions;
- CALM manages national parks, conservation parks and marine parks, the State forests and timber reserves, nature reserves and marine nature reserves, other reserves and lease areas and any associated fauna, flora and forest produce under the legislation that it administers; and
- CALM is responsible for the conservation of flora and fauna throughout the State.

Key Management Issues on the NWS:

- status, protection and recovery of threatened, endangered or listed species;

- identification and protection of biodiversity;
- identification and establishment of a system of marine protected areas (two areas are currently undergoing planning for possible reservation under the CALM Act 1984, and these are: proposed Montebello/Barrow Islands marine conservation reserve and proposed Dampier Archipelago/Cape Preston marine conservation reserve); and
- Management of existing marine protected areas (ie Rowley Shoals Marine Park and Ningaloo Marine Park).

Main Management Measures:

- three of the key mechanisms used by CALM for the protection and conservation of the ecological and social values of the lands and waters it is responsible for under these two acts are area management plans, threatened species recovery plans and wildlife management programs; and
- with respect to marine conservation through reserves, Western Australia operates under a multiple use policy framework for this purpose. Marine Conservation Reserves (MCRs) in Western Australia are classed into three categories, in increasing order of protection as follows: Marine Management Area, Marine Park and Marine Nature Reserve, respectively, as specified in the CALM Act 1984.

Department of Minerals and Petroleum Resources

Key Responsibilities:

- the environmental management of petroleum activities is administered under various Acts and Regulations on behalf of the W.A. government and the Commonwealth. For example (Commonwealth Petroleum (Submerged Lands) (Management of Environment) Regulations) 1999;
- the Environmental Protection and Biodiversity Act (1999) gives the Commonwealth regulatory powers for all actions likely to have a negative impact on a matter of “national environmental significance”;
- responsible management of Western Australia's minerals and petroleum industry; and
- ensure that the community receives benefits in exchange for use of its natural resources.

Key Management Issues on the NWS:

- ensuring that appropriate standards for environmental management and health and safety are met;
- achieving the potential for resource exploration and development; and
- facilitating access to land and provide secure title for resource exploration and development.

Main Management Measures:

- zoning of the type of activity (e.g. exploration, production), the quantity, content and type of discharges or released that can be made into the environment, and required risk assessments or monitoring programs; and
- zones for exploration and for production.

Department of Environmental Protection

Key Responsibilities:

- the Environmental Protection and Biodiversity Act (1999) gives the Commonwealth regulatory powers for all actions likely to have a negative impact on a matter of "national environmental significance";
- to ensure, with people across the community, that our environment, with the life it supports, is protected now and into the future; and
- explicitly the Department of Environmental Protection has a responsibility to ensure that the environment is conserved and enhanced, that development in Western Australia is environmentally acceptable and that ecological integrity is not compromised.

Key Management Issues on the NWS:

- increased environmental pressures from population growth, tourism, coastal infrastructure and industrial development;
- evaluating the environmental impacts of development proposals, both with respect to the individual proposal and in combination with other existing or proposed developments; and
- setting limits on environmental change (e.g. loss of habitats or reduction in water quality) that will still ensure the maintenance of ecosystem integrity, and the conservation of the marine environment and the life it supports.

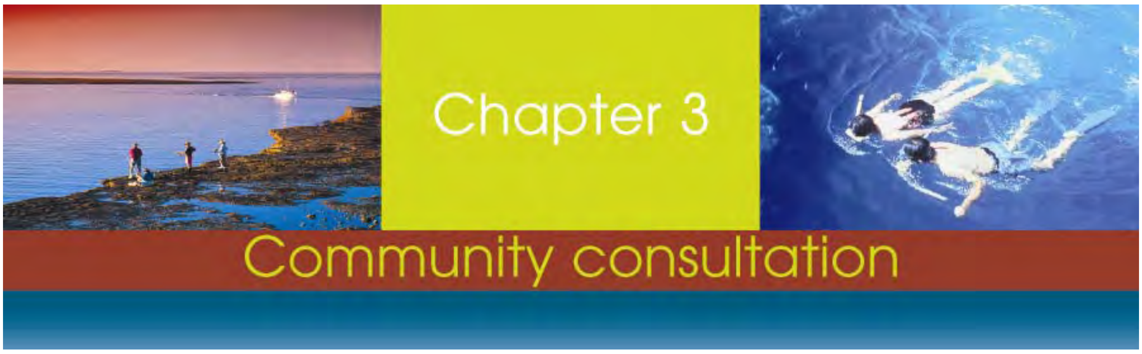
Main Management Measures:

- setting enforceable limits on the quantity, content and concentration of waste emissions through regulation; and
- auditing of environmental performance of activities with potential environmental impacts. Performance based on assessing environmental quality against agreed criteria, which in turn are linked to specified and spatially-defined environmental quality objectives.

2.5 Concluding Remarks

With the rapid growth of marine industries on the NWS across a range of sectors, the potential for conflict between different users and uses of the marine environment is increasing. These industries also operate in a region recognised for its rich marine biodiversity. Experience elsewhere in the world suggests that environmental quality and the ecological sustainability of industries, with their associated employment and wealth generation, may be compromised at some point unless development occurs in an integrated and ecologically based management framework.

Though incomplete, there clearly exists a substantial body of information on the physical, chemical, and biological characteristics of the NWS system, as well as past and current human activities. A major task for NWSJEMS is to bring this information together into a coherent description (Chapter 5 Inventory of Ecosystem Characterisation and Human Uses), from which more detailed process understanding can be developed for the system as a whole (Chapter 6 Ecosystem Dynamics and Human Impacts).



3.1 Introduction

Information exchange between the Study team and the broader stakeholder and community groups has been critical for the success of the Study. This communication process allows mutual understanding between the scientists, regulators, stakeholders and community, and preferred outcomes and options in environmental and sectoral management of the NWS.

3.2 Background

There is a wide range of stakeholders who have been involved in the communication and consultation process. These include:

- relevant government agencies;
- industry;
- non government organisations (NGOs);
- community groups including indigenous groups and environmental groups; and
- individual residents of the study area.

These stakeholders represent a broad range of groups with different management responsibilities, interests, and values.

Environmental management and regulation of natural resource management on the NWS are the responsibility of several departments of the Western Australian (State) Government, Local Government and the Australian Federal Government. From a regional perspective State departments play the major role in environmental and resource management. Each of the departments has particular responsibilities but they are also required to act collaboratively in exercising these responsibilities. WA State Government Agencies are represented on the NWSJEMS Technical Committee and include Department of Conservation, Department of Environment Protection, Department of Fisheries, and Department of Minerals and Petroleum Resources.

3.3 Methods

A wide range of approaches is being used to facilitate the communication and consultation process, and to raise the profile of the Study. These include:

- an official launch in August 2000;
- workshops and Forums;
- consultation and presentations by members of the Study team;
- community consultation program;
- media releases, newsletters, and interviews;
- web page information; and
- a survey.

Official Launch, August 2000

The Study was launched on the 1st August 2000 in Perth, Western Australia. The Minister for the Environment, Hon Cheryl Edwardes, and Senator Alan Eggleston, representing the Federal Minister for Science, Hon Nick Minchin, formally launched the Study. Cheryl Edwardes said "This is a new approach between, local, state and federal governments to marine research in Australia, providing a model which will help strengthen management in a key region of our vast EEZ"

Workshop, August 2000

The launch was followed by a workshop, which provided a forum for developing options for improved coordination and integration of management planning strategies on the NWS. State and federal government representatives presented information on sectoral management plans, policies and strategies operating on the NWS at State and Commonwealth levels, and possible options for improved coordination and integration. Members from the Study team provided an overview of NWSJEMS and how its technical deliverables would support environmental management on the NWS. Proceedings of the workshop can be found on the NWSJEMS web site at http://www.marine.csiro.au/nwsjems/index.html.

Forum, Perth, August 2001: "One Year Later"

The main focus of the forum, chaired by the WA Chairman of the Environmental Protection Agency (EPA), Bernard Bowen, was to provide an update on progress to date and demonstrate the MSE prototype model, noting that at this stage it only provides a simple and illustrative example of the final product. Data Trawler, which provides access to data via the internet, was also demonstrated.

Tonia Swetman, the NWSJEMS Community Liaison Officer, outlined the community communication and consultation processes and presented findings from the pilot study for the survey. She also introduced two community members Anna and Robert Vitenberg from the Pilbara region, who outlined the history of the area and the changes associated with the development of various industries, and of the growth of townships such as Dampier and Karratha. They raised a number of environmental concerns associated with the rapid development of the region, including poor fishing practices, mangrove damage and poorly designed coastal infrastructure resulting in environmental damage. Proceedings of the workshop can be found on the NWSJEMS web site at http://www.marine.csiro.au/nwsjems/index.html.

Consultation by Study Team Members

Throughout the Study various members from the Study team have met and consulted with stakeholders in key sectors to discuss a range of topics, including:

- management responsibilities and issues;
- sector objectives and performance indicators; and
- identifying data and its availability to the Study

Interviews with key experts were also conducted to obtain valuable data and information about the NWS ecosystem. This information is integrated into the NWSJEMS GIS.

Presentations by Study Team Members

In addition to the workshops, approximately 25 presentations have been given by members of the NWSJEMS team to a range of target groups including government agencies, community groups, industry bodies and universities. The aims of these presentations were to provide information about the Study, explain the objectives and benefits and obtain community input.

Community Consultation

Key activities and outcomes to date are:

- a Community Liaison Officer, Ms Tonia Swetman, was appointed as a consultant to the Study for a period from March to December 2001. She has lived and worked in the Pilbara area for many years, is highly respected in the region and has extensive experience in community consultation;
- meetings with major regional stakeholders;
- a database of over 290 key stakeholders. Maintenance of this database will be ongoing;
- letters and fact sheets which were sent to all the key stakeholders explaining what the Study is about, and the key elements of the consultation process;
- a survey seeking the community, regulator and other stakeholders' values and preferred outcomes and options for the environmental management of the NWS. About 3000 questionnaires were widely distributed throughout the NWS region. Another 1000 questionnaires were included as inserts in the WA subscriber’s of the National magazine 'Waves' (A Marine and Coastal Community Network initiative);
- posters, which were displayed at various centres in the NWS region;
- a tour of the major population centres with face-to-face consultations with stakeholders was conducted;
- the MSE prototype model was demonstrated in Karratha in August 2001;

- two long time residents of the NWS region represented local interests at the Perth workshop;
- media coverage; and
- communication and consultation with stakeholders and the community has enabled the development of a set of relevant indicators and performance measures, including environmental quality objectives that will guide strategic planning, and the development and evaluation of multiple-use management strategies.

Local Forums
Members of the scientific study team have and will continue to visit the region to provide information about the study and seek input and feedback from community members.

Newsletters and Press Releases

Several newsletters and press releases have been prepared over the course of the Study. Six monthly newsletter which provides both an educative and information sharing role have been published on the NWSJEMS Web Page at
http://www.marine.csiro.au/nwsjems/index.html.
Some hard copies have been distributed in the study area. The first edition was released in November 2001, and the second edition was February 2002. The third edition will be published in August 2002.

Web Site

A NWSJEMS web site has been established. It contains an extensive amount of information about the Study as well as aerial photographs of the region, a metadata base of data, completed reports and workshop proceedings. These can be accessed at:

http://epagate.environ.wa.gov.au
http://www.marine.csiro.au/nwsjems/index.html

3.4 North West Shelf Survey and Results

Pilbara residents have been surveyed to provide data about preferred development options for the NWS. The survey was part of the community consultation process initiated through the NWS Joint Environmental Management Study by the Department of Environment, Water and Catchment Protection and CSIRO.

Consulting with all regional user groups, and the broader community, is important in building an understanding of research and to create links between organisations. The survey asked questions regarding resource uses, perceived threats, community values, and preferred outcomes. Survey forms were distributed widely. For a copy of the Survey see Appendix A.

Information from the community is critical to the study. The survey provided the following information:

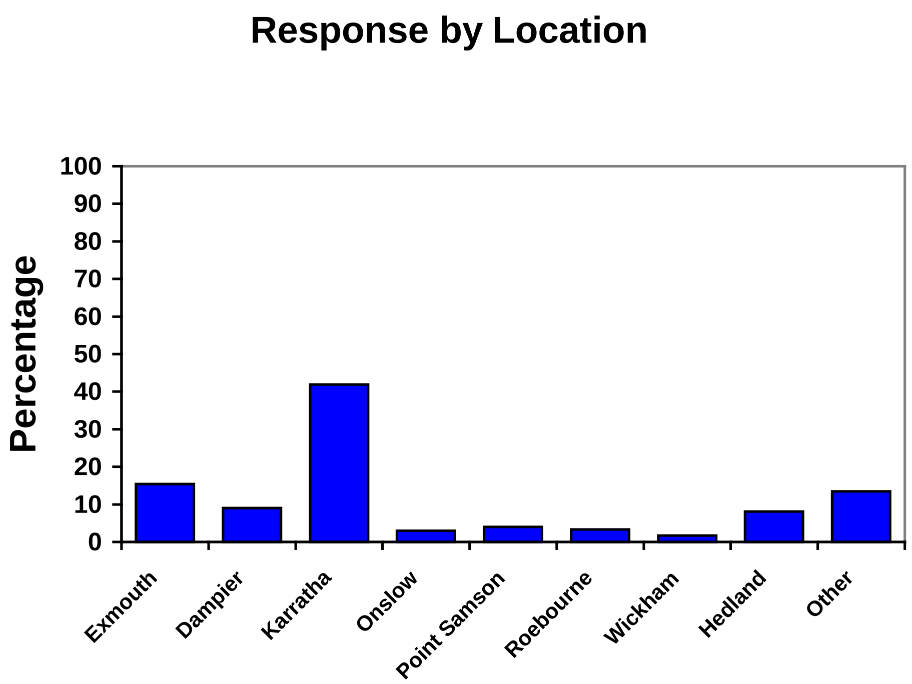
- where people live, and an indication of coastal recreational activities;
- the value residents place on the natural qualities of the NWS marine environment, and important uses of this environment;
- the perceived threats to the marine environment in the study area;
- important issues that should be considered by the study, and future management of the region;
- respondents understanding of ecological sustainability and its importance; and
- preferred goals for the study area.

The outcomes of the survey, when added to other research results will contribute to options and opportunities in the way this environment is managed for the future.

The Results

Questions 1-7 were aimed at gathering information about the people who responded to the survey.

Question 5: Where do you live?



- 40% of the completed surveys were from residents of Karratha. This is a representative sample size given that Karratha residents comprise approximately 36 percent of total population for the study area.

Question 6: Who do you represent?
We wanted to know if respondents we speaking as citizens, or as a member of an organisation or group. The results were as follows:

- 75% of respondents represented themselves as residents of the area;
- 7 % of respondents were visitors to the area;
- 4% of the respondents represented the tourism industry;
- 3% represented a conservation or environmental group; and
- 11% for all other sectors.

Question 7: What are your recreational activities?
We also wanted to know how our respondents made use of the area's recreational potential. The recreational activities, in which respondents regularly participate, are ranked below:

Activity	Percentage of Respondents
Walking along the shore	79%
Enjoying the view	73%
Fishing	70%
Looking for / watching marine life	68%
Swimming	67%
Boating	60%
Diving / snorkeling	55%
4 Wheel driving	48%
Viewing Aboriginal Rock Art	40%
Collecting seafood / shellfish	33%
Collecting shells	29%
Other	22%
Surfing	13%
Skiing	8%

Summary of Questions 1-7
We learned something about where respondents live; that most respondents replied as residents of the area; and an indication of the recreational activities undertaken in the area

Questions 8 - 13 examined how respondents felt about the region and the manner of its development.

Question 8: If you had a choice from a number of outcomes for the region, which would be most important to you?

Important outcomes respondents would like to see happen in the study area	
% of respondents	Possible outcomes
61-70%	Protection of marine plants and animals
51-60%	Unpolluted waters
21-30%	Accessible beaches for swimming, diving and boating
11-20%	Increased employment opportunities
	Thorough approval process for development
	Recognition of Aboriginal heritage
	Community education about the marine environment
	Being able to access the islands
	Having more marine parks
0-10%	Speedy approval process for development
	Easy and safe shipping for imports and exports
	Natural view(s)
	Increased national income from resource developments
	Increase in local business trade
	Simplified regulation and management
	Scientific research
	Mangrove protection
	Open and easily understood government approval process
	Unrestricted access for small boats
	Sharing the marine environment with visitors
	Publishing study results
	Safe waters
	Diversification of industry
	Being able to camp on the islands
	Being able to build infrastructure on the islands

- 62% of respondents rated protection of marine plants and animals as important outcomes that they would like to see happen in the study area in the future;
- 55% of respondents rated unpolluted waters as important outcomes that they would like to see happen in the study area in the future; and
- 22% of respondents rated accessible beaches for swimming, diving and boating as important outcomes that they would like to see happen in the study area in the future.

Question 10: How important would you rate the following natural qualities of the NWS marine environment?

Natural Qualities	Very Important	Fairly Important	Not Important
Water quality	95%	5%	1%
Healthy and natural environment (ecosystem integrity)	93%	6%	1%
Health of animals	92%	7%	1%
Health of plants	91%	8%	1%
Variety of plants and animals (biodiversity)	89%	10%	1%
Number of plants and animals	77%	22%	1%
Aesthetic (or attractiveness) values	46%	46%	7%

- 95% rated water quality as very important;
- 93% rated healthy and natural environment (ecosystem integrity) as very important;
- 92% rated health of animals as very important; and
- 91% rated health of plants as very important.

Question 12: Respondents were also asked to rank the most important uses of the NWS marine environment from the following list:

Important uses of the North West Shelf marine environment	
% of respondents	Uses
41-50%	Tourism
	Recreational Fishing
21-30%	Boating
	Camping
	Resource extraction
	Monitoring activities
11-20%	Swimming
	Diving
	Aquaculture
	Indigenous cultural activities
	Coastal development (associated with industrial and population growth)
0-10%	Skiing and surface water sports
	Crabbing
	4 wheel driving
	Commercial fish trawling
	Commercial non-trawl fishing
	Transportation
	Pearling

- 47% respondents believed tourism to be an important use of the NWS marine environment;

- 44% of respondents rated recreational fishing to be an important uses of the NWS marine environment; and
- 21 – 30% of respondents rated boating, camping, resources extraction, and monitoring activities to be an important use of the NWS marine environment.

Summary Questions 8-13
Respondents indicated that protection of marine plants and animals; ecosystem integrity, as well as water quality are important outcomes; and that tourism and recreational fishing are important uses of the NWS marine environment.

Questions 14-16 asked respondents to consider major threats to the marine environment, and where these occurred.

Question 14: What are the greatest threats to the marine environment?

Threats	%
Commercial fish trawling	61%
Coastal effluents (e.g. sewage)	42%
Oil and gas industry	28%
Coastal development (associated with industrial and population growth)	26%
Dredging	24%
Shipping	24%
Iron ore industry	16%
Cyclones	14%
Climate change	12%
Industry	10%
Commercial non trawl fishing	10%
Tourism	10%
Recreational fishing	8%
Pastoral (coastal) land use	6%
Pollution	3%
Aquaculture	3%
Pearling operations	2%
Small boats	2%
Litter	1%
Diving	1%
Ecotourism	0.00%

- 61% rated commercial fish trawling as the biggest threat to the marine environment of the NWS; followed by
- 42% for coastal effluents; and
- 28% for oil and gas industry

Question 15: What are the greatest threats to the marine environment and where in the study area are they of most concern?

Locality	Greatest threats to the marine environment	%
Exmouth	Commercial fish trawling	67%
	Coastal effluents	38%
	Oil & gas industry	33%
Onslow	Commercial fish trawling	61%
	Cyclones	42%
	Small boats / Coastal development	25%
Dampier	Commercial fish trawling	74%
	Coastal development	49%
	Shipping	37%
Karratha	Commercial fish trawling	69%
	Coastal effluents	43%
	Dredging	27%
Point Samson	Commercial fish trawling	69%
	Oil & gas industry	60%
	Shipping	44%
Wickham /Roebourne	Iron ore industry	82%
	Industry in general	44%
	Oil & gas industry	43%
Hedland	Coastal effluents	71%
	Oil & gas industry	46%
	Dredging	42%

Identification of threats varied from one locality to another

Question 16: We also asked whether there were any other activities or events (natural and human) apart from those suggested, which were considered to be major threats to the marine environment in the NWS Study area? Although a wide variety of responses were elicited, a number of common themes were prevalent, including:

- over fishing;
- uncontrolled tourism;
- litter;
- ignorance / lack of knowledge / lack of education;
- industry;

- illegal fishing;
- poor access to beaches (people make their own roadway and destroy dunes etc);
- dust (this was a more common response from Dampier and Wickham residents);
- structures that are built and cause a change in water flow;
- the size of the study area / lack of monitoring / lack of Fisheries officers / poorly guarded coastline;
- jet skis;
- unmanaged coastal dwellings (Cleaverville and Dampier Archipelago shacks);
- spear fishing; and
- wheel drives on dunes / beaches.

A number of participants, from the Exmouth area, expressed concern regarding the proposed development at Coral Bay (Maud's Landing) as a threat to the environment in that locality.

Summary Questions 14 - 16
Natural resource use; impacts from coastal developments and industry; and shipping were perceived as the greatest threats to the NWS marine environment.

Questions 17 – 18 asked what important issues should be addressed by the study, and about preferred management options for the region.

Question 17: What are the important issues that should be considered by the study?

Responses varied but highlighted two main themes that of:
- impacts of natural resource use and coastal development; and
- the need to protect the natural environment.

Question 18: What would you like to see in place for future management of the region?

Responses ranged from the very specific to more general. A comment that was made and which best summarises the various points made is:

" Needs to be a happy medium between industry and jobs and preservation/conservation"

Summary of Questions 17 and 18
Responses to these two questions highlighted the need for a balanced approach between the environment and economic development when considering issues and management options.

Questions 19 – 21 since the Western Australian government's overall goal is that of ecological sustainable development (ESD) of the NWS region, we though it important to know if respondents understood what was meant by the term ecological sustainability, and whether it was felt to be important.

Question 19: What do you understand by the term ecological sustainability?

The level of understanding of the respondents was rated as follows:

Level of Understanding	Excellent	Some	None
Percentage	45%	48%	67%

- 45% had an excellent understanding.

Question 20: Do you think ecological sustainability of the marine environment is important?

- 99% believed that ecological sustainability of the marine environment to be important.

Question 21: Why is it important or why is it not important?

Respondent's rationale for their belief that ecological sustainability of the marine environment is important followed a common theme. The following comments summarise the general response:

"We have a wonderful environment here in the Pilbara and we need to make sure we plan for its future, or it may not have one."

"So our kids can use it."

Summary Questions 19 – 21
Overall respondents demonstrated a good understanding of the term ecological sustainability, and believed it to be important to the marine environment

Question 22 asked respondents to rank a list of goals in terms of importance to them, from most important to least important. The results were as follows:

1st Maintenance of sustainable relationships among plants, animals and people.

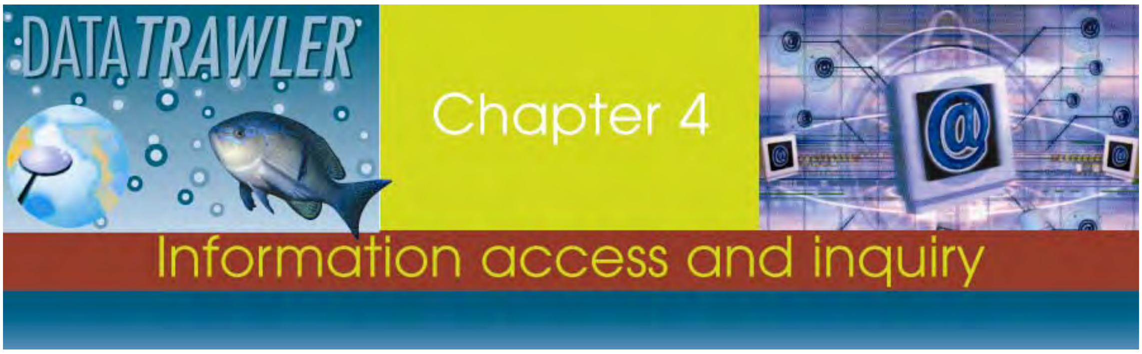
2nd Having processes in place to manage the region's environment

3rd Growth in Employment, income and standard of living.

4th Pleasant environment with features available for the public to use.

Summary of Findings
The general direction of the survey strongly indicated a desire to preserve the region's water quality and ecosystems, and to protect the environment, while allowing development of the area.

The response indicated, however, that environmental protection is the more important outcome. This highlights the importance of the Management Strategy Evaluation (MSE) approach being developed by the study. Through the use of MSE, managers and regulators will have access to a tool to evaluate the effectiveness of a proposed management strategy.



4.1 Introduction

NWSJEMS was established to allow an ecosystem-wide and multiple use perspective to the management of the North West Shelf. During planning of NWSJEMS it was quickly recognised that a significant impediment to taking this wider view was the difficulty in accessing and integrating information. There have been numerous studies and reports completed on various aspects of the North West Shelf ecosystem and the human uses of it. However, the resulting knowledge, data and reports were scattered among numerous private business entities (ranging in size from individual consultants to multinational Corporations) and Government agencies (straddling many research, regulation and policy agencies across the three tiers of Government). And the relevant information was in many different forms – ranging from written reports with various levels of accessibility, through computer data-bases in various kinds of computer and managed through various computer programs. Some of the knowledge was ‘in the heads’ of people with various levels of expertise.

A data management framework has been developed for NWSJEMS, to identify and enable access to this information, and to allow its more efficient integration and analysis. The framework has been used to gather and/or make available data from many public and private sector sources, and to share data between the several research projects within the study. This framework has been designed so that it can provide the infrastructure to support ongoing management of data and information about the North West Shelf, and to make these data available to stakeholders and decision-makers.

The objectives in developing the framework were to:

- identify sources of relevant data from the NWSJEMS study area;
- seek and prioritise data gathered from these sources in a systematic way;
- establish and share information about the data holdings (metadata) within the Study and with the public;
- set up data use agreements and systems for appropriate access and sharing of data and information; and
- establish a spatially enabled marine data management system containing key environmental information, including observed and modeled data.

4.2 Background

It was acknowledged at the outset that managing all the information required for, and generated by the study was of prime importance. It was recognised that this would require close collaboration between the project team and the WA State agencies. A NWSJEMS Data Management Project team was established with members from both the Department of Environmental Protection and the CSIRO Marine Research (CMR) Data Centre. This team developed the NWSJEMS information strategies. They set up management procedures to deal with fundamental issues, particularly those relating to information access and ownership. They also designed and implemented the systems necessary to support the data management components of the study.

The Department of Environmental Protection, other WA agencies and CMR all had existing data management arrangements and requirements, and these were largely unchangeable. New systems developed for NWSJEMS were therefore to integrate with, and complement the existing arrangements and requirements of each agency. Within the Department of Environmental Protection, NWSJEMS has been integrated with corporate activities of the Geographic Information System (GIS) branch. This GIS branch is primarily responsible for managing the Department's spatial data. The Department of Environmental Protection data management system was to be based on GIS, and needed to be capable of being managed and maintained by Department of Environmental Protection staff to ensure the system had a life beyond the end of the study.

While GIS is a very convenient and commonly used tool for visualising spatial information it was recognised that it had some important limitations in presenting information for ecosystem management decision making. In particular GIS is limited in its ability to efficiently manage complex or distributed data sets and to represent spatial changes through time – both of which are important in ecosystem models and management strategy evaluation. Because GIS technology was likely to continue to be a commonly used tool among stakeholders and regulators it was decided that the data management framework would need to couple it with relational database software and allow it to function over the world wide web (www). Deficiencies GIS systems have in displaying the 'time' component of any marine spatial data sets would be overcome with custom-built visualisation tools. This would build on existing CMR information systems that were based on www technologies. The resulting framework would allow agencies and users to continue their use of GIS for visualisation, but would also allow use of the enhanced data and visualisation management facilities available from other software.

4.3 Methods and Results

All the specific objectives identified for the Data Management Project of NWSJEMS have been completed. The project has had considerable support from the other NWSJEMS projects and collaborators, from elsewhere within Department of Environmental Protection and CMR, and from data contributors.
The approach taken and the related achievements are outlined below.

Data Sources and Metadata
A comprehensive review of research and data, relevant to the environmental management of the North West Shelf, was undertaken and released in 1999. This provided the basis of an on-line database now maintained on the Department of Environmental Protection web site:

http://epagate.environ.wa.gov.au/nws/bibliography.htm

The bibliography included the published material, grey literature, maps and data products. This review established which of the data sources suited the needs of the various projects. Data rich and data poor subjects and areas were identified and the process of obtaining data was planned.

Important basic data sets were available from CMR and Geoscience Australia (formerly AGSO). Others were identified through the Australian Spatial Data directory (ASDD), the Western Australian Land Information Service (WALIS) Interragator database and through contact with individual agencies and through interviews with data managers within industry, mainly oil, gas and mining companies.

Metadata is fundamental to managing data for re-use. This 'data about data' comprises descriptive information, details about the data supplier, information on data quality, storage format information, currency and status details, access constraints and licensing conditions.

These comprehensive descriptions of data holdings, from all sources, were loaded into Department of Environmental Protection and CMR metadata databases. All data sets identified for NWSJEMS, which had not previously been submitted to a national data directory, were provided to WALIS for inclusion on the WA node of the Australian Spatial Data Directory (ASDD) at http://www.walis.wa.gov.au. Marine Laboratories Information Network (MARLIN), the CMR metadata database, at http://www.marine.csiro.au/marlin is also a node of the ASDD. Note NWSJEMS metadata records in MARLIN are available only to the Study collaborators. They are not being published through the ASDD.

Data Acquisition and Data Use Agreements

License agreements were developed with the agencies and industry contributing data sets to the Study. The type of agreement related to whether the data came from State or Federal Government or from Industry.

All data obtained from WA Government agencies was negotiated under the WALIS data exchange agreement. This allows access to data for the cost of extraction for non-commercial use. License agreements with Commonwealth agencies varied on an agency by agency basis.

A master license agreement for use of data from the oil and gas sector was initially negotiated with the Australian Petroleum Production and Exploration Association (APPEA), Apache Energy, and the Department of Environmental Protection on behalf on NWSJEMS. The aim of the agreement was to make the data as accessible to as many agencies as possible. This agreement was then used as the basis for further licenses between other APPEA members.

While many of the data sets compiled through NWSJEMS were based on existing data sets held by agencies, some were compiled from interviews with experts and others with special knowledge of the NWS ecosystem or the human uses of it. This was to summarise and make available the often considerable understanding that such people had developed – understanding that was not recorded in any reports or data sets. To facilitate the electronic capture and storage of this understanding a GIS based package was developed. This allowed experts to graphically 'sketch' into a GIS where they had seen events or ecosystem attributes. This easily allows other points of reference, for example depth or headlands, to be overlaid to help with the accuracy of geo-location. It also easily allows comparison of the information provided by several sources and experts, and for work-shop based resolution of any differences. This software generates GIS data files and was used, for example, to collect and review the knowledge of many long-term divers and marine scientists about the shallow water habitats on the NWS (see Chapter 5 Inventory of Ecosystem Characterisation and Human Uses).

Guidelines for access to the NWSJEMS Study data products were drawn up based on the terms of the collaborative research agreement established between Department of Environmental Protection and CSIRO.

Data Management and Visualisation Tools

The NWSJEMS Data Management Project has developed two major products. The first is the Department of Environmental Protection Marine GIS Data Management System that establishes effective data access linkages between GIS and database data management structures. Use of this system is from within Department of Environmental Protection computing network. The second product, CMR Data Trawler, is a web-based data tool that allows data to be accessed, reviewed and stored for later use by other programs (including but not limited to GIS). Being web-based it is largely independent of the type of computer and programs used. Both products are described in the following section.

As planned both of these two major products of the NWSJEMS Data Management Project were available for use within the first year of the Study. They now support development of knowledge-based products and environmental management applications through other NWSJEMS Projects.

4.4 Products

1. Department of Environmental Protection Marine GIS Data Management System

Geographic Information System provides a powerful tool for the visualisation and analysis of spatial datasets and for the integration of a wide variety of different data formats. So development of the marine oriented GIS was a key component of NWSJEMS data management. The GIS allows spatial data to be viewed and analysed, and overlain with a range of data types. Data types which can be viewed include GIS themes (points, lines, polygons), imagery and tabular information.

A desktop GIS package was chosen as the development environment. Already used within Department of Environmental Protection ArcView provided tools for establishing data linkages with the metadata system and for geo-spatial processing. An existing metadata system, made available by the Australian and New Zealand Land Information Council (ANZLIC), was modified to accommodate Department of Environmental Protection data management structures. An ArcView extension was developed to integrate the metadata system with data management functionality for data discovery, viewing and reporting. This system is not internet enabled.

NWSJEMS GIS Data

Data obtained for NWSJEMS and available in this system includes:

- GIS layers in the form of ArcView Shapefiles;
- ArcINFO coverages, Mapinfo Tab files;
- Microstation Design Files;
- AutoCAD drawings;
- images and raster datasets;
- tabular data including text files;
- spreadsheets; and
- conductivity-temperature-depth CDF files containing spatial locations or information.

The vector data themes include:

- marine and coastal habitats;
- pipeline locations and information;
- port limits, maritime boundaries and zones;
- bathymetric and terrestrial contours ;
- drainage lines;
- catchment boundaries;
- coastal development and town planning boundaries;
- land tenure and use;
- nature conservation reserve boundaries;
- flora and fauna;
- infrastructure;
- fishing licence boundaries;
- aquaculture sites; and
- indexes to other data sources such as aerial photography, bibliography and surveys.

Image and raster data formats include:

- satellite imagery;
- aerial photography; and

- bathymetry.

The various data formats were converted into a common data format and common coordinate system allowing all of the layers to be visualised in relation to one another. This allows spatial comparison and analysis across previously disparate data sets.

The data supports the information requirements of the other projects within NWSJEMS. For example, information such as benthic habitats and dugong sightings assist in the development of models for dugong distribution patterns to be used in MSE. Aerial photography and satellite imagery provide important contextual information for the other GIS layers and give a thorough visual representation of the services in the region, as well as being sources for capture of data layers.

The Department of Environmental Protection data management system consists of an application built using Avenue Scripting to integrate with the metadata system. Functionality provided by the data management system includes: textual and spatial searches for data, metadata reporting and export, coordinate system management, and data conversion and export. Extended functionality may be available in the Data Management System as additional data formats are acquired by or generated from within the study.

The data management system application within ArcView consists of a basic textual search interface (Figure 4.4.1). Once data sets have been identified from a search, the metadata is displayed and the theme can be loaded into the GIS for display or analysis (Figure 4.4.2). Spatial searches are also available from within the GIS.

Figure 4.4.1: ArcView metadata search interface. Basic search on keywords, custodian and on abstract

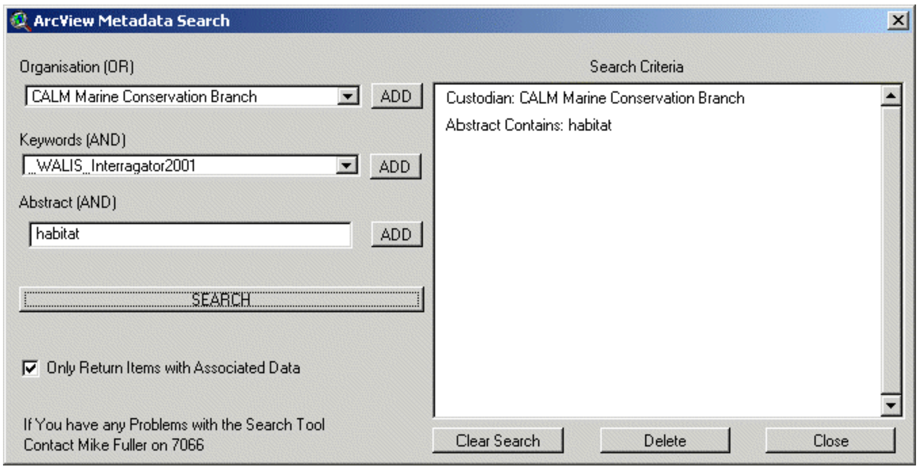
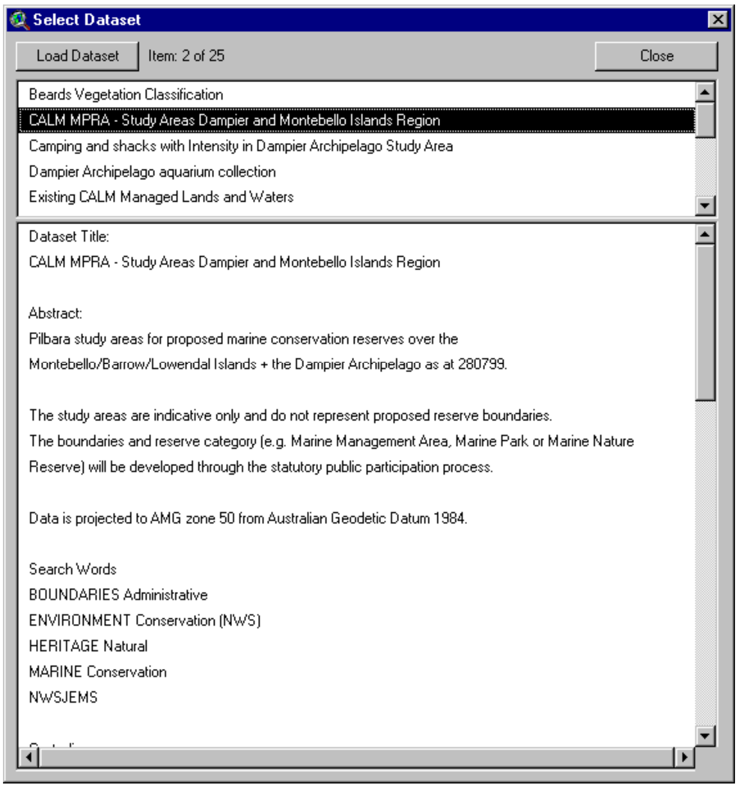


Figure 4.4.2: Results of the metadata search show available datasets and associated metadata



2. CSIRO CMR Data Trawler

The Data Trawler was launched at the North West Shelf Joint Environmental Management Study Forum in August 2001. This web-enabled custom built Java application presents maps generated using the MapInfo Corporation product MapXtreme for Java. It accesses all NWSJEMS data, as well as other data held by CMR. It accesses an Oracle 8i data repository called the Data Warehouse.

The primary functions of this tool are to:

- discover data of interest using geographic, temporal and category search criteria;
- investigate - view a summary;
- preview the spatial distribution of the results of a search and
- download data sets as required to the user's local computer.

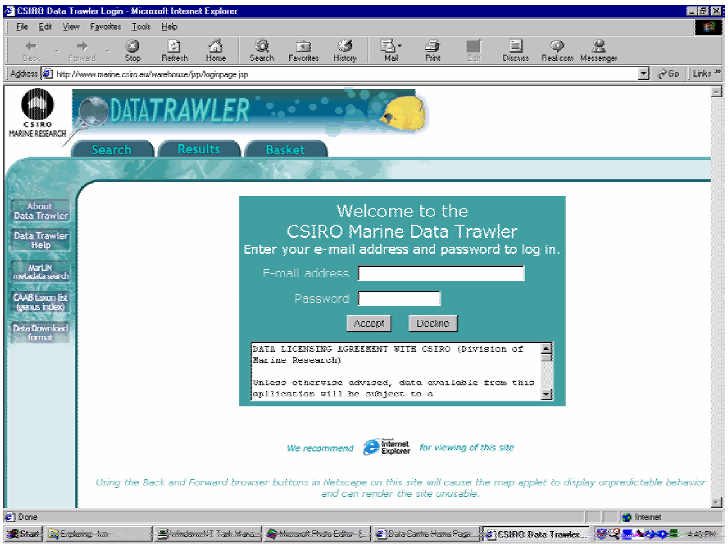
The Warehouse data available through the interface includes:

- CTD (conductivity-temperature-depth) profile data from CMR research vessels, covering the NWS region and other ocean areas;
- hydrological (bottle sample) data from CMR research vessels, covering the NWS region and other ocean areas;

- biological (catch) data from CMR research vessels, and other sources as presently held in the CMR archive (e.g. Soviet fishery data from the 1960s and 1970s), covering the NWS region and other ocean areas;
- GIS layers covering a range of themes obtained from WA agencies and Industry for use in the NWSJEMS project, mainly covering the NWS region (i.e. including GIS layers in the Department of environmental Protection Marine GIS Management system) ;
- moored instrument data from CMR research deployments depicting currents for various ocean regions; and
- model data from selected model runs undertaken by NWSJEMS scientists.

Based upon an extended version of the classic in-line store model, the interface presents the user with the means, not of shopping, but of 'trawling' for data. The user-friendly tool is available at http://www.marine.csiro.au/warehouse/jsp/loginpage.jsp

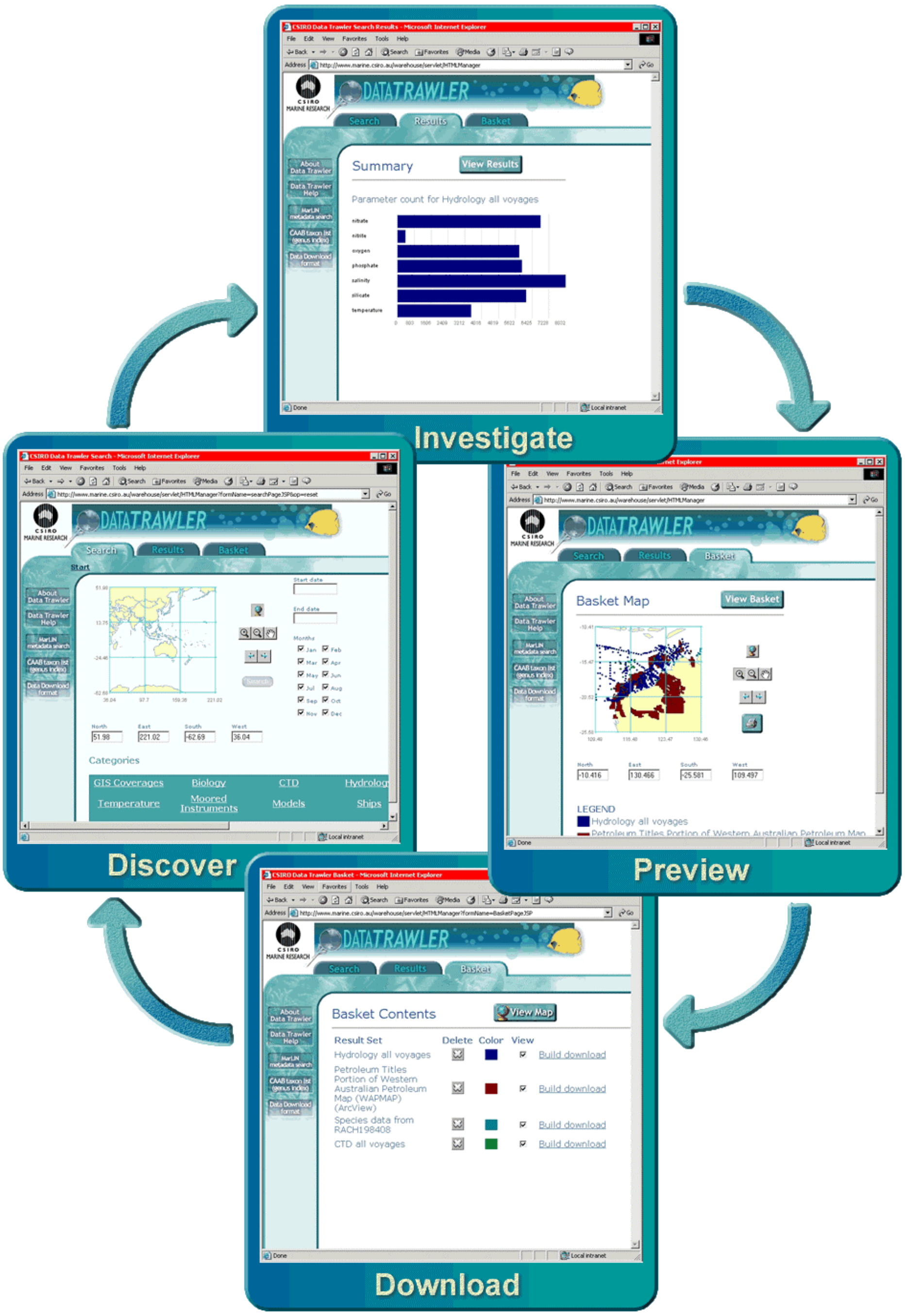
Figure 4.4.3: Data Trawler login page with data use agreement



The entry point to the DataTrawler is the login page seen above in Figure 4.4.3. Public users of this web tool can proceed by simply accepting the general CMR Data Licensing Agreement. If they wish to download data the public users can enter an email address but they have only limited access to the Warehouse content. Secure access is available to restricted data by an authorised user. Authorisation is available to those within collaborating agencies nominated by NWSJEMS collaborators. An email address for such a user is registered and they receive a password for the Data Trawler.

In Figure 4.4.4 below four Data Trawler screens illustrate the essential functions and flow of the interface.

Figure 4.4.4: The functions and flow of the Data Trawler interface



After login the user can navigate within the application using three tabs at the top of every screen: Search, Results and Basket. Firstly a flexible search screen is presented. From here the user frames a search for data in any of the current eight category trees based on time and spatial area (described with a mouse or with typed coordinates). A second level of search definition is available according to the category selected.

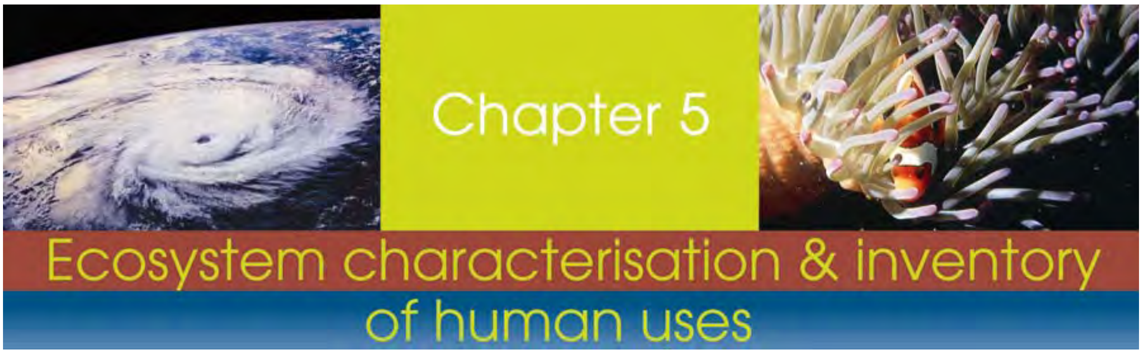
Under the Results tab the result set from each search performed during the session is listed. These data can be investigated further using the 'View Summary' button. Here the 'Add to Basket' button can be checked for the data sets to be further explored. From the Basket tab the spatial distribution of the data from any or all of the four searches can be previewed using the 'View Map' button. The user can decide which data to download and check the 'Build Download' tag, also in the Basket tab. The user is notified when the download file is built with an email containing a link to the file. The data can then be copied to the local hard drive.

Also on the Basket tab items can be deleted from the basket, or extra ones added by reviewing the Results tab. Alternatively the user could return to the Search tab and refine the search or start a completely new search.

4.5 Concluding Remarks

Within the NWSJEMS work-plan, the Data Management Project had to complete its objectives relatively early so as to provide the data and data-management tools required by the other projects and by data users more generally. This has been achieved. For the first time, the data sets compiled through NWSJEMS consolidate a great deal of previously scattered information from a wide range of sources. In some cases data sets previously available only in obscure reports has been made electronically available. And an effective GIS approach to facilitate gathering of 'expert opinion' has been developed and applied so as to make this knowledge electronically available. The Department of Environmental Protection Marine GIS Data Management System has been considerably enhanced in both its content and capability, and is available to support decision making at regional level and within each of the sectors of human use. A web-based tool Data Trawler has been developed that allows data access, review and transfer across different computers and programs. This provides for 'distributed' access and use of information, while maintaining data confidentiality requirements, and opens the way for information to be used and exchanged in many contexts – from sending a stakeholder a map through to linking with detailed scientific models.

While some data acquisition and management will continue, the main emphasis for the remainder of NSWJEMS is on use of the information available in models of the NWS and evaluation of management strategies. These activities are expected to require some further refinement of the data management and access system. In particular, the scope and possibility of a 'user friendly' interface for the management strategy evaluation scenarios is being examined.



5.1 Introduction

This chapter describes the key characteristics of the NWS ecosystem. It provides a new description of the physical, chemical, and ecological environment of the NWS. Analysis of available physical and chemical data has produced a comprehensive seasonal description of wind patterns, ocean temperatures, salinities, nutrients, and chlorophyll. An inventory and interpretation of contaminant inputs on the NWS has also been developed. The NWS ecosystem has been categorised by identifying a hierarchy of bioregions corresponding to different spatial scales, and each described in terms of the habitat units and ecological units relevant at that scale. Some potential interactions between human uses and several of these ecosystem bioregions are also outlined.

The descriptions developed here provide the basis for understanding many aspects of ecosystem variability, such as the impacts of tropical cyclone events and interannual changes associated with El Nino events. They also provide some of the key information and interpretations needed to identify and model the underlying dynamical processes operating on the North West Shelf.

5.2 The Physical and Chemical Environment

Seasonal wind patterns

Regional wind patterns over the NWS have been studied using the National Centre for Environmental Prediction – National Centre for Atmospheric Research (NCEP-NCAR) 40-year Reanalysis data set (Kalnay et al. 1996). Seasonal wind patterns have been derived by vector averaging the 12 hourly outputs of the NCEP-NCAR dataset across the years 1982 to 1999. The results demonstrate the seasonal cycle of southeasterly trade winds over winter, switching to southwesterlies over summer as the trades are displaced to the south by equatorial westerlies (figure 5.2.1). While this product provides an excellent representation of the seasonal wind patterns, its relatively coarse temporal and spatial resolution (12 hourly and 1.8°) means that it cannot represent well the coastal sea breeze (figure 5.2.2) and tropical cyclones (Condie and Andrewartha 2001).

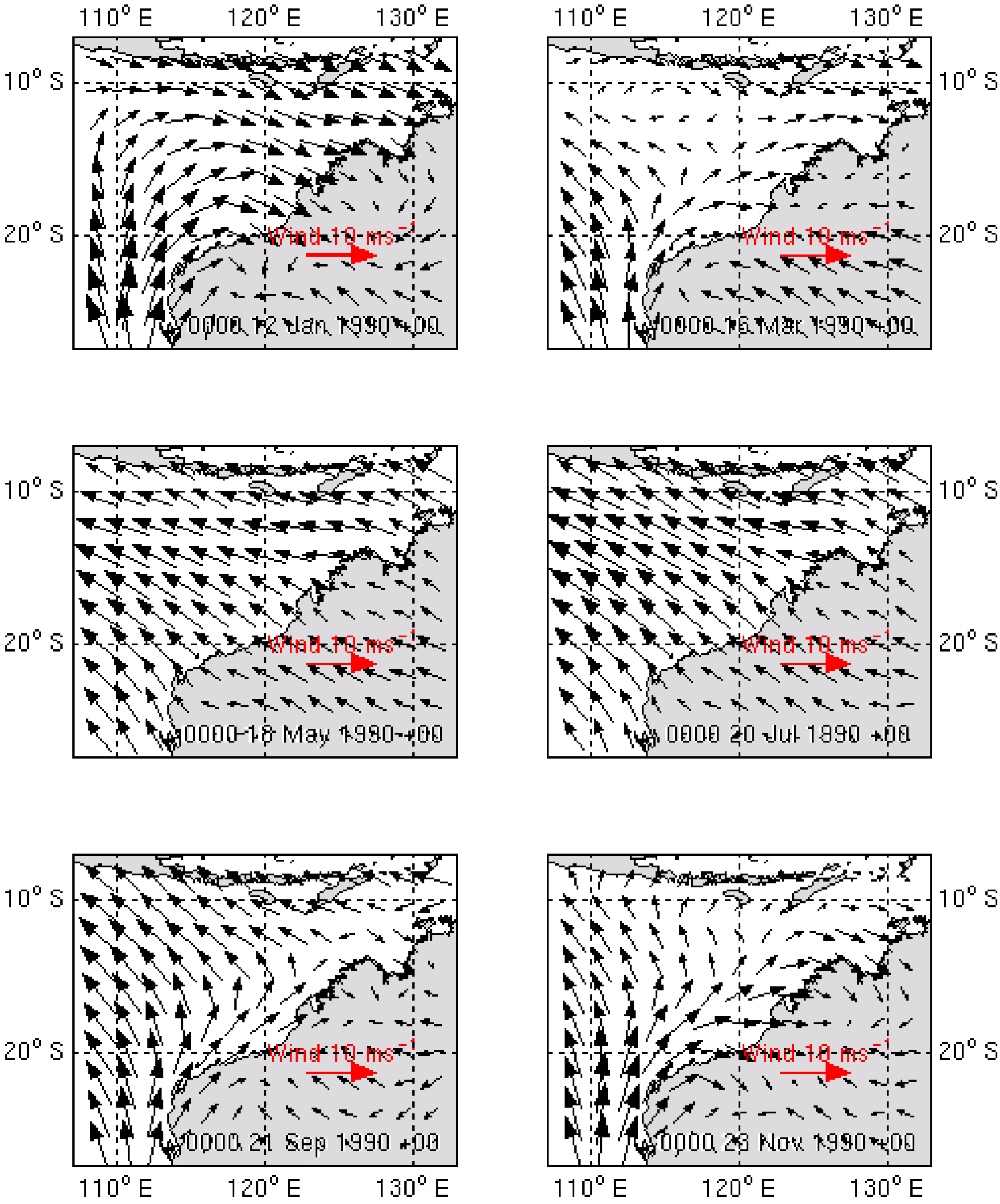


Figure 5.2.1: Seasonally averaged winds on the NWS at a height of 10 m above mean sealevel during January, March, May, July, September, and November. These fields were calculated by vector averaging the 12 hourly outputs of the NCEP-NCAR dataset across the years 1982 to 1999.

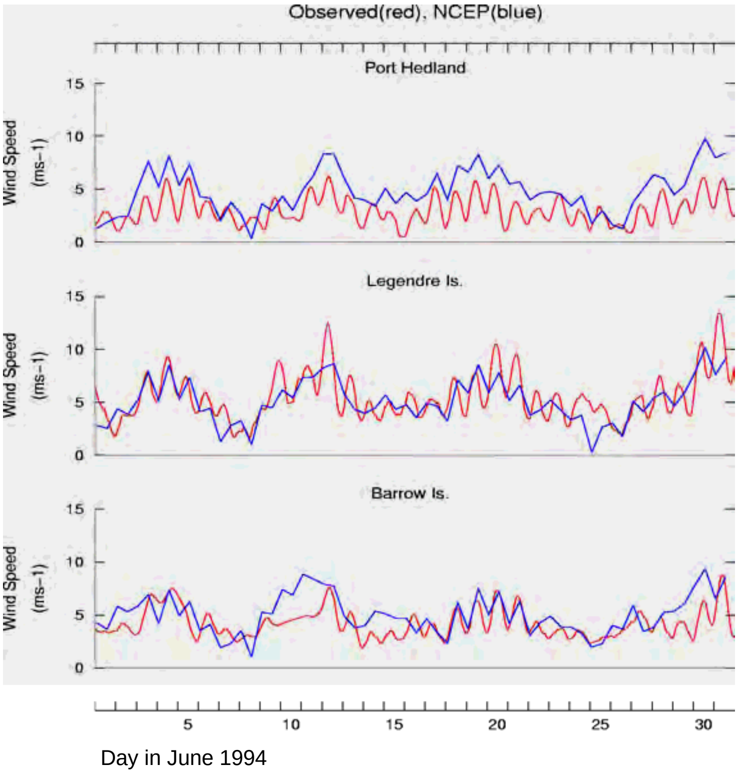


Figure 5.2.2: Time-series comparisons of locally observed wind speeds (red lines) verses NCEP-NCAR wind speeds (blue lines) at coastal stations for June 1994.

Seasonal patterns of ocean temperature and salinity

A comprehensive dataset of conductivity-temperature-depth (CTD) and hydrographic casts has been assembled from sources such as the World Ocean Database (WOD98, Conkright et al., 1998) and CSIRO archives. After applying stringent quality control measures to the dataset, individual casts were interpolated vertically onto a series of standard depth levels and horizontally onto a 0.125° grid using a locally-weighted least squares filter (Cleveland and Devlin, 1988). Seasonal patterns (annual and semiannual harmonics) were simultaneously fitted to minimise the impact of seasonal biases in sampling. Special schemes were also developed to reduce smearing of the tracer structure across land barriers and between shelf and offshore waters (Dunn and Ridgway 2001), so as to preserve structural differences between regions such as Exmouth Gulf and the open waters to the west.

The summer temperature field on the NWS shows values ranging from 25°C in Exmouth Gulf to around 28°C near Dampier and Port Hedland (figure 5.2.3). However, gradients in the offshore direction are quite weak. This contrasts to the winter fields, where the shelf waters are preferentially cooled below 23°C, with significant gradients maintained across the shelf break. The salinity field shows less seasonal variability, although values fall over autumn as the low salinity water from the Leeuwin Current and Indonesian Throughflow arrives (figure 5.2.4). The summer salinity peak is amplified over the shelf by high evaporation rates, particularly around the Dampier Archipelago.

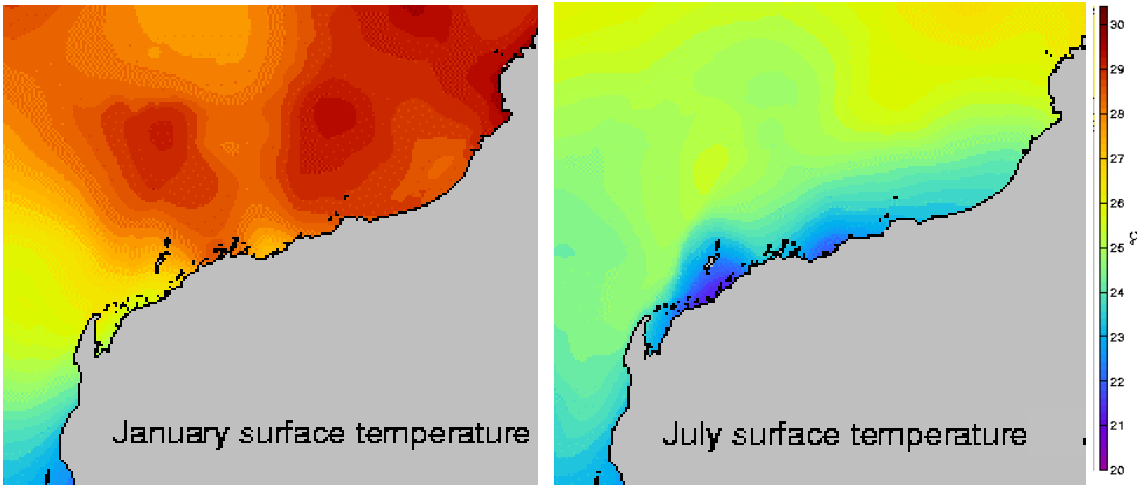


Figure 5.2.3: Seasonally mapped surface temperature field (°C) in summer (left) and winter (right).

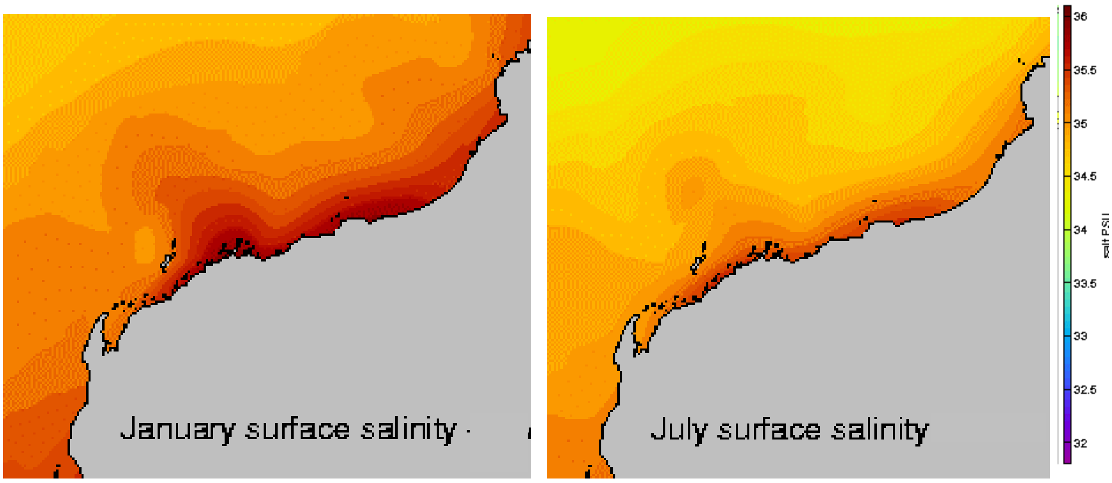


Figure 5.2.4: Seasonally mapped surface salinity field (PSU) in summer (left) and winter (right).

Seasonal nutrient patterns

The seasonal patterns of nutrients such as nitrate, phosphate, and silicate have been mapped using the methodology described for temperature and salinity (Dunn and Ridgway 2001). The only significant source of nutrients is through upwelling. Since this process tends to be suppressed by the Leeuwin Current and Indonesian Throughflow, seasonal cycles for all of the nutrients are weak. Surface nitrate levels are low throughout the year and likely limit primary production, particularly in Exmouth Gulf and east of the Dampier Archipelago (figure 5.2.5).

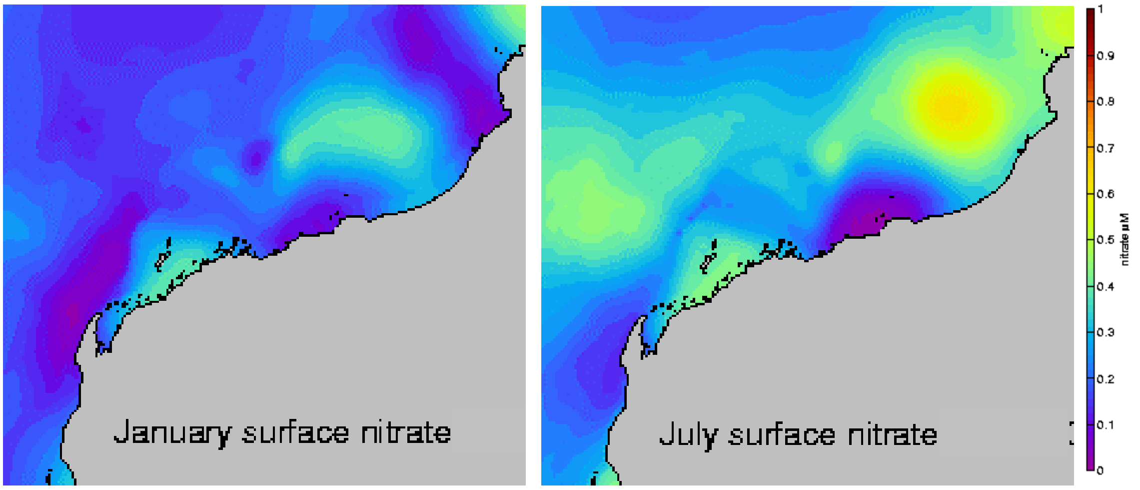


Figure 5.2.5: Seasonally mapped surface nitrate (NO_3: µmol) in summer (left) and winter (right).

Other sources of nutrients

The major anthropogenic sources of nutrients being discharged into the NWS are from wastewater treatment plants at Dampier, Woodside's onshore treatment facility on Withnell Bay, and at the Dampier salt ponds. Another wastewater treatment plant at Wickham ceased discharging into the ocean in 1999. The total nitrogen loadings from these sources (Table 5.2.1) are very small compared to more developed areas in Australia such as Cockburn Sound (3000 tonnes/year, Department of Environmental Protection November 1996, *Southern Metropolitan Coastal Waters Study (1991 – 1994): Final Report, Report 17*) and Port Phillip Bay (6000 tonnes/year, CSIRO 1996, *Port Phillip Bay Environmental Study: Final Report*,). They are also smaller than estimates of the natural groundwater loading (13 tonnes/year per kilometre of coastline, Appleyard 2000) and do not appear to have had any local impact. Flushing by large tidal currents should ensure rapid assimilation of these inputs through natural biogeochemical processes.

Table 5.2.1: Annual loadings of nitrogen (tonnes/year) from major point source discharge locations.

	Location			
	Dampier Salt	Woodside OTP	Wickham WWTP	Dampier WWTP
Maximum (year)	0.229 (1999)	8.787 (1989)	3.073 (1998)	1.821(1999)
In year 2000	0.180	0.283	ceased	0.776

Seasonal ocean colour patterns

A measure of phytoplankton biomass in the surface waters of the NWS can be derived from satellite ocean colour measurements. Seasonal patterns of phytoplankton have been mapped using the SeaWiFS ocean colour dataset (figure 5.2.6). Off the shelf, phytoplankton concentrations are very low in summer, but increase over winter in response to higher nitrate levels (figure 5.2.5). The seasonal cycle on the shelf is more unusual in that phytoplankton increase over summer as the mixed layer depth diminishes and surface nutrient levels fall. This is confirmed by in situ measurements and appears to be a consequence of summer upwelling of nutrient rich slope water supporting higher productivity below the mixed layer (Holloway et al. 1985, Tranter and Leech 1987). With the very shallow mixed layer, the subsurface phytoplankton maximum is at least partially visible to the ocean colour instrument.

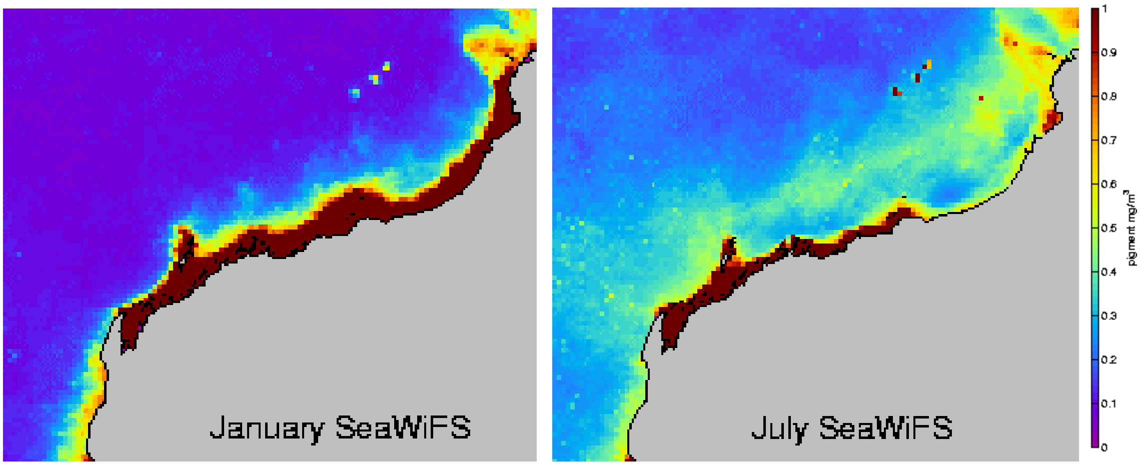


Figure 5.2.6: Seasonally mapped chlorophyll concentration (Chl-a: mg m^{-3}) derived from SeaWiFS ocean colour data in January (left) and July (right). Nearshore values may be contaminated by suspended sediments (SeaWiFs Technical Report 1997).

5.3 Contaminants

The NWS has been subject to inputs of contaminants (toxicants and nutrients) from a variety of point and diffuse sources over the last 30 years. Effective environmental management relies on an understanding of the sources, types and quantities of wastes discharged, and their cumulative environmental consequences. It was noted above that nutrient inputs are likely to be of limited concern. However, there is a range of toxicants which also needs to be quantified. These include oil and produced formation water (PFW) from oil and gas production, drilling fluids used for exploration, tributyltin (TBT) leaching from ship hulls, and heavy metals from industrial processes.

A contaminants input inventory of historic contaminant inputs from known point and diffuse sources on the NWS has been developed to help determine the loads on the marine ecosystem and the potential for detrimental impacts. Contaminants data have been acquired from sources such as industry reports and government departments (Department of Minerals and Petroleum Resources, and Department of Environmental Protection). The petroleum industry is required to report data on discharges of oil and assess the environmental effects and risks of PFW to Department of Minerals and Petroleum Resources, while the Department of Environmental Protection licenses discharges containing a variety of contaminants in WA state waters. The point source data consist mainly of petroleum-based compounds, heavy metals and various other chemicals associated with industrial effluents, and nutrients from sewage treatment plants (table 5.2.2). The inventory is an electronic database covering the period 1985 to 2001 and includes discharges at 17 locations (figure 5.3.1). It is linked to a GIS, which allows time-series of annual contaminant loadings to be displayed (figure 5.3.2) by selecting a discharge sited on the map of the NWS.

Contaminant (year 2000)	Location															
	Dampier Salt Ponds	Airlie Island	Harriet A	Harriet B	Harriet C	Stag	Griffin	Vicksburg	Wandoo	Thevenard Island	Cossack Pioneer	Goodwyn	North Rankin	Woodside OTP	Wickham WWTP	Parker Pt Power St	Dampier WWTP
Arsenic (kg/yr)			6.7														
BOD (kg/yr)																	362
Cadmium (kg/yr)			13											< .8		252	
Calcium (tonnes/yr)	231																
Chlorine																	
Chromium (kg/yr)			154													1494	
Cod (tonnes/yr)														7.6			
Copper (kg/yr)			31											< .8		450	2.2
Glycol (tonnes/yr)														1.6			
Iron (tonnes/yr)			2.7														
Lead (kg/yr)			62											< .8		565	
Manganese (kg/yr)			57														
Mercury (kg/yr)			.62													0	
Nickel (kg/yr)			62														
Oil (tonnes/yr)		5.6	56	0	0	5.5	35	0	93	0	1.6	5	2.5	.26			
PFW (million kl/yr)		.41	2.7	0	0	.29	1.7	0	6.0	0	.25	.24	.06				
Surfactants (kg/yr)														50			
Susp. Solids (tonnes/yr)			33											1.8			1.3
Sulfinol (kg/yr)														0			
Sulphate (tonnes/yr)	274													23			
Sulphide (kg/yr)														36			
TDS (tonnes/yr)																	34
Total N (tonnes/yr)	.18		140											.28	0		.78
Total P (kg/yr)			679											71			
Zinc (kg/yr)			31											4.3		8145	4

Table 5.3.1: Summary of contaminants and their discharge location contained in the contaminants inputs inventory for the year 2000. A blank entry means that there is no data or no discharge for these contaminants. A zero value means that discharges have occurred in previous years but are reported to be zero for this particular year. Discharge locations are shown in figure 5.3.1.

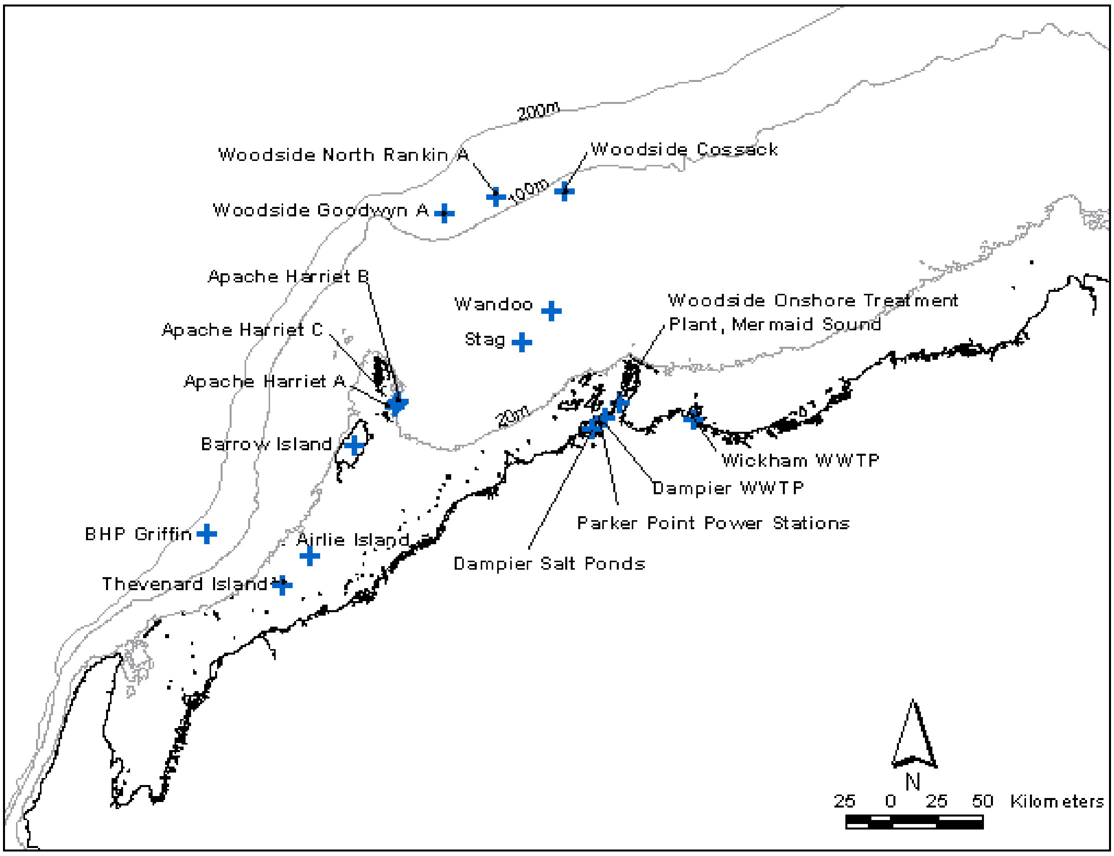


Figure 5.3.1: Contaminant discharge locations within the study area.

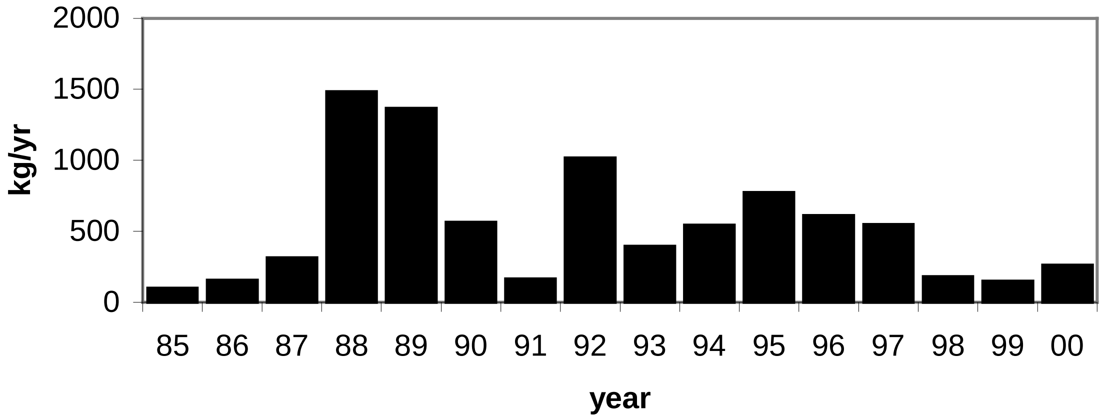


Figure 5.3.2: An example of the GIS time-series display for oil discharged at Woodside's onshore treatment plant on Withnell Bay.

Produced formation water

PFW containing oil is discharged from 9 offshore petroleum facilities in the study area, with total annual loads increasing from 7.5 million tonnes in 1996 to over 12 million tonnes in 2000. Over the same period the component of oil discharged increased from 110 tonnes to 214 tonnes per year (figure 5.3.3). These quantities are low compared to major tanker spills such as the Kirki in 1991 (18,000 tonnes). They are also most likely to be much lower than the amount of natural oil seeps, which are known to be very prevalent on the NWS. Based on geological considerations, Wilson et al (1974) estimated that the amount of hydrocarbons from natural seeps entering the ocean on a global basis each year is about 0.6 million tonnes. They also estimated that 45% of this seepage comes from areas of high seepage, 55% from areas of moderate seepage and less than 1% from areas of low seepage. The NWS is identified as an area of moderate seepage, and probably accounts for at least 1% of the global moderate seepage areas. On this basis, natural seepage of oil on the NWS is at least 3300 tonnes annually. This is an order of magnitude larger than discharges from production platforms. However, the ecological impacts of these discharges remain largely unknown.

There are few acute toxicity data for the effects of hydrocarbons on NWS biota, and even less for chronic and sublethal data (DA Lord Science and Engineering, 2002). The ANZECC/ARMCANZ (2000) guidelines are of limited use because of the widely varying composition of petroleum hydrocarbons. In the absence of toxicity data for specific hydrocarbons the ANZECC/ARMCANZ (2000) guidelines have adopted an interim chronic value for total petroleum hydrocarbons of 7µg/l (Tsvetnenko, 1998).

The only detailed study of the fates and effects of hydrocarbon discharges on the NWS was carried out by Burns and Codi (1999) in 1994-95 around the Harriet A production platform (fig. 5.3.1) when the annual oil discharge was around 65 tonnes. They found sublethal effects on marine plankton and bacteria up to 1.8 km from the platform, corresponding to hydrocarbon concentration levels in the surface microlayer of between 9.4 and 111µg/l. In high seawater samples the largest measured concentration was 8.5 µg/l at a station 720 m from the platform. Oysters showed some uptake and accumulation of hydrocarbons at stations up to 1 km from the platform.

Further characterisation and toxicity data for the effects of hydrocarbon discharges from petroleum facilities on the NWS is needed. While acute effects have not been observed the major concern is with chronic and sublethal effects, and the ANZECC/ARMCANZ (2000) approach of developing tests for a minimum of five species from four trophic levels is recommended (DA Lord Science and Engineering, 2002).

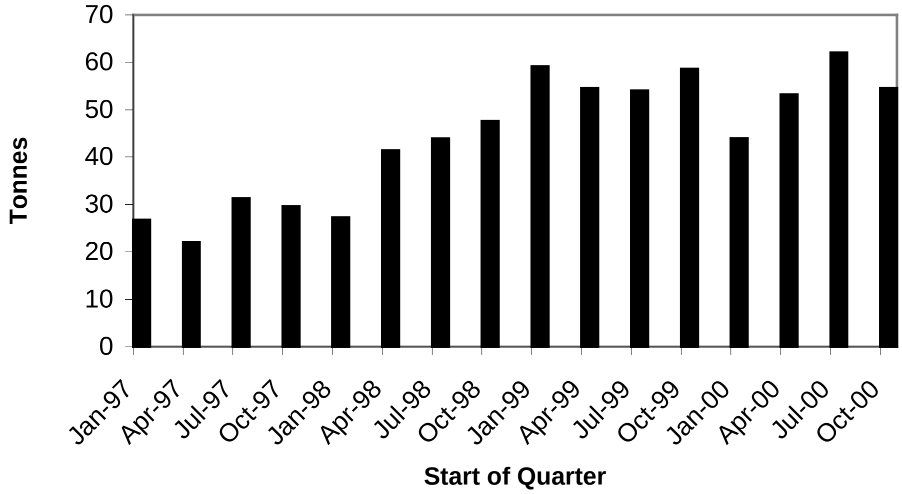


Figure 5.3.3: Quarterly discharge of oil in PFW from all production platforms in the study region.

Heavy metals

Another potentially significant component of industrial wastewaters discharged into NWS waters is heavy metals. At all but Hamersley Iron Parker Point Power Stations, the reported annual loads are small (Table 5.3.1) and have decreased considerably over the past 8 years. For example at Woodside's onshore treatment plant at Withnell Bay, zinc discharges have decreased from 100kg/year in 1993 to 4.3kg/year in 2000. Discharges of copper have not exceeded 11kg/year (1995), while discharges of cadmium and lead were less than 5.5kg/year (1997) and 24.4kg/year (1995) respectively. In 2000 the discharge loads of copper and cadmium and lead were less than 0.8kg/year.

At the Parker Point sites annual loads of cadmium, chromium, copper, lead and zinc ranged from 252 kg/yr for cadmium to 8145 kg/yr for zinc. These are far higher than those at the other site and may be cause for concern, particularly for benthic habitats exposed to high concentrations of heavy metals that are likely to be accumulating in the bottom sediments. To determine the potential environmental impact, an investigation of heavy metals in sediments affected by the effluent discharges from the Parker Point power stations will be required.

Apache Energy reported discharges in 2000 of cadmium, copper, lead and zinc at the Harriet A platform of 12.8, 30.9, 61.7 and 30.9 kg/year respectively. The concentration levels in surrounding waters were estimated to be less than 0.02µg/l for cadmium and less than 0.1µg/l for copper, lead and zinc. These levels are all much lower than the highest level of protection specified in the ANZECC/ARMCANZ (2000) guidelines, which are 0.7µg/l for cadmium, 0.3µg/l for copper, 2.2µg/l for lead and 7µg/l for zinc. Accumulated levels in sediments around Woodside's onshore facilities at Withnell Bay and King Bay were also lower than the ANZECC/ARMCANZ (2000) screening levels, except for one site where lead exceeded the guidelines by 30%. Accumulated levels in oysters in the same area were generally within National Food Authority Guidelines (NFA, 1994), with slightly higher levels for copper and zinc.

Metal concentrations are also elevated above background in cuttings piles around Woodside's production platforms due to the use of drilling fluids containing a variety of metals (Oliver and Fischer, 1999). While metal concentrations are still well below the ANZECC/ARMCANZ (2000) guidelines, continued monitoring will be necessary to ensure that they remain at safe levels.

Tributyltin (TBT)

The predominant contaminant of concern in ports is the antifoulant ingredient, tributyltin (tbt). TBT is toxic to a wide range of organisms, at concentrations as low as 0.001 to 0.1µg/l (DA Lord Science and Engineering, 2002). By estimating the potential loading of TBT into the major NWS shipping ports of Port Lambert, Port Hedland and Dampier, Crawley (2000) calculated the TBT concentration in the harbour waters to be 0.008µg/l. This exceeds the 95% species protection level in the ANZECC/ARMCANZ (2000) guidelines of 0.006µg/l. While this may be of concern, these calculations ignore the dynamical effects of tides and other ocean currents which would cause flushing and dilution.

Reitsema and Spickett (1999) surveyed TBT levels in water and biota along the coast in the Dampier Archipelago and found concentrations of TBT in water to range from 0.0003 to 0.025µg/l. They found imposex and other effects, such as reduced growth and reproduction in neogastropods, at concentrations as low as 0.002µg/l. At these TBT concentrations, Negri and Heyward (2000) also reported effects on coral. These data suggest that the ANZECC/ARMCANZ (2000) 95% guideline value may not be sufficiently protective in NWS waters and the highest level of protection of 0.0004µg/l, TBT, may be necessary.

5.4 Spatial Units and Characterisation of the Ecosystem

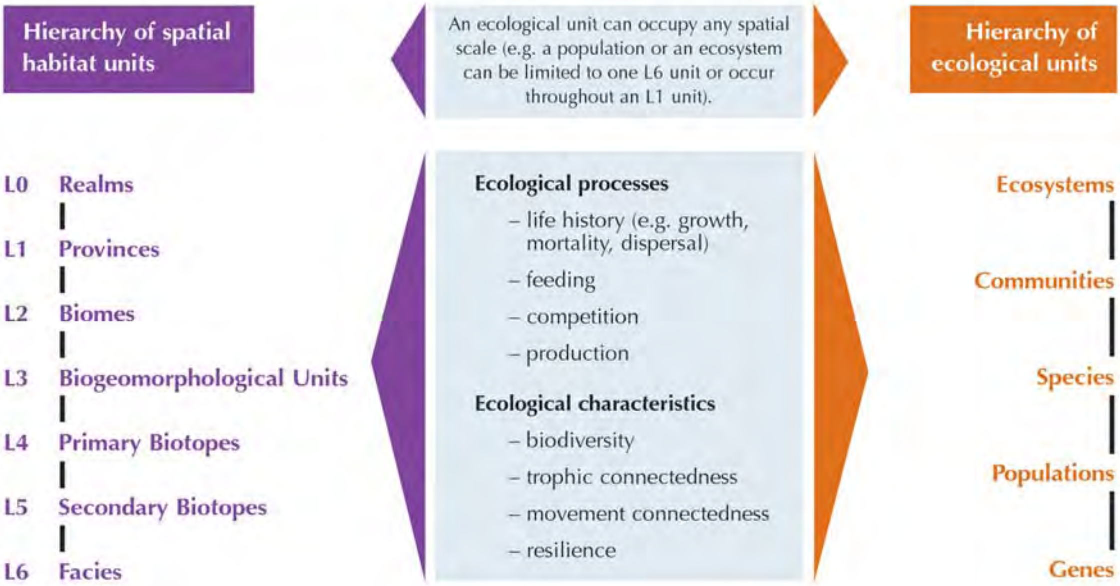
Ecosystems are structured and function at all space and time scales, including across a large range of space scales. For example the NWS ecosystem includes microbial communities that occupy millimetres and the seasonal migration of large pelagic species that can straddle several of the earth's oceans. Different scales are relevant for different purposes and considerations. Scientific description of ecosystems and practical resource management both require and use the concept of habitat units and spatially structured units, either implicitly or explicitly. For example spatial structure and spatial units are used in zoning and management of human activities, for planning and locating marine protected areas, for assessing biodiversity, and to structure scientific analysis of the impacts of human use. One part of the scientific support for understanding ecosystems, and the human impacts on them, is the systematic identification and description of the ecosystem on different scales. This applies particularly to the description of habitats, as habitats are commonly used as a surrogate for many other ecological attributes and functions that are difficult to measure (eg biodiversity).

A hierarchical description of the habitats on the NWS was developed through NWSJEMS. This first involved developing a conceptual framework for classifying coastal and marine habitats. The application of this framework to the NWS illustrates the integration of diverse physical, biological and geological information of various types and scales. Ideally the hierarchical description of habitats would include consideration of variability in time. The seasonal patterns of change could be identified on the NWS for some physical and chemical properties, as described in Section 5.2 above. The data available on the biota were generally insufficient to allow this analysis of the habitats, and so only static spatial representations of the NWS habitats were identified.

A hierarchical classification of ecosystems

A hierarchical classification scheme was developed to describe the benthic habitats of the NWS, although its generic structure means that it would be applicable to most marine systems. This scheme was developed after reviewing classification schemes published elsewhere around the world, taking into account conditions on the NWS, and collecting additional information from relevant experts. This classification scheme is described in detail in Appendix B and illustrated in Figure 5.4.1.

Figure 5.4.1. The hierarchical classification framework used for habitat units on the North West Shelf, and its relationship to ecological units. The ecological and habitat units are structural units of the ecosystem, and are related by ecosystem function. Level 1 is the largest spatial unit and level 7 the smallest in this classification.



This approach to habitat classification treats habitats and ecological units (e.g. community, population, species, genes) as complementary elements which are linked by ecological processes. The hierarchy of habitat units proceeds through a number of space scales from large (biomes) to smaller (e.g. facies) units, with each having a specific set of characteristics. While the habitat units and ecological units can each be regarded as hierarchical within themselves, they are each hierarchical in relation to different concepts and so there is no necessary matching between the hierarchies. For example a population is relatively low in the hierarchy of ecological units but this does not necessarily imply that the relevant habitat is also low on the hierarchy of habitat units. General and illustrative examples of the kinds of habitats that might be relevant at each Level on the NWS are provided in Table 5.4.1. Also see Appendix B for a full description of a hierarchical classification system for marine habitats. The actual habitats defined for the NWS ecosystem are described later in this Chapter.

Level	Names	Examples
1	Province	The whole NWS is one province
2	2a Biome	Demersal shelf
	2b Sub-biome	Inner, mid-, outer shelf
3	Biogeomorphological units	Sandbanks, rocky banks, seamounts
4	Primary Biotopes	Shelly/sandy regions within coral reefs
5	Secondary Biotopes	Sediment types (calcareous…) or biota (seagrasses…)
6	Biological Facies	Biological indicator (a seagrass species …)
7	Microcommunities	Species that depend … (seahorse species on seagrass…)

Table 5.4.1 General examples of the hierarchical scheme for habitat mapping and classification shown in Figure 5.4.1.

Information sources

The information used to develop the hierarchical description included both existing electronic data and the knowledge in the memories of experts who have lived or worked on the NWS. The electronic data were obtained from the holdings of numerous private companies and local, State and Commonwealth Government agencies and include in situ measurements, photographic data, and satellite imagery.

The various data types were converted into a common data format and common coordinate system. The standardisation to a common spatial reference system allows all of the layers to be visualised and compared within the NWSJEMS Geographical Information System (GIS), as well as supporting more sophisticated spatial analysis. The data layers now available in the GIS include:

- marine and coastal habitats;
- bathymetric and terrestrial contours;
- catchment boundaries; and
- flora and fauna.

Key habitats or ecosystem attributes mapped include coastal mangroves, mudflats, coral reefs, sub-tidal vegetation, sessile faunal gardens, water bodies, sediments, and nutrients (figures 5.4.2 and 5.4.3).

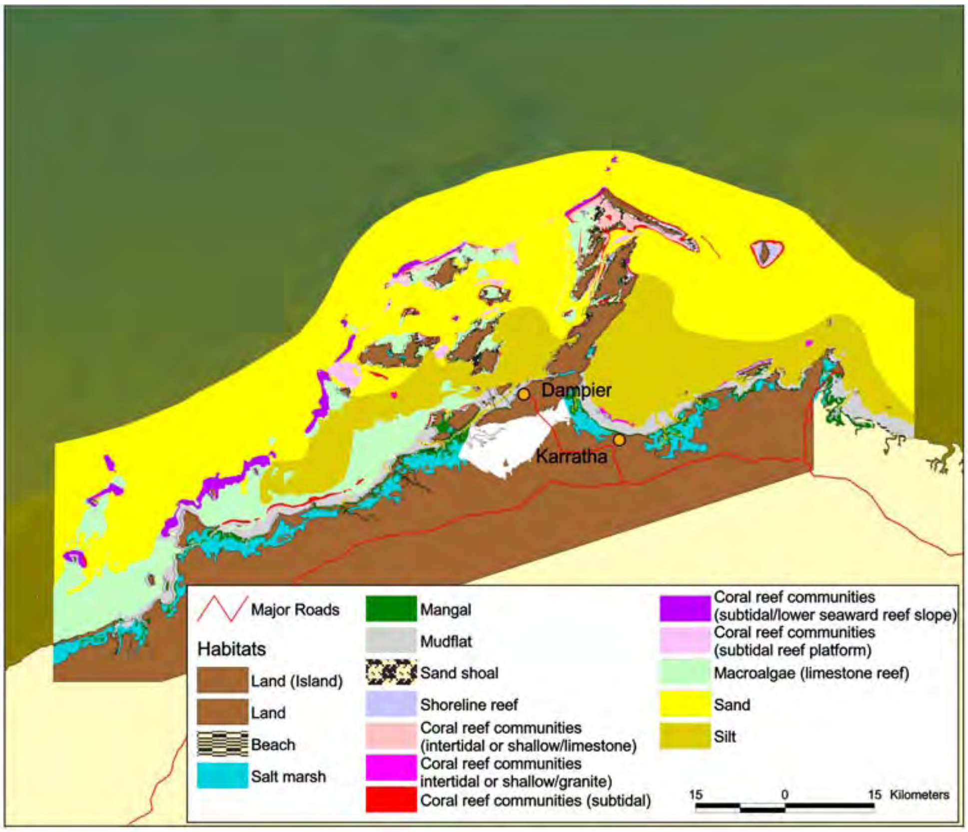


Figure 5.4.2: Compilation of habitat information around the Dampier Archipelago (Department of Conservation and Land Management).

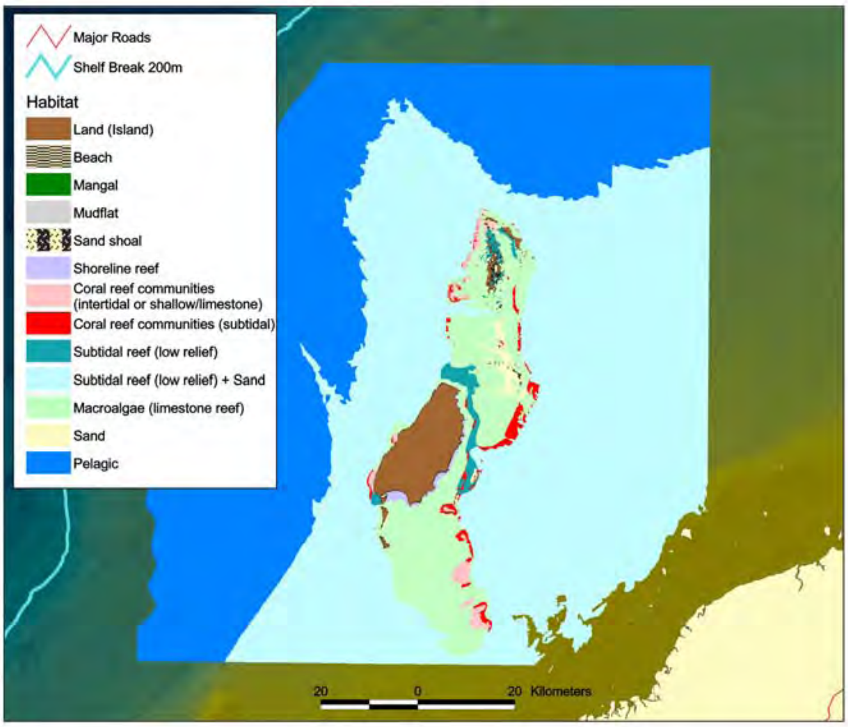


Figure 5.4.3: Compilation of habitat information around Barrow Island.

The knowledge of field experts was captured through a series of personal interviews. An interactive laptop computer query system was developed to provide a wide range of information about the study area for experts to comment on and modify as appropriate. This is system was also used to record new information provided by the experts (as described in Section 4.3). Much of this information was related to the locations and extent of habitat types, such as sandflats, mangroves, and coral reefs (figure 5.4.4). The data were quality-checked and entered into a GIS database. Maps were presented at a workshop in Perth in late 2000, where the experts again had the opportunity to correct any errors, provide additional information and suggest sources of additional information.

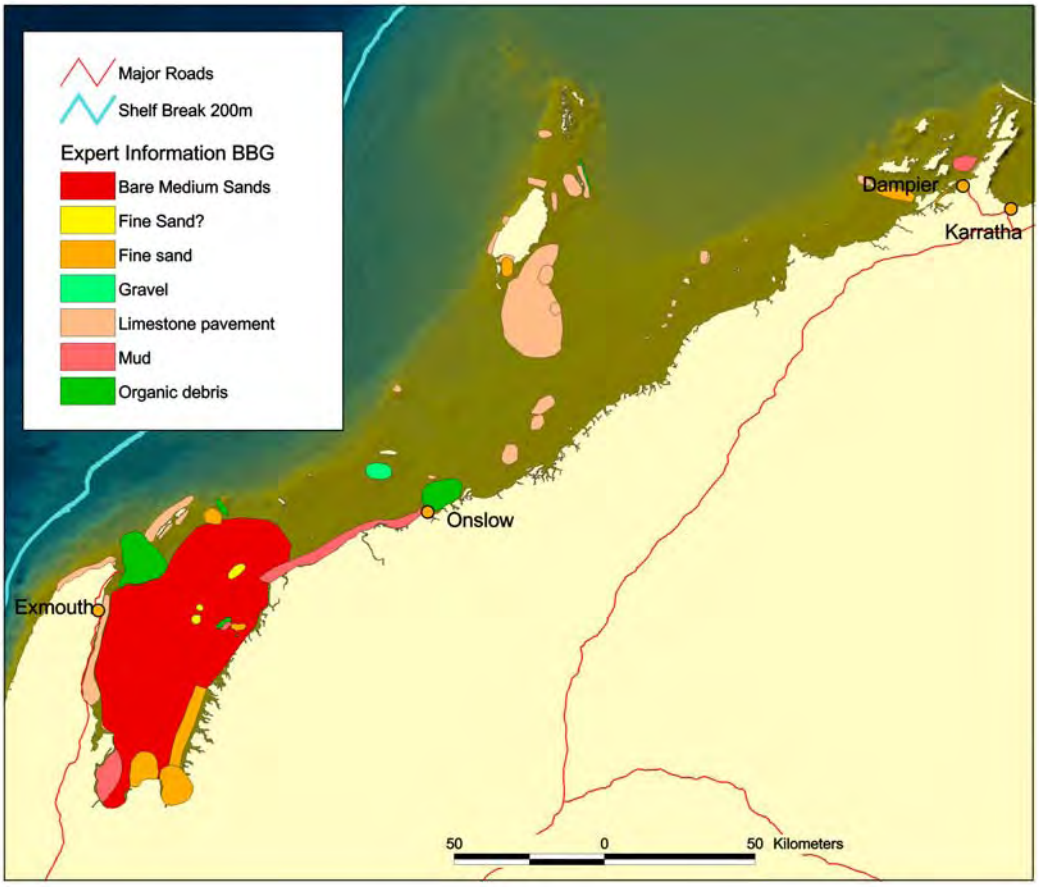


Figure 5.4.4: Seabed characteristics based on information from experts.

Characterisation of the NWS Ecosystem

By combining the available data from all sources, it was possible to regionalise the entire study area at hierarchical levels 1, 2 and 3 (i.e. to biogeomorphological units), and to regionalise the near-shore region to level 4 (primary biotopes, Table 5.4.1)). These regionalisations are available through the NWSJEMS data management tools such as Data Trawler (see Chapter 4 Information Access and Inquiry). While these regionalisation maps are available, they are regarded as interim at this stage in the study.

Level 1 is the provincial level, and on the basis of evolutionary biogeography and species ranges the entire NWS study area falls within one province. Level 2 distinguishes estuarine, coastal marine, and shelf biomes. These were mapped for the NWS on the basis of information on topography and general ecology. Identification of sub-biomic structure (level 2b and level 3), on the open shelf area of the NWS (ie from about 30m to 200m water depth), was based on statistical analysis of the fish species composition and photographs of the seabed habitat. Both of these data sets were collected from extensive trawl surveys. This analysis identified spatial units that are strongly related to depth, but also reveal significant along-shelf structure (figure 5.4.5). Such analyses were used to identify 43 Level 3 biogeomorphological units on the NWS (see Figure 5.4.6).

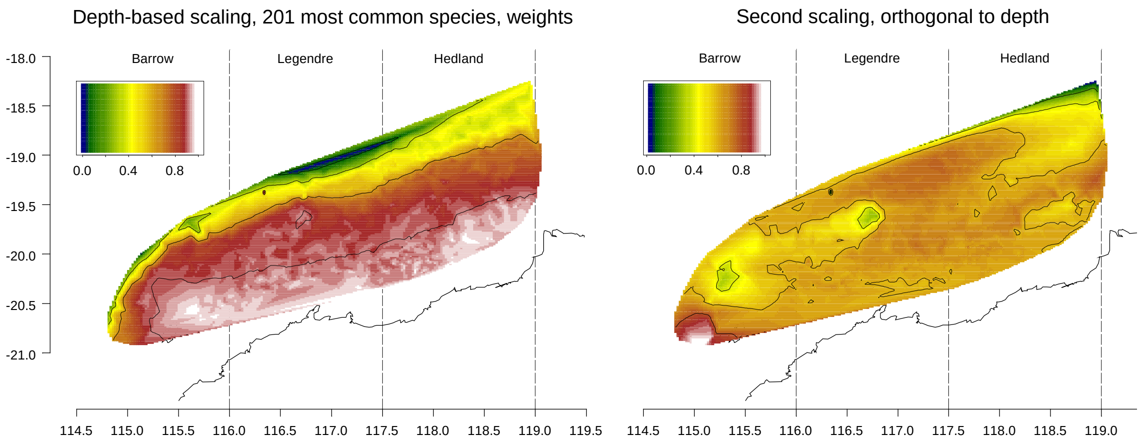


Figure 5.4.5: A detrended correspondence analysis (DCA) of the species composition of fish catches in research trawls. It shows distinct regions related to depth (left), and also patterns not related to depth (right). The contour lines delimit regions of similarity in both cases.

Regionalisation of the near-shore part of the NWS (ie within about 30m depth) was possible to Level 4 (i.e. primary biotopes). Some finer structure (levels 4 to 6) was also evident in the near-shore data (figures 5.4.2, 5.4.3, and 5.4.4). The near-shore regionalisation used ‘delphic’, expert opinion based methods because the available information was collected at different scales using a variety of techniques and could not be analysed using available statistical techniques. Through a series of analyses and workshops 115 Level 4 primary biotopes were identified in the near-shore region (figure 5.4.6).

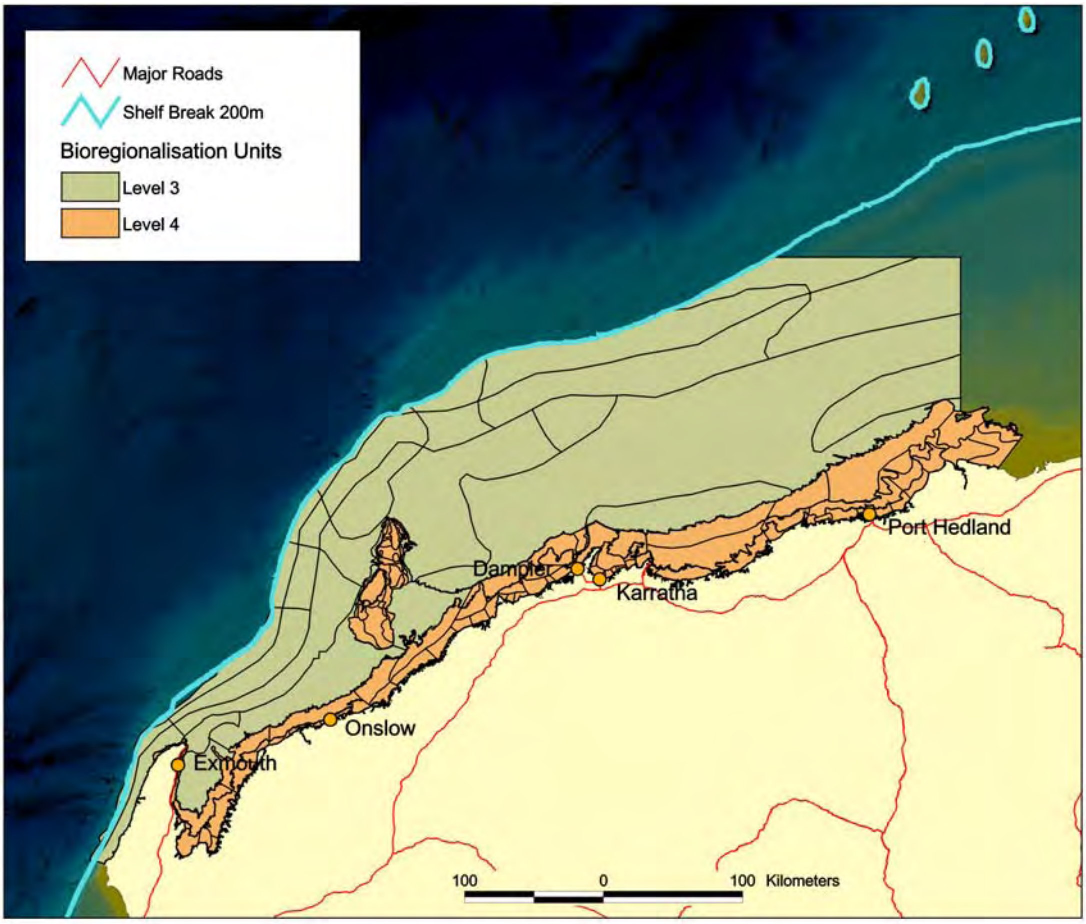


Figure 5.4.6: Ecosystem characterisation for the NWS showing biogeomorphological units for the offshore (level 3) and primary biotopes for the nearshore (level 4).

Interactions of ecosystem units with human activities and planning

The Level 3 and Level 4 bioregions identified in Figure 5.4.6 summarise a great deal of information about the NWS ecosystem and map some basic spatial units of the ecosystem. It is expected, for example, that these units would be broadly indicative of ecological features such as ecological communities, spatial patterns of biodiversity and spatial patterns in some ecological interactions (eg direct encounter and predation between individuals and species). These bioregions can also be considered in conjunction with the spatial distribution of human activities, impacts and zoning for management. Some examples of maps detailing key human activities have already been presented in Chapter 2 (figres 2.3.1, 2.3.3, and 2.3.4) and many others are available through the NWS GIS system (see section 4.4).

It is a simple matter to overlay maps of the bioregions and human uses to gain an initial and broad indication of how they might interact.

One example is in the design and evaluation of marine reserves on the NWS. The system of reserves currently proposed, cover many of the nearshore level 4 primary biotopes identified here, but none of the offshore level 3 units are currently represented (figure 5.4.7). A related feature of the proposed reserves is that they have little overlap with the trawl fishery (figure 5.4.8), and so they would not impact that industry's operations. However, the proposed reserves do encompass a significant number of oil and gas platforms around Barrow Island and the Monte Bellos (figure 5.4.9).

Oil and gas activities also coincide with a relatively large number of the level 3 ecological units identified on the NWS (figure 5.4.10). Oil and gas activities also coincide with the trawl zones in the western half of the study area (figure 5.4.11). The commercial trawl fishing zones in that area, currently closed to trawling, protect several of the off-shore ecological units in the western part of the NWS, and one of the units in the eastern part.

So even this simple examination indicates that there is potential for both fishing and oil and gas operations to impact on many of the off-shore ecosystem units, and that the proposed reserves would not be expected to protect these off-shore units or biodiversity. It also indicates that the oil and gas facilities are expected to directly impact only a relatively small number of the coastal Level 4 ecological units. Of course a more comprehensive assessment of interactions and impacts, such as that outlined in Chapter 7: Development Scenarios and Management Strategy Evaluation, would be necessary to evaluate the management options. But this ecosystem characterisation provides both the basis for initial qualitative assessments and information for more thorough analysis.

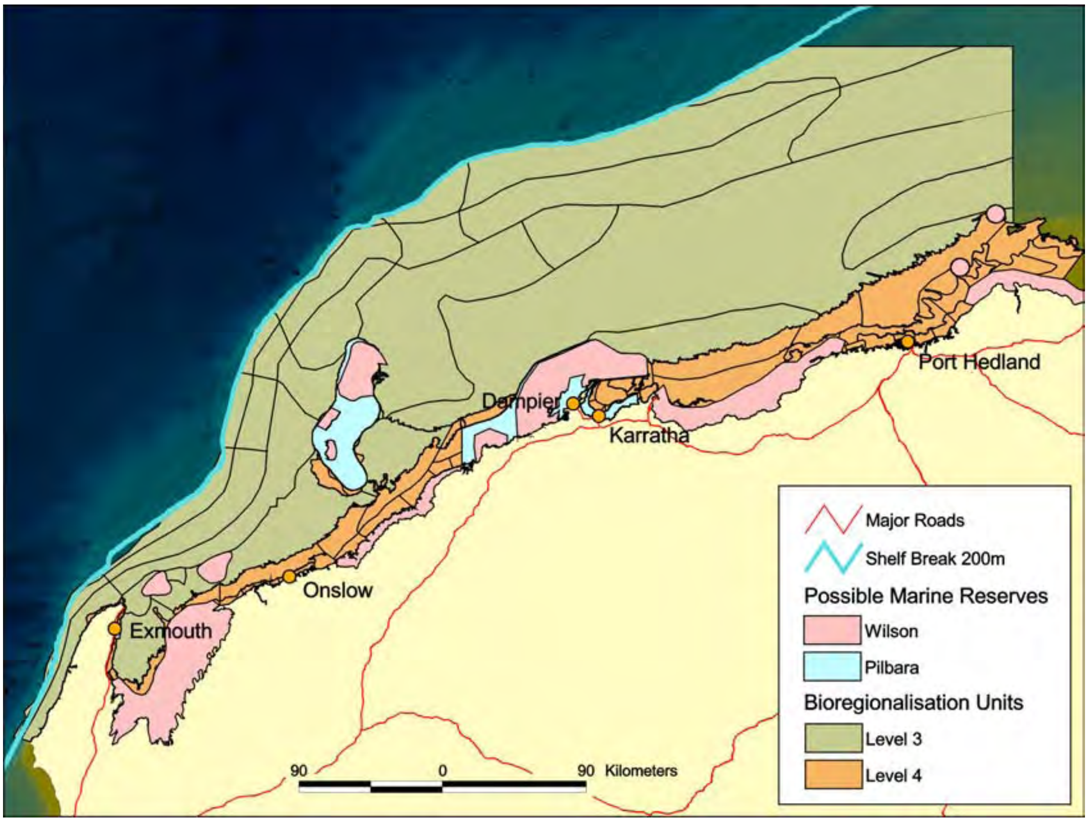


Figure 5.4.7: Proposed marine reserves overlaid on the level 3 to 4 bioregionalisation.

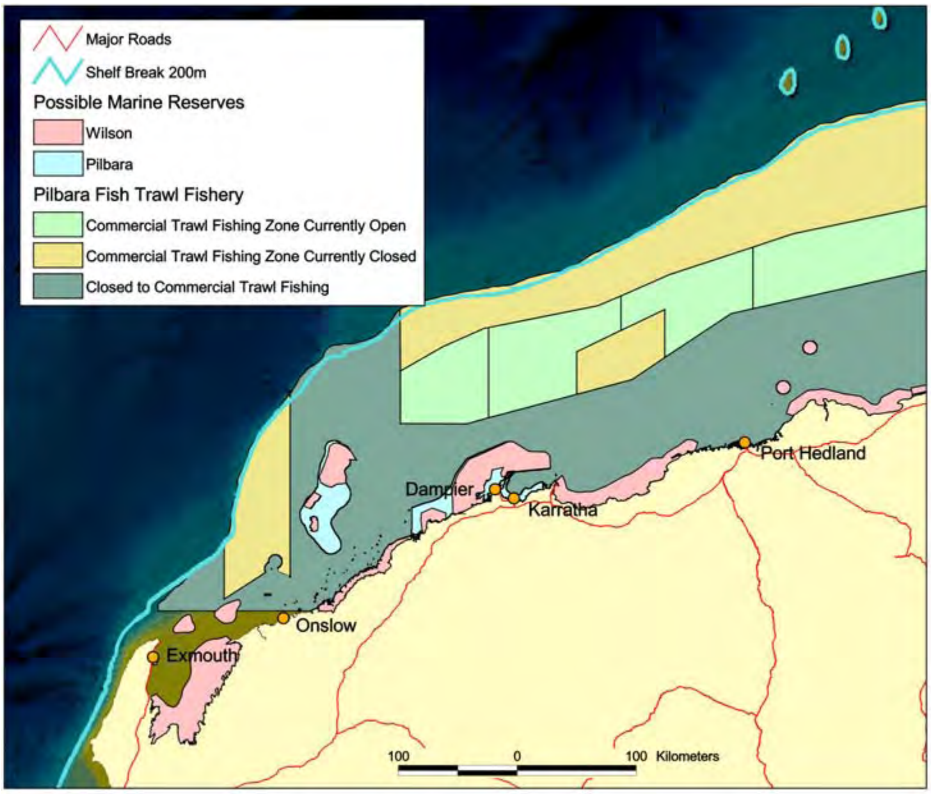


Figure 5.4.8: Proposed marine reserves overlaid on the commercial trawling zones.

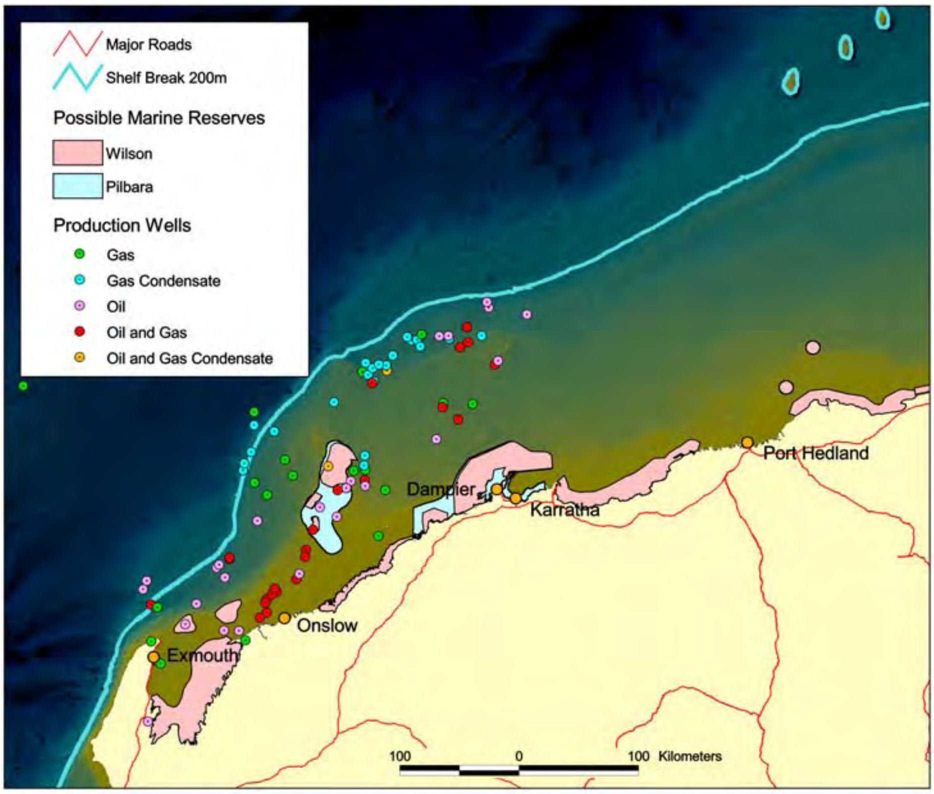


Figure 5.4.9: Location of production wells overlaid on proposed marine reserves.

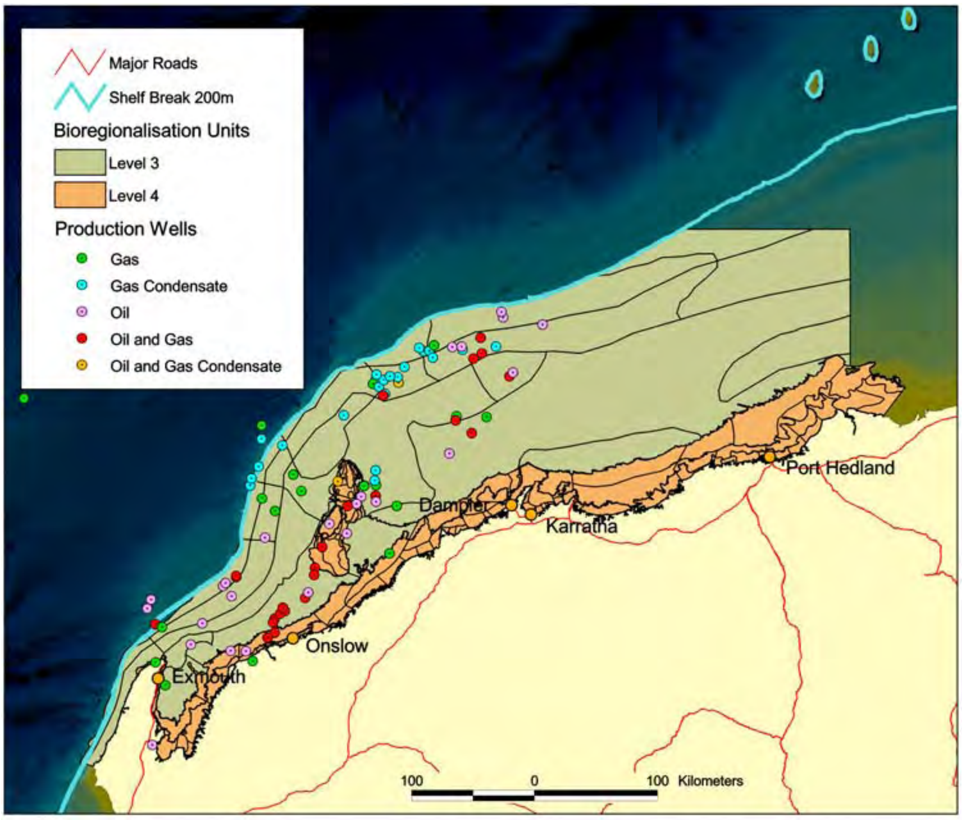


Figure 5.4.10: Location of production wells overlaid on the level 3 and 4 ecosystem regionalisation.

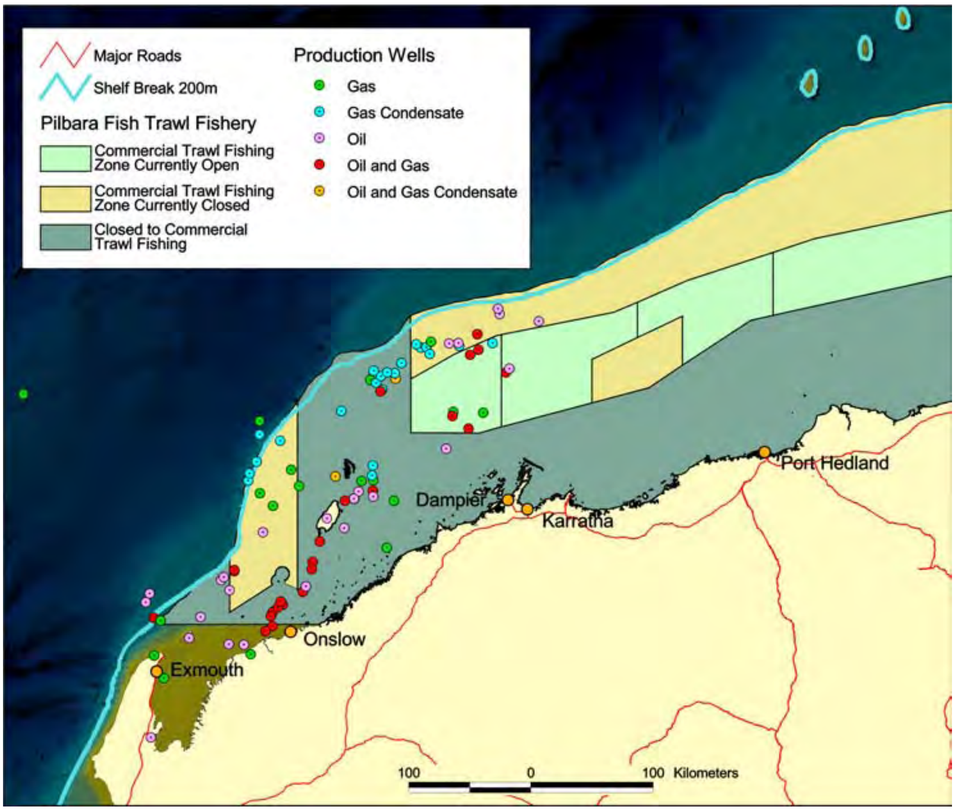
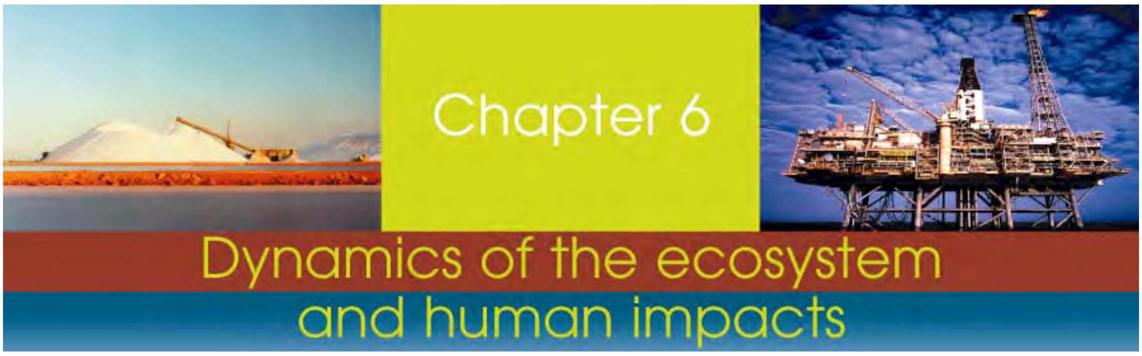


Figure 5.4.11: Location of production wells overlaid on commercial trawl zoning.

5.5 Concluding Remarks

The study's characterisation of the NWS environment is nearing completion. It has consolidated and analysed a very large amount of data and information from the NWS, and has produced easily available interpretations for use by industry, regulators, stakeholders and scientists. A comprehensive description of the physical and chemical environment is now available that allows users to access detailed information on winds, ocean water properties (temperature, salinity, nutrients etc), and chlorophyll concentration. Previously scattered information on contaminant inputs to the NWS has been compiled, analysed and made easily accessible. And a consistent characterisation of the main habitats and bioregions of the NWS ecosystem has been provided that is based on the available biophysical data, and the combined knowledge of many experts.

This component of NWSJEMS provides a comprehensive description of the NWS ecosystem, and a sound and accessible basis for improved understanding and management of this region. It also provides some of the key information and interpretations needed to identify and model the underlying dynamical processes operating on the North West Shelf.



6.1 Introduction

The physical, chemical, and biological processes, on the NWS, are complex and many are closely coupled. The NWS experiences large semidiurnal tides and internal tides, and is influenced by the monsoon wind patterns and larger scale ocean circulation of the eastern Indian Ocean. The incidence of tropical cyclones is also the highest along this part of Australia's coastline, with an average of two to three cyclones occurring in the study area per year. These processes each contribute to the movement of sediments, especially in the turbid coastal waters of the NWS, and control the supply of nutrients that support primary production in both coastal and off-shore waters. Intermittent disturbances, by processes such as tropical cyclones, are also thought to contribute to the high biodiversity found in the shelf habitats, such as coral reefs and benthic sponge gardens.

Human impacts are most clearly apparent in the coastal zone, where clearing of mangroves, dredging, construction of causeways, and other infrastructure developments change the ecosystem landscape and introduce various contaminants into the system. However, fishing, both recreational and commercial, is probably the most widespread human activity on the NWS and can be expected to have similarly widespread effects on the ecosystem in both coastal and off-shore areas. Trawl fishing is considered to be particularly likely to affect the off-shore marine ecosystem, because it catches a wide range of target and by-catch species and can damage seabed habitats. In addition, the large volume of shipping and offshore installations also poses a credible risk to both coastal and off-shore areas on the NWS, through introduction of contaminants or foreign marine organisms.

The ecosystem characterisation and bioregions described in Chapter 5: Inventory of Ecosystem Characterisations and Human Uses, provide a baseline description of the physical, chemical and biological properties of the NWS. This is mainly a 'static picture' of the NWS ecosystem. To represent the interactions and impacts of various human uses of the NWS ecosystem, and their interaction with natural variability, a range of ecosystem models is being developed through NWSJEMS. These models will provide predictions and scenarios for use in risk assessment and management strategy evaluation (see Chapter 7 Development Scenarios and Management Strategy Evaluation).

Various models have been developed and used to represent different processes operating in the NWS ecosystem. This allows different processes, for example water circulation, or the passage of contaminants through the food web, to be examined individually, if that is required. The modelling approaches vary from the solution of a set of deterministic dynamical equations, for predicting quantities such as circulation and primary productivity, through to empirical and statistical models for predicting characteristics of fish and benthic communities. However, all the models are also dynamically coupled and can resolve both spatial and temporal dynamics. For example, the circulation models take outputs from wind and wave models, that in turn drive sediment and productivity models, and all of these provide inputs to the fish and benthic community models (figure 6.1.1).

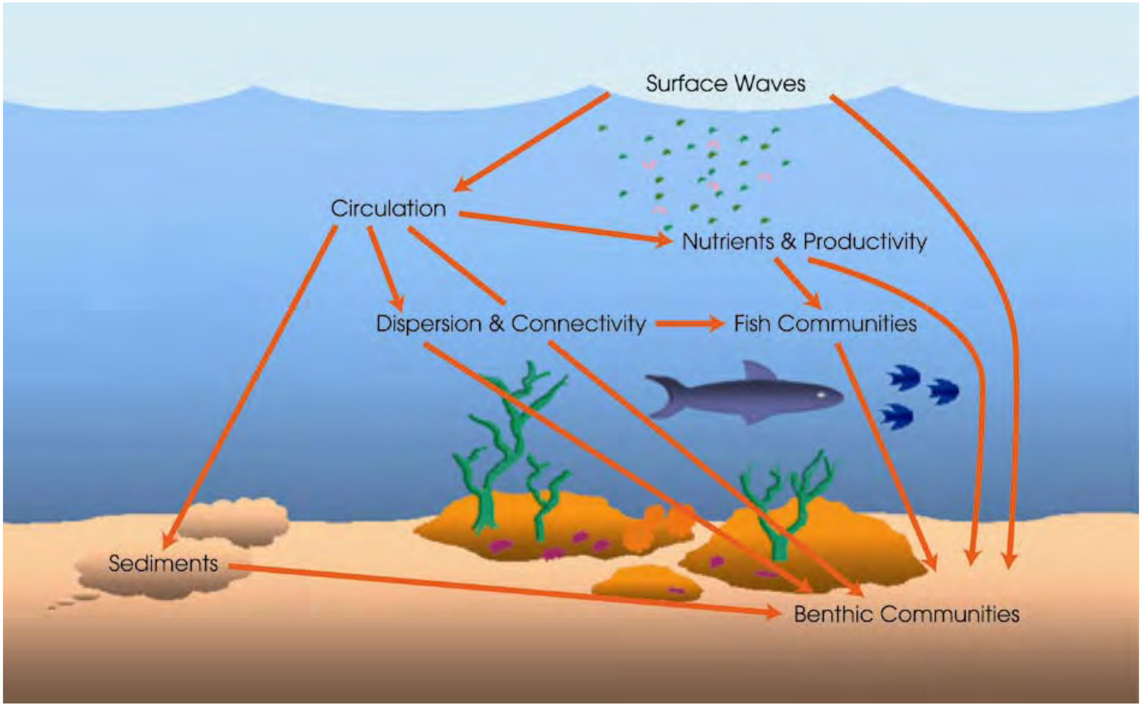


Figure 6.1.1: Schematic representation of major interactions operating in the NWS ecosystem. The red arrows indicate flow of information between the models being developed for each of these components.

6.2 Waves

An empirical wave model was developed to estimate wave characteristics from wind fields, fetch, and water depth. The purpose of the model was to provide spatial and temporal patterns of wave exposure on the NWS, as well as wave orbital velocities for use in the coastal circulation and sediment transport models. It is not suitable for operational predictions or engineering design.

Swell generated by weather systems to the southwest of the region can encroach onto the NWS. However, wave heights are observed to be strongly dependent on local winds (Semeniuk et al. 1982, Buchan and Stroud 1993, Hamilton 1997) and have been modelled using a simple empirical formulation (U.S. Army Coastal Engineering

Research Center, 1973, 1984). This approach assumes a fully developed sea state and uses only the wind speed, fetch, and water depth to calculate wave characteristics. These predicted wave characteristics matched field observations over the shelf quite well, but tended to deteriorate closer to shore. This is because the windfields used in the predictions did not have sufficient temporal resolution to adequately resolve the sea breeze (Condie and Andrewartha 2001).

Model results have been presented in terms of the significant wave height, which is defined as the average of the highest one-third of individual wave heights. These results suggest that mean significant wave heights over the shelf are less than 2 m throughout the year and generally less that 1 m in the shallow coastal zone (figure 6.2.1). During summer, the wave field is maintained by winds from the west (figure 5.2.1), with some sheltering evident to the east of Monte Bello and Barrow Islands. Southeastly offshore winds over winter further reduce wave fields in the coastal zone, until winds again switch to alongshore in spring. The upper 10% of significant wave heights show similar spatial patterns, but reach average values of 4 m off the shelf (figure 6.2.2). Individual wave crests might be expected to reach three times this value, and even more under cyclone conditions.

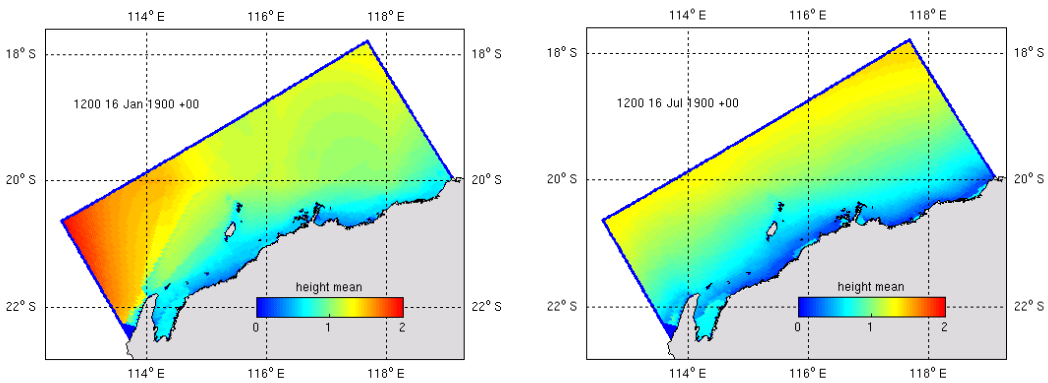


Figure 6.2.1: Mean monthly significant wave height for January and July based on model hindcasts from 1982 to 1999.

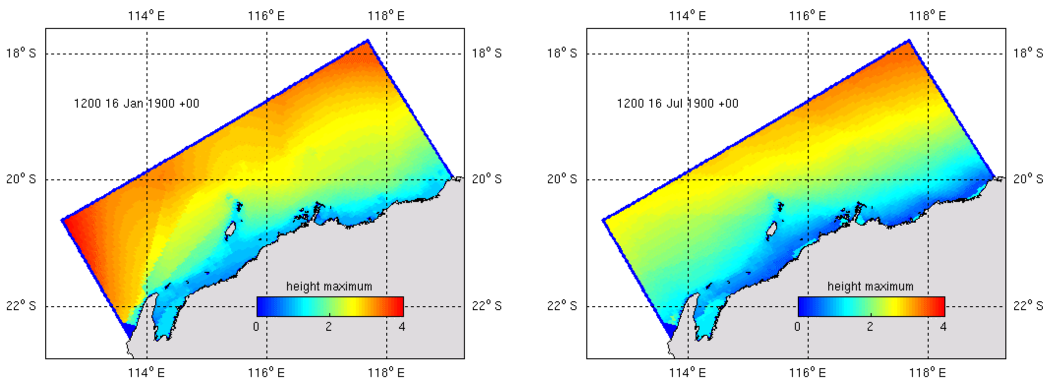


Figure 6.2.2: Mean of the upper 10% of significant wave heights for January and July based on model hindcasts from 1982 to 1999.

There is significant interannual variability in the winds over the NWS, due to factors such as changes in the monsoon, and the frequency and strength of tropical cyclones. Annual model statistics suggest that the level of interannual variability increased from 1982 to 1995, before returning to levels similar to the early eighties (figure 6.2.3). While the number of cyclones tends to be lower under El Nino conditions, there is no strong relationship between the southern oscillation index (SOI) and wave heights. For instance, the strongest El Nino and La Nina conditions within the modelling period correspond to 1983 and 1989 respectively, but differences in the wave statistics for these years are relatively minor east of North West Cape.

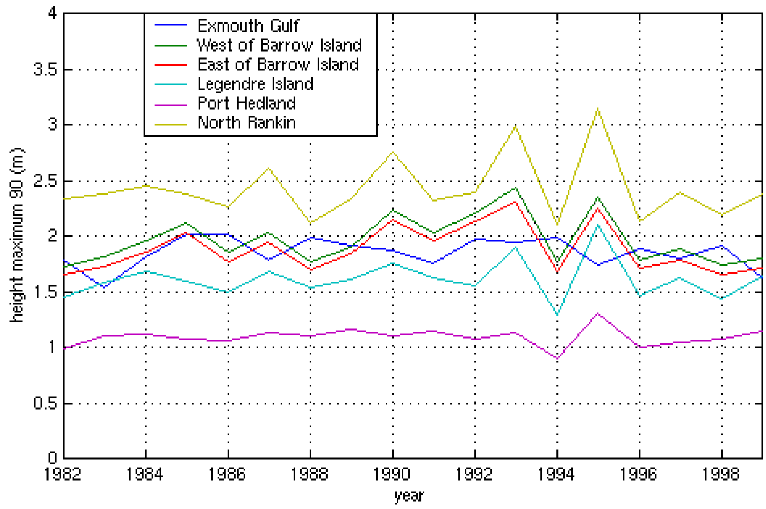


Figure 6.2.3: Annual mean of the upper 10% of significant wave-heights at selected sites for the period 1982 to 1999.

6.3 Circulation

Circulation on the NWS is modelled using the three-dimensional non-linear hydrodynamic model referred to as MECO (Model of Estuaries and Coastal Oceans). This model has previously been applied to a range of estuarine and shelf systems, including the Gulf of Carpentaria (Condie *et al.* 1998), Port Philip Bay (Walker 1999), and southeastern Australia (Bruce *et al.* 2001). Outputs from the circulation model typically include the three-dimensional temperature, salinity, and current fields, as well as sealevel, and bottom stress.

Numerical solutions are computed on a number of rotated latitude-longitude grids. These include a 20 km resolution grid extending from Carnarvon to Darwin, a 10 km grid from the Bonaparte Archipelago to Ningaloo, a 5 km grid from Port Hedland to Ningaloo, and a 1 km grid around the Dampier Archipelago. The vertical resolution is the same in each case, expanding from 3 m near the surface to a maximum of 200 m at depths below 1000 m. The two largest scale models are being forced by the NCEP-NCAR wind fields at the surface, with tropical cyclone winds being generated by other finer scale models (figure 6.3.1). Temperature and salinity fields around the lateral boundaries are interpolated from a global circulation model known as the Australian Community Ocean Model (ACOM, Schiller et al. 2000). Sealevels on the boundaries are also taken from ACOM output, with the addition of a tidal component derived from a combination of coastal sealevel data and output from a global tidal model. Boundary conditions for the 5 km resolution model was provided by a similar nesting strategy, this time using temperature, salinity, and sealevel outputs from the 20 km or 10 km model.

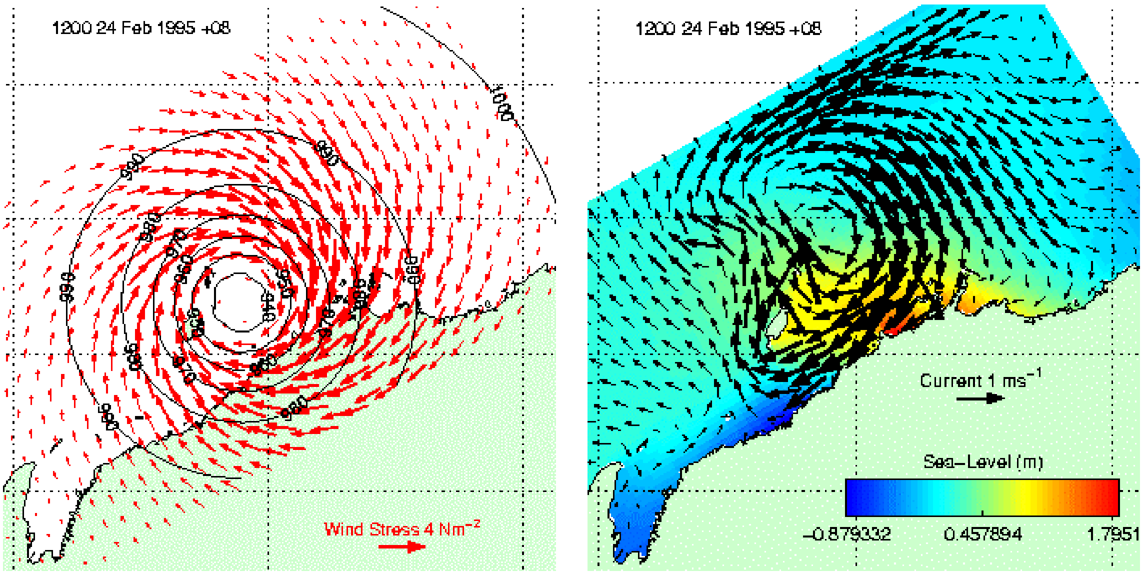


Figure 6.3.1: Modelled winds and pressures during cyclone Bobby (left) and modelled sealevel and current response (right) based on the 5 km resolution model.

6.4 Dispersion and Connectivity

A number of dispersion studies have been undertaken on the NWS to assess the contamination risk associated with both coastal and offshore industry developments. However, longer-term regional patterns of dispersion and connectivity have not previously been investigated. The modelling approach used here is to track large numbers of individual particles moving with the circulation. These computations are run simultaneously with the circulation model so that particle positions can be updated far more regularly than would be possible with archived model current fields. Particles follow complex paths, which are very sensitive to their initial location (figure 6.4.1). This suggests the need for a statistical description of the dispersion results based on large numbers of particle trajectories.

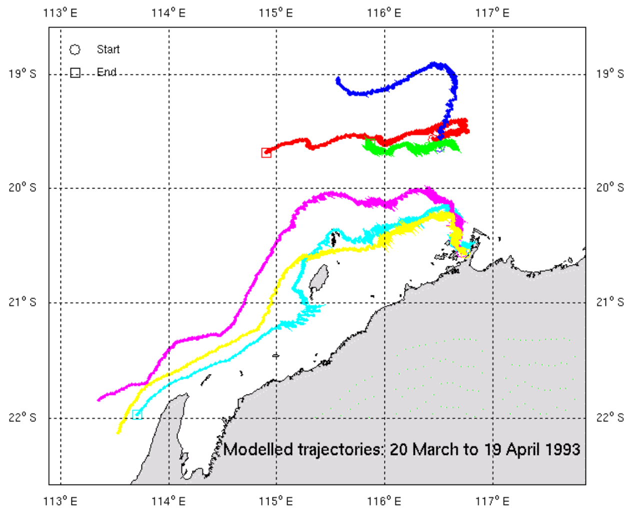


Figure 6.4.1: Modelled particle trajectories from three simultaneous releases in the Dampier Archipelago and three released off-shore near the North Rankin oil platform. Note the divergence in the paths of particles released together.

The statistical description provides the probability of any two regions within the model domain being connected by the prevailing circulation within a specified dispersion time. This can be generalized to produce maps showing the probability distribution for a specified source region and dispersion time (eg Figure 6.4.2). This capability has been automated in a web-based tool called ConnIe (Connectivity Interface), which is currently being installed on a web address to provide user access through NWSJEMS. ConnIe allows the user to graphically select the source region, dispersion time, and period over which the statistics are computed. This approach will support investigations of larval dispersion and recruitment, and provide contaminant dispersal scenarios for risk assessment and management strategy evaluation.

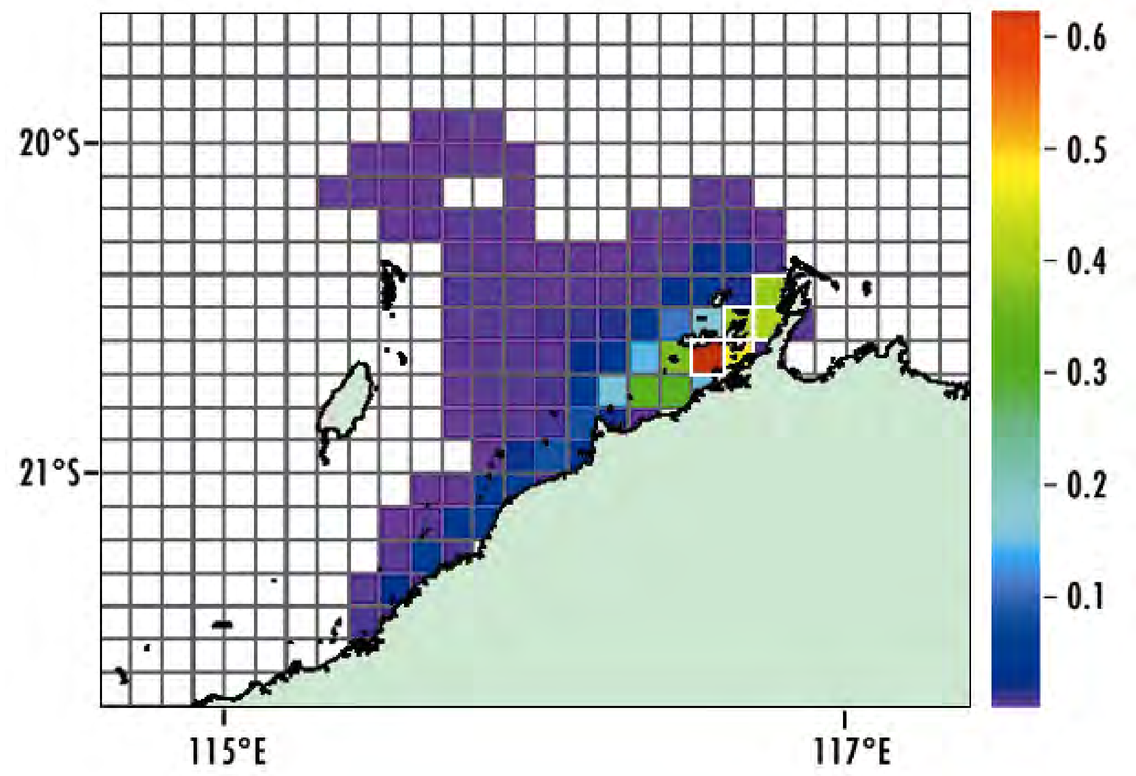


Figure 6.4.2: An example of the probability map for particles dispersing over a ten day period from the grid cells outlined in white. If a cell has a probability of say 0.1, then 10% of the particles originating in the dotted grid cells passed through that cell ten days later.

6.5 Sediments

Previous modelling of sediment behaviour on the NWS has been restricted to short term simulations using simplified sediment transport formulations (Ribbe and Holloway 2001). However, simulations covering a variety of spatial and temporal scales have been developed through NWSJEMS by coupling a sediment transport model (figure 6.5.1) to the 5 km resolution circulation model described in section 6.3. The sediment is represented by a discrete set of fractions with differing settling velocities. Simple empirical formulations are utilised to parameterise cohesive sediment flocculation. The sediment bed is represented by a number of discrete time varying layers. Sediment bed thickness varies due to sediment resuspension and deposition, with different formulations for cohesive and non-cohesive bed sediments. Bottom shear stresses under combined wave-current action are determined using the approach of Grant and Madsen (1979).

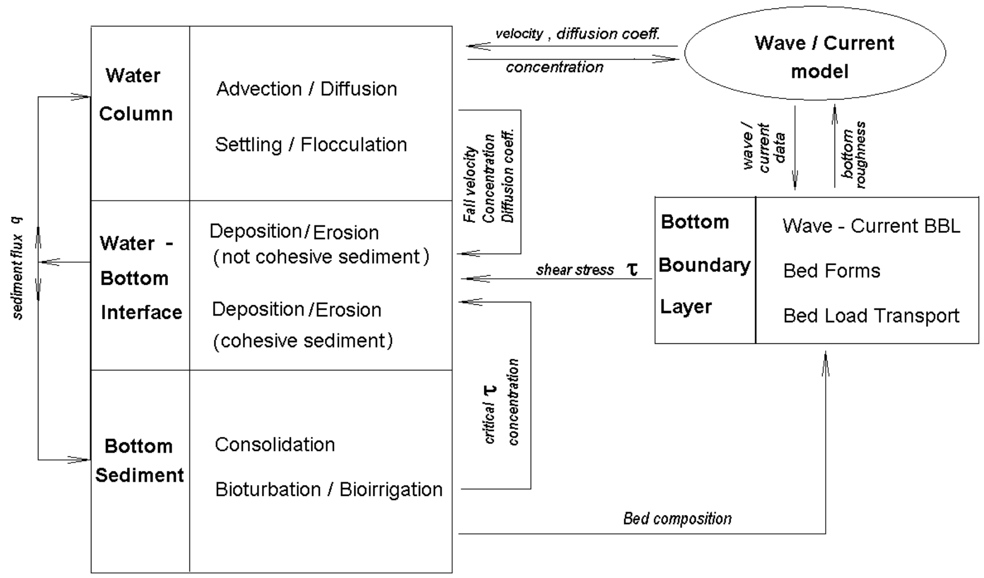


Figure 6.5.1: General scheme of the sediment transport model.

Model simulations indicate that resuspension and deposition are highly correlated with current induced bottom stresses in both time (figure 6.5.2) and space (figure 6.5.3). In the high energy environment of the shelf, winnowing and transportation of fine sediment is reproduced by the model, resulting in high concentrations of the sand fraction in the bed (figure 6.5.3). Low sand concentration in deep water can be attributed to fine sediment accumulation rather than to sand resuspension. The simulations also predict a strip of high suspended sediment load on the inner shelf (figure 6.5.4), qualitatively similar to the high turbidity zone evident in the SeaWiFS data (figure 2.2.1b). Preliminary investigations of the physical mechanisms maintaining high turbidity in coastal water show a weak but persistent shoreward flux across the shelf. However, flux variability needs to be investigated across a wider range of time scales to establish long-term transport patterns.

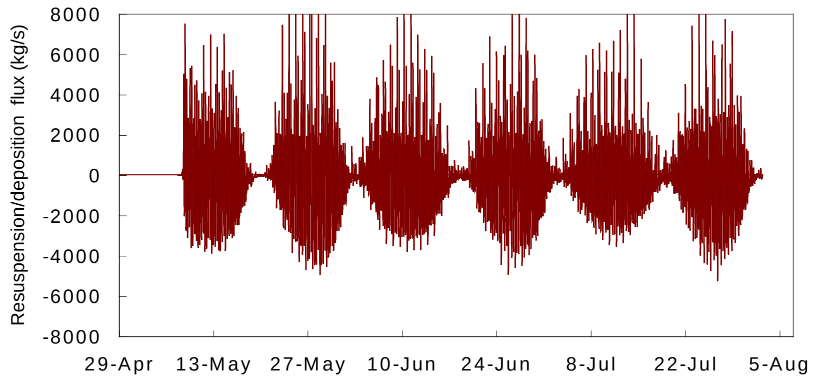
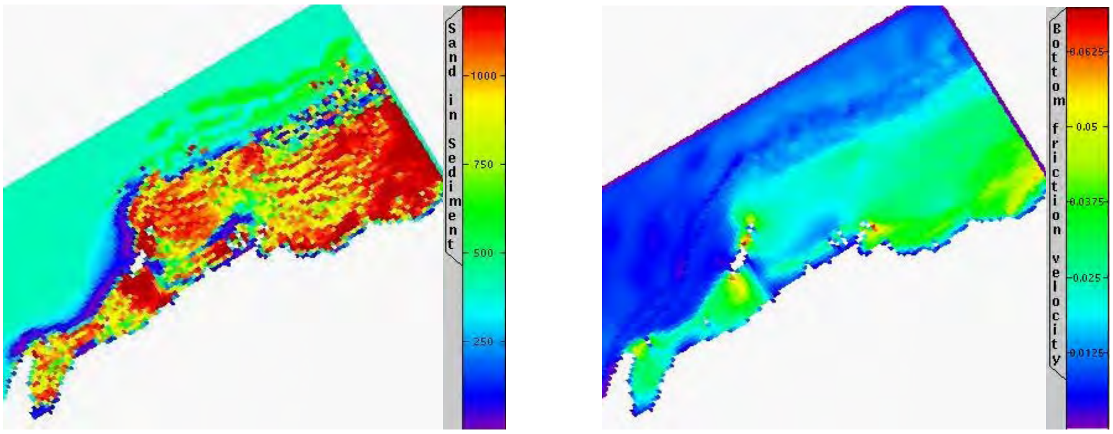


Figure 6.5.2: Modelled time series of silt resuspension flux (positive) and deposition flux (negative) integrated across the NWS (1982). There is a clear correlation with the spring-neap tidal cycle.



(a) **(b)**

Figure 6.5.3: Model estimates of (a) concentration of sand in the sediment bed (kg m^{-3}) and (b) bottom friction velocity (m s^{-1}) in July 1982.

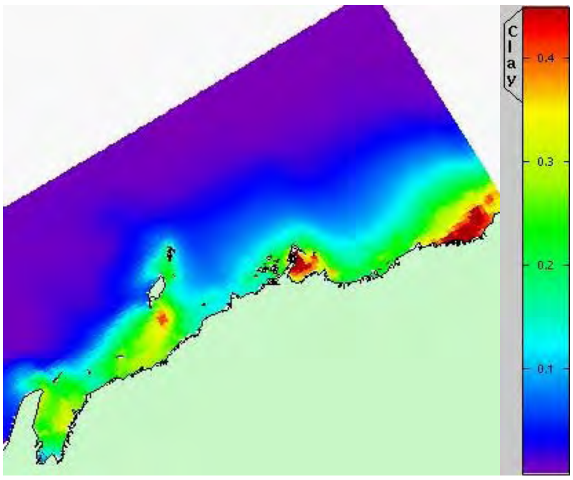


Figure 6.5.4: Model estimates of suspended fine sediment concentration near the sea surface (kg m^{-3}) in July 1982.

6.6 Nutrients and Productivity

The model being used to investigate primary productivity and nutrient dynamics on the NWS is a general model of biogeochemical and ecological processes, which is coupled directly to the circulation model. It represents the cycling of nitrogen, phosphorous and carbon through both pelagic and benthic ecosystems. The ecological model has three modules: water column, sediment, and epibenthos (figure 6.6.1). The water column module describes a simple planktonic food web and currently includes small phytoflagellates (~ 5 μm), large bloom-forming phytoplankton (~ 20 μm), and two size classes of zooplankton which graze respectively on the small and large phytoplankton. Non living particulate and dissolved organic matter (DOM) is represented in a range of forms, as well as inorganic nutrient species, dissolved inorganic carbon (DIC) and dissolved oxygen. The sediment module represents the breakdown of particulate and dissolved organic matter through microbial and detritivore activity, which consumes oxygen and releases DIC and inorganic nutrients. It also includes the processes of nitrification and denitrification. The epibenthic module represents two functional classes of attached macrophytes: macroalgae, which take up nutrients from the water column, and seagrass, which take up nutrients from the sediment pore water.

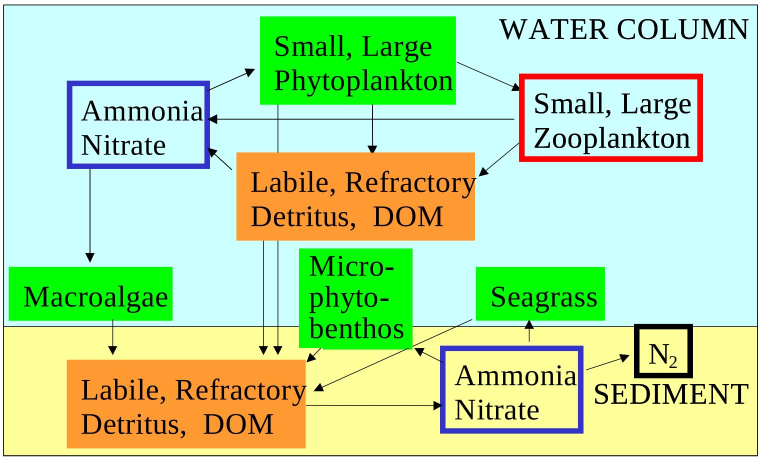


Figure 6.6.1: A schematic picture of nitrogen cycling in the model including water column, sediment and epibenthic components.

Preliminary model output shows a significant subsurface chlorophyll maximum at the base of the mixed layer (figure 6.6.2a). This feature disappears shoreward of the 50 m isobath, where mixing extends to the bottom (figure 6.6.2b) and light conditions are less favourable to plankton growth. While this pattern is consistent with observations, surface concentrations tend to be higher than those indicated by satellite imagery (figure 5.2.6), even though nitrate levels are close to observed values (figure 6.6.2c). Ammonia shows high concentrations on the slope (figure 6.6.2d), presumably the result of sediment fluxes fuelled by detrital nitrogen settling from the sub-surface phytoplankton maximum.

Many aspects of the biogeochemical cycling remain to be investigated including the impacts of anthropogenic inputs. While inputs of nutrients and contaminants from human activities are currently relatively localised, the modelling capabilities being developed here will allow the impacts of increased loads from future developments to be evaluated in detail.

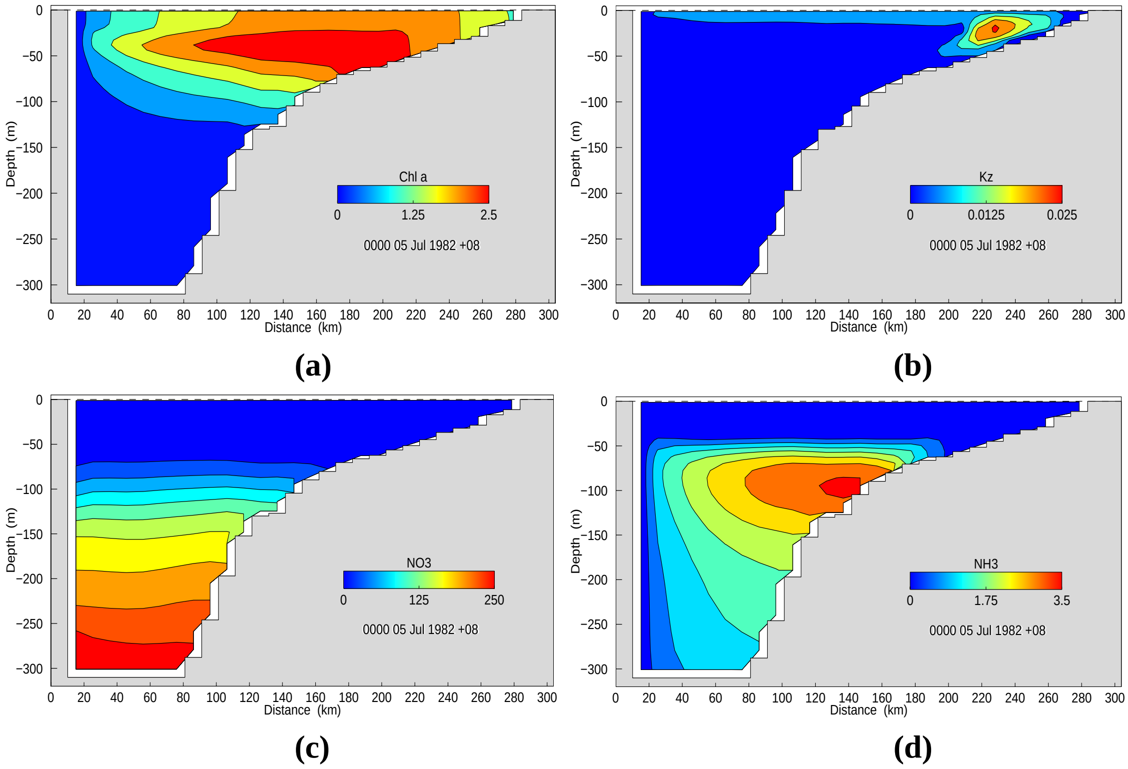


Figure 6.6.2: A section of model output offshore from Port Hedland for winter 1982. The fields are (a) chorophyll (Chl a: $\mu g\ l^{-1}$), (b) vertical diffusivity (Kz: $m^2\ s^{-1}$), (c) nitrate (NO_3: mg l^{-1}), and (d) ammonia (NH_3: mg l^{-1}).

6.7 Food web model of the fish community on the North West Shelf

Chapter 5: Inventory of Ecosystem Characterisation and Human Uses, provides a description of the major units of the NWS ecosystem, including maps of the three major sub-biomes on the inner, middle and outer shelf, respectively. A food-web model of these interconnected sub-biomes is being developed through NWSJEMS. This model is a simple and coarse representation of the feeding interactions on the NWS, but it is designed to reasonably portray the broad processes and interdependencies that occur. In particular, it illustrates the broad trophic connections between the sub-biomes and between the major groups of organism. The model combines information on primary production and the lower end of the food web (e.g. see Section 6.6 Nutrients and Productivity), diets and feeding, surveys of the abundance of various types of organism (from sediment fauna to fish), fishery catches, and the shared species across the sub-biomes. The model initially gives a static or ‘average’ snapshot of the food-web flows that are consistent with all of this information. It can be used to broadly examine such things as the major trophic interdependencies, passage of contaminants through the food-web, changes in the food-web resulting from harvesting or otherwise reducing various parts of the food-web, and the broad amount of fishery yield that is possible from different parts of the food-web.

A conceptual model of the main feeding interactions is shown in figure 6.7.1.

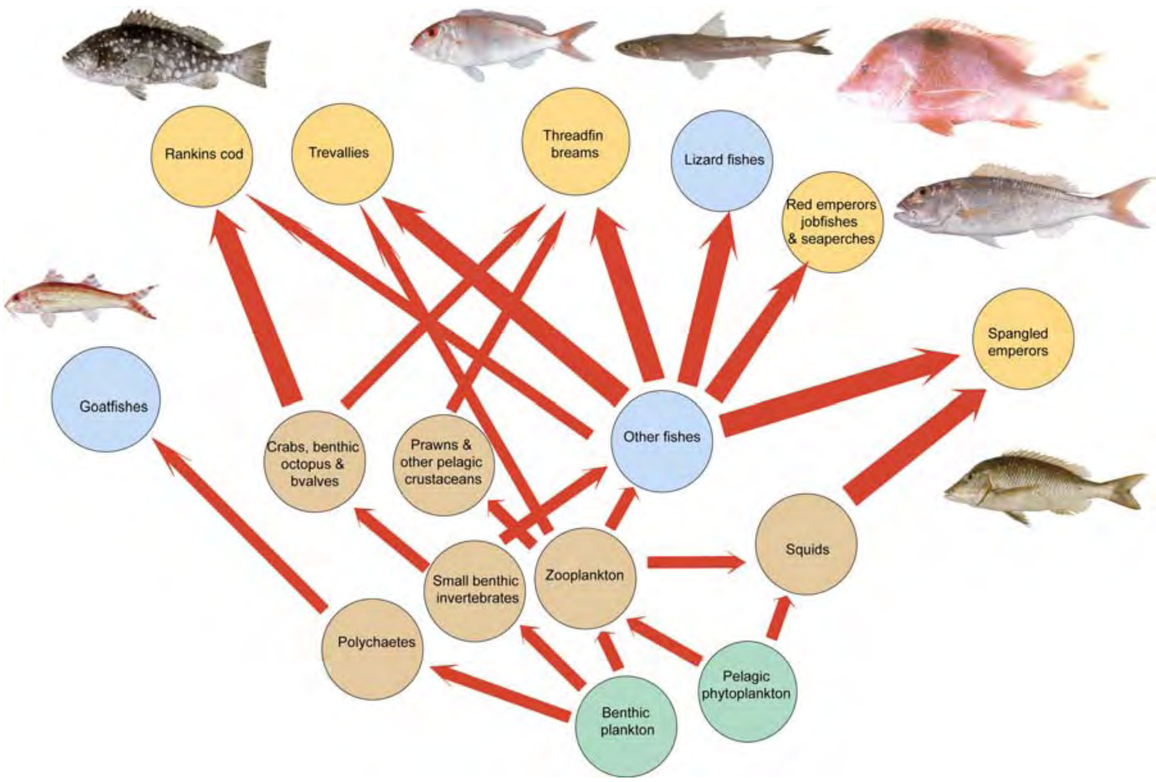


Figure 6.7.1: A conceptual food web diagram for the NWS. Green indicates primary production, brown invertebrate prey species, yellow commercial finfish, and blue non-commercial finfish.

Recognising that some of the elements in this conceptual food-web are shared among sub-biomes, while others are restricted to within a sub-biome, and incorporating the other information available results in the static food-web shown in figure 6.7.2.

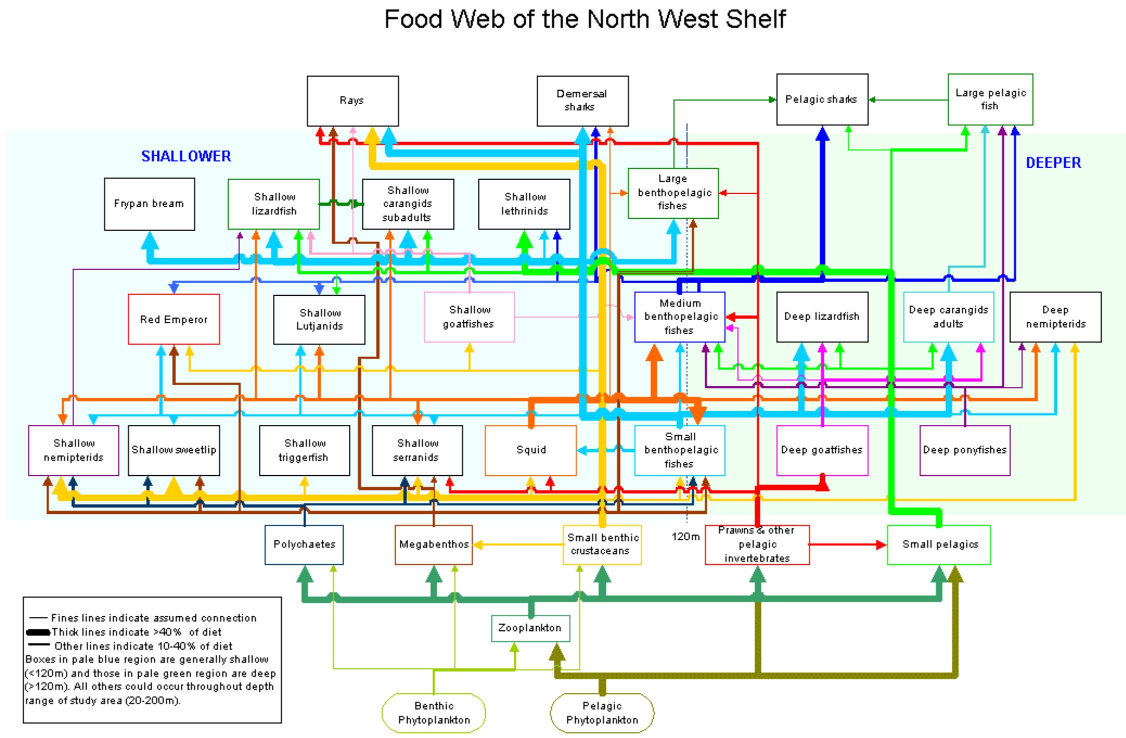


Figure 6.7.2. The static food-web for the main sub-biomes (represented by shallow, medium and deep parts on the NWS) and groups of organism on the North West Shelf. This provides the 'average' flow along pathways in the food-web that is consistent with a wide range of consolidated information and data.

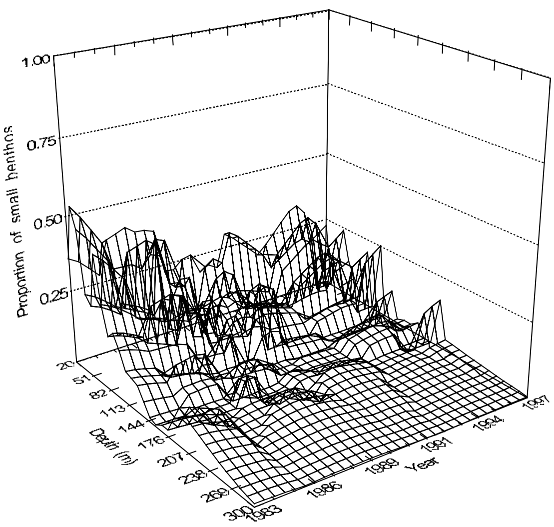
A dynamic model of the food-chain is also being finalised through NWSJEMS. This can represent the sequential responses of the food-web to changing conditions, rather than just the static 'average' food-web under a particular set of fixed conditions. The dynamic model allows a high level of spatial resolution. It is 'agent based', where the 'agents' can be chosen to represent individuals, groups (e.g. schools), populations or general types of organism. This model draws on information from the static food web model, but reduces the representation of individual species to a smaller set of functional groups such as prey fish, reef fish, pelagic fish, sharks, and prawns. The model assumes logistic growth of age structured populations for these groups and includes spawning, schooling of year classes, searching for preferred habitats (carrying capacity dependent on the benthic habitat), depletion by fishing or other human impacts, and impacts of natural changes in the environment. Schools respond to local physical conditions, such as currents and temperatures, and to local habitat availability, including mangroves, seagrasses, coral reefs, sponge gardens, and open waters. They also respond to other species through predatory or evasive behaviours. This dynamic model is used in the risk assessment and management strategy evaluation component of NWSJEMS.

6.8 Dynamics of the seabed communities of large epibenthic animals

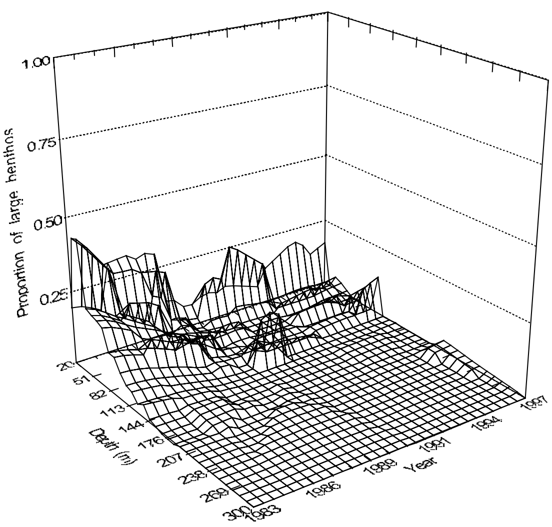
Many parts of the seabed of the NWS support many species of large epibenthic animals, such as sponges, soft corals, seafans and sea whips. In many areas these epibenthic animals are an important part of the seabed habitat, much like trees define habitats on land. It is expected that they influence the broad patterns of biodiversity on the NWS.

Some aspects of the Level 2 and 3 habitat units mapped in Chapter 5: Inventory of Ecosystem Characterisations and Human Uses, relate to these epibenthic communities. These epibenthic communities can be impacted by human activities such as trawl fishing and dredging, and by natural events such as cyclones and tidal currents. The NWS was intensively trawled during the 1970s before it was under Australian jurisdiction.

The distribution and dynamics of epibenthic communities in waters deeper than 20 m, have been studied using a photographic data set collected during more than 1000 trawl transects between 1983 and 1997. These data were analysed to provide a time series of the proportion of the seabed covered by two broad size classes of epibenthos – small (5-25cm high) and large (greater than 25cm). The data and results are available through NWSJEMS and accessible through Data Trawler. The results (eg figure 6.8.1) show a general reduction in coverage with increasing water depth - small epibenthos is rare beyond the 200 m shelf break, and large epibenthos is rare beyond 100 m water depth. While there is significant interannual variability, there is an overall decline in large epibenthos from 1983 to 1989 with stabilisation, and some evidence of a partial recovery on the inner shelf, in more recent years. Similarly, the seabed coverage of small benthos decreased during the 1980s, but has stabilised or shown some limited recovery in more recent years. In interpreting the seabed coverage by epibenthos shown in figure 6.8.1 it should be recalled that intensive fishing took place in the 1970s, and so the early years in figure 6.8.1 do not represent the unfished coverage.



(a)



(b)

Figure 6.8.1: Observed proportion of (a) small epibenthos (5 to 25 cm high) and (b) large epibenthos (more than 25 cm high).

A model of the dynamics of the epibenthic communities was developed to allow interpretation and prediction of the changes caused by natural processes and fishing. The model includes the influence of environmental conditions, including depth, sediment type (figure 6.5.3), wave exposure (figure 6.2.1), and tidal and cyclone induced bottom stresses (figure 6.3.1). The model also includes the effects of removal by trawling. The epibenthic community model is structured to include the recruitment (settlement), growth, and mortality of epibenthic organisms on a fine space scale. The model has been used, to make comparisons of the predicted and observed spatial distribution of epibenthic communities, to examine the importance of the different environmental conditions in determining the spatial distribution and to predict the consequence of a cessation in trawl fishing.

The model can reasonably predict the spatial distribution of epibenthic communities on the NWS (figure 6.8.2). And the analysis indicates that fishing effort, depth, and sediment type all have a strong effect on the spatial distribution of epibenthic communities, but that cyclone occurrence and bottom stress have a weak effect. The model has been used to predict the likely response to changes in the amount of trawl fishing conducted on the NWS, and these predictions are used as scenarios in risk assessment and management startegy evaluation. For example, figure 6.8.3 shows the predicted change in the seabed cover of large and small epibenthic communities if trawling were stopped in 1997.

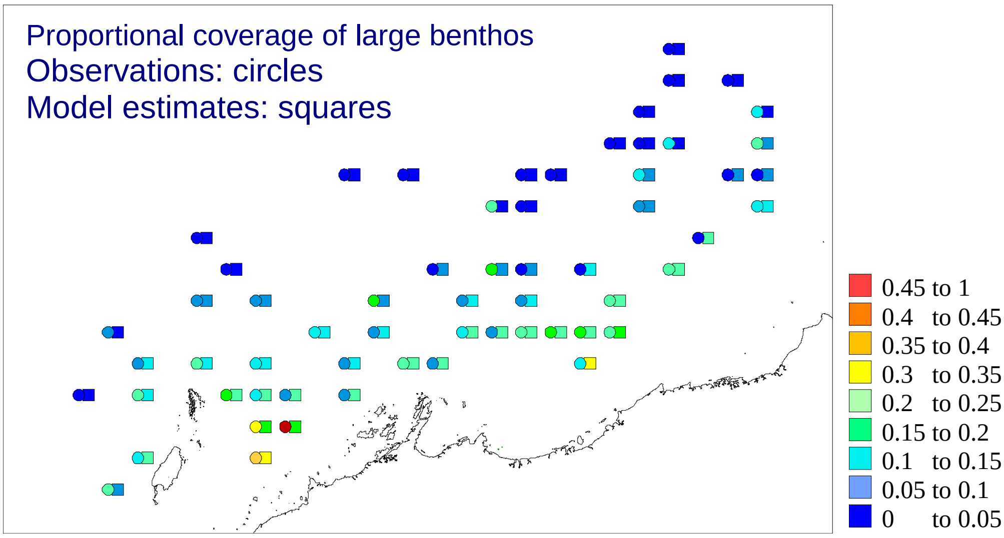


Figure 6.8.2: A comparison of observed proportional coverage of large benthos on the NWS (❍) with model estimates (❑) for the year 1988.

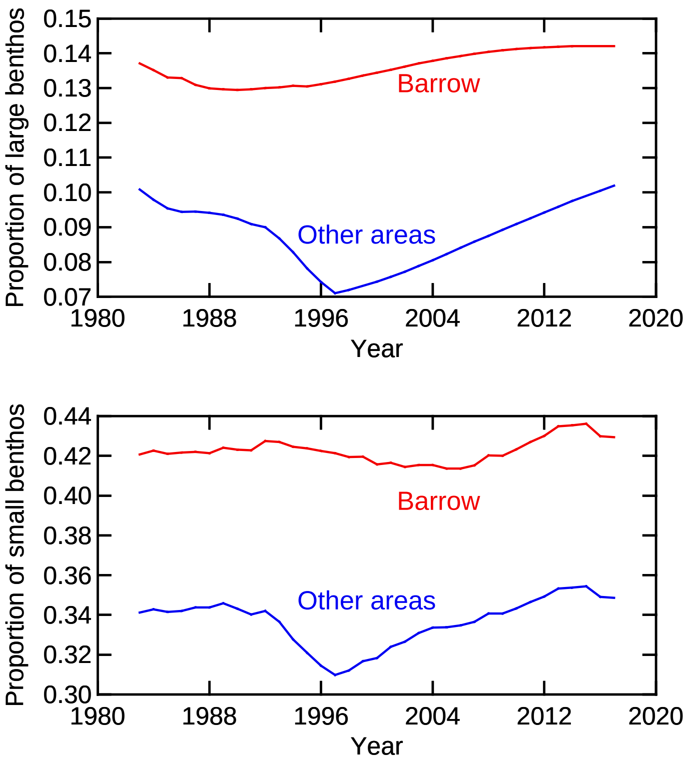


Figure 6.8.3: Modelled mean proportions of large benthos (top panel) and small benthos (bottom panel) for depths between 50 and 100m from a scenario in which fishing ceased in 1997. Mean proportions are shown for two areas (Barrow = West of 116^{o}, other areas = East of 116^{o}). The model predicts limited impact in the Barrow region, but relatively rapid recovery of both large and small benthos in other regions.

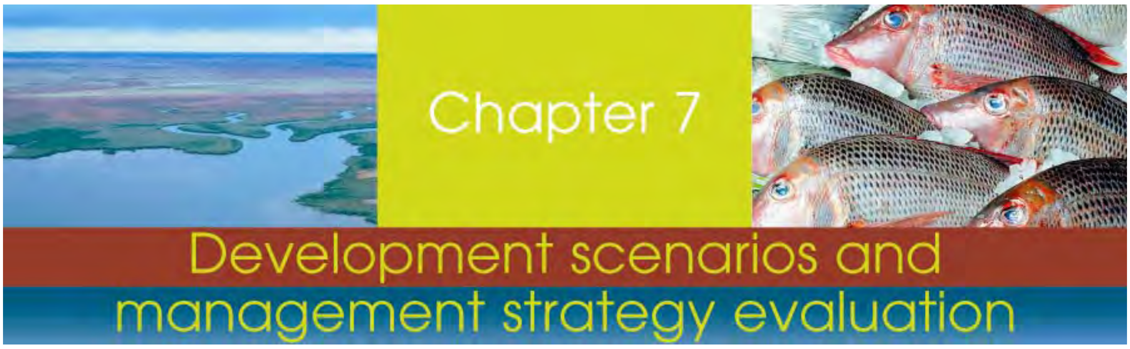
6.9 Concluding Remarks

This Chapter provides a description of models and interpretations for the dynamics of several of the important physical and ecological processes on the NWS.

Individually, these models provide an ability to examine and make predictions or interpolations about specific features on the NWS – including the wave environment, circulation and stress at the seabed, dispersal of particles, movement of sediments, nutrients and productivity, food webs and seabed 'landscape' dynamics. In many cases these models are prototypes that are still under development, but already they provide a comprehensive suite of tools for the prediction and interpretation of natural and human impacts on the NWS.

The factor differentiating NWSJEMS from many other environmental management studies is its focus on integrating the physical, biological, and management models. Linkage between the physical and biological models is already apparent in the capabilities described in this chapter. The models of physical processes are integral to the models of several ecological processes. For example the circulation model is embedded in the model of nutrient dynamics and primary productivity. The primary productivity model predictions (including spatial and temporal variability) are one driver for the food-web models. The epibenthic community dynamics model uses a wide range of outputs from the circulation, dispersal and sediment models.

These linkages are being enhanced, and made more efficient, through development and finalisation of the agent based model of the NWS ecosystem. This is the model that is used for risk assessment and management strategy evaluation (Chapter 7: Development Scenarios and Management Strategy Evaluation). Variously, the agent based model embeds the models described in here, accesses information produced by them, or uses simplified versions of the models described here. Where simplified models are used the more comprehensive models described in this chapter provide the process understanding needed to develop and verify the simplified models.



7.1 Introduction

Environmental management is characterised by multiple and conflicting objectives, multiple stakeholders with divergent interests, and high levels of uncertainty about the dynamics of the resources being managed. This combination of circumstances can result in high levels of contention and difficulties in the management process. Management strategy evaluation (MSE) and risk assessment can assist in the resolution of some of these issues.

A management strategy in this context is a combination of observations (e.g. monitoring) of the managed system; analysis of these observations (often by updating chosen indicators and performance measures); management decision making (potentially including ‘decision rules’ based on the updated indicators and performance measures); and implementation of management decisions.

An indicator is a quantity that can be measured or estimated to track a feature of interest, while the corresponding performance measure, at a point in time, measures how close the indicator is to the management target or other benchmark for that indicator.

MSE involves assessing the consequences of a range of management options and laying bare the tradeoffs in performance of options, across a range of management objectives. The approach involves close co-operation and collaboration with stakeholders and management agencies to:

- identify a range of proposed management options (the strategies);
- turn broad objectives into specific and quantifiable indicators and performance measures;
- identify and incorporate key uncertainties into an evaluation of the consequences, for the chosen indicators and performance measures, of the proposed management strategies; and
- communicate the results effectively to client groups and decsison-makers.

MSE is ideally suited to development of adaptive management strategies and monitoring programs. An adaptive management system measures progress against objectives and modifies strategies over time, to better achieve those objectives. At a technical level the

MSE and risk assessment frameworks facilitate dealing with multiple objectives and uncertainties in prediction. At the implementation level, it facilitates stakeholder engagement and recognition of issues, uncertainties and trade-offs.

The MSE project integrates the results of the other projects of the North West Shelf Joint Environmental Management Study in a management context. This integration involves using mathematical and statistical outputs, as well as broad understanding from the other projects, as part of the process to determine the impacts of various human uses and management strategies on the NWS ecosystem. Outputs from the project include indicators and performance measures for agreed environmental and economic values, evaluation of the risks associated with major threats and development opportunities, and assessment of potential management strategies and options. A major contribution of the project is development of the modelling framework and software to evaluate the effects and performance of management strategies, based on the zoning of uses on the NWS regional ecosystem.

The specific objectives of the MSE project are:

1. to evaluate and recommend a range of environmental indicators and performance measures for Ecologically Sustainable Development of the NWS regional ecosystem;
2. to develop integrated models of the NWS regional ecosystem and human impacts for use by industry sectors and management agencies; and
3. to evaluate strategies for regional zoning, monitoring and adaptive multiple-use management of the NWS regional ecosystem.

This chapter describes the overall MSE model being developed for the NWS regional ecosystem and the major human uses of it. These uses are oil and gas, fishing, coastal development and conservation. The MSE model is still being finalised and tested, but an application of the MSE approach is illustrated. This illustration examines the consequences to production and conservation of a change in the zoning of commercial trawl fishing.

7.2 Background

Management Strategy Evaluation involves assessing the consequences of a range of prospective management strategies. It involves clearly enumerating the trade-offs in performance, of each strategy, across the range of management objectives. Then it compares the performance of different strategies across a range of scenarios that represent the way the real world might behave. MSE requires an explicit statement of management objectives, and identification of quantifiable performance indicators, that relate to these objectives. It also requires use of a model to represent the dynamics of the natural system, the impacts of human use on it, the generation of production within each of the industry sectors, and the process of management decision making and implementation. All of these modelled processes are complex and poorly understood. The models used in MSE are designed to represent the uncertainty in understanding and predictions.

The models in MSE are used to provide possible situations or scenarios that a prospective management strategy may have to cope with, rather than to make exact predictions of the future. The emphasis in MSE is on comparing the performance of different strategies across the range of scenarios used to represent uncertainty about the natural world and human impacts on it. The aim of MSE is often to find a strategy that 'works' (i.e. achieves the objectives) robustly across all the scenarios that are represented. Alternatively, MSE can be used to identify the particular scenarios under which an otherwise desirable strategy fails and to design an adaptive strategy to detect and correct such failure if it occurs in the real world. So the models in MSE have a fundamentally different function to models used solely for prediction. MSE can proceed even if the models used contain many uncertainties and give highly uncertain predictions of the future. This is because the emphasis is on finding strategies that can succeed despite these uncertainties.

The MSE framework that has been developed for the NWS is shown in figure 7.2.1. The framework includes a model of the natural system, a model of each of the important sectors of human activity, and a model of how decisions are made, including monitoring activities.

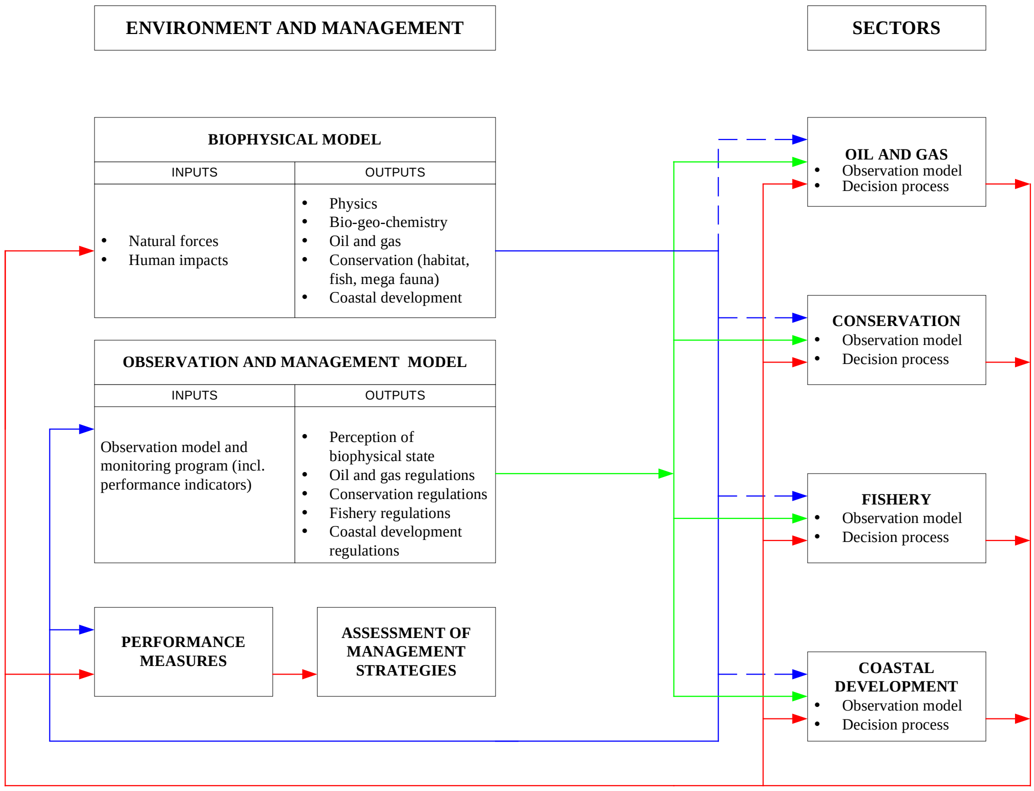


Figure 7.2.1 The Management Strategy Evaluation framework of interconnected models developed for the North West Shelf.

Each model may include many different interpretations and scenarios to represent uncertainties in understanding and prediction. The computer program used for MSE traces the impact of a particular management strategy on the actions of sector firms or agencies. It then tracks the affect that these actions have on the natural environment. In so doing, the program keeps track of details on sector response to management actions, sector performance, the way the natural system changes in response to sector-specific actions and important random events, and any strategy-mandated adjustments by managers, as a result of sector and/or system response.

The Biophysical Model describes the ecosystem as influenced by natural processes and human impacts. Output from the biophysical model effects each of the models of the human use sectors directly (e.g. through sector production, costs and revenue achieved) and indirectly (e.g. through operational and planning decisions made at the sector level). These effects are modelled separately for each Sector, and include sectoral development and management strategies that are in place or proposed. The biophysical model emulates the physical and biological features of the natural marine ecosystem, including the bathymetry, currents, waves, type of seabottom, benthic flora and fauna, local animal populations and migratory animals. This model also includes a representation of the impact of natural forces and human activity. Outputs from this model include information about the state of the physical environment, about stocks of both renewable and non-renewable resources, and about other important features of the ecosystem. An assessment of variability is also included, thus providing an indication of the implicit uncertainty in models, observations and the bio-physical processes themselves.

The Observation and Management Model represents decision making by regulators and particularly the regulations and management strategies that are in place or proposed. Both sectoral and regulator decision-makers base their decisions in part on observations of the biophysical system. These observations can be different for different decision making groups. The Performance Measures component calculates the measures that are used to compare management strategies. The observation and management model simulates the actions of public management agencies. In this model management objectives are given quantitative interpretation, as are the management strategies and decision rules. The management strategy is then implemented within each of the sectors, which constrains their activities and potentially their production and impact on the natural system. Uncertainty in the success of implementation can also be included.

The sectors represent human activity in petroleum exploration and extraction, conservation, fisheries and coastal development. Key players in each of these sectors observe the natural system imperfectly and make decisions about levels and locations of their activities. Sector activities have an impact on the natural system and also on public management agencies that monitor and regulate the activities of the sectors.

MSE provides a practical and useful framework for evaluating the effectiveness of prospective management strategies. The aim of the MSE is to highlight the tradeoffs among alternative management strategies in terms of their ability to meet key regional management objectives. When the implications of a particular management strategy have been recorded in a model run it is then possible to examine the performance measures that indicate how well the management strategy achieves the management objectives. Rerunning the computer program with alternative management strategies provides the information with which to compare strategies.

The computer models in MSE are used are to provide possible situations to test the adequacy of management strategies, rather than to make exact predictions of the future. But obviously the MSE models should be capable of reproducing historical trends and responses to major events. Indeed, the model components are calibrated to ensure they can reasonably reproduce what has happened under past management strategies that have actually been in place. The strength of the approach, however, lies in projecting the outcomes of management strategies that have not been used in the past. This is made possible by ensuring that the main features of the natural system, including uncertainty, are captured in the model, as well as by realistic depiction of sector responses to management strategies.

7.3 Methods

Software Development

The computer software for MSE in the NWSJEMS comprises a set of linked dynamical models, user interface, visualization, and data retrieval and storage. The dynamical modelling is implemented using the agent-based "Invitro" modelling software.

The salient difference between agent-based models (also known as individual-based models) and traditional models is that the locations and local environments of "individuals" in a population are important. Traditionally, there is an assumption that the effect of individuals can be "averaged out" across the population. When the effects of local interactions among individuals and with their environment cannot be adequately represented by an average (or similar statistical measure) across the population, an agent-based model is appropriate (Caswell and John 1992, DeAngelis and Rose, 1992). Indeed, such models provide a very convenient structure for dealing with many types of ecological entities, including individuals, populations and communities.

Agent-based models are particularly well suited to evaluating multiple-use management strategies, where the concept of "agents" applies not only to biophysical environmental entities such as populations and habitats, but also to the human activities and interventions in the biophysical environment. In the NWS context for example, agents include fishing vessels, oil production platforms, shore-based industrial facilities, and management agencies.

Agent-based models are both spatially and temporally explicit. At each time step agents, of various types, interact with each other and with the environment. The spatial behaviour that they exhibit is modelled as passive responses, or on the basis of decision rules, depending on the agent concerned. After characterising the spatial behaviour at a given time, the system evolves according to spatially-explicit dynamical models and the state of the system is updated in preparation for determination of the spatial behaviour of agents at the next time step.

The MSE software simulates management decisions, and the bio-physical environment, with the outcomes of these models impacting on various sectors of industry and the community (oil and gas, conservation, fishery, and coastal development - all models in themselves). Outcomes from the sectors (levels and locations of sector activities) are fed back into the management and bio-physical models, and into an observation model that monitors changes and provides input to the management models. A key output, from simulations, is a set of performance measures. These measure how well particular management strategies have achieved management objectives.

Models

The modelling framework for the NWSJEMS encompasses components that deal with the dynamics of the ecosystem (the biophysical model), four human use or activity sectors (oil and gas, fisheries, conservation and coastal development), and a management agency. The activity sectors not only serve roles in the production of goods and services but also lobby the management agency for their desired policy outcomes. The management agency regulates the sectors in order to promote particular environmental and social outcomes.

The Biophysical Model

The biophysical model encompasses the state and internal dynamics of the marine living and non-living resources. It consists of both biological and geophysical agents.

Biological agents include[1]:

- pelagic primary production
- mesozooplankton
- benthic filter feeders (especially habitat forming biota)
- seagrass
- mangroves (modelling root and crown biomass explicitly)
- larval/settler and adult forms of finfish (at least for groups matching the ones identified by Sainsbury 1988), harvested invertebrates and k-selected bycatch groups (e.g. large elasmobranchs)
- r-selected bycatch groups
- turtles
- marine mammals (e.g. dugongs)
- seabirds
- carcasses and detritus

The number of individuals represented by any one of these agents will vary with the agent. For example pelagic primary producer agents in the model represent the entire suit of primary producers, and the model will be 'tuned' to match the estimates and distribution of primary production given in the output of the detailed biogeochemical model described in Section 6.6 of this Report. Benthic filter agents represent regional populations (or patches), finfish agents represent schools, and marine mammals agents represent a small pod or herd. The agents that represent habitat patches or communities

[1] The agent based nature of the model means that representation of further groups is easily accomplished by implementing an agent with alternative parameters. For example a specific agent to represent the deep crustaceans (Ward and Rainer 1988) could be added if the food-web modelling described in Section 6.7 of this report concluded that these crustaceans were extremely important.

also have an associated biodiversity index (based on a modified species area curve) so that broad patterns of biodiversity can be represented without requiring models for each of the many hundreds species involved.

The geophysical agents include:

- bathymetry
- habitats (other than those defined by biological groups mentioned above)
- nutrients
- contaminants
- light
- winds
- tides
- estuarine flows
- and ocean currents.

The interactions between these entities represent the internal dynamics of the model. And while the biophysical model used for MSE is based on the models described in Chapter 6, some models have been simplified due to their computational demands. For instance, rather than explicitly link nutrients and pelagic primary production background fields, as in the biogeochemical model in Section 6.6, of these are modelled in the MSE analysis based on the outputs of the detailed biogeochemical model and monthly harmonics. Explicit process equations for the primary production and nutrient fields are used in the MSE model only then perturbation events are considered that might significantly alter the values of these fields.

The biophysical model also interacts extensively with the external socio-economic sectors. These sectors may impact directly or indirectly on the biophysical agents and both regular events as well as rare perturbation events (such as cyclones or oil spills). Direct on-going impacts include:

- depletion of harvested populations by fishing (commercial and recreational)
- the destruction of habitat by trawling and coastal development
- incidental capture of bycatch or marine vertebrates by fishing vessels
- boat strikes on dugongs and sea turtles
- stress, migration or death caused by bittern releases
- contaminant releases due to fuel oils etc leeching from harbours, boat ramps etc

There are also irregular impact events including:
- cyclones
- oil spills
- foundering or collision of boats

In addition to the direct impacts the dependence of biological agents on food groups and habitat defining groups (both adult and nursery habitat) allows for the expression of indirect impacts of the events listed above. For example the removal of seagrass by trawling would impact upon any of the invertebrate of finfish agents using it as nursery habitat.

The Observation and Management Model
Observation of the biophysical and sector states is accomplished by a simple monitor agent. This agent uses a set of performance indicators to summarise the state of the system. This agent can represent various types of observation errors. The observation model can simulate various types of monitoring program, and so provide the stream of observational data to the management model for use in assessment and the management feedback loop that is relevant to the management strategy being examined. This allows the management strategy model in each sector to (imperfectly) observe the system and then make decisions according to that sector's management strategy about the location and intensity of that sector's activities.

The Oil and Gas Sector Model
The oil and gas sector model emulates the actions of petroleum companies that lead to discovery of reserves, production of oil and gas, and outflows to the marine environment such as, release of produced formation water, drilling muds and spilled petroleum products. The discovery and production processes are modelled as constrained firm-level control problems. Outflows to the marine environment are described by scenarios. Their transport (dispersal, advection and/or diffusion) within the study area, is driven by spatial and temporal forcing (the output from modelling hydrodynamic circulation patterns and atmospheric wind fields). The physical and chemical changes of outflows are tracked through time, as they move away from the point at which they enter the marine environment. The impact of these outflows on important elements of the bio-physical system is also traced, as they move and change, and their feedback influence on commercial decisions is characterised.

The major management issues examined in the MSE are:

- lease decisions (expiry dates, renewal, and basis for boundaries);
- recovery (maximum recovery versus optimal recovery from firm's perspective); and
- monitoring (purposes, programs, reporting, actions arising from information).

The evaluation of various management strategies will be carried out for a number of scenarios for future sector activities and how these might be affected by management policies and strategies. For example, it might be desirable to determine which types of policy will lead to high, medium and low annual rates of oil and gas extraction and, therefore, lead to various proportions of total reserve recovery.

Identification of management objectives and strategies for MSE depend on discussions among managers and modellers. These have been used to establish models of the management process (i.e. observation and decision processes that lead to regulation of resource extraction). Given scenarios and/or plausible sector (production) models for petroleum exploration and extraction, it is possible to evaluate alternative management strategies using appropriate performance indicators.

The Fishery Sector Model

The fishery sector is made up of three prawn trawl fisheries, a finfish trawl fishery, a trap-and-line fishery, and a recreational line fishery. The sector is modelled to reflect the combined impact of the fishery decisions of individual fishers on the natural environment and the regional community. The basic decision model tracks the spatial allocation of fishing effort, through time, for a given fleet that is subject to management constraints. The impact of fishing effort is then determined, within the components of the underlying biophysical model that deal with habitat and fish population dynamics.

For MSE purposes, the region occupied by each fishery is divided into zones. These zones can be aggregated to match the fishery management zones that have been or are currently in place. This zonal structure can then be used to examine the implications of spatial and seasonal closures for both effort allocation decisions, and the impact of the fishery on the state of the regional ecosystem.

The effort allocation algorithm determines the spatial (i.e. regional) distribution of fishing effort at each time step, given a specification for the total fishing effort by time step. This algorithm represents the net effect of the individual decisions of skippers at fleet level. By applying the effort allocation algorithm to the entire fleet, or to groups of vessels in particular regions, both data requirements and computer search time are reduced without necessarily sacrificing the ability of the model to mimic historical, and predict future, effort.

Briefly, the algorithm works for a given region and fleet by ranking zones in that region according to their historical catch rates, and then distributing the total effort for the region starting with the highest-ranked zone. Limits are placed on the amount of effort that can be allocated to each zone.

The information required is the level of effort (by fleet and region) for the first year of the projection period (1997) and the rate at which annual effort increases (effort is assumed to change linearly with time). For each year of the projection period, the annual effort is apportioned by time step to capture seasonal patterns. Seasonality in effort is based on the distributions of effort by time step for 1989–96. Specifically, this involves selecting a year at random from 1989–96, calculating the fraction of effort by time step for that year, and using these fractions for the year for which a seasonal breakdown in effort is needed.

The underlying biophysical models, necessary for tracking fishery impacts on target fish populations, bycatch species and habitat are either under development or are available from previous studies. We make use of the work of Sainsbury (1988) for a model of the major four species groups in the North West Shelf finfish community that is exploited by the trawl, trap and line fisheries. The spatial and temporal dynamics of the prawn populations are characterised using models developed for the Northern Prawn fishery (Clark and Kirkwood, 1979, Punt et al., 2000). Habitat dynamics models for the NW shelf are currently being developed.

The major management issues for which alternative strategies will be evaluated are zoning and bycatch.

The Conservation Sector Model

The conservation sector is made up of two major components: the conservation movement, which lobbies for protection of the natural environment, and the marine park authority, which manages conservation reserves. It is the clear separation of these lobbying and productive activities distinguishes the conservation sector from other sectors in the MSE modelling framework. Production of access services and facilities will be handled as a series of alternative scenarios. The mechanisms for achieving conservation objectives will be specified, where practicable, according to models arising from the public choice literature (see, for example, Downing, 1984 and Carpenter et al., 1999).

The conservation sector is affected both directly and indirectly by each of the other sectors. Trawl fishing, for example, has physical impact on seabed habitats and prompts changes in fish species composition. By-catch is also important for endangered and threatened species, as well as for biodiversity and other ecosystem characteristics. The light crude oil and gas produced on the NWS is unlikely to have a large impact, except at local scales, because of its volatile nature. However, production of much heavier crude oils is proposed at Woodside’s Deep Vincent field, and its potential impact in the case of a spill could be of concern.

Shipping creates risk due to paints, spills and collisions (routing is clearly an important issue). Coastal infrastructure development also causes local disruption to habitat and marine biota, sometimes irreversibly.

The key management issues for this sector relate to biodiversity indices, indicator species and monitoring, as well as impacts from and compliance with conservation regulations in other sectors. Key habitats and species include mangroves, sea grasses, corals and sponges, dugong, turtles, whales and whale sharks.

The Coastal Development Sector Model

The coastal development sector provides goods, services and production facilities to other sectors and the management agencies of the NWS region. With respect to the marine environment, the major focus is on habitat modification that results from physical disturbance (associated with construction, dredging and production processes) and discharges. The quantities, transport and (chemical and physical) changes of discharges are clearly important. Such discharges include industrial waste, dust and sewage, as well as highly-saline and cooling water.

This sector is concentrated in the major population centres of the region: Exmouth, Onslow, Dampier, Point Samson and Port Hedland. Impacts from existing and proposed developments in these centres, as well as human population projections, will be assessed for alternative scenarios. Modelling for this sector is directed primarily at transport and change of discharges in the ecosystem. Environmental impact modelling will also play a central role for the conservation sector.

The major management issues relate to zoning, monitoring, discharges and compliance with requirements specified in both the approvals process and revised regulations.

Management of the NWS regional ecosystem

Management of the NWS regional ecosystem is conducted by government agencies at federal, state and local levels. Management agencies correspond to the activity sectors in the main, although all four sectors are regulated by more than one agency. In the MSE framework the main focus is on local and state government agencies, although an integrating entity is specified for our research purposes. The integrating management agency serves to account for co-ordination among agencies as well as the influence of federal jurisdiction and civil law.

For each of the management issues identified in the course of the NWSJEMS the following are specified for MSE:

- *Management objectives* expressed in terms of their intended impact on the regional ecosystem and/or local environment;
- *Management strategies* for achieving specified objectives (including identification of feasible control variables, monitoring programs and feedback mechanisms, as well as specification of decision rules); and
- *Indicators and performance measures* (from the biophysical model) and *indicators* (from management observation and monitoring) for assessing how well management objectives have been achieved.

The various management strategies are evaluated by comparing performance measures and indicators. This project has built on the existing indicators, targets and performance measures in management plans and policies. The set of indicators used includes: water quality; habitats and biodiversity; food-chain integrity; endangered species, habitats, communities; public amenity; ecosystem services.

Particular indicators and performance measures have been developed in consultation with stakeholders and extended to include a range of economic indicators. MSE will be carried out while considering biophysical uncertainty, although accounting explicitly for the response of managers to this uncertainty will not be done in the first instance. The use of monitoring programs by managers (and sectors) will be examined, however. Initially, the three main management control variables, considered for each sector, will be present zoning structure, types of activity permitted (and excluded), and the levels permitted for each activity. Management strategies currently in use and minor variations of them, are considered in the first application of the framework.

For each sector, a selection of competing scenarios, stipulated by interest groups, will be represented. These scenarios include trajectories for future sectoral activities (and impacts) and the sectoral response to management policy and strategies. Evaluation under various scenarios will then enable determination of a range of outcomes that assist in identifying the types of policy that lead to various (i.e low, medium and high) levels of production or development in sectoral activities.

7.4 Illustrative Example of Management Strategy Evaluation

The MSE computer program is, at this stage of the Study, neither fully specified nor calibrated sufficiently to evaluate management strategies at the regional ecosystem level. However, an illustrative example of the approach is provided. This example considers a simple variation in the zoning of commercial trawl fishing, and specifically the opening of a presently closed area to fishing. So two management strategies are being compared which differ only in whether trawling is allowed in a zone that is presently closed to trawling.

The first strategy involves opening all fishing areas except Area 3 (see Figure 7.4.1) to commercial trawl fishing. This is similar to current management in the Pilbara trawl fishery.

The second strategy is to open all Areas, including Area 3, to commercial trawl fishing. These strategies are evaluated in the context of objectives and activities relating to all the other main human use sectors (ie oil and gas, fisheries, conservation and coastal development), although in this simple example the alternative management strategies effect performance of only the fisheries and conservation sectors.

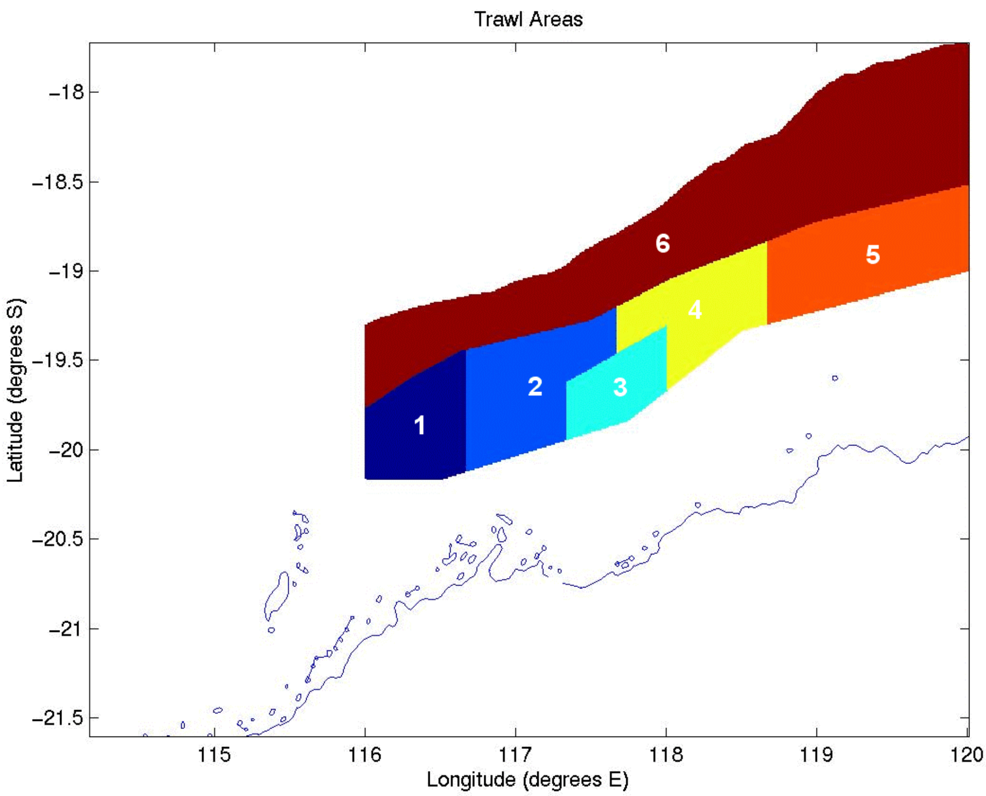


Figure 7.4.1 The areas within trawl fishing Zone 2 where trawling may be permitted. Currently commercial fishing is not permitted in Area 3. The illustrative example of MSE compares opening Area 3 to its continued closure.

The application of MSE requires description of the management objectives, performance measures, management strategies and key uncertainties. In this illustrative example these were specified for each sector as follows (but noting that the strategies being compared in this illustration do not influence the oil and gas or coastal sectors performance measures):

Management Objectives

- Oil and Gas: maximum oil and gas recovery;
- Conservation: maintain nursery and refuge areas to protect ecosystem integrity and threatened species;
- Fishery: maintain fish populations to ensure long-term sustainable fisheries; and
- Coastal Development: maintain water quality above minimum human health standards.

Performance Measures

- Oil and Gas: production (quantity and $ value);
- Conservation: habitat impact index; animal population levels;
- Fishery: catch per unit effort (CPUE); and
- Coastal Development: coliform count (sewage).

Management Strategies

1. Zoning for particular uses
    - Oil and gas: existing lease areas;
    - Conservation: existing marine protected areas;
    - Fishery: two strategies compared - existing fishing zones and one zone opened to trawling that is currently closed (see Figure 6.3); and
    - Coastal Development: existing location of coastal industries and ports.

2. Monitoring used in feedback rules
    - impact of outflows on habitat (in relation to productive activities in commercial fishing, coastal development, conservation, and mineral and energy resource extraction);
    - key species population level (in relation to methods and intensity of fishing);
    - key species migration and reproductive strategies (in relation to mineral and energy exploration, fishing and recreational activity); and
    - ecosystem health (in relation to permitted uses in MPAs and industrial discharges).

Quantified Uncertainties

- environmental uncertainty (e.g. cyclone frequency, temperature variation, global warming);
- biological uncertainty (e.g. recruitment and survival rates, recovery and growth, fecundity);
- model uncertainty (limitation of scientific knowledge leads to uncertainty in model

parameters and model structure);

- measurement uncertainty (some measurements are subject to significant error);
- management implementation uncertainty (there is not perfect compliance with management measures).

The model is run under each strategy many times to take account of uncertainties, and strategies are compared according to the indicators and performance measures.
The results are viewed and compared through indicator scoreboards, maps, graphs, and tables that are generated by the MSE software.

The two strategies being compared (opening or closing trawl Area 3) have almost no impact on either the oil and gas sector or the coastal development sector, and so performance measures relating to these sectors are not shown here. The performance indicators used to compare the success of the two strategies in achieving the stated management objectives are the habitat impact index, size of animal populations and the catch per unit effort of the fishing fleet.

The results from each of the two strategies are displayed in Figures 7.4.2 – 7.4.6. These Figures illustrate the direct output available to a user of the current MSE software. The displayed results are the predicted annual average response over 12 years under each management strategy.

Three comparisons of the two different strategies are shown. These are i) Redistribution of fishing effort under the two strategies; ii) Impact on seabed habitats under the two strategies; and iii) Scoreboard of catch, catch rate and habitat impact under each strategy.

i) Redistribution of fishing effort under the two strategies
One response to the opening or closing of Area 3 is the redistribution of fishing effort among the areas available to trawling. This is the result of operational decisions by fishers as they seek to optimise their financial returns from the areas available for fishing.

Figure 7.4.2 illustrates the effort-allocation response of fishers to the opening of Area 3 to commercial trawl fishing. Effort is measured in hours of trawl time per annum for the fleet. The most obvious changes are the attraction of effort to Area 3 when it is opened, but there are also significant changes in the fishing effort in other Areas. Most notably opening Area 3 removes the concentration of effort in Area 1 and results in a more even distribution of fishing effort across all areas, including a moderate increase of effort in the Area 6 that is little fished when Area 3 is closed. Figure 7.4.3 shows different representations of these changes that are available from the MSE software. Figure 7.4.4 shows a selection of predicted individual vessel tracks (including transit steaming) when Area 3 is closed.

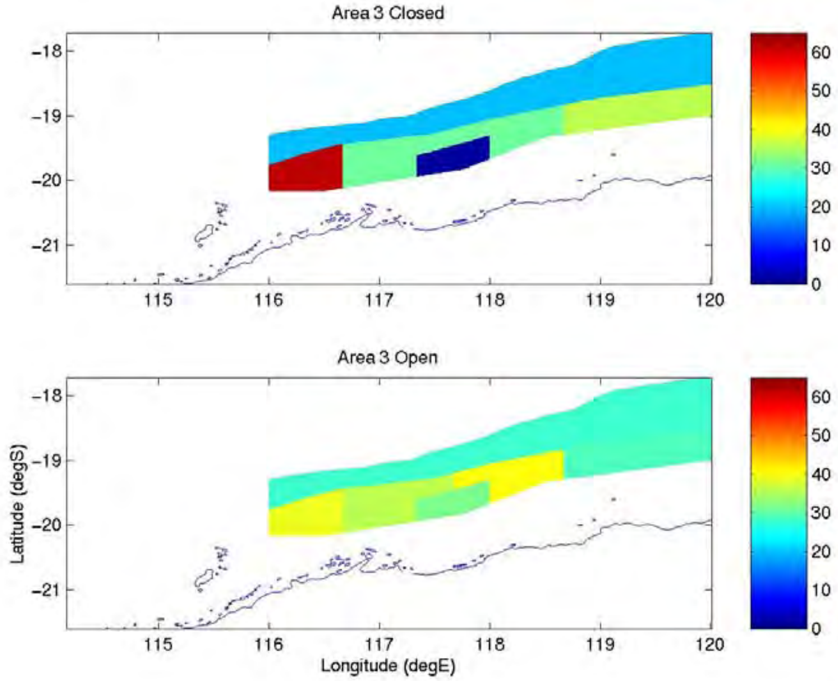


Figure 7.4.2 Commercial trawl-fishing effort distribution with Area 3 open and with Area 3 closed. Fishing effort is measured in trawl hours. Notice that closing or opening Area 3 is predicted to cause a major redistribution of fishing effort among the other areas as a result of operational constraints and incentives. Closing Area 3 is predicted to result in a significant concentration of fishing effort in Area 1 and very little fishing in Area 6. Opening Area 3 is predicted to result in a more even distribution of effort among Areas 1-4 and an increase on effort in Area 6.

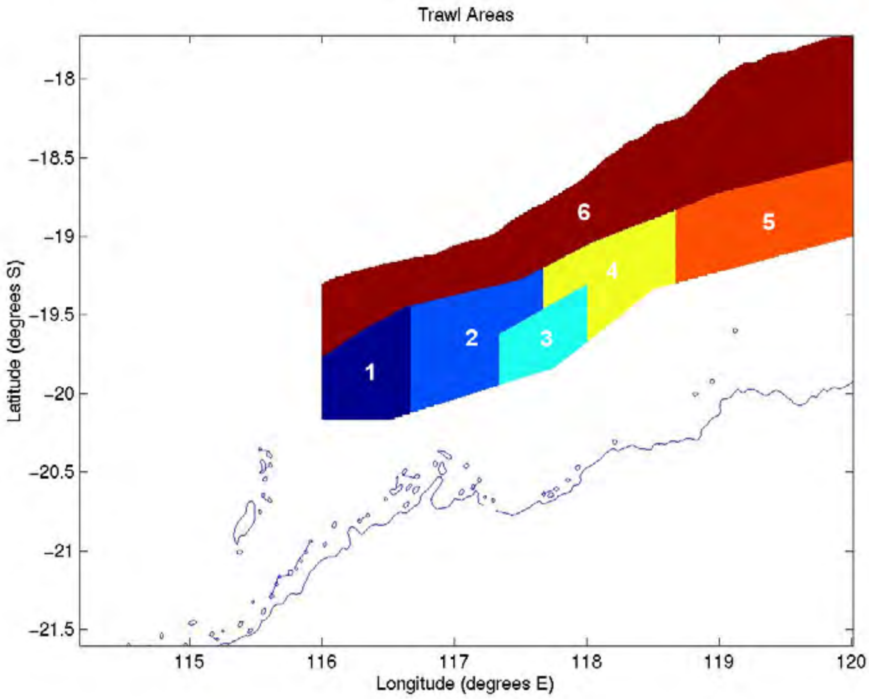


Figure 7.4.3 The proportionate change in commercial fishing effort after Area 3 is opened. The fishing effort is predicted to increase in areas 2, 3, 4 and 6, and to decrease in Areas 1 and 5.

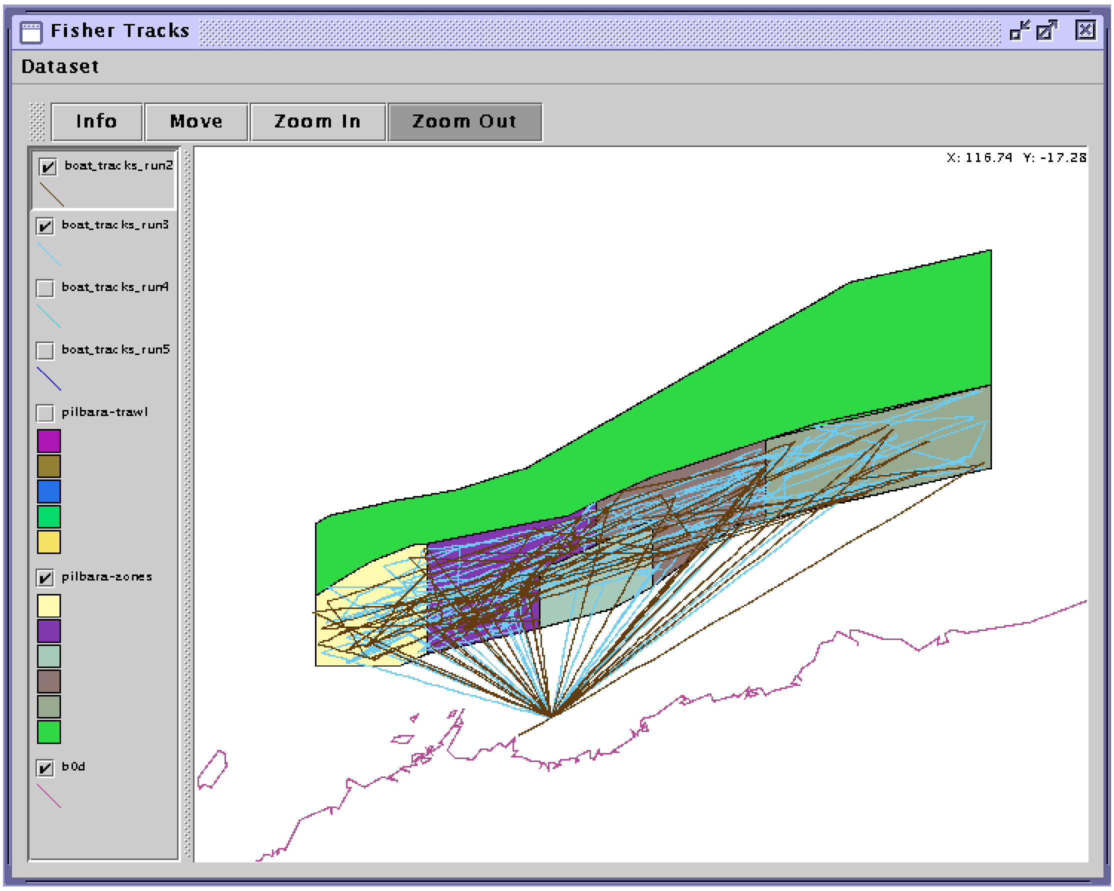


Figure 7.4.4 Predicted commercial trawl-fishing vessel tracks with Area 3 closed. These tracks are predicted on the basis of operational decisions made by individual fishers as they seek to optimise their returns from the fishing areas available.

ii) Impact on seabed habitats under the two strategies

The benthic habitat impact resulting from trawl fishing under each strategy is illustrated in Figure 7.4.5. This shows the proportion of benthic habitat that is trawled during the 12 year assessment period. All areas experience a change in habitat impact as a result of opening Area 3. As one would expect, the greatest change is seen in Area 3 which experiences an increase in habitat impact. But Areas 2, 4 and 6 also receive increased habitat impact. Areas 1 and 5 experience a reduction in habitat impact as a result of reduced fishing pressure, the most notable being in Area 1. Opening Area 3 results in a somewhat uniform level of habitat impact across all areas, whereas with Area 3 closed there is a in very high impact in Area 1 and almost no impact in Area 3.

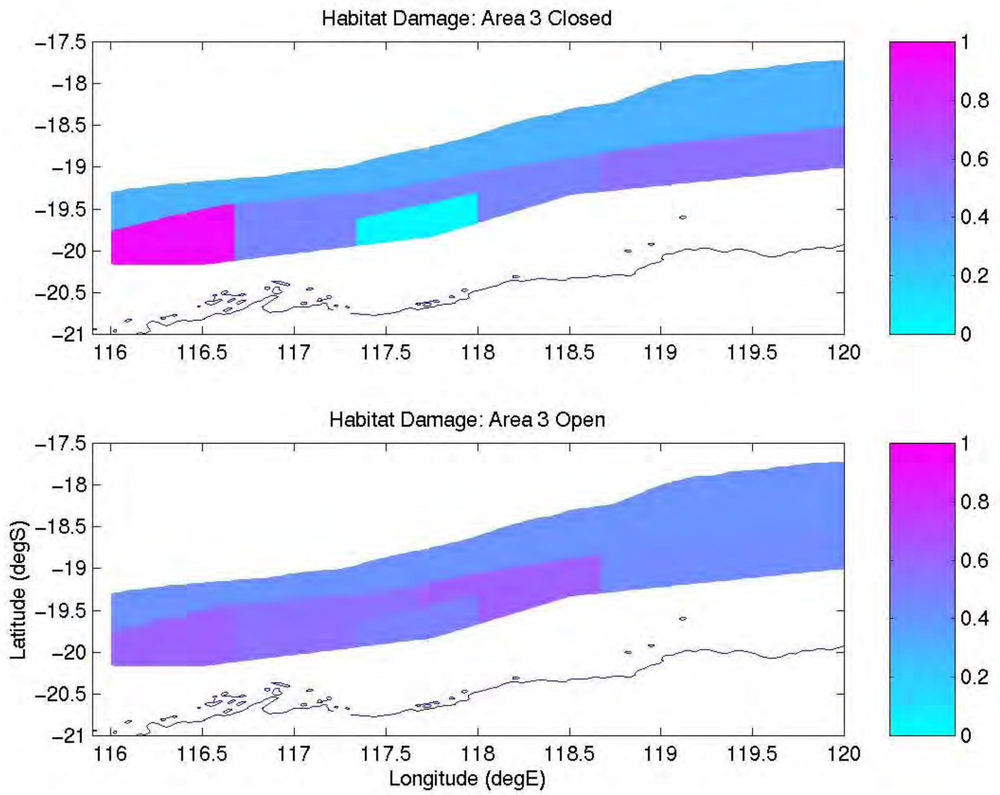


Figure 7.4.5 Impact on sea-bed habitat caused by commercial trawl-fishing with Area 3 closed or open. Impact is measured by the proportion of the seabed in each area that is trawled during the 12 year assessment period. Opening Area 3 to commercial fishing increases the habitat impact in Areas 2, 3, 4 and 6, and decreases it in Areas 1 and 5. Opening Area 3 results in a somewhat uniform level of habitat impact across all areas, whereas with Area 3 closed there is a very high impact in Area 1 and very low impact in Area 3.

iii) Scoreboard of catch, catch rate and habitat impact under each strategy
Figure 7.4.6 illustrates a summary ‘scoreboard’ for how the four indicators respond to the change in management strategy. The change in fishing effort distribution across the trawl fishing zone mimics that in the previous figures. The implications for the fishing fleet are that catch declines overall when Area 3 is opened (508.6t compared to 551.8t per annum) but the distribution of effort (and therefore catch) is more concentrated. This follows because cost is included in the effort-allocation model in which fishers seek to maximise their net returns by balancing revenues and costs in deciding where it is best to fish. This is reinforced by changes in the economic-efficiency indicator catch per unit effort (CPUE). Except for Area 6, which maintains a reasonably constant CPUE, all Areas experience a significant increase in CPUE. This coincides with an overall annual effort reduction of around 3½ percent and reflects the nonlinearities in the relationship among effort, catch, CPUE and net revenue.

The habitat impact index shows the widespread change that results from the effort response to opening Area 3. Concurrent with increased effort, Areas 2, 3, 4 and 6 show a marked increase in habitat impact. Likewise, the reduction in effort allocated to Areas 1 and 5 causes a decline in habitat impact there.

Scoreboard - Fishery Strategies		
Measure	**Area 3 Open**	**Area3 Closed**
Effort Area 1	1509	3741
Effort Area 2	1332	939
Effort Area 3	1009	3
Effort Area 4	1612	977
Effort Area 5	847	1271
Effort Area 6	752	379
Catch Area 1	201522	376426
Catch Area 2	78627	66817
Catch Area 3	66708	16
Catch Area 4	89687	44432
Catch Area 5	54001	53827
Catch Area 6	18051	10308
CPUE Area 1	134	101
CPUE Area 2	59	71
CPUE Area 3	66	5
CPUE Area 4	56	46
CPUE Area 5	64	42
CPUE Area 6	24.004	27
Habitat Impact Area 1	0.3773	0.9353
Habitat Impact Area 2	0.3330	0.2348
Habitat Impact Area 3	0.2523	0.0008
Habitat Impact Area 4	0.4030	0.2443
Habitat Impact Area 5	0.2118	0.3178
Habitat Impact Area 6	0.1880	0.0948

very high	high	medium	low

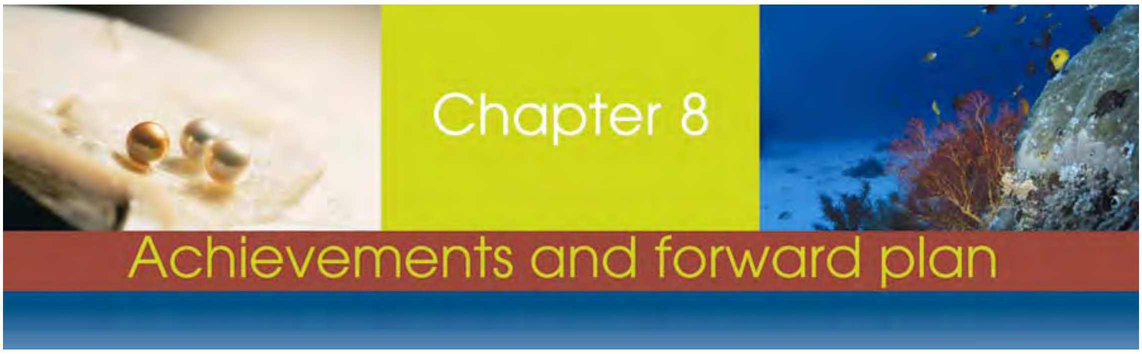
Figure 7.4.6 Indicator scoreboard for Area 3 open and Area 3 closed. In this form of presentation colour coding is used to highlight substantial differences in outcome between the two strategies being examined – Area 3 open and Area 3 closed to commercial trawl fishing.

7.5 Concluding Remarks

NWSJEMS contains a complex array of modelling, observation, data-collection and consultative tasks. The MSE project plays an important role in integrating these elements. This requires close collaboration among all members of the Study team, as well as with stakeholders. Management agencies have been especially helpful in providing guidance on management objectives, development scenarios and potential future management strategies.

The MSE approach has been applied to many management situations elsewhere but this is the first time an attempt has been made to develop and apply it to multiple use management of a whole regional ecosystem. The MSE models and information inputs are challengingly complex, but the project is demonstrating that application of MSE to a regional ecosystem is achievable.

The illustrative example is relatively simple, but it demonstrates the approach and the trade-offs that can be explored and quantified using the MSE framework. It also illustrates the interplay between different levels of decision making – in this case the sectoral operator and the regulator. A decision by the regulator to make a simple change in zoning for the commercial trawl fishery results in a significant redistribution of fishing effort on the NWS because of the decisions made by fishery operators within the changed regulatory environment. Consequently, the relatively small change in zoning not only has an impact on the fishery itself, through a change in catch and economic performance (CPUE), but also affects conservation values in many widespread parts of the NWS. Even in this simple illustration it is clear that MSE at the regional ecosystem level requires a comprehensive model that takes account of important interconnections and causal relationships among the sectors and bio-physical units of the ecosystem.



Chapter 8

Achievements and forward plan

The North West Shelf Joint Environmental Management Study (NWSJEMS) was established with challenging and ground breaking objectives. It was motivated by the desire for science to support a new management approach to the sustainable development of marine industries. That approach involves integrated planning and management of the multiple uses that may impact the NWS marine ecosystems.

The challenges to this approach arise at many levels. These include: amassing and interpreting previously scattered information about all aspects of the ecosystem, and human uses of it; building the tools to effectively access this information; developing explanatory and predictive models and scenarios for the natural system and human impacts on it; developing methods to predict the range of outcomes expected under different development scenarios and management regimes; developing methods to design effective monitoring programs to support ongoing management decision-making.

The three key objectives of NWSJEMS are:

1. Compile, extend and integrate the scientific information and understanding of the marine and coastal ecosystems of the NWS so as to:
   - improve the quality, quantity and accessibility of data and understanding about the ecosystems and human uses of it;
   - describe the ecosystems; and
   - predict the impacts of natural events and human use.

2. Develop and demonstrate practical, science-based methods, which support integrated regional planning and multiple-use management, for ecologically sustainable development of marine ecosystems.

3. Provide improved scientific understanding and methods for multiple-use planning and management of the resources and environment of the NWS, under existing statutory arrangements.

The study is now about three quarters complete and, as planned, it has made very significant progress towards these objectives.

In relation to the first objective the study has:

- compiled and reviewed the previous scientific studies in the region;
- developed a data-base of information and observations from numerous previous studies and surveys, including from government sources, industry sources and the ‘expert knowledge’ of people very familiar with the NWS;
- compiled an inventory of important pollutants and contaminants, including their sources and quantities;
- developed user-friendly tools to access and view the data that has been assembled, including tools that are based on world wide web technologies and so are functional across different computers and locations;
- provided a hierarchical classification and mapping of the main ecosystems and habitats that comprise the NWS regional ecosystem;
- developed models of some of the key oceanographic and ecological processes, including water currents and dispersal of particles (eg pollutants or larvae), the cycling of key nutrients, primary productivity, the dynamics of seabed and coastal habitats, food webs, the dynamics of key species, and broad patterns of biodiversity; and
- developed models of the impacts of some of the main human uses of the NWS regional ecosystem.

In relation to the second and third objective the study has:

- identified with stakeholders initial sets of industry development scenarios, objectives and performance measures for comparison of multiple-use management strategies;
- developed a functional although simplified model of the ecosystem, the ecological impacts of the main human uses, and the economic returns generated from those uses;
- developed a functional although simplified model of the management strategies currently being used to regulate some industry users of the ecosystem, and of the industry response to these management measures;
- combined the ecosystem model, impacts model and management models to demonstrate their combined use in exploring the effect of a changed sectoral management strategy on that sector, other sectors and the ecosystem as a whole; and
- demonstrated the approach to a stakeholder workshop.

While this study is clearly focused on the NWS regional ecosystem, the models, methods and tools have been developed as generally and flexibly as possible. This will allow relatively easy transfer of the capability developed for the NWS to other regional ecosystems.

Information exchange between the Study team and the broader stakeholder and community groups has been critical for the success of the Study. This communication process allows mutual understanding between the scientists, regulators, stakeholders and community, and preferred outcomes and options in environmental and sectoral management of the NWS.

The methods used include workshops and forums in Perth, Dampier and Karratha, a community liaison consultant based on the NWS, face-to-face interviews with key stakeholders, newsletters and media releases, and a web page. In addition frequent meetings are held between the scientists and staff of the main government departments. A survey of residents from the NWS region was also conducted, which indicated a desire to preserve the region's water quality and ecosystems while also allowing development of the area.

There is still considerable development to be undertaken through the NWS Joint Environmental Study, especially in refining the currently simple models and tools used to achieve the second and third objectives. But progress so far demonstrates that it is technically feasible to assemble and integrate the wide variety of information and issues into models that can be used to explore and compare the environmental and economic consequences of alternative sectoral management strategies. This is a necessary first step in providing pro-active science support for multiple use management of marine ecosystems.

Forward Plan

The remaining time of the NWS Joint Environmental Management Study will be used in four main activities – the first two relating to completion of the technical tasks of the study and the second two relating to the ongoing application of the capabilities developed by the study. These activities are:

- Further compilation and interpretation of existing data and knowledge.

    - This will focus on several selected examples where long-term monitoring and research can provide understanding about the dynamics of key processes. These are expected to involve the monitoring and research studies conducted by the oil and gas industry on coastal and offshore habitats and by the WA Fisheries Department on inshore habitats and fishery by-catch.

- Refinement of the ecosystem models, human impact models and management strategy evaluation tools.

    - This will be the main focus of activity in the next several months, and will involve refinement of several aspects of the modelling and evaluation tools. The model representations of the ecological processes and management strategies will be improved. There will be more complete treatment of uncertainties as reflected by different model structures and parameter values. Capability will be added to allow explicit evaluation of feed-back or adaptive management strategies, including the design of monitoring strategies. And the user interface and 'visualisation' of the model and management strategy evaluation software will be made more user-friendly.

- Increase linkage to the NWS Marine Environmental Management Study (NWSMEMS),

- NWSMEMS is responsible for ensuring that any necessary institutional arrangements are in place to allow for integrated management and decision making for the NWS. The WA regulating agencies have been closely involved with the activities and products developed through NWSJEMS, and as these products become increasingly operational they will be demonstrated and made available to NWSMEMS. It is expected that this will both provide additional feedback to the activities of NWSJEMS and help identify any necessary actions on behalf of NWSMEMS.

- Transfer of capability to Western Australia for ongoing maintenance, access and use of NWSJEMS products.

    - Some of the key products of NWSJEMS are data sets, data management tools, models and management strategy evaluation tools. To enable their ongoing use and application, beyond the life of NWSJEMS, these products require ongoing maintenance, updating and a pool of people familiar with their use. Consequently transfer of the products of NWSJEMS to a suitable support facility in Western Australia is critical to their ongoing use and ongoing benefit from the study. Various options will be explored, but it is expected that the transfer will be under the auspices of the Strategic Research Fund for the Marine Environment (SRFME) – a joint venture between the Government of Western Australia and CSIRO.

In summary, all aspects of the Study are on track and progressing well. The scientific information available from the NWS has been largely consolidated and interpreted, and has been used to develop models of the main biophysical processes on the NWS and the impacts of some human activities. The tools to apply management strategy evaluation methods to multiple use management of the NWS have also been developed.

The workplan from this point on will refine the models and the data they are based on, and will further engage user in their application.

Abbreviations

ACCOM	Australian Community Ocean Model
AFMA	Australian Fisheries Management Authority
AGSO	Australian Geological Survey Organisation now Geoscience Australia
AIMS	Australian Institute of Marine Science
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZLIC	Australian and New Zealand Land Information Council
APPEA	Australian Petroleum, Production and Exploration Association
ARMCANZ	Agricultural Resources Management council of Australia and New Zealand
ASDD	Australian Spatial Data Directory
CAES	Catch and Effort Statistics
CDF	Common data format
CTD	conductivity-temperature-depth
CMR	CSIRO Marine Research
ConnIe	Connectivity Interface
CPUE	Catch per unit effort
CSIRO	Commonwealth Science and Industrial Research Organisation
DCA	detrended correspondence analysis
DIC	Dissolved inorganic carbon
DOM	Dissolved organic matter
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
ENSO	El Nino Southern Oscillation
ESD	Ecologically Sustainable Development
FRDC	Fisheries Research and Development Corporation
GA	Geoscience Australia formerly AGSO
GIS	Geographic Information System
LNG	Liquified natural gas
MARLIN	Marine Laboratories Information Network
MECO	Model of Estuaries and Coastal Oceans
MPAs	Marine Protected Areas
MEMS	Marine Environmental Management Study
MSE	Management Strategy Evaluation
NCEP - NCAR	National Centre for Environmental Prediction – National Centre for Atmospheric Research
NGOs	Non government organisations
NWS	North West Shelf
NWSJEMS	North West Shelf Joint Environmental Management Study
NWSMEMS	North West Shelf Marine Environmental Study
PFW	Produced formation water
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SOI	Southern Oscillation Index
TBT	Tributyl Tin
WALIS	Western Australian Land Information Service
WOD	World Ocean Database
www	world wide web

Bibliography

Appleyard, S.J. January 2000, *Discharge of Nitrogen by Groundwater to the Marine Environment in the Pilbara Region: Preliminary Assessment.* Hydrogeology Report No. HR 152. Unpublished report. WA Waters and Rivers Commission, Perth, W.A.

ANZECC (1997). *Best Practice in Performance Reporting in Natural Resource Management*. Department of Natural Resources and Environment, Melbourne, Australia.

ANZECC (1998). *ANZECC Interim Marine and Coastal Regionalisation for Australia - an ecosystem-based classification for marine and coastal environments*. Version 3.3, Environment Australia, Canberra.

ANZECC (1999). *Strategic Plan of Action for the National Representative System of Marine Protected Areas: A Guide for Action by Australian Governments*. ANZECC Task Force on Marine Protected Areas. Environment Australia, Canberra.

Australian and New Zealand Environment and Conservation Council (ANZECC), Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1*, Australian and New Zealand Environment and Conservation Council, and Agricultural and Resource Management Council of Australia and New Zealand. Canberra, ACT, Australia.

Batteen, M.L., Rutherford, M.J., and Bayler, E.J., 1992, "A numerical study of wind- and thermal-forcing effects on the ocean circulation off Western Australia", *J. Phys. Oceanogr.*, 22, 1406-1433.

Blaber, S.J.M.,Young, J.W., and Dunning, M.C., 1985, " Community structure and zoogeographic affinities of the coastal fishes of the Dampier region of north-western Australia", *Aust. J. Mar. Freshwat. Res.,* 36, 247-266.

Bruce, B. D., Condie, S.A., and Sutton, C.A., 2001, "Larval distribution of blue grenadier (Macruronus novaezelandiae Hector) in south-eastern Australia: further evidence for a second spawning area", *Mar. Freshwat. Res.,* 52: 603-610.

Brunskill, G., Orpin, A., Zagorskis, I., Woolfe, K., Ellison, J. 2001, "Geochemistry and particle size of surface sediments of Exmouth Gulf, Northwest Shelf, Australia", *Cont. Shelf Res.,* 21, 157-201

Buchan, S. J. and Stroud, S.A. 1993, *Review of oceanography of North West Shelf and Timor Sea regions pertaining to the environmental impact of the offshore oil and gas industry,* Unpublished report, Steedman Science and Engineering Report No. R644, Perth.

Burns, K.A. and Codi, S. 1999, Non-volatile Hydrocarbon Chemistry Studies Around a Production Platform on Australia's Northwest Shelf. Estuarine, *Coastal and Shelf Science,* 49, 853 – 876.

CALM (1994). *A Representative Marine Reserve System for Western Australia*. Report of the Marine Parks and Reserves Selection Working Group. Department of Conservation and Land Management, Perth, Western Australia.

CALM (2000). *Corporate Plan 2000-2005.* Department of Conservation and Land Management, Western Australia.

Carr, B., N. Livesey and Paling, E. 1996a, *Pilbara Mangrove Study, Volume 1* NEDP Report No. 18, Murdoch University, Western Australia. 102pp.

Carr, B., N. Livesey and Paling, E. (1996b) *Pilbara Mangrove Study, Volume 2B Introduction, Site Criteria Lists, Selected Site Information and Maps. NEDP Report No. 18,* Murdoch University, Western Australia.

Carr, B., N. Livesey and Paling, E. (1996c) *Pilbara Mangrove Study, Volume 2A Introduction, Site Lists and Site Information, Mangrove Site Database. NEDP Report No. 18,* Murdoch University, Western Australia.

Carpenter, S., Brock, W., and Hanson, P. 1999, "Ecological and social dynamics in simple models of ecosystem management", *Conservation Ecology,* 3 (2): 4. [online] URL://www.consecol.org/vol3/iss2/art4

Caswell, H. and John, A.M. (1992) "From the individual to the population in demographic models" in *Individual-Based Models and Approaches in Ecology,* eds D. DeAngelis, D. and L. Gross, Chapman & Hall, New York, New York. pp 36-61

Clarke, C.W., and Kirkwood, G.P. 1979, "Bioenconomic model of the Gulf of Carpentaria Prawn Fishery", *Journal of the Fisheries Research Board of Canada,* 36, 11, 1304 – 1312.

Cleveland, W.S. and Devlin, S.J. 1988, "Locally weighted regression: An approach to regression analysis by local fitting", *J. Amer. Stat. Assoc.,* 83, 596-610.

Condie, S. A. and Andrewartha, J. 2002, *North West Shelf Joint Environmental Management Study: Technical Report No. 2.2: Surface Waves.* Unpublished report, CSIRO Marine Research Report

Condie, S. A., N. R. Loneragan and D. J. Die 1999, "Modelling the recruitment of tiger prawns (Penaeus esculentus and P. semisulcatus) to nursery grounds in the Gulf of Carpentaria, northern Australia: implications for assessing stock-recruitment relationships", *Mar. Ecol. Prog. Ser.* 178: 55 - 68.

Crawley, K. March 2000, *Estimated Tribulytin Inputs into Port Waters in the North West Shelf.* Unpublished report. Department of Environmental Protection. Perth, W.A. pp. 1 - 12.

CSIRO 1996, *Port Phillip Bay Environmental Study: Final Report*, CSIRO, Dickson, ACT, Australia.

DeAngelis, D. and Gross, L. 1992, *Individual-Based Models and Approaches in Ecology,* Chapman & Hall, New York, U.S.A.

Department of Environmental Protection November 1996, *Southern Metropolitan Coastal Waters Study (1991 – 1994): Final Report, Report 17.*, Department of Environmental Protection, Perth, W.A.

Downing, P.B. 1984, *Environmental Economics and Policy,* Little, Brown and Company (Canada) Ltd., Boston, U.S.A.

Dunn, J. R. and Ridgway, K.R. 2002, " Mapping ocean properties in regions of complex topography", *Deep-Sea Res. I*, 49, 591-604.

Fandry, C. B. and Steedman, R.K. 1994, "Modelling the dynamics of the transient, barotropic response of continental shelf waters to tropical cyclones.", *Cont. Shelf Res.*, 14, 1723-1750.

Cresswell, G.R., Frische, A., Peterson, J., and Quadfasel, D. 1993, "Circulation in the Timor Sea", *J. Geophys. Res.* 98, 14379-14389.

Godfrey, J.S. and Ridgway, K.R. 1985, "The large-scale environment of the poleward-flowing Leeuwin Current, Western Australia: Longshore steric height gradients, wind stresses and geostrophic flow", *J. Phys. Oceanogr.* 15, 481-495.

Gordon, D. 1999, *Summary of International Conventions, Commonwealth and State Legislation and Other Instruments Affecting Marine Resource Allocation, Use, Conservation and Environmental Protection on the North West Shelf of Australia. A report prepared for the North West Shelf Marine Environmental Management Study,* Unpublished Report. Department of Environmental Protection, Western Australia.

Grant, W. D. and Madsen, O.S. 1979, "Combined wave and current interaction with a rough bottom" *J. Geophys. Res.*, 84, 1797-1808.

Hamilton, L. J. 1997, "Methods to obtain representative surface wave spectra, illustrated for two ports of north-western Australia", *Mar. Freshwater Res.*, 48, 43-57.

Hearn, C.J. and Holloway, P.E. 1990, "A three-dimensional barotropic model of the response of the Australian North West Shelf to tropical cyclones", *J. Phys. Oceanogr.*, 20, 60-80.

Heyward, A.J., Revill, A.T., Sherwood, C.R. January 2000, *Reiview of Research and Data Relevant to Marine environmental Management of Australia's North West Shelf,* Unpublished report. Department of Environmental Protection, Perth.

Holloway, P. E. 1983, "Tides on the Australian North-West Shelf", *Aust. J. Mar. Freshwat. Res.,* 34, 213-230.

Holloway, P.E. 1984, "On the semidiurnal internal tide at a shelf-break region on the Australian North West Shelf", *J. Phys. Oceanogr.*, 14, 1787-1799.

Holloway, P.E. 1985, "A comparison of semidiurnal internal tides from different bathymetric locations on the Australian North West shelf", *J. Phys. Oceanogr.,* 15, 240-251.

Holloway, P.E. 1987, "Internal hydraulic jumps and solitons at a shelf break region on the Australian North West Shelf", *J. Geophys. Res.* 92, 5405-5416.

Holloway, P.E. 1995, "Leeuwin Current observations on the Australian North West Shelf, May-June 1993", *Deep Sea Res.* 42, 285-305.

Holloway, P.E. 2001, "A regional model of the semidiurnal internal tide on the Australian North West Shelf", *J. Geophys. Res.* 106, 19625-19638.

Holloway, P.E., Humphries, S.E., Atkinson, M., and Imberger, J. 1985, "Mechanisms for nitrogen supply to the Australian North West Shelf", *Aust. J. Mar. Freshwat. Res.* 36, 753-764.

Holloway, P. E. and Nye, H.C. 1985, " Leeuwin Current and wind distributions on the southern part of the Australian North West Shelf between January 1982 and July 1983", *Aust. J. Mar. Freshwat. Res.*, 36, 123-137.

Johnson, D. B., Hebbert, D.R., and Moran, M.J. 1993, "Genetic analysis of populations of north-western Australian fish species", *Australian Journal of Marine and Freshwater Research* 44, 673-685.

Jones, H.A. 1973, "Marine Geology of the Northwest Australian continental shelf", *BMR Bull.,* 136.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C. Wang, J., Leetmaa, A., Reynolds, R., Jenne, R.,and Joseph, D.,1996, "The NCEP/NCAR 40-year reanalysis project", *Bull. Amer. Meteor. Soc.,* 77, 437-471.

Marsh, L.M., and Marshall, J.L. 1983, "Some aspects of the zoogeography of north western Australian echinoderms (other than holothurians)", *Bull. Mar. Sci.* 33, 671-687.

McLoughlin, R.J. and Young, P.C. 1985, “Sedimentary provinces of the fishing grounds of the North West Shelf of Australia: grain-size frequency analysis of surficial sediments”, *Aust. J. Mar. Freshwat. Res.*, 36, 671–681.

Meyers, G., Bailey, R.J., and Worby, A.P. 1995, “Geostrophic transport of Indonesian throughflow”, *Deep Sea Res.*, Part I, 42, 1163-1174.

Moran, M.J., Jenke, J., Cassells, G., and Nowra, G. 1995, Research for Allocation of North-West Marine Finfish Resources Among Diverse User Groups. FRDC Final Report: Project no. 91/28, 73. WA Fisheries, Western Australia.

National Food Authority 1994, *Australian Food Standards Code 1994,* Australian Government Publishing Services, Canberra.

Paling, E.I. and McComb, A.J. 1994 “Cyanobacterial mats: a possible nitrogen source to arid coast mangroves”, *Int. J. Ecol. Envir. Sci.,* 20, 47-54.

Rainer, S.F. 1991, “High species diversity in demersal polychaetes of the north west shelf of Australia”, *Ophelia, Systematics, Biology and Morphology of World Polychaeta Supplement* 5, 497-505.

Ribbe J. and Holloway, P. 2001, “A model of suspended sediment transport by internal tides”, *Cont. Shelf Res.,* 21, 395-422.

Robertson, A. (1993) *Study of the Impact of Pilbara Coastal Development on Arid Zone Mangroves Stage 1,* Unpublished report. AIMS, Townsville, QLD.,41pp.

Sainsbury, K.J. (1987) “Assessment and management of the demersal fishery on the continental shelf of north western Australia”, in *Tropical Snappers and Groupers, Biology and Fisheries Management,* edited by J. J. Polovina and S. Ralston, Westview Press, Boulder, USA, pp. 465-503.

Sainsbury, K. J. 1988, “The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia”, in *Fish Population Dynamics: the implications for management,* ed. J.A. Gulland, second edition, John Wiley and Sons Ltd., Chichester, U.K.

Sainsbury, K.J., Campbell, R.A. and Whitelaw, A.W. 1993, “Effects of trawling on the marine habitat on the north west shelf of Australia and implications for sustainable fisheries management,” ed. D.A. Hancock, Australia, Australian Government Publishing Service, Canberra.

Schiller, A., Godfrey, J.S., McIntosh, P.C., Meyers, G., and Fiedler, R. 2000, “Interannual dynamics and thermodynamics of the Indo-Pacific Oceans”, *J. Phys. Oceanogr.,* 30, 987-1012.

SeaWiFS Technical Report 1997, Yeh, e-n., Barnes, R.A., Darzi, M., Kumar, L., Early, E.A., Johnson, B.C., Mueller, J. L., and Trees, C.C., *Case Studies for SeaWiFS*

Calibration and Validation, Part 4. NASA Tech. Memo. 104566, Vol. 41, Eds., S.B. Hooker and E.R. Firestone, NASA Goddard Space flight Centre, Greenbelt, Maryland, pp.35.

Semeniuk, V. 1983, "Mangrove distribution in north western Australia in relationship of region and local freshwater seepage", *Vegetatio*, 53, 11-31.

Semeniuk, V. 1993, "The mangrove systems of Western Australia: 1993 Presidential Address", *Journal of the Royal Society of Western Australia*, 76, 99-122.

Semeniuk, V., P. N., Charmer and Le Provost, I. 1982, "The marine environments of the Dampier Archipelago" *J. Roy. Soc. West. Aust.,* 65, 97-114.

Simpson, C.J. 1985, "Mass spawning of Sceleratinian Corals in the Dampier Archipelago and the implications from management of coral reefs in Western Australia", *Department of Conservation and Environment Bulletin,* 244, pp.35.

Simpson, C.J. (1991) Mass spawning of scleractinian corals on Western Australian reefs and comparisons with the Great Barrier Reef. J. Roy. Soc. West. Aust., 74, 85-91.

Somers, I.F., and Kirkwood, G.P. 1991, "Population ecology of the grooved tiger prawn, *Penaeus semisulcatus,* in the North-western Gulf of Carpentaria, Australia: growth, movement, age structure and infestation by the bopyrid parasite *Epipenaeon ingens",* *Aust. J. Freshwater Res.,* 42, 349 – 367.

Tranter, D.J. and Leech, G.S. 1987, " Factors influencing the standard crop of phytoplankton on the Australian North West Shelf seaward of the 40m isobath", *Cont. Shelf Res.*, 7, 115-133.

Tsvetnenko, Y. 1998, "Derivation of Australian Tropical Marine Water Quality Criteria for Protection of Aquatic Life from Adverse Effects of Petroleum Hydrocarbons", *Environmental Toxicology and Water Quality,* 13,273 – 284.

U.S. Army Coastal Engineering Research Center (1973) *Shore Protection Manual,* U.S. Government Printing Office, Washington, D.C.

U.S. Army Coastal Engineering Research Center (1984) *Shore Protection Manual,* U.S. Government Printing Office, Washington, D.C.

Walker, S. J. 1999, " Coupled hydrodynamic and transport models of Port Phillip Bay, a semi-enclosed bay in south-eastern Australia", *Mar. Freshwat. Res.* 50: 469-481.

Ward, T.J. and Rainer, S.F. (1988) "Decapod crustaceans of the North West Shelf, a tropical continental shelf off north western Australia." *Australian Journal of Marine and Freshwater Research* 39: 751-765.

Webster, I. 1985, "Wind-driven circulation on the North West Shelf of Australia", *J. Phys. Oceanogr.,* 15, 1357-1368.

Williams, S.T. and Benzie, J.A.H. 1996, “Genetic uniformity of widely separated populations of the coral reef starfish *Linkia laevigata* from the West Pacific and East Indian Oceans, revealed by allozyme electrophoresis”, *Marine Biology*, 126, 99-108.

Wilson, R.D., Monaghan, P.H., Osanik, A., Price, L.C, and Roger, M.A. 1974, “Natural marine oil seepage”, *Science,* 24 May 1974, Volume 184, Number 4139, pp.857 – 865.

ACTS
Petroleum (Submerged Lands) Act 1982; also known as p(SL)A 1982
P(SL) Acts Schedule Specific Requirements as to Offshore Petroleum Exploration and Production 1995 (regulates both State and Commonwealth activities);

The Environment Protection and Biodiversity Conservation Act 1999 (also known as the EPBC Act 1999)

1. Web sites

http://epagate.environ.wa.gov.au
This is the link to the Department of Environmental Protection web page for the North west shelf Joint Environmental Study (NWSJEMS). This web page includes: papers and reports; arial photographs; information on the Study collaborators; and background information to the Study.

http://www.marine.csiro.au/nwsjems/index.html
This is the link CSIRO Marine Research web page for the North west shelf Joint Environmental Study (NWSJEMS). This web page includes: an introduction to the Study; Newsletters “Off the Shelf”; fact sheets about the Study; web links to the W.A. government agencies; media releases; and questionnaire.

http://epagate.environ.wa.gov.au/nws/bibliography.htm
This is the link to the searchable Bibliography of Research and Data Relevant to Marine Environmental Management of Australia's North West Shelf. The bibliography was released in early 1999 by staff from CSIRO Division of Marine Research and the Australian Institute of Marine Science. NWSJEMS now maintains the database.

http://www.walis.wa.gov.au/content/wa_atlas_popup.html
The WALIS web page contains this link to the Western Australian Atlas, a web-mapping tool for Western Australia. The WA Atlas originated as the West Australian node of Environment Australia's Australian Coastal Atlas. The Australian Coastal Atlas is a network of Commonwealth and State/Territory nodes using a variety of interactive mapping tools to provide information about the Australian coastal environment.

http://www.marine.csiro.au/marlin
The CMR metadatabase MarLIN (CSIRO Marine Laboratories Information Network) is a searchable directory of datasets. Some records are available only to CMR internal users. All other dataset descriptions from MarLIN are now accessible via the nationwide Australian Spatial Data Directory (ASDD).

http://www.marine.csiro.au/warehouse/jsp/loginpage.jsp
The Trawler login page, used to access the CMR web-based data discovery and download tool. It is recommended that Internet Explorer be used for this interface. The public user can login by reading the data agreement and pressing the ‘accept’ button. An email address is optional, used if data is to be downloaded. A password is required for NWSJEMS users to access information restricted to Study participants.

APPENDIX A: North West Shelf Survey

North West Shelf

JOINT ENVIRONMENTAL MANAGEMENT STUDY

North West Shelf

Dear Community Member,

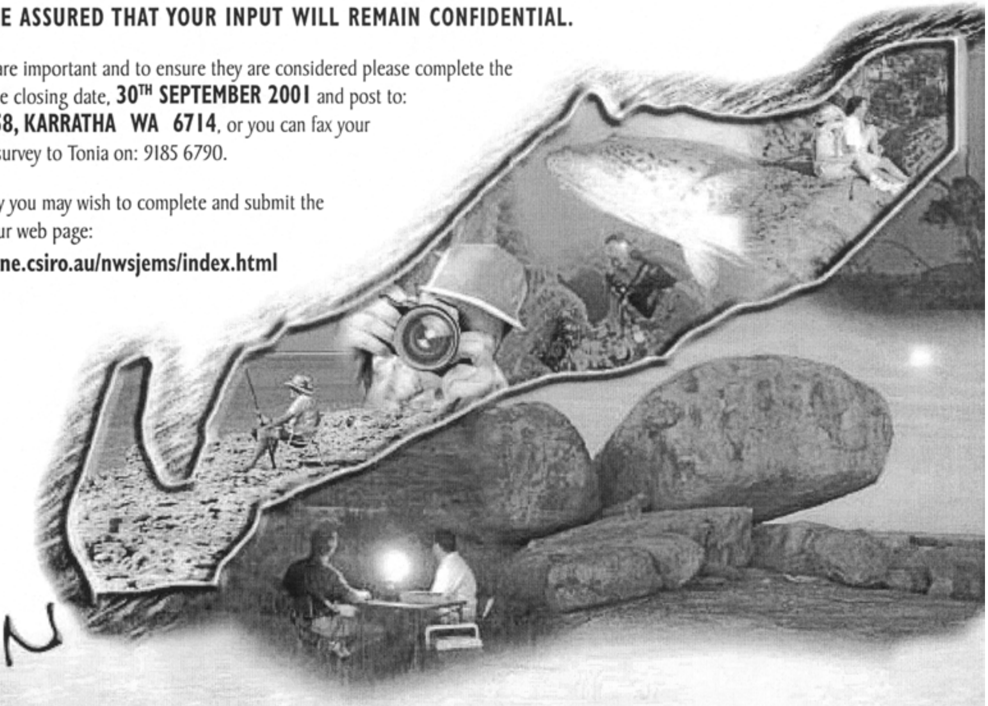
You are being asked to help in the environmental management of the North West Shelf waters – the coastal waters from Exmouth to Port Hedland. You can help by having your say as part of the community consultation process conducted by the Department of Environmental Protection and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Just complete the attached survey, which will take you approximately 30 - 45 minutes, to enable us to understand the community values and aspirations for the North West Shelf marine area.

PLEASE BE ASSURED THAT YOUR INPUT WILL REMAIN CONFIDENTIAL.

Your views are important and to ensure they are considered please complete the survey by the closing date, **30TH SEPTEMBER 2001** and post to: **PO Box 658, KARRATHA WA 6714**, or you can fax your completed survey to Tonia on: 9185 6790.

Alternatively you may wish to complete and submit the survey on our web page:
www.marine.csiro.au/nwsjems/index.html



WIN

By completing the survey, you also have the chance of winning a trip for two to Tasmania*, the Apple Isle, which includes:

- Two return tickets flying ANSETT from Karratha to Tasmania
- One week fully paid accommodation in beautiful Launceston
- One week free hire car
- PLUS
- Complementary Tour of CSIRO Marine Research Laboratories in Hobart.

THERE'S MORE TO EXPLORE

Just imagine, you could be enjoying an autumn break in one of Australia's most scenic states!
The winner will be contacted and announced in local newspapers by the 31st October 2001.

The NWSJEMS is proudly supported by Ansett Australia 'Absolutely' and Tas Vacations 'Tasmania's Largest Independent Travel Specialist'.

* some conditions apply.

About the study

The North West Shelf Joint Environmental Management Study is a joint initiative between Western Australia and CSIRO Marine Research. The study officially commenced in June 2000.

The study area extends from the coast to the 200-metre depth contour, from Exmouth to Port Hedland. This is an area of 110,000 square kilometers. It does not include the Ningaloo Marine Park.

The major objective of the study is to gather as much information about the region as possible and to use it in combination with models of the marine ecosystem. This will help to predict the impacts of natural events and human activities on the North West Shelf. Natural events include tropical cyclones, coral bleaching and events related to the effects of El-Nino, while human activities include fishing, oil and gas exploration and production, mineral processing, recreation and tourism.

The information will be combined with environmental, economic and social objectives to develop a computer system that will enable the evaluation of existing and proposed management strategies for the many uses of the North West Shelf. This system will assist in the development of a more integrated approach to planning and management of the North West Shelf region with the goal of achieving ecologically sustainable development.

A collaborative approach to integrated management is essential to balancing these uses, and avoiding conflict. This will provide a holistic framework for future decisions about competing uses of the marine ecosystem.

Critical to the study is information from the community about development options for the North West Shelf environment. Therefore, the values the community places on the environment and economic development, as well as their components, are an important part of the study.

The community consultation process will help to achieve this.

FURTHER INFORMATION ABOUT THE STUDY IS AVAILABLE FROM:

Web Pages: **http://www.marine.csiro.au/nwsjems/index.html**
http://epagate.environ.wa.gov.au/

Tonia Swetman - Cognito Consulting
Ph: (08) 91856790 Email: cognito@kisser.net.au

Dr Chris Fandry - WA Department of Environmental Protection
Ph: (08) 9222 7019 Email: fandry@environ.wa.gov.au

North West Shelf - Joint Environmental Management Study - Community Survey

1. Name: (essential to enter competition)

2. Phone Number and/or Postal Address:

3. Email Address:

4. Are you of Indigenous descent? (please tick ✓one box ONLY) ☐ Yes ☐ No

5. Where do you live, or live closest? (please tick ✓one box ONLY)

- Exmouth
- Dampier
- Karratha
- Onslow
- Point Samson
- Port Hedland
- Roebourne
- Wickham
- Other (list) ____________________

6. In answering this survey, who do you best represent? (please tick ✓one box ONLY)

- Myself, as a resident of the area
- Myself, as a visitor to the area
- Oil and Gas Industry
- Pearling Industry
- Commercial Fishing Industry
- Pastoral Industry
- Tourism Industry
- Salt Industry
- Iron Ore Industry
- Conservation / Environmental Group
- Recreational Group
- Local Government
- State Government
- Federal Government
- Other (list) ____________________

7. Which of the following recreational activities do you do regularly — or would like to do regularly - in or around the study area? (please tick ✓as many as you like)

- Fishing
- Walking along the shore
- Surfing
- Boating
- Swimming
- Collecting shells
- Diving / Snorkeling
- 4 Wheel Driving
- Collecting seafood, shellfish
- Skiing
- Looking for/watching marine wildlife
- Enjoying the view
- Viewing Aboriginal rock art
- Other (list) ____________________

____

____

____

- I don't do — or want to do — anything at the coast regularly

8. Rate the following possible future outcomes concerning the study area according to their importance to you. (please tick ✓whether you believe the possible outcome is 1 very important, 2 fairly important or 3 not important.)

	1	2	3
Increased employment opportunities			
Speedy approval process for development			
Thorough approval process for development			
Easy and safe shipping for imports and exports			
Unpolluted waters			
Accessible beaches for swimming, diving and boating			
Natural view(s)			
Increased national income from resource developments			
Increase in local business trade			
Simplified regulation and management			
Scientific research			
Mangrove protection			
Recognition of Aboriginal heritage			
Protection of marine plants and animals			
Open, easily understood government approval process			
Unrestricted access for small boats			
Community education about the marine environment			
Sharing the marine environment with visitors			
Publishing study results			
Safe waters			
Diversification of industry			
Being able to access the islands			
Being able to camp on the islands			
Being able to build infrastructure on the islands			
Having more marine parks			

9. What are the three **(3) most important outcomes** from question 8 that you would like to see happen?

i. ______________________________

ii. ______________________________

iii. ______________________________

10. The marine environment has many **natural qualities** and **uses**. How important would you rate the following **natural qualities** of the North West Shelf marine environment? (please place one tick ✓whether you believe the possible outcome is **1** very important, **2** fairly important or **3** not important for each natural quality.)

	1	2	3		1	2	3
Water quality				Healthy and natural environment *(ecosystem integrity)*			
Variety of plants and animals *(biodiversity)*				Other (list)			
Number of plants and animals							
Health of plants							
Health of animals							
Aesthetic (*or attractiveness*) values							

11. What are the **three (3) most important** natural qualities to you in question 10?

i. ______________________________

ii. ______________________________

iii. ______________________________

12. How important would you rate the following **uses** of the North West Shelf marine environment? (please place one tick ✓whether you believe each use is **1** very important, **2** fairly important or **3** not important for each.)

	1	2	3		1	2	3
Recreational Fishing				Transportation			
Skiing and surface water sports				Aquaculture			
Swimming				Pearling			
Crabbing				Indigenous cultural activities			
Diving				Monitoring activities			
Boating				Coastal development (associated with industrial and population growth)			
4 wheel driving							
Camping				Other (list)			
Commercial non-trawl fishing							
Commercial fish trawling							
Tourism							
Resource extraction							

13. List what you believe to be the **three (3) most important uses** in question 12.

i. ______________________________

ii. ______________________________

iii. ______________________________

14. The following activities (natural and human) that occur in the study area impact upon the environment in different ways. Rate them according to the level of threat they are to the marine environment. (please tick ✓whether you believe the activities **1** pose a great threat, **2** pose some threat or **3** are not a threat to the marine environment.)

	1	2	3
Commercial non-trawl fishing			
Eco tourism			
Pearling operations			
Aquaculture			
Tourism			
Diving			
Small boats			
Shipping			
Pastoral (coastal) land use			
Cyclones			
Recreational fishing			

	1	2	3
Dredging			
Oil and gas industry			
Iron ore industry			
Climate change			
Coastal effluents (e.g. sewage)			
Commercial trawling			
Coastal development (associated with industrial and population growth)			
Other (list) ______________			
______________			
______________			

15. List the **three (3) greatest threats** to the marine environment from question 14 and explain why they are threats and where in the study area they are of most concern to you.

i. ______________________________

____

ii. ______________________________

____

iii. ______________________________

____

16. Are there any other activities or events (natural and human) apart from those listed above, that you consider to be major threats to the marine environment in the North West Shelf study area? If so, **what** are they, **where** are they threats and **why** are they threats?

____

____

____

____

____

____

17. In your opinion, what are the most important issues that should be addressed in this environmental study?

18. List things that you would you like to see put in place for the future environmental management in the study region.

19. What do you understand by the term 'ecological sustainability'?

20. Do you think ecological sustainability of the marine environment is important? ☐ Yes ☐ No ☐ Don't Know

21. Why / Why not?

22. For the study area, rank the following goals from 1 - 4 in terms of importance to you, from most important (1) to least important (4).

GOAL	RANK
Having processes in place to manage the region's environment.	☐
Maintenance of sustainable relationships among plants, animals and people.	☐
Growth in employment, income and standard of living.	☐
Pleasant environment with features available for the public to use.	☐

23. In the study area, where do you spend a significant amount of your time and what do you do there? Please be specific.

24. Do you have any other comments, concerns, issues or suggestions concerning the management of the marine environment?

Thankyou for completing this survey!

PLEASE RETURN BY 31ST SEPTEMBER 2001 TO:

Tonia Swetman
Community Liaison Manager
North West Shelf Joint Environmental Management Study
PO Box 658
KARRATHA WA 6714

LIKE TO KNOW MORE ABOUT THE STUDY?

Contact Tonia on: 9185 6790 or email: cognito@kisser.net.au

Appendix B: Hierarchical classification system for marine habitats

The procedure used here develops a hierarchy of levels at which we can consider the habitat structure of an ecosystem.

A hierarchical view of marine ecosystems

The natural world is a hierarchically structured system (Allen and Starr, 1982; O'Neill *et al.*, 1986). It is now widely recognised that the structure and function of marine ecosystems is a multi-scale process (e.g. Greene *et al.*, 1994, 1995, 1999; Holling, 1992; Langton *et al.*, 1995; Garcia-Charton and Perez-Ruzafa, 1999; Poiani *et al.*, 2000; Roff and Taylor, 2000) and that this must be taken into account in management practice. The ecosystem-based approach to planning uses natural regions as planning units, but natural regions need to be identified on a range of hierarchically nested scales for different planning and management purposes. The property of *scale* that distinguishes different hierarchical levels in natural systems is a continuously-varying function (Allen and Starr, 1982) – thus, sharp, unequivocal boundaries are the exception rather than the rule. Nevertheless, in most systems there are real discontinuities that can be recognised, and these have allowed the development of a number of classification schemes for different purposes. Examples in habitat classification include Greene *et al.* (1994, 1995, 1999), and Davies and Moss (1999). These authors (e.g. Greene, pers. comm.) are not wedded to the fine details; what they stress is the importance of the hierarchical view, and the need for an agreed classification scheme as a working language for their particular purposes.

Within the complexity of the natural world, different hierarchies can be identified that allow different interpretations and uses, and there are fundamental conceptual differences, not merely small details, behind these various forms. In brief, the differences are about appropriate surrogates and indicators (for habitats, "biodiversity" and "ecosystem" structuring), and about providing the hierarchical context whenever one speaks of such things as habitats. We need to think of biodiversity as a hierarchy and not as a singular concept such as indicator species or "habitats". The classification scheme adopted in our case must be linked to management actions (what actions are appropriate at what level).

The levels in habitat classification schemes cannot usually be specified simply in terms of a spatial scale. This is because it is difficult to put even rough spatial scales on the units being mapped, unless they are first placed in the context of the level above. Thus, deep ocean biotopes are likely to have very different (greater) spatial scales than those in the coastal environment.

A scheme of habitat classification

The following hierarchical scheme to classify the structure of marine habitats has been developed by CSIRO Marine Research for the North West Shelf Joint Environmental Management Study. It takes account of other published schemes but is adapted for Australian needs.

The scheme recognises a series of nested Levels in the structure of habitats, each reflecting the influence of different characteristics and processes.

Level 1. Province: Evolutionary biogeography is the key process at this Level as reflected by the presence of regions of endemism determined from the presence/absence and distributional range of informative species. These regions correspond to the biogeographic IMCRA Provincial units and comprise both pelagic and continental shelf demersal provinces along with the overlap regions or biotones between provinces (Thackway and Cresswell 1995, IMCRA 1998, Lyne et al 1998).

Level 2a. Biome: At this Level the sea is divided into the neritic and oceanic zones with the boundary between the two at the continental shelf break (nominally defined by the 200m isobath). The neritic zone has four primary biomes: estuarine, coastal marine, demersal shelf and pelagic shelf. The oceanic zone consists of: three primary demersal biomes (continental slope, abyssal, and hadal), and five pelagic biomes (epi-, meso-, bathy-, abysso- and hadopelagic biomes).

Level 2b. **Sub-biome**: Mesoscale structuring or subdivisions within the Level 2a biomic units which may be operationally more useful units at this level. For example, on the SE shelf, Williams and Bax (2001) identified seven sub-biomic units from a multivariate analysis of informative fish species: northern and southern communities on the inner, outer and shelf-break. On the NW shelf, data on demersal fish and benthic invertebrates led to the recognition of inner-, mid- and outer-shelf sub-biomes. Generally sub-biomic units may be expected to contain distinct collections of biotas.

Level 2c. Sub-biomic structure: Further mesoscale substructure, again based on recognisably distinct composition of the biota, within level 2b. For example, along-shelf subdivision of the inner-, mid- and outer-shelf sub-biomes. (Note: At a national scale the IMCRA-derived "mesoscale regions" contain a mixture of biomes (Level 2) and morphological units (Level 3).)

Level 3. Biogeomorphological units: Within each biome, there are major meso-scale biogeomorphological subdivisions that can be easily identified and which usually have distinct biotas. These biotas can be mapped within levels above to provide a generalised expression of a geographic area. On the continental shelf, typical units include (Shepard, 1959): glaciation structures, sand banks and depressions, deltaic bottoms, submarine plains and valleys, seamounts, bioherms ("hills that owe their growth to some type of calcareous organism" - Shepard, 1959), rocky banks and islands, coral atolls, and regions of strong current/bottom stress. In the coastal biome typical units include fringing reefs, beaches, tidal flats, mudflats, and shallow embayments. (Note use of plural forms (e.g., beaches not beach) to denote a general category, not denying that there are various types within it). On the continental shelf these units include biotas associated with sediment plains, rocky banks, and valleys and cliffs at the shelf-break. Continental slope units include biotas associated with canyons and seamounts.

Level 4. Primary Biotopes: Within a geomorphological level, primary biotopes refer to soft, hard or mixed substrate-based units, together with their associated suites/collections of floral and faunal communities, modified by hydrological variables such as wave exposure, turbidity, tidal effects and current speed. Maps to this level can generally be obtained from some targeted acoustic discrimination work (hardness/softness and roughness, and bathymetry) and a desktop study – although without providing details of community structure and compositon or biodiversity. Delineation of features, with relief and approximate boundary positions may be possible.

Level 5. Secondary Biotopes: Substructural units of the primary biotopes distinguished by the generalised types of biological and physical substrate within the soft/hard/mixed types (e.g. igneous, calcareous, silts, sands, gravels, seagrasses, sponges). Biological and physical sampling provides ground-truthing for geological, biological and ecological understanding (community structure and composition or biodiversity) at this level.

Level 6. Biological Facies: These are identifiable biological and physical units defined by a biological indicator, or suite of indicator species, that identify a biological assemblage used as surrogate for a biocoenosis or community. They include, for example, a particular species of seagrass, or group of corals, sponges, or other macro-fauna strongly adherent to the facies. Down to this level, the hierarchy is pseudo-spatial and involves a mix of biogeophysical definitions that reflect the primary scale-dependent biogeophysical processes and associations needed by biodiversity managers.

Level 7. Micro Communities: Within Facies there exist assemblages of species that depend on member species of the Facies (e.g. holdfast communities in *Macrocystis*). It is assumed that conservation of the Facies will generally ensure conservation of associated micro-communities.

This scheme is summarised in Table 1.

Table 1 Hierarchical scheme for habitat mapping and classification

Level	Names	Examples
	Province	Large-scale biogeographic units. For example, IMCRA Technical Group (1998) recognised three demersal provinces and two biotones on the continental shelf in southeastern Australia and one for Macquarie Island.. Provinces are typically of the order of ~1,000 km in extent.
2	2a Biome	Continental shelf, slope, abyssal plain and offshore continental blocks (e.g. South Tasman Rise) are dictated by gross geomorphology. These are nested within provincial units and are typically several 100's of km or more in extent.
	2b Sub-biomes	Shelf-break and upper slope; lower slope. These subdivisions are dictated by the distributions of animal communities, some of which have quite narrow depth ranges.
	2c Mesoscale units	Along-slope subdivisions within, e.g., mid-slope unit, again typically dictated by faunal distributions. For example IMCRA identified 12 mesoscale units on the continental shelf in the SE Australia, from 50 to 350 km in size.
3	Geomorphological units	Areas characterised by similar geomorphology. These may include (on the continental shelf) fields of sand-waves, rocky outcrops, incised valleys, flat muddy seabeds, etc., and (on the slope and at abyssal depths) submarine canyons, seamounts, oceanic ridges and troughs, etc. Such units may typically be about 100 km in extent.
4	Primary Biotopes	Low-profile reefs; soft-sediment areas between reefs. Such units may be 10s of km in extent.
5	Secondary Biotopes	Rock types (e.g. fossiliferous limestone; granite); sediment types (e.g. poorly sorted shelly sands) or biota (e.g. seagrasses)
6	Biological Facies	Biological indicator (e.g. a seagrass species)
7	Microcommunities	Species that depend on facies (e.g. isopods on seagrass)

Note in Table 1 that *size* is not a criterion for level in the hierarchy. Thus, some level 2b units may actually cover less area than some level 3 units. Nevertheless, size typically decreases from level 1 to level 7, and so in Table 1 we give some indicators of spatial extent.

References Appendix B

Allen, T.F.H. and Starr, T.B. (1982) *Hierarchy*. *Perspectives for ecological complexity*. University of Chicago Press, Chicago and London.

Garcia-Charton, J.A. and Perez-Ruzafa, A. (1999). Ecological heterogeneity and the evaluation of the effects of marine reserves. *Fisheries Research*, 42, 1-20.

Greene, HG, Yoklavich, MM, Barry, JP, Orange, DL, Sullivan, DE, Cailliet, GM (1994) Geology and related benthic habitats of Monterey canyon, central California. *EOS transactions of the American Geophysical Union Supplement* 75:3, p.203

Greene, H.G., Yoklavich, M.M., Sullivan, D., and Cailliet, G.M. (1995). A geophysical approach to classifying marine benthic habitats: Monterey Bay as a model. In 'Applications of Side-Scan Sonar and Laser-Line Systems in Fisheries Research'. pp. 15-30. (Alaska Department Fish and Game Special Publication No. 9, Juneau, Alaska.)

Greene, H.G., Yoklavich, M.M., Starr, R.M., O'Connell, V.E., Wakefield, W.W., Sullivan, D.E., McRea, J.E. Jr., and Cailliet, G.M. (1999). A classification scheme for deep seafloor habitats. *Oceanologica Acta* 22, 663-678.

Holling, C.S. (1992). Cross-scale morphology, geometry and dynamics of ecosystems. *Ecological Monographs* 62, 447-502.

IMCRA Technical Group (1998). *Interim Marine and Coastal Regionalisation for Australia: an ecosystem-based classification for marine and coastal environments*. Version 3.3. Environment Australia, Canberra.

Langton, R.W., Auster, P.J. and Schneider, D.C. (1995). A spatial and temporal perspective on research and management of groundfish in the northwest Atlantic. *Reviews in Fisheries Science* 3, 201-229

Lyne, V., Last, P., Scott, R., Dunn, J., Peters, D. and Ward, T. (1998) *Large Marine Domains Of Australia's EEZ.* Report to Environment Australia. CSIRO Division of Marine Research, Hobart.

O'Neill, R.V., DeAnglelis, D.L., Waide, J.B. and Allen, T.F.H. (1986) *A hierarchical concept of ecosystems*. Princeton University Press., Princeton, New Jersey

Poiani, K.A., Richter, B.D., Anderson, M.G., and Richter, H.E. (2000). Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. *Bioscience* 50, 133-146.

Roff, J.C. and Taylor, M.E. (2000). National frameworks for marine conservation – a hierarchical geophysical approach. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 209-223.

Shepard, F.P. (1959) *The Earth Beneath the Sea*. Johns Hopkins Press. Baltimore. 275pp

Thackway, R. and I. Cresswell (1995). *An Interim Biogeographic Regionalisation for Australia: a framework for establishing the national system of reserves*. Version 4. Australian Nature Conservation Agency, Canberra.

Williams, A. and Bax, N. (2001). Delineating fish-habitat associations for spatially-based management: an example from the south-eastern Australian continental shelf. *Marine and Freshwater Research*. 52, 513-536.

APPENDIX C: Contributors to the Study

Study Directors
Chris Fandry, Department of Environmental Protection
Keith Sainsbury, CSIRO Marine Research

Technical Committee
Department of Environmental Protection: Chris Fandry, Ray Masini
Department of Minerals and Petroleum Resources: Graham Cobby
Department of Conservation and Land Management: Nick D'Adamo
Department of Fisheries: Steve Newman
AIMS: Andrew Heyward
CSIRO Marine Research: Keith Sainsbury, Pamela Brodie, Scott Condie, Alan Butler, David McDonald

Project Leaders and Team Members

Project 1: Data Management
Project Leaders: Pamela Brodie, CSIRO Marine Research and Mike Fuller, Department of Environmental Protection
Team Members
CSIRO Marine Research: Brett Miller, Kim Finney
Department of Environmental Protection: Katrina Baxter

Project 2: Ecological Modelling
Project Leader: Scott Condie, CSIRO Marine Research
Team Members
CSIRO Marine Research: John Parslow, He Xi, Cathy Bulman, John Andrewartha, Mike Herzfeld, Nugzar Margveashvili, Jason Waring, Jeff Dunn, Chris Rathbone, Franzis Althaus, Brian Hatfield

Project 3: Sources, Impacts and Environmental Quality Indicators
Project Leader: Chris Fandry, Department of Environmental Protection
Team Members
CSIRO Marine Research: Andy Revill
Department of Environmental Protection: Des Mills

Project 4: Ecosystem Characterisation and Habitat Mapping
Project Leader: Alan Butler, CSIRO Marine Research
Team Members
CSIRO Marine Research: CSIRO Marine Research: Peter Last, Vincent Lyne, Bill Venables, Melanie Martin, Roger Scott, Franzis Althaus, Robert Campbell Xi He, Rudy Kloser, Tim Ryan, Keith Sainsbury, Roger Scott, Helen Webb, Alan Williams, Robin Thompson
Department of Environmental Protection: Mike Fuller, Chris Fandry,

Project 5: Management Strategy Evaluation and Risk Assessment
Project Leader: David McDonald, CSIRO Marine Research
Team Members
CSIRO Marine Research: Tony Smith, Keith Sainsbury, Randall Gray, Roger Scott, Melanie Martin, Vince Lyne, Rich Little, Beth Futlon, Helen Webb

Project 6: Communication and Consultation
Project Leader: Chris Fandry, Department of Environmental Protection
Team Members
CSIRO Marine Research: Don Michel, Helen Webb, Craig Macaulay

Project 7: Project Management
Project Leaders: Chris Fandry, Department of Environmental Protection and Keith Sainsbury, CSIRO Marine Research
Team Members
CSIRO Marine Research: Helen Webb, Tim Mangan

Scientific Editors
CSIRO Marine Research: Keith Sainsbury, Helen Webb, Don Michel
Department of Environmental Protection: Chris Fandry

Design Cover and Chapter Headings
Louise Bell, CSIRO Marine Research