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Research priorities for improving the capacity to manage dredging impacts on tropical coral communities in Western Australia

Workshop Discussion and Outcomes

Held at the Tradewinds Hotel, Fremantle, Perth, WA

24-25th November 2008

Dr Paul Lavery [1]

Dr Kathryn McMahon [1]

[1] Edith Cowan University, Perth, Western Australia

September 2009

WAMSI Dredging Science Node

The WAMSI Dredging Science Node is a strategic research initiative that evolved in response to uncertainties in the environmental impact assessment and management of large-scale dredging operations and coastal infrastructure developments. Its goal is to enhance capacity within government and the private sector to predict and manage the environmental impacts of dredging in Western Australia, delivered through a combination of reviews, field studies, laboratory experimentation, relationship testing and development of standardised protocols and guidance for impact prediction, monitoring and management.

Funding Sources

The $20 million Dredging Science Node is delivering one of the largest single-issue environmental research programs in Australia. This applied research is funded by **Woodside Energy, Chevron Australia, BHP Billiton and the WAMSI Partners** and designed to provide a significant and meaningful improvement in the certainty around the effects, and management, of dredging operations in Western Australia. Although focussed on port and coastal development in Western Australia, the outputs will also be broadly applicable across Australia and globally.

This remarkable **collaboration between industry, government and research** extends beyond the classical funder-provider model. End-users of science in regulator and conservation agencies, and consultant and industry groups are actively involved in the governance of the node, to ensure ongoing focus on applicable science and converting the outputs into fit-for-purpose and usable products. The governance structure includes clear delineation between end-user focussed scoping and the arms-length research activity to ensure it is independent, unbiased and defensible.

And critically, the trusted across-sector collaboration developed through the WAMSI model has allowed the sharing of hundreds of millions of dollars worth of environmental monitoring data, much of it collected by environmental consultants on behalf of industry. By providing access to this usually **confidential data,** the **Industry Partners** are substantially enhancing WAMSI researchers' ability to determine the real-world impacts of dredging projects, and how they can best be managed. Rio Tinto's voluntary data contribution is particularly noteworthy, as it is not one of the funding contributors to the Node.

Funding and critical data **Critical data**

Citation: Lavery P and McMahon K (2009) Research priorities for improving the capacity to manage dredging impacts on tropical coral communities in Western Australia. Workshop discussion and outcomes. Report No 2009-4. Prepared for Woodside Energy Ltd by the Centre for Marine Ecosystems Research, Edith Cowan University, Perth, Australia.

Front cover image: Atmospherically corrected, colour corrected, pan sharpened satellite image from the United States Geological Survey (USGS) Operational Land Imager (OLI) instrument showing sediment plumes caused by dredging and dredge material placement near Onslow in the Pilbara region of Western Australia (courtesy of Mark Broomhall and Peter Fearns (Curtin University of Technology, Perth, WA).

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1 INTRODUCTION

With the high level of capital dredging activity underway and proposed for industrial development projects in north-western Australia, the Western Australian government has identified a need to improve capacity to predict and manage the impacts of marine dredging activities, as reflected in recent conditions of environmental approval set by the WA Minister for the Environment on major projects involving significant dredging components with potential to impact the marine environment.

For example, as part of the conditions of approval for its Pluto Liquid Natural Gas (LNG) Project in north-western Australia, Woodside Energy Limited (Woodside) is required to offset the predicted impacts on coral communities from its marine dredging works in Mermaid Sound (EPA 2007). The predicted impacts on coral communities from dredging of the Pluto shipping channel and gas trunkline route are described in the Public Environment Report / Public Environmental Review (PER) for the Pluto LNG Project (Woodside 2006) and PER Addendum to Supplement and Response to Submissions (Woodside 2007). The PER predicted a defined area of coral loss associated with dredging in the vicinity of Holden Point, located in the inner harbour of the Port of Dampier.

Under the Ministerial Statement and conditions of approval for the Pluto LNG Project released in December 2006, Woodside shall acquire field and laboratory data as a contributory offset, with the specific purpose of *improving capacity within government and the private sector to manage dredging impacts on tropical coral reef communities.*

As a first stage to acquiring data to build capacity for predicting and managing impacts of dredging, Woodside commissioned Edith Cowan University (ECU) in 2008 to plan and conduct a research scoping workshop. The workshop brought together invited participants from Woodside, the WA Department of Environment and Conservation (DEC), other state government agencies, environmental consultancies and scientists from government research organisations and universities, to identify the key information needs and priority research areas required to build capacity to manage impacts of dredging in the context of the tropical coral reef communities occurring in north-western Australia. The workshop participants are listed in Appendix 1 and a summary of the workshop structure in Figure 1. Further information on the workshop is provided below.

1.1 Purpose of Workshop

The workshop was conducted over 24-25 November 2008. Its purpose was to:

- Identify key research areas that will improve the capacity of Government and the private sector to predict and manage the impacts of dredging on tropical coral communities;
- Prioritise identified research needs in order to subsequently allocate resources; and
- Provide a basis and a guide for development of detailed research briefs.

1.2 Background to the Workshop

Terms of reference for the workshop were established and agreed beforehand by the workshop facilitators in consultation with Woodside and the participants from the DEC. These terms set the context, provided interpretation of the wording in the Ministerial Statement, defined the intended scope and breadth of the discussion and outlined the expected outcomes from the workshop.

The terms of reference included the following:

- The workshop discussion should consider research needs and priorities for building capacity to predict as well as to manage impacts, from the standpoint that there is uncertainty for several key areas important to assessment as well as management of environmental impacts of dredging;

- The discussion should not be confined by particular views and approaches. It should be broad in identifying priorities so that workshop outcomes are relevant to building capacity to wider projects and locations in north-western Australia;

- The discussion should consider key information needs identified in background information provided to workshop participants, including the WA State Government's current framework for evaluating potential impacts and management plans for dredging projects that may impact coral communities;

- The term 'tropical coral reef communities' in respect of research required to build capacity, should be interpreted widely to encompass hard corals as well as other components such as primary producers, filter feeders and macro-invertebrates and with relevance to communities in north-western Australia;

- The discussion should consider information needs in respect of coral communities in turbid as well as clear-water environments and should not be restricted to any particular geographic location if this would unnecessarily limit the benefits to capacity building;

- The workshop should consider approaches to filling gaps in knowledge and other practical advice considered valuable to informing research, such as preferred experimental approaches and the sites of research work;

- The expected outcome of the workshop is a comprehensive framework setting out research priorities for different communities to be used to better inform the development of pressure-response relationships required to improve understanding of impacts of dredging; and

- The expected workshop outcomes should be made available widely for the benefit of Government and industry.

Pre-workshop information

Background information was distributed to workshop participants before the workshop. This outlined the terms of reference for the workshop and also provided information about the WA Environmental Protection Authority's draft guidance for predicting, assessing and managing impacts of marine dredging as well as technical findings of recent water quality and coral health monitoring conducted by Woodside and a review of responses of coral communities to stressors (Woodside 2008).

Workshop presentations

To facilitate discussion, a series of background presentations was provided to the workshop group (Figure 1) by a number of the workshop participants. These included:

- Introductory information for interpreting the research commitment (presented by the workshop facilitator);
- The WA government's expectations for environmental impact assessment (EIA) and the management of dredging activities (presented by a DEC participant);
- An outline of monitoring challenges and research priorities for building capacity in predicting and managing impacts of dredging, by reference to experiences in applying the

monitoring programs to management of Pluto dredging activities (presented by the Pluto LNG Project dredging environmental co-ordinator);

- The findings of a review of effects of dredging on coral communities (undertaken and presented by the ECU participant);
- A perspective on coral monitoring in north-western Australia, illustrating the challenges and issues faced by those predicting and managing impacts of dredging on coral communities, from experience investigating condition of coral communities for various industry-related projects with dredging components (presented by the principal of the scientific consultancy, Mscience Pty Ltd);
- A case study of research undertaken on the effects of dredging-induced light reduction on seagrasses, with reference to a dredging project in Geraldton, Western Australia (presented by an ECU participant);
- An outline of the experimental approach being used in controlled laboratory experiments to investigate effects of sediment deposition on coral taxa (presented by the participant from the Australian Institute of Marine Science; AIMS); and
- An overview of information gaps in predicting and modelling stress fields, with reference to the physical environment (presented by the principal of Des Mills Marine Environmental Reviews).

Workshop discussion

The views of the assembled group of experts were canvassed over two days to identify key research needs from the perspectives of the biological as well as the physical environment.

The input of workshop participants was restricted to the two-day workshop session. This information was then taken into a post-workshop session to further consider the research priorities (see below). The key inputs of participants during the workshop sessions are outlined in Appendix 2. Participants that provided background presentations to guide the workshop discussion have reviewed the summaries of their presentations as presented in this document.

Post-workshop discussion

The outcomes of the workshop were taken into a post-workshop meeting on 26 November 2008 by the workshop facilitators and involving the Woodside and DEC representatives. The purpose of this meeting was to review the information assembled from the contributions of the expert group and, from this, to establish a list of the high, medium and low priorities for research required to build capacity for predicting and managing impacts of dredging on tropical coral communities in Western Australia.

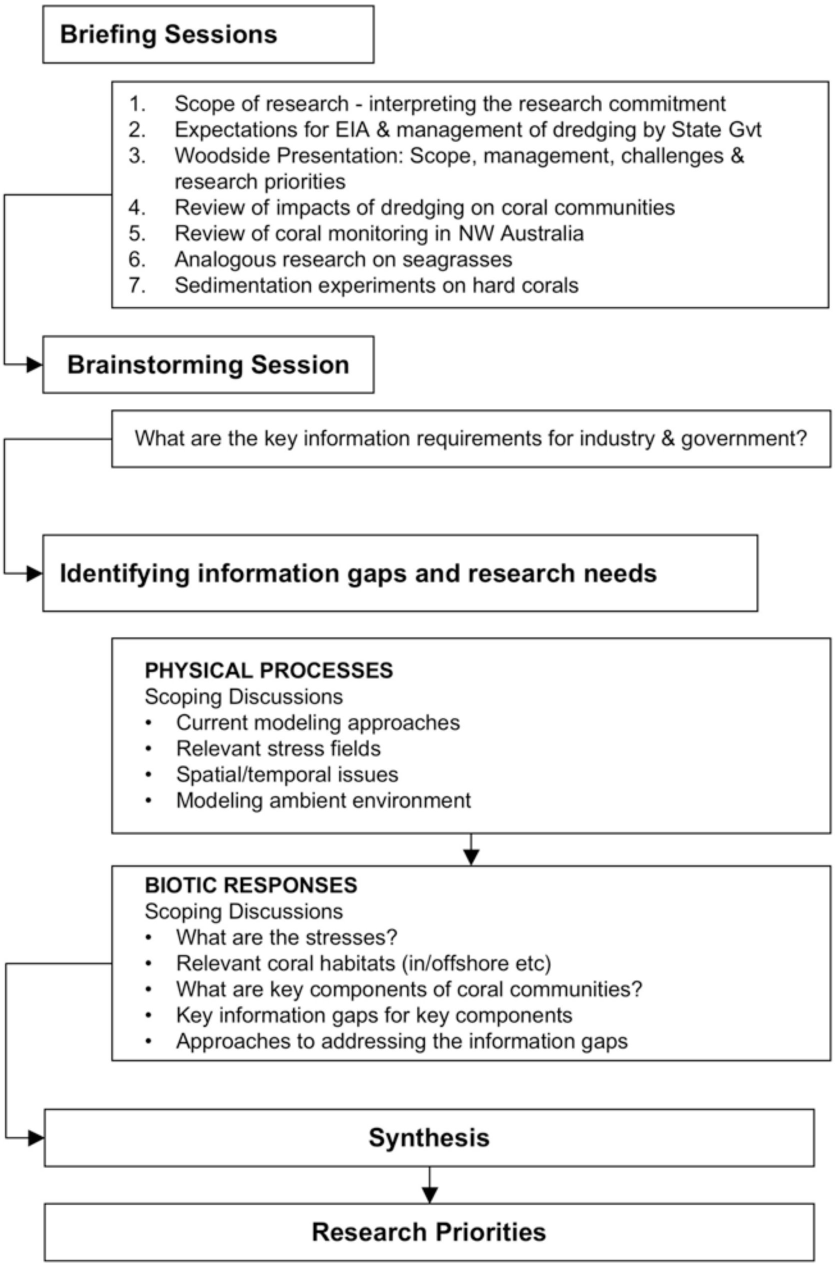

Figure 1 Overview of workshop structure and key components.

1.3 This document

This document describes the workshop, its purpose, the challenges and issues that were identified out of information and views shared in discussion, and the key outcome: a prioritised list of research topics indicating where information is most needed to build capacity for predicting and managing impacts of dredging on tropical coral communities in Western Australia.

The intention is for the findings from the workshop to be widely available as a reference to guide scoping of future research supporting management of dredging operations in north-western Australia. In the same way, the findings will be used also to guide the scoping of studies for the Pluto LNG Project, these targeting the high priority research topics identified from the workshop.

The workshop concerned the technical information required to build capacity and did not extend to discussion of possible arrangements by which research might be implemented, although views shared on those aspects during the workshop are reported. There is likely to be a range of options for implementing the research. The options will be influenced by the particular circumstances of individual projects. For example, this could involve implementation through partnerships established among different agencies, companies and research groups. As implementation aspects of the research were outside the terms of reference for the workshop they are not considered further in this document.

There are three subsequent sections and two appendices:

Section 2: presents the key information gaps that were identified through the discussions that formed the major part of the two-day workshop. Those discussions were focussed around a series of briefing presentations (see Figure 1). The presentations and subsequent discussions that led to the identification of key information gaps are summarised in Appendix 2. The key information gaps have directly informed the research priorities.

Section 3: outlines the research priorities. These are presented in two ways. Firstly, the research priorities are presented by theme (Physical processes, Coral, Primary producers and Filter-feeders), and classified as high, medium or low priorities. Secondly, the research needs are presented in a table classified by priority. It is intended that this information will be used as a guide to those framing detailed proposals and research briefs.

Section 4: lists references and other information sources referred to in the main document and in Appendix 2.

Appendix 1: lists the workshop participants.

Appendix 2: provides an overview of the themes presented and discussed at the workshop and overarching considerations that have influenced the identification of information needs and the prioritising of research required to build capacity. The section provides summaries of information contributed during the workshop in presentations from several of the participants. This includes information about the WA Government's current approach to assessing the impacts and management of dredging proposals and information from the perspectives and experiences of industry and research scientists working with dredging programs and conducting research on effects of stressors on coral communities.

2 KEY INFORMATION GAPS

This section outlines the key information gaps that were identified from the workshop discussion as needing to be considered in identifying and establishing priorities for research aimed at building capacity to predict and manage impacts of dredging activities on coral communities in north-western Australia.

The information gaps below are based on the contributed views and advice of the workshop participants. This advice, and its implications for the setting of research priorities, are summarised in Appendix 2. Research priorities are outlined and discussed in Section 3.

The information needs are considered in relation to three aspects of dredging works:

- The Activity: understanding the nature of the dredging activity and how that results in change to the environment;
- The Setting: characterising the environment in which the activity is occurring and will therefore affect; and
- The Response: the response of the benthic communities to the environmental changes caused by the activity.

For each information gap identified below, the relevant aspect of dredging activity that it addresses, from those above, is indicated in parentheses in the section headings.

To clarify the relationship between each information gap and research priorities presented in Section 3, each information gap below has been cross-referenced to its relevant research priorities. These priorities are depicted by labels shown in the boxes on the right hand margin of the page. Refer to Section 3 for further explanation of the labels.

2.1 Information gap 1: Physical processes (Activity)

Informs Research Priorities:

P1, P2 P3 and C1

The workshop identified (Sections 2, 3, 6 and 8 of Appendix 2) the need for models capable of delivering:

- Predictions of relevant stress fields (e.g. light, total suspended sediments, light attenuation and size fractions of settling sediments stratified through the water column);
- Inputs to risk, physiological and ecological models that express the effects of dredging in terms of parameters that impact on biota; and
- Comparative scenarios of the stress fields under ambient conditions, with and without dredging effects super-imposed on these.

Currently, there are significant inadequacies in the existing transport models, which generally cannot accurately reflect ambient conditions and therefore cannot reliably predict the additional effect of dredging on the environment above ambient. Nor do the models relate TSS to relevant stresses on the biotic community.

The above inadequacies relate primarily to poor understanding of key sediment transport processes, lack of data on the environment, lack of information on the dredge characteristics and absence of adequate near- and far-field data sets to aid in the parameterisation and validation of models.

Research is needed in relation to:

- Near-field sediment dynamics, particularly:
  - Settling velocity,
  - Aggregation/disaggregation of particles,
  - Suspended sediment profiles under different physical conditions,
  - Bottom boundary layers (e.g. very fine suspensions),
  - Plume dispersion under different physical conditions;
- Far-field sediment dynamics, particularly:
  - Sedimentation and re-suspension as functions of shear stress;
- Relationships between TSS fields and biologically-relevant stress fields, possibly:
  - Total suspended solids (TSS; total or by size fraction),
  - Light attenuation coefficient (LAC),
  - Burial and surface accumulation of sediments (frequency and magnitude),
  - Nutrients in the water column; and
  - Benthic changes (e.g. dissolved oxygen fluxes, redox potential).

2.2 Information gap 2: Protocols for data collection and determining key relationships (Activity and Setting)

Informs Research Priority:

P3

Some of the important deficiencies identified in existing physical models relate to relationships between key parameters, especially TSS, nephelometric turbidity units (NTU) and a range of other environmental factors that they influence (see Section 8 of Appendix 2). In many cases, it may be impossible to develop relationships among these variables that are transferable across sites. For example, the relationship between TSS and light extinction is complex and so profoundly influenced by a multitude of particle characteristics that it would be fruitless to attempt to develop a universal relationship. In such circumstances, site-specific relationships need to be determined.

There is a need for universally accepted protocols for developing site-specific relationships between easily measured water quality parameters (i.e. TSS and turbidity) and other environmental variables of more direct relevance to biotic responses (e.g. light attenuation coefficients bottom light and sedimentation rate). These protocols would establish the types of data required and the appropriate methods for collecting samples, analyzing data and deriving the relationships so that both industry and government have confidence in the relationships.

2.3 Information gap 3: Understanding community responses (Response)

Informs Research Priorities:

C1, C2, C3, C4, PP1 and FF1

The workshop confirmed a need to improve understanding of how coral communities respond to dredging-related stresses (see Sections 1, 2, 3, 4, 5, 7 and 9 of Appendix 2). There is an inadequate understanding of the thresholds of response of biota to dredging-induced stresses.

The workshop participants confirmed that improving the capacity to manage the impacts of dredging requires both impact prediction and subsequent impact management activities to be addressed (see Section 1 of Appendix 2) and that this would require research into three priority taxa: hard corals; primary producers; and filter-feeding organisms (Sections 1, 4 and 9 of Appendix 2).

The main information requirements for all three groups of taxa were summarised into three classes (Section 2 of Appendix 2):

Environmental Modeling

- Understanding the validity of modeling to predict the effects of dredging on the environment, and to deliver valid predictions of the stress fields.

Impact prediction

- What are the levels of susceptibility/resilience of the different types of coral communities (which types are most sensitive and should be avoided)?
- What are the levels of susceptibility/resilience of different components of the coral community (do corals, algae, filter-feeders show different levels of susceptibility)?
- What drives the susceptibility/resilience (is it linked to morphology, ability to clear sediments of different size or ‘stickiness’, depth of sediment cover, blockage of filtering apparatus, biogeochemical changes in sediments)?
- Does resilience/susceptibility vary with the intensity, duration, frequency and timing (of year) of impact?

Impact management

- What are the indicators of sub-lethal stress in the dominant coral communities (these could be species indicators, assemblage indicators or community-level indicators useful for monitoring program design)?
- What magnitudes and durations of pressure are associated with the indicators of stress (i.e. cause-effect relationships useful for establishing alert and action criteria)?
- What are the pathways of recovery and how long does it take (post-development monitoring and project closure plans)?

Related knowledge gaps include:

- The sensitivity of different life-stages, including coral spawning (Sections 3, 4 and 9 of Appendix 2). Industry has specifically identified coral spawning research as a priority in terms of building capacity around understanding of impacts related to managing dredging activities in the lead up to, during and after coral spawning events;
- Appropriate ways of quantifying effects of dredging on different life-history stages;
- The potential effects on reproductive process and, therefore, the potential for delayed impact on a population (Sections 4, 5, 7 and 9 of Appendix 2); and
- The sensitivity to timing of dredging, due to seasonal variation in either the metabolic condition of organisms (e.g. differences in energy reserves following reproduction) or ambient conditions (e.g. seasonal thermal stress may affecting sensitivity to other stresses; Sections 5, 6 and 9 of Appendix 2).

In identifying the above information gaps, it is also acknowledged that there is some uncertainty regarding how to describe impacts on early life-history or reproductive stages of corals. Research aimed at clarifying these impacts will need to establish appropriate protocols for quantifying effects.

Informing impact prediction

Hard coral mortality was considered to be an appropriate variable around which impact predictions could be based, though it has limitations for use in reactive monitoring programs (Section 5 of Appendix 2). The research should therefore improve our understanding of coral mortality responses to dredging in order to inform impact prediction.

With respect to hard corals, key gaps related to:

- The response of different life-history stages;
- Whether TSS plumes have any significant effect on coral spawning events;
- The responses of different morphological types to dredging-related stress;
- Understanding the cause-effect pathway at individual, population and assemblage levels and the relative importance of different stresses produced by dredging (e.g. light reduction, sediment deposition); and
- Understanding the importance of duration, intensity, frequency and timing of dredging-related stress.

Informing impact management: cause-effect pathways

Hard corals mortality was considered unlikely to provide the basis for ongoing management programs (Section 5 of Appendix 2). Understanding the responses of other taxa can provide:

- An improved understanding of the cause-effect pathway of dredging impacts on coral communities, potentially yielding sub-lethal indicators of impact; and
- Multiple lines of evidence of cause and effect needed to confirm that any observed changes to coral communities are dredging-related changes.

Primary producers and filter-feeders were seen as important ecological components of coral communities. Any impact on primary producers or filter-feeders could have significant consequences for higher trophic levels in the community. In addition, they may be sensitive to changes in light availability and sediment deposition and so have potential to serve as early warning indicators of environmental change before impacts are realised on other components of the community, such as corals.

Currently, little is known about the relative sensitivities or the threshold levels of the primary producers in north-western Australia, and even less for filter-feeders

2.4 Information gap 4: Understanding the responses of coral communities in different habitats (Response)

Informs Research Priority:

P1

The workshop participants recognised that coral communities occur across a wide range of environmental conditions, including turbidity. It is reasonable to expect that coral communities experiencing turbid conditions will be adapted to higher levels of turbidity than those occurring in locations with higher water clarity, such as offshore atolls. The extent to which differences in water clarity affect responses of the communities to additional sediment inputs from dredging is not clear. While most of the recent and current dredging activities in north-western Australia involve operations in relatively turbid coastal waters, there is a very real possibility that future dredging may extend to activities in clearer, offshore waters. There is a need, therefore, to understand the responses of coral communities in both clear and turbid environments (Section 1 of Appendix 2).

2.5 Information gap 5: Effect of sediment types and grain size (Activity and Response)

Informs Research Priorities: C1, C5, and PP2

While the generalised effects of increased sediment load on key environmental parameters are reasonably well understood, there is a poor understanding of how the nature of the sediment itself influences those effects. Sediment grain size and sediment composition were considered two important characteristics that could modify the physical transport and effect of the sediment plume (Sections 1, 7 and 9 of Appendix 2). Sediment grain size can affect suspension, and therefore the transport, characteristics of sediments. This also affects light scattering and may affect the ability of corals to clear sediment and the ability of filter-feeders to maintain their feeding. Similarly, the capacity of carbonate and non-carbonate sediments to behave differently with respect to flocculation and transport process was felt sufficiently important to warrant investigation.

Despite recognizing the potential importance of these sediment characteristics, the understanding of their effect on key physical processes and biotic response is so poor as to warrant investigation.

2.6 Information gap 6: Decision-making tool

Informs Research Priority: P1

The workshop participants felt that in addition to filling the above information gaps on that relate to understanding dredging activity and ecosystem response, there is a need to improve the capacity to use this information for more informed decision-making (Section 2 of Appendix 2). Often, the application of information is hindered by the lack of tools that are capable of integrating the relevant sets of information. Therefore, there is a need for decision-making tools that can incorporate the types of information identified above for site-specific conditions to assist proponents and regulators in assessing various dredging scenarios.

2.7 Information gap 7: Awareness of pre-existing and compliance monitoring data

Informs Research Priorities: C1 and C6

The workshop participants repeatedly drew attention to the large volume of physical modelling and bio-physical compliance monitoring data that have been collected in the region but which may subsequently be difficult to access (Sections 3, 6 and 8 of Appendix 2). While recognising that issues of commercial confidentiality may apply in some instances, it was also the workshop view that other data may not have this constraint or that there could be significant benefit in developing protocols for making the data available.

The principal value of these data would be in:

- Informing the focus and design of future research;
- Validating existing physical and ecological response models;

- Providing first-instance information on the response of poorly studied biota to environmental gradients (e.g. filter-feeders); and
- Avoiding unnecessary duplication of data collection.

The identified information gaps were in knowing what data have been collected, where they reside and in providing a mechanism for co-ordinating access to such data so this can be made more widely available.

2.8 Information gap 8: Trophic and biotic interactions

Informs Research Priority:

O1

Several discussions in the workshop drew attention to the poor understanding of ecological interactions occurring in north-western Australian benthic marine ecosystems (e.g. Sections 1, 4 and 9 of Appendix 2). Two examples are:

- The trophic interactions of coral communities, and therefore the importance of different primary producers and filter-feeders for coral community food webs; and

- Possible interactions between sediments, algal turfs and corals, whereby algal turfs may exacerbate the trapping of sediments with positive (reduced re-suspension) or negative (preventing re-suspension and transport of sediment out of the system) effects.

The specific application of the above information is difficult to identify. However, ecological interactions among trophic groups are likely to be so fundamentally important that they will strongly influence the flow-on effects of any dredging-related impact on any single component of the community.

3 RESEARCH PRIORITIES

This section addresses the key research priorities based on information needs outlined and discussed in Section 2. The boxes on the right hand margin of the pages in Sections 3.1 to 3.5 below show the links between the research priorities discussed in the sections and corresponding information needs that were discussed in the previous section.

The workshop facilitators, along with DEC and Woodside participants from the workshop used the priorities identified by workshop participants, together with their own understanding from industry and government experience predicting, assessing and managing effects of dredging operations, to refine and rank the priorities that emerged from the workshop sessions. No research priorities were removed or added, but the relative ranking of the priorities were clarified.

The priorities focus on two broad areas:

- Improving transport models capable of delivering:
  - Predictions of light, total suspended sediment concentrations (TSS), light attenuation coefficients (LAC) and size fractions of settling sediments stratified through the water column;
  - Inputs to risk, physiological and ecological models that express the effects of dredging in terms of parameters that are most meaningful for predicting and managing impacts on biota; and
  - Comparative scenarios of the stress fields under ambient conditions with and without dredging effects super-imposed on these.
- Improved understanding of the susceptibility/tolerance of the biotic community to the physical and chemical changes that are induced by dredging, in order to identify thresholds of effect and indicators of effect. Thresholds refer to a particular level of stress at which the biota will exhibit undesirable change. These thresholds may be lethal, or sub-lethal, such as the point at which coral growth may be reduced but is still sufficient to maintain the animal or colony in perpetuity, albeit at reduced rates of growth.

Two information gaps identified in the previous section are not addressed by any of the research priorities. These relate to the following:

Development of decision-making tools

The workshop identified the need to incorporate improved physical and ecological modelling into appropriate decision-making tools. These decision-making tools would allow proponents and regulators to identify the key information requirements, and data collection and modelling protocols to evaluate and manage environmental impacts of different dredging scenarios. While the information gap was identified in the previous section, it is not specifically addressed in research priorities. At this point, the research priorities focus on improving the physical and ecological models on which any subsequent development of decision-making tools will depend, though improved understanding of important physical and biological processes.

Use of existing data

The workshop participants repeatedly highlighted the large volume of physical modelling and bio-physical compliance monitoring data that have been collected in north-western Australia but which may subsequently be difficult to access. While recognising that issues of commercial confidentiality may apply in certain circumstances, it was also the view that other data may not have this constraint or that there could be significant benefit from developing protocols that would allow the data to be made available. Protocols would need to consider information that can be shared, that which may be commercially sensitive and unable to be shared without consent and payment arrangements that may be part of sharing protocols.

The principal value of these data would be in:

- Informing the focus and design of future research;
- Validating existing physical and ecological response models;
- Providing first-instance information on the response of poorly studied biota to environmental gradients (e.g. filter-feeders); and
- Avoiding unnecessary duplication of data collection.

Addressing this issue is not technically a research issue and so it is not aligned against a single research priority. Clearly, however, the approach to any of the research priorities should take the workshop advice into account.

3.1 Physical processes and modelling

The workshop discussion identified a number of gaps in the ability to predict and model stress fields. The inadequacies largely related to the current poor understanding of some sediment transport processes, lack of information required to validate transport models and the difficulty in describing ambient conditions in highly variable environments (see Section 2.1). Existing generic transport models have the capability to deliver a higher level of accuracy if the quality of input data is improved. Consequently, the research priorities focus on the acquisition of appropriate data that can be used to improve understanding of key process or validate models, rather than on the development of new models. Since the usefulness of the models depends on the quality of the input data and the data that has driven the development of algorithms within the models, protocols for the collection of high quality data is a pre-requisite for research aimed at improving sediment transport models (see Section 2.2).

HIGH PRIORITY

P1 Near-field plume characterisation

Addresses Information Gap 1

(Section 2.1)

i. Development of protocols for the collection of field data needed to improve predictions of source sediment characteristics, and both near- and far-field sediment plume characteristics;

ii. Application of those protocols in commercial or experimental dredging programs to improve understanding of source sediment characteristics and resultant near- and far-field TSS plumes, particularly:
   - Dredge-induced sediment mass release,
   - Aggregation/disaggregation of particles,
   - Suspended sediment profiles,
   - Plume dispersion and settling,
   - Bottom boundary layers of suspended particles,
   - Particle size distributions, and
   - Under a range of physical conditions and in relation to dredge type and in-situ sediment characteristics; and

iii. Simulation and calibration of the processes in representative sediment transport models.

P2 Far-field plume characterisation sediment re-suspension and settling algorithms

Addresses Information Gap 1

(Section 2.1)

i. Develop improved understanding and algorithms that describe the relationships between Bottom Shear Stress and:

- Sediment settlement rates in the far-field; and
- Re-suspension in the far-field.

ii. Simulation and calibration of the processes in representative sediment transport models.

MODERATE PRIORITY

P3 Protocols for establishing site-specific water quality relationships

Addresses Information Gaps 1 and 2

(Sections 2.1, 2.2)

Development of protocols that can be applied in site- or project-specific situations to establish:

- Relationships between TSS and LAC (correlative or process-based approach); and
- Relationships between NTU and other water quality variables, which describe the stress, imposed on biota.

Approaches

Research Priorities P1-P3 above may take advantage of opportunities to gather relevant data in relation to either commercial or experimental dredging operations.

The improved understanding gained from addressing Research Priorities P1 and P2 above should be incorporated in data sets and report that can inform the development, calibration and validation of future models.

In all cases, it is strongly recommended that standard protocols for data collection be developed before field data collection programs are initiated. The protocols can then be tested in the field and refined/revised as appropriate based on experience.

For Priority P3, there is likely to be limited value in attempting to produce transferable empirical or numerical relationships; experience shows such relationships to be highly site- and sediment-specific. Therefore the approach should be based around the development of protocols to guide the generation of site- and sediment-specific relationships that can be used in site-specific impact assessment.

3.2 Hard Corals

Hard corals are assigned a high priority for research due to their keystone ecological role (e.g. as a habitat provider), their iconic status and their importance as an indicator of impact (Sections 1, 5 and 9 of Appendix 2).

Within the region, relatively little is known about the thresholds of corals to sediment deposition or to reduced light availability, or about the sensitivities of different life-history stages. Filling these information gaps (Sections 3, 4 and 5 of Appendix 2) is seen as the highest research priority for this group of organisms.

Research will need to carefully target species or assemblages that are representative of particular sub-sets of coral and maximise the transferability of the outcomes. With the above in mind, the research priorities are:

HIGH PRIORITY

C1 Defining thresholds and indicators of coral response to dredging-related pressures

Addresses Information Gaps 3, 4 and 5

(Sections 2.3, 0, 2.5)

i. Determine the appropriate component(s) and life-history stages of hard coral assemblages from ‘turbid’ and ‘clear’ water environments that are appropriate for the focus of subsequent research into thresholds and indicators of response to dredging-related pressures.

A variety of taxa or whole assemblage studies may be appropriate and some of the characteristics that should be taken into account include:

- The presumed or known sensitivity/responsiveness of the taxa;
- How common they are;
- How widely distributed;
- Their representativeness of the coral assemblage;
- Their status as iconic, threatened or other types of taxa, and
- Their robustness for use in laboratory or other experiments that might be required for stage (ii), below.

ii. Determine the Pressure-Response thresholds (e.g. mortality, moderate recoverable impact and lowest observable effects) that relate the effects of suspended sediments, sediment deposition and light reduction to condition of the hard corals identified in (i) above, by addressing the following questions:

Environmental modeling

- What are the physiological requirements of key habitat forming corals and their environmental tolerances to varying levels of light, suspended sediment and sediment deposition?

Impact prediction

- What are the levels of susceptibility/resilience of the dominant corals (which are most sensitive and should be avoided/least sensitive and able to withstand pressure)?

- What drives the susceptibility/resilience? (Why does this occur, is it linked to energy storage capacity, reduced feeding efficiency, reduced reproductive success, etc?)
- Does resilience/susceptibility vary with season, intensity, duration or frequency of dredging –related pressures (used to design dredging programs and minimize impact)?

Impact management

- What are the primary and secondary indicators of sub-lethal stress in the dominant coral communities (useful for monitoring program design)?
- What levels (intensity, duration, frequency) of physical/chemical pressure are associated with the primary and secondary biological indicators of stress (useful for establishing alert and action criteria), including the No Observable Effects levels?
- What are the pathways of recovery and how long does it take (post development monitoring and project closure plans)?

With respect to (ii), above, the research should:

- Determine whether life-history stage is an important determinant of sensitivity;
- Clarify the most appropriate descriptors of dredging-related stress for hard corals to inform the development of stress fields in the Physical Models; and
- Establish whether the type of sediment (carbonate versus non-carbonate) is a significant determinant of any effect on hard corals.

Addresses Information Gaps 1and 5

(Sections 2.1, 2.5)

Approaches

Priority C1 should include a significant review of existing information, including that held by industry and in compliance monitoring reports, to screen for those taxa/assemblages that are likely to be sensitive to dredging-related impacts. This should inform the subsequent field/laboratory studies that will establish the Pressure-Response curves and tolerance thresholds. Much of this information is for turbid, inshore waters where corals may have experienced severe selection pressures favouring the more tolerant taxa. This should be taken into consideration when designing research intended to produce transferable outcomes for north-western Australia, which includes areas of relatively clear waters that may come under dredging pressure. Consequently, the research should address both turbid water and clear water hard coral communities.

The relationships and thresholds should be established for appropriate turbid- and clear-water corals. As a wide variety of approaches could be employed to address C1, any proposal should detail the approach that will be used and justify this in terms of its capacity to deliver the outcomes listed above under the headings Environmental modelling, Impact prediction and Impact management.

Information presented at the workshop suggested that laboratory-based manipulative experiments were feasible for determining coral response to sediment deposition (see Appendix 2, Section 7). Similarly, commercial or experimental dredging events might afford for experimental tests of coral response. This offers the possibility of a combined approach of manipulative experiments and field observational data to validate laboratory findings, which has proved successful in analogous studies of seagrass communities affected by dredging (see Section 6 of Appendix 2)

Any experimental approach will need to give consideration to either establishing appropriate infrastructure or assessing the viability of conducting the research in other locations. In addition, north-western Australia presents some serious logistical constraints for conducting research, among them health and safety issues, including those associated with working in those areas supporting crocodiles. While neither of these issues should compromise the ability to address the research, they will present challenges to be addressed.

C2 Effects of dredging activities on key coral reproduction processes

Addresses Information Gaps 3, 4 and 5

(Sections 2.3, 0, 2.5)

- Determine the effects of suspended sediment, sediment deposition and light reduction on key reproductive processes (such as, but not restricted to: embryogenesis; larval survival; settlement; and metamorphosis).

The research should determine whether TSS plumes during spawning events are detrimental to coral community viability and should provide data that will be useful to informing management decisions, for example, the extent to which precautionary cessation of dredging during spawning events is warranted.

The research should take into account the potential effect of different types (carbonate versus non-carbonate) of sediment.

MODERATE PRIORITY

C3 Effect of temperature coral tolerance thresholds

Addresses Information Gap 3

(Section 2.3)

- Improve the understanding of the effects of temperature on the Pressure-Response relationships and thresholds of adult corals identified in (C1 and C2).

C4 Standard protocols for measurement of reproductive processes

Addresses Information Gap 3

(Section 2.3)

- Develop standard operating procedures for measurement of the effects of dredging-related stress on coral fecundity, larval viability and settlement (e.g. substrate preference and early post-settlement survival).

LOW PRIORITY

C5 Interaction among corals and primary producers

Addresses Information Gap 3

(Section 2.3)

- Consider the dependency of any effects on the interaction between corals and primary producers such as turfing algae, crustose-coralline algae or seagrasses, which may affect sediment deposition and trapping.

3.3 Primary Producers

While coral mortality may be a useful predictor of impact for impact assessment purposes, it is not suitable for application in reactive management frameworks as it is generally a lag indicator of impact. Information gap 3 (Section 2.3) highlighted the need to understand the responses of other biota, including primary producers, to dredging activities.

Some of the mechanisms by which dredging affects primary producers are likely to be similar to those described for corals. However, light reduction may be more crucial for the more upright forms of macro-algae, while sediment deposition may be relatively more significant for turfing species. Overall, the fundamental research needs for primary producers are similar to those outlined earlier for corals.

HIGH PRIORITY

PP1 Defining thresholds and indicators of primary producer responses to dredging-related pressures

Addresses Information Gaps 3, 4 and 5

(Sections 2.3, 0, 2.5)

i. Identify which primary producers (e.g. ephemerals/annuals/perennials), or different functional groups of primary producer, are the most appropriate to determine Pressure-Response relationships for dredging stressors (primarily reduced light availability, sediment deposition and suspended sediments) for turbid and clear water habitats.

A variety of taxa or whole assemblage studies may be appropriate, including algal turfs, non-turfing macro-algae, crustose coralline algae, seagrasses and endolithic micro-algae. Characteristics that should be taken into account when considering which taxa are appropriate for inclusion in studies related to priority PP1 (ii) include:

- The presumed or know sensitivity/responsiveness of the taxa;
- How common they are;
- How widely distributed;
- Their representativeness of the primary producer assemblage; and
- Their robustness for use in laboratory or other experiments that might be required for stage (ii), below.

ii. Determine the Pressure-Response thresholds (mortality, moderate impact and lowest observable effects) and cause-effect pathways relating the effects of sediment deposition and light reduction to the condition of key primary producers identified in (i), above, by addressing the following questions:

Environmental modeling

- What are the physiological requirements and of key habitat forming primary producers and their environmental tolerances to varying levels of light, suspended sediment and sediment deposition?

Impact prediction

- What are the levels of susceptibility/resilience of the key primary producers (which are most sensitive and should be avoided/least sensitive and able to withstand pressure)?
- What drives the susceptibility/resilience? (Why does this occur, is it linked to energy storage capacity, photosynthetic efficiency, etc?)
- Does resilience/susceptibility vary with season, intensity, duration or frequency of dredging –related pressures (used to design dredging programs and minimize impact)?

Impact management

- What are the primary and secondary indicators of sub-lethal stress in the key primary producers (useful for monitoring program design)?
- What levels (intensity, duration, frequency) of physical/chemical pressure are associated with the primary and secondary biological indicators of stress (useful for establishing alert and action criteria), including the No Observable Effects levels?
- What are the pathways of recovery and how long does it take (post development monitoring and project closure plans)?

The research should:

Addresses Information Gap 1 (Section 2.1)

- Clarify the most appropriate/biologically relevant descriptors/measures of stress in relation to reduced light availability, sediment deposition; and
- Establish whether there is any difference in the ecological effects of carbonate and non-carbonate sediments, within the range of natural and/or artificially generated (i.e. by dredging) sediment types likely to be encountered in north-western Australia.

Approaches

PP1 (i) and (ii) should be undertaken as an integrated task, incorporating analysis of existing data and an appropriate field/laboratory experiments.

Based on experience from similar research undertaken for primary producers, it may be complement manipulative field experiments with observational data from commercial dredging events to validate experimental findings.

Any experimental approach will need to give consideration to either establishing appropriate infrastructure or assessing the viability of conducting the research in other locations. In addition, north-western Australia presents some serious logistical constraints for conducting research safely, as discussed previously. While neither of these issues should compromise the ability to address the research, they will present challenges to be addressed.

MODERATE PRIORITY

PP2 Effect of sediment characteristics on tolerance thresholds of primary producers

Addresses Information Gap 5 (Section 2.5)

- Improve understanding of any dependency of thresholds established in PP1 on sediment type, in particular, grain size, cohesiveness and organic content, within the range of sediment characteristics typical of north-western Australia.

LOW PRIORITY

PP3 Effect of dredging on reproductive processes of primary producers

Addresses Information Gap 3

(Section 2.3)

- Determine the effect of stresses associated with dredging (light reduction, sediment deposition and suspended sediments) on reproductive processes of the key primary producers, especially settlement and survival.

3.4 Filter-feeders

The abundance and diversity of filter-feeders in a variety of habitats throughout NW Australia suggests that they are an important component of the community. The assemblages typically include sponges, bivalves and ascidians. They have the potential to be significantly affected by: changes in suspended sediment loads or size classes may reduce feeding efficiency; smother adult or juvenile organisms and inhibit settlement. The responses of filter-feeders to dredging is likely to improve understanding of the cause-effect pathway of dredging impacts on coral communities, and may yield indicators of sub-lethal stress for application in ongoing management of dredging impacts (see Section 2.3).

HIGH PRIORITY

FF1 Thresholds and indicators of filter-feeder response to dredging-related pressures

Addresses Information Gaps 3, 4 and 5

(Sections 2.3, 0, 2.5)

i. Identify which components of the filter-feeder assemblages are the most appropriate to determine Pressure-Response relationships from dredging stressors (primarily, reduced light availability, sediment deposition and suspended sediments).

ii. Determine the Pressure-Response relationships and estimate thresholds (mortality, moderate impact and lowest observable effects) that relate the effects of suspended sediments, sediment deposition and/or light reduction to the key species of filter-feeders from turbid and near-shore and clear offshore habitats and for different types and size fractions of sediment.

Approaches

Given the relatively low knowledge of this group of organisms, the most appropriate approach to filling information gaps is likely to be through observational studies of communities experiencing natural gradients in turbidity, substrate type and hydrodynamics, to identify sensitive components of the assemblages. With suitable deployment of instrumentation to measure and subsequently describe the habitat characteristics including light, TSS and sediment deposition, it may also be possible to develop initial threshold values or assemblage ‘health indices’ through correlative or associative approaches. These studies could be complemented by observations on the responses to pressures along gradients away from newly dredged areas.

Observational studies would provide information on which components of the assemblage would be worth considering for more detailed studies of the type suggested for corals and primary producers.

MODERATE PRIORITY

FF2 Ecological significance of filter-feeders

Addresses Information Gap 3

(Section 2.3)

Improve the understanding of the ecological significance of filter-feeding biota in tropical north-western Australia, including:

- Distribution and abundance in relation to habitat characteristics;
- Filtration capacity; and
- Trophic significance.

Approaches

The approach proposed addresses a need for fundamental biological and ecological information, and may not be well suited to a targeted research project. The task may be better served through a program of research-student projects, supported through the offset research program and complemented with co-investments through schemes such as ARC-linkage.

3.5 Other

An additional information gap is the absence of a sound understanding of the trophic inter-relationships of the key components of the coral communities in north-western Australia (see Section 9 of Appendix 2). The significance of these relationships lies in the potential for an impact on one component to have consequences for other components or the ecological integrity of habitats. Key information gaps include the nature of possible impacts and the timescales over which they might be realised. It is currently possible to conceptualise possible trophic links and, therefore, the likely consequences of changes in one component for other components of the community. However, increased certainty in the relative rates of production and the pathways of energy transfer will dramatically increase confidence in these predictions.

LOW PRIORITY

O1 Trophodynamic relationships

Addresses Information Gap 8

(Section 2.8)

Clarify the productivity of, and trophodynamic relationships among, corals, key primary producers and filter-feeders using biomarkers and other techniques for different types of coral communities in tropical north-western Australia.

Table 1: Research needs categorised by priority. Within priority rankings, all items have equal priority.

Priority		***Research Need***
High	P1	**Near-field plume characterisation** i. Development of protocols for the collection of field data needed to improve predictions of source sediment characteristics, and near- and far-field sediment plume characteristics. ii. Application of those protocols in commercial or experimental dredging programs to improve understanding of source sediment characteristics and resultant near- and far-field TSS plumes and to provide calibration and validation data for models applied under a range of physical conditions.
	P2	**Far-field plume characterisation sediment re-suspension and settling algorithms** i. Develop improved understanding and algorithms that describe the relationships between Bottom Shear Stress and: • Sediment settlement rates in the far-field; and • Sediment re-suspension in the far-field. ii. Simulation and calibration of the processes in representative sediment transport models
	C1	**Defining thresholds and indicators of coral response to dredging-related pressures** i. Determine the appropriate component(s) of hard coral assemblages that are appropriate for the focus of subsequent research into thresholds and indicators of response to dredging-related pressures. ii. Determine the Pressure-Response relationships, including physical/chemical thresholds (e.g. mortality, moderate recoverable impact and lowest observable effects) that relate the effects of suspended sediments, sediment deposition and light reduction to coral condition.
	C2	**Effects of dredging activities on key coral reproduction processes** Determine the effects of suspended sediment, sediment deposition and light reduction on key reproductive processes (such as, but not restricted to: embryogenesis; larval survival; settlement; metamorphosis and coral spawning.
	PP1	**Defining thresholds and indicators of primary producer responses to dredging-related pressures** i. Identify which primary producers (e.g. ephemerals/annuals/perennials) or different functional groups are the most appropriate to determine Pressure-Response relationships from dredging stressors (primarily reduced light availability, sediment deposition and suspended sediments). ii. Determine the Pressure-Response relationships and physical/chemical thresholds (mortality, moderate impact and lowest observable effects) that relate the effects of suspended sediments, sediment deposition and light reduction to the condition of key primary producers.
	FF1	**Thresholds and indicators of filter-feeder response to dredging-related pressures** i. Identify which components of the filter-feeder assemblages are the most appropriate to determine Pressure-Response relationships from dredging stressors (primarily, reduced light availability, sediment deposition and suspended sediments). ii. Determine the Pressure-Response relationships and estimate thresholds (mortality, moderate impact and lowest observable effects) that relate the effects of suspended sediments, sediment deposition and light reduction to the key species of filter-feeders from turbid and near-shore and clear offshore coal habitats.

Table 1 (con't): Research needs categorised by priority. Within Priority rankings all items have equal priority.

Priority	***Research Need***
Moderate	
P3	**Protocols for establishing site-specific water quality relationships** Development of protocols that can be applied in site- or project-specific situations to establish: • Relationships between TSS and LAC (correlative or process-based approach); and • Relationships between NTU and other water quality variables, which describe the stress, imposed on biota.
C3	**Effect of temperature on coral tolerance thresholds** Improve the understanding of the effects of temperature on the Pressure-Response relationships and thresholds of adult corals identified in (C1).
C4	**Standard Operating Procedures for measurement of reproductive processes** Develop Standard Operating Procedures for measurement of the effects of dredging-related stress on coral fecundity, larval viability and settlement (e.g. substrate preference and early post-settlement survival)
PP2	**Effect of sediment characteristics on tolerance thresholds of primary producers** Improve understanding of any dependency of thresholds established in PP2 on sediment type, in particular, grain size, cohesiveness and organic content, within the range of sediment characteristics typical of north-western Australia.
FF2	**Ecological significance of filter-feeders** Improve the understanding of the ecological significance of filter-feeding biota in tropical north-western Australia, including: • Distribution and abundance in relation to habitat characteristics; • Filtration capacity; and • Trophic significance.
Low	
C5	**Interaction among corals and primary producers** Consider the dependency of any effects on the interaction between corals and primary producers such as turfing algae, crustose-coralline algae, or seagrasses, which may affect sediment deposition and trapping.
PP3	**Effect of dredging on reproductive processes of primary producers** Determine the effect of stresses associated with dredging (light reduction, sediment deposition and suspended sediments) on reproductive processes of the key primary producers.
O1	**Trophodynamic relationships** Clarify the productivity of, and trophodynamic relationships among, corals, key primary producers and filter-feeders using biomarkers and other techniques for different types of coral communities in tropical north-western Australia.

4 REFERENCES

The following references were cited in the main body of this report, or are referred to in Sections of Appendix 2 which were referred to in the main report.

1. EPA (2007) Pluto Ministerial Statement. Pluto Liquefied Natural Gas Development (Site B Option) Burrup Peninsula, Shire of Roebourne (Assessment No. 1632), December 2007.
2. HR Wallingford Ltd and Dredging Research Ltd (2003). Protocol for the Field Measurement of Sediment Release from Dredgers. Issue 1. Report produced for VBKO TASS Project by HR Wallingford Ltd and Dredging Research Ltd. Published by Vereniging van Waterbouwers in Bagger- Kust en Oeverwerken (VBKO).
3. McMahon, K. and Lavery, P.S. (2008). The responses of *Amphibolis griffithii* to reduced light availability. Final Report on the Strategic Research Fund for the Marine Environment (SRFME) Collaborative Research Project: Eco-physiology of benthic primary producers. 141 p. Centre for Marine Ecosystems Research, Edith Cowan University, Joondalup, Western Australia. Final Report to SRFME / WAMSI and Geraldton Port Authority.
4. *PIANC The World Association for Waterborne Transport.* Dredging and Port Construction around Coral Reefs. Unpublished Report of working group 15 of the Environmental Commission.
5. Woodside (2006) Woodside Energy Ltd. Pluto LNG Development. Public Environment Report / Public Environmental Review. EPBC Referral 2006/2968. Assessment No. 1632. December 2006.
6. Woodside (2007) Pluto LNG Development. Public Environment Report / Public Environmental Review (PER), December 2006 and PER Addendum to Supplement and Response to Submissions. June 2007.
7. Woodside (2008). Workshop to Identify Research Priorities for Improving Capacity to Manage Dredging Impacts on Tropical Coral Reef Communities, Tradewinds Hotel, Fremantle, 24-25 November 2008. Confidential information pack prepared for reference of participants during the workshop.

5 ACKNOWLEDGEMENTS

Woodside Energy Ltd and the workshop facilitators thank workshop participants for generously contributing and sharing their views and ideas over the two days of workshop discussion. Thanks are extended also to Dr Katharina Fabricius for contributing information prior to the workshop and to Dr Des Lord for his valuable insights as an observer at the workshop. Thanks are also extended to Ms Tegan Box and Ms Wendy Mills for their able assistance in recording the workshop discussions and in preparing workshop briefing material, respectively. The authors sincerely thank Dr David Gordon and Dr Luke Smith for their valuable comments on draft versions of the report.

APPENDIX 1: WORKSHOP PARTICIPANTS

Dr Ken Anthony	Senior Research Fellow, University of Queensland k.anthony@uq.edu.au
Dr Russ Babcock	Senior Research Scientist Centre for Marine and Atmospheric Research CSIRO russ.babcock@csiro.au
Dr Chris Battershill	Research Team Leader Biodiversity, Australian Institute of Marine Science, Townsville QLD c.battershill@aims.gov.au
Dr Tony Chiffings	State Manager Western Australia, DHI Water and Environment twc@dhigroup.com
Dr David Gordon	Senior Environmental Adviser, Pluto LNG Project, Woodside Energy Ltd. Pluto LNG Project Woodside Energy Ltd. DAVID.GORDON@woodside.com.au
Dr Andrew Heyward	Principal Research Scientist, Australian Institute of Marine Science Principal Research Scientist Australian Institute of Marine Science a.heyward@aims.gov.au
Mr Nick Jones	Environmental Coordinator – Dredging Pluto LNG Project Woodside Energy Ltd. Nick.Jones@woodside.com.au
Mr Scott Langtry	Director and Senior Environmental Scientist, Asia-Pacific ASA. slangtry@apasa.com.au
Dr Paul Lavery	Professor of Marine Ecology, Centre for Marine Ecosystems Research Edith Cowan University p.lavery@ecu.edu.au
Dr Russell Hanley	Executive Marine Scientist, SKM - Marine and Coastal Services JHanley@skm.com.au
Dr Ray Masini	Manager, Marine Ecosystems Branch, Western Australian Department of Environment and Conservation ray.masini@dec.wa.gov.au

Dr David Masters
Principal Scientist,
MScience Pty Ltd
David.Masters@mscience.net.au

Dr Kathryn McMahon
Research Fellow,
Centre for Marine Ecosystems Research,
Edith Cowan University
k.mcmahon@ecu.edu.au

Dr Des Mills
Marine Environmental Reviews
Principal
Des Mills Marine Environmental Reviews
desm3@iinet.net.au

Dr Andrew Negri
Senior Research Scientist,
Australian Institute of Marine Science
a.negri@aims.gov.au

Dr Cameron Sim
Senior Policy Officer (Marine),
Marine Ecosystems Branch,
WA Department of Environment and Conservation
cameron.sim@dec.wa.gov.au

Dr Chris Simpson
Program Leader, Marine Science Program
WA Department of Environment and Conservation
Chris.Simpson@dec.wa.gov.au

Dr Luke Smith
Principal Research Scientist,
Browse LNG Project, Woodside Energy Ltd.
Luke.Smith@woodside.com.au

Dr Jim Stoddart
Principal Scientist, MScience Pty Ltd
Principal Scientist
MScience Pty Ltd
239 Beaufort St, Perth, WA 6003
jim@mscience.net.au

Mr Wayne Young
Environment Manager,
Dampier Port Authority
wayne.young@dpa.wa.gov.au

Observer
Dr Des Lord
Chairman, Pluto LNG Project Dredge Environmental Management Group
deslord@cyllene.uwa.edu.au

APPENDIX 2: SUMMARY OF WORKSHOP PRESENTATIONS

Presentations by several participants were conducted during the workshop to provide an overview of existing knowledge and to guide and inform workshop discussion. Summaries of each presentation are provided in Sections 1 to 9 of this appendix, along with the major discussion points that followed each presentation and the implications of those points for the identification of research priorities.

The information gaps and research priorities outlined here reflect the views of the workshop participants. In some instances, the views of participants were not unanimous, and this is highlighted where appropriate. The participants' discussions were taken into a post-workshop session involving the workshop facilitators and representatives from Woodside and the DEC and used as the basis for identifying the key information gaps and for prioritising research needs, as described in Sections 2 and 3 of the main report.

1 INTERPRETING THE RESEARCH COMMITMENT

Presented by Professor Paul Lavery (ECU)

The intended scope of discussion, as outlined in the terms of reference provided in the workshop information pack issued to participants, was re-iterated at the start of the workshop, particularly with respect to the following questions:

- What coral communities should be considered: nearshore or offshore, turbid or clear water?
- Where should research be focussed: on impact prediction, management or both?
- What forms of field and laboratory research need to be considered, in what proportion and when?
- What biotic components constitute a coral community in the context of research needs for capacity building?
- What are the priority research needs?

Relevant types of coral communities?

The workshop discussions confirmed that the *research should encompass both turbid water and clear water coral communities and should not be restricted to any particular geographic location.*

While much of the current capital dredging in Western Australia is taking place in relatively turbid waters, such as Mermaid Sound, future dredging could occur in waters further offshore, including atoll environments. It was the view of workshop participants that the proposed research offered an outstanding opportunity to initiate the development of decision-making tools that do not currently exist for government or industry. In this respect, research with a broad focus was considered likely to support the development of generic tools.

To provide research relevant to the immediate needs of industry as well as for placing government and industry in a better position for dealing with future dredging projects, it was generally agreed that a range of coral environments should be considered. Turbid, inshore waters and clear, offshore waters were considered appropriate end points of the range of coral community environments on which to focus the discussion on research needs.

Research Focus: impact prediction and impact management

The workshop participants confirmed that improving the capacity to manage the impacts of dredging requires addressing both impact prediction and subsequent impact management activities.

It was recognised that:

- Predicting impacts is the first component of managing impacts and, therefore, should be included in the scope of research.
- The knowledge of coral communities and dredging processes required to predict impacts may be different to that required for the subsequent management of impacts. For example, the components used to describe potential impact (e.g. coral mortality) may be inappropriate for adaptive management due to response rates, sensitivity or other factors.
- Research is required to improve the capacity to:
    - Model the effect of dredging on the physico-chemical environment and express this in terms of relevant spatial and temporal patterns of stress for the biota (i.e. pressure-field);
    - Understand the cause-effect pathways by which dredging has an adverse outcome for biota;
    - Identify thresholds of tolerance/resilience to physical/chemical stress among biota; and
    - Identify appropriate biological indicators of lethal and sub-lethal effects of dredging on biota.

Weighting of field- or laboratory-based research

The workshop confirmed the appropriateness of using both field and laboratory studies and both observational and experimental approaches. It also confirmed that:

- The weighting given to any particular type of research, or the phasing of field versus laboratory studies, should not be pre-determined but should be driven by the types or timing of research that will would yield the greatest benefit most efficiently.
- The acquisition of field data should allow for a wide range of possibilities, including mensurative, manipulative and other experimental approaches
- 'Laboratory experiments' should be interpreted as manipulative experiments that may be conducted within controlled laboratory settings or as manipulative field experiments; and
- The timing of field and experimental components should be determined by sound scientific principles in order to best answer the research questions, and not be overly dictated by the timing to coincide with commercial dredging events. This may require deliberate 'experimental dredging' exercises if it is not possible to appropriately align field research studies with commercial dredging operations.

Interpreting the term 'coral community'

Two views emerged regarding which biotic components of a coral community should be considered in the context of the research priorities. These views were that:

- Hard corals should be the focus of the research since these are the principal value associated with coral communities and would adequately reflect the overall condition of the community; and
- Other components of the community should be included in the research since this will: improve our understand of the cause-effect pathways of dredging impacts; may identify early-warning indicators of potential change to coral communities; and will increase confidence in assessing the condition of a community by providing multiple and corroborating lines of evidence of stress related to the pressure of concern.

Subsequent discussion failed to clearly resolve this issue in this first briefing session. The issue was addressed in several subsequent discussions over the two days (see Sections 4, 5, 6 and 9 of this Appendix). The outcomes are best synthesised in Section 9 of this Appendix.

Prioritising research needs

The workshop discussion confirmed that the scope of the research needed to meet the objectives was potentially open-ended and that it would be necessary to prioritise the research needs.

2 DEPARTMENT OF ENVIRONMENT AND CONSERVATION (WA) PERSPECTIVES ON THE ASSESSMENT AND MANAGEMENT OF LARGE-SCALE DREDGING PROJECTS AND CRITICAL INFORMATION GAPS

Presented by Dr Cameron Sim (WA Department of Environment and Conservation)

The WA Environmental Protection Authority and the DEC have responsibilities relating to environmental protection, environmental impact assessment (EIA) and environmental management of development proposals and projects with potential to impact the environment in Western Australia.

EIA and management of activities relies on predictions of what parts of the environment will be impacted, the severity and persistence of impacts, and what parts of the environment will not be impacted. Clear, spatially-defined predictions of environmental impacts during EIA minimise ambiguity with respect to extent, severity and duration of 'approved' impacts, with benefits for both proponents and regulators. Generically, the framework within which the WA State Government expects proponents to couch their predictions of potential environmental impacts and management plans for dredging projects is underpinned by understanding of cause-effect pathways associated with dredging activities. This understanding relies on three key sets of information that proponents are requested to provide:

The Activity: An understanding of how dredging affects the physico-chemical characteristics of the environment and how these changes translate into stresses for benthic communities.

Numerical modelling should be used to predict how dredge-related physical pressures propagate, behave and attenuate in the environment (i.e. the 'pressure field'). Modelling the behaviour and fate of sediments liberated to the water column by dredging is particularly important. Numerical models, in particular hydrodynamic and sediment transport models, underpin many of the interpretations of the physical, biological and ecological effects of dredging proposals. It is recognised that, at present, hydrodynamic models are generally better developed than are sediment transport models.

The modeling exercises require appropriate data for model validation and calibration and an understanding of sediment-source characteristics and sediment production rates, dredge plume characteristics, dispersion patterns and fate, the substrate being dredged, dredging techniques and physical processes acting on particles.

A desired outcome of modeling for EIA is a reliable prediction of a boundary defining the zone of influence, that is, the area within which changes in environmental conditions due to dredging activities relative to ambient conditions can be expected. Therefore, the models need to be able to reliably describe ambient conditions and then to determine the zone in which dredging will cause a deviation from those conditions.

The Setting: Characterisation of the benthic communities within a predicted zone of influence as well as at appropriate reference locations. Proponents are expected to provide information on the benthic communities present within the anticipated zone of influence, including a benthic habitat map.

The Response: Direct impacts and indirect effects of dredging on benthic communities and environmental quality needs to be defined. Predicting indirect environmental effects is more complicated than predicting direct impacts as it requires:

- Knowledge of extent and distribution of biota (i.e. the 'receptor field');

- Understanding of the responses of biota to dredge-related pressures (i.e. the ‘cause-effect pathway’); and
- Capability to simulate how pressures such as turbidity and sediment deposition propagate and attenuate away from dredge/dump sites (i.e. pressure fields).

Proponents are asked to couch the likely ecological impacts of their dredging proposal in terms of:

- *Zone of High Impact*: the area within which severe and largely irreversibly losses of habitat are predicted. Predicted irreversible losses of benthic primary producer habitats will be considered in the context of relevant WA EPA policy (i.e. EPA Guidance Statement No.29);
- *Zone of Moderate Impact*: the area where reversible/recoverable change (preferably sub-lethal) in condition of benthic communities is predicted;
- *Zone of Influence*: where a detectable change in environmental conditions is predicted but with no resultant ecological impacts; and
- *Outside the Zone of Influence*: the area where no influence of the proposal is predicted, which would be suitable for locating reference sites.

This framework for presenting predictions of environmental impacts can be linked to environmental monitoring and management of dredging and provides the basis for informed decision-making, and setting auditable and enforceable project approvals.

From previous experience, the WA State Government has identified the following key information gaps:

- Information that enables the dredging activity to be correlated with the generation of pressure fields;
- Inadequate sediment transport models often due to lack of site-specific geotechnical data, poor understanding of the dredging equipment and its operation in conditions at the dredging site and poor understanding of fundamental processes such as particle re-suspension and deposition; and
- Three classes of Information Gaps in relation to assessing and managing the impacts of dredging on benthic communities (detailed in Table A1):
    - Conceptual understanding of how the ecosystem/biota is affected by dredging;
    - Impact prediction; and
    - Impact management.

2.1 Workshop Feedback

The following points were raised in the workshop discussion:

- The appropriate variables for defining stress field need to be established.

  The relevant description of the pressure that dredging is producing is that aspect of the environment representing a stress to the biota or environmental value of concern. This may not be TSS concentration (the most commonly used model output to define stress fields) but, for example, the deviation in light fields from ambient, the rate of sediment deposition, the thickness of an accumulated sediment layer, or the frequency of deposition events. Identifying the appropriate variables to describe the pressure fields is important.

***Table A 1**:* Key Information gaps identified by the WA Department of Environment and Conservation in the context of predicting and managing the impacts of dredging activities on benthic communities.

Information Gap	Specific Information Needs
Environmental Modeling	Understanding the validity of modeling to predict the effects of dredging on TSS and light attenuation coefficients (LAC)
Impact prediction	What are the levels of susceptibility of the different types of coral communities (which types are most sensitive and should be avoided)?
	What are the levels of susceptibility of different components of the coral community (do corals, algae, filter-feeders, infauna show different levels of susceptibility)?
	What are the relative levels of resilience of the dominant coral communities (which are least sensitive and can withstand greater levels of pressure than others)?
	What drives the susceptibility/resilience (why does this occur, is it linked to morphology, ability to clear sediments of different size or 'stickiness', depth of sediment cover, blockage of filtering apparatus, biogeochemical changes in sediments)?
	Does resilience/susceptibility vary with the intensity, duration, frequency and season of imposed sediment deposition or light reduction?
Impact management	What are the primary and secondary indicators of sub-lethal stress in the dominant coral communities (these could be species-, assemblage- or whole community-level indicators; useful for monitoring program design)?
	What levels of pressure (e.g. total suspended solids (TSS), sediment deposition rates or light reduction) are associated with the indicators of stress (i.e. cause effect relationships - useful for establishing alert and action criteria)?
	What is the duration of pressure that is tolerable before the indicators of stress are exceeded (temporal component of alert and action management regimes and criteria to recommence dredging after management intervention)?
	What are the pathways of recovery and how long does it take (post-development monitoring and project closure plans)?

- The ability to model ambient conditions is crucial to be able to predict the additional impact of dredging, but is difficult to do and existing models are inadequate.

  North-western Australian coastal waters have a high degree of temporal and spatial variability in TSS characteristics. This presents great difficulty for modeling ambient conditions. There was some divergence of view on the potential to ever accurately model ambient conditions. Some participants expressed the view that it was unlikely that models could ever accurately reflect ambient TSS characteristics in some parts of north-western Australia. Experienced physical modellers at the workshop felt that this was more an issue of improving our understanding of near- and far-field plume dispersion processes, and that appropriate research could see significant improvements in the accuracy of the models.

- Dredging-induced stresses and, therefore, the stress field (e.g. TSS) are transient, and this needs to be recognised in delineating impact zones.

  Zones of impact needed to take into account appropriate timescales and will probably need to be derived statistically from the raw model outputs, for example the zone in which total reduction in available light over a given period, or frequency of significant sediment deposition events over a given period may occur. This emphasised the need to understand the cause-effect pathways so that the stress field can be defined in the relevant terms.

- Physical (hydrodynamic and transport) models were often inaccurate due to poor understanding of physical process or dredging operations

  Some of this was due to inadequacies in our understanding of some key physical processes, particularly sedimentation and re-suspension (Section 2.8 of this Appendix provides a more detailed exploration of this issue that emerged in subsequent discussions). Anther contributor was the inability of proponents to predict the specific dredging equipment they would be using since this was often not determined until some time after the impact assessment was undertaken.

- Management of dredging impacts requires monitoring indicators that respond rapidly and can, in turn, allow rapid management responses.

  The capacity to manage dredging activity on the ground is often limited by the capacity to respond to monitoring data. This highlighted the need for robust monitoring indicators that ideally can give indication of potential exceedence of environmental criteria rapidly and sufficiently in advance that management responses can be initiated in a timely fashion. It was generally agreed that this required an improved understanding of the cause-effect pathways of impacts so that appropriate indicators, other than coral mortality, could be developed.

  (NB: not withstanding the above, industry representatives highlighted the fact that contractual agreements often prevent management responses to breaches of dredging environmental criteria. The dredge operators are often on contract and the contract may not allow for environmental-related stoppages. Subsequent discussion agreed that this was an operational issue that could not drive the research priorities except to highlight the need for clear indicators of coral community condition and associated environmental criteria/triggers that can be written into dredging contracts.)

- Decision-making tools are required.

  Once adequate physical models can be coupled with adequate ecological knowledge, these two capabilities need to be combined to allow scenario-testing and decision-making. Currently this is done on a project-by-project basis. Ideally, improved knowledge and capacity will allow generic tools to be developed that can be populated with project- or site-specific data and which incorporate widely agreed approaches, data requirements and outputs.

2.2 Implications for Research Priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Sections 3 and 4 of the main report:

- Research is needed to address significant inadequacies in both the existing physical models that predict the effect of dredging on the environment and in the ecological models that predict the response of the environment;

- Improvement of physical models is required so that they can better represent ambient conditions and, therefore, predict additional effects of dredging on the environment. This improvement requires:

  -Improved understanding of key sediment transport processes, principally sedimentation and re-suspension;

  -More and better quality calibration and validation data for near- and far-field plume dynamics; and

  -Better understanding of the relationships between TSS and other environmental factors representing stress to biota.

- Improved ecological modelling is required in order to define the spatial and temporal extent of impacts, and to understand the relevant stresses so that appropriate stress-fields can be generated. Key areas for research are summarised in Table A1; and

- Ideally, these improvements could be incorporated into decision-making tools that can be adapted to site-specific conditions to assist proponents and regulators in assessing various dredging scenarios.

3 DREDGING – A PROPONENT'S PERSPECTIVE ON MONITORING AND RESEARCH PRIORITIES

Presented by Mr Nick Jones (Woodside Energy Ltd)

Capital dredging for the Pluto LNG Project has been approved for construction of a berth pocket, ship turning basin and channel to facilitate the passage of LNG and condensate carriers and for accommodating a gas export trunkline connecting the offshore gas field with the onshore gas plant. The Dampier Port Authority spoil grounds are used for disposal of capital dredging material.

At the time of the research workshop, in 2008, significant dredging activities had commenced, with the first stage, construction of the berth pocket, already completed. This involved intensive work using a cutter suction dredge and a trailer suction dredge operating in the inner turning basin and jetty exclusion zone to remove dredged material. The remaining channel and trunkline dredging works are scheduled to be completed during 2009 and 2010.

Extensive compliance environmental monitoring programs for water quality and coral health have been established to detect sub-lethal and lethal effects of dredging-induced turbidity and sediment deposition on coral habitat. Fortnightly coral health surveys are conducted, and coral sites are equipped with either satellite telemetered or logging water quality instruments. The environmental conditions of approval for the dredging activities set water quality and coral health trigger criteria for three management zones: Zone A (zone of predicted high coral impact); Zone B (zone of predicted moderate coral impact); and Zone C (no coral impact; representing locations within the proposed Dampier Archipelago Marine Park).

The configuration and extent of the monitoring programs were based on sediment transport modelling conducted during the environmental impact assessment for the project (Woodside 2006; see Section 4 of the main document for a full reference). A variety of coral impact thresholds was investigated in order to define the zone of potential influence of dredging activities. At the request of the DEC, the outer extent of this zone of influence was set using frequency-intensity-duration thresholds based on the 95th percentile of baseline (pre-Pluto LNG Project dredging) turbidity data.

Observations made from monitoring of water quality and coral communities following the initial phase of dredging include the following:

- No sustained increase in turbidity relative to established reference sites or baseline data at potential impact sites established within the zone of potential influence of dredging in Zone C;
- Dissipation of turbidity to background concentrations during dredging within a distance of approximately 1.5 kilometres of the dredge;
- Cyclones and low intra-site variability in turbidity have frequently triggered the water quality criteria set for managing dredging impacts, with over 30 resulting investigations;
- No water quality exceedences in Zone C have been directly attributed to dredging activities;
- The level of coral mortality in Zone C is consistent with thermal bleaching over the 2007-8 summer being the single driving factor;
- No net coral mortality has been recorded in Zone B; and
- Coral cover in Zone A has remained similar to pre-dredging levels.

The challenges of implementing the monitoring program include:

- The large size and long duration (~2 years) of the program, which is labour intensive and includes diving on a weekly basis, with attendant health and safety risk;
- Difficulty in being able to separate dredging influences (if present) from (high) background variability at the range of required monitoring. The program is based on a highly conservative footprint and driven by a sediment re-suspension factor of unknown accuracy. This has resulted in a large predicted “footprint” where some potential impact sites are more than 15 km away from dredging activities. The Ministerial Condition assigns a reactive dredge management program to water quality events at these locations;
- Difficulty in identifying the potential involvement of dredging activities in, and their contribution to, changing water quality and changes in coral health, where water quality and coral health are each naturally dynamic and variable. Significant effort has been invested to assess the potential for a dredging contribution in the lead up to and during the passage of tropical cyclones and before a regional thermal bleaching event that occurred during the 2007/2008 summer. In both cases, the findings of investigations attributed changes in water quality and coral health to natural variation, not to dredging impact. These investigations have focussed on sites that are located a significant distance from dredging activities (as above), therefore suggesting an overly conservative impact footprint as the basis for the scope of monitoring;
- The susceptibility of assigned water quality trigger levels to the influence of factors other than dredging-related effects. For sites in Zone C, the 7-day running 80^{th} percentile at reference sites must be compared with the 7 day running median at potential impact sites. Where the median exceeds the 80^{th} percentile, a detailed investigation is triggered. This trigger is susceptible to: a) spatially- and temporally- variable responses among sites in response to adverse metocean conditions, such as sites that are more / less exposed and/or do not respond simultaneously to prevailing conditions; and b) periods with low intra-site variability, where a slight variation, in the order of 1 NTU, can result in exceedance;
- Difficulty in assigning a level of risk to a particular water quality event in the absence of definitive information on the tolerance thresholds of Mermaid Sound coral communities to suspended solids and sediment deposition. The water quality trigger criterion assigned to the program is intended to trigger investigation where dredging activities are involved and application of reactive management to prevent impact on coral health; and
- Significant resources and costs required to run the program where evidence from results to date suggests relatively localised effects of dredging activities. This raises a question as to whether or not the scale of monitoring is commensurate with the level of risk to regional coral communities.

3.1 Workshop Feedback

The following points emerged in discussions following the presentation:

- Participants who have experience working in the region affirmed the difficulty that highly variable ‘background’ turbidity presents in determining the contributions of dredging. This background variability arise from several sources, but notably: natural processes such as re-suspension due to wind waves, swell, cyclonic events and tidal movements; and re-suspension due to shipping movements;

- The presentation highlighted the requirement for site-specific relationship to be developed between sediment concentrations and other key environmental parameters such as light attenuation coefficients;

- The reliance on turbidity data was seen as problematic, since relationships between turbidity and other parameters are generally not well understood. In addition, the variability and technical issues associated with turbidity measures is considerable and can make the information difficult to interpret;

- The discussion reinforced the earlier one that relationships between easily measured parameters and the environmental variables of real interest (i.e. those that directly affect community responses) need to be determined, but that these may need to be site specific. Therefore the research need may be for protocols to establish these relationships rather than attempting to develop universally applicable relationships;

- There were generally low impacts on corals, in terms of coral mortality, but the discussion highlighted the difficulty in interpreting this. Some key uncertainties were whether the coral at the site simply represent those that have been selected for under historical conditions of increasing sediment loads from regional activity, and therefore the data may not be transferable to 'green-field' sites;

- The studies and compliance monitoring undertaken to date are representative of the enormous amount of data that have been collected by numerous proponents throughout the region. The question of where these data reside was raised, and how it can be accessed to inform the research program, industry and the State as a whole. These data could provide information on background conditions and biotic responses to environmental changes. They could be a valuable source of validation data for the improvement of physical models, particularly in understanding near- and far-field plume dynamics by providing valuable calibration or validation data for a range of different sediment types and hydrodynamic conditions; and

- While existing compliance data will be valuable in improving our knowledge, this value will invariably be limited. Compliance monitoring programs are not designed to answer specific research questions about ecological processes. Consequently, they are often confounded by other factors or suffer from regulatory or logistical constraints. Improving our understanding of processes will still require well designed observational or manipulative experimental studies, though compliance data sets may well be a component of, or inform the design of, those studies.

3.2 Implications for Research Priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Sections 3 and 4 of the main report:

- Improved accuracy in the prediction of impacts requires a better understanding of re-suspension processes in order to more reliably model far-field sediment dispersion. The currently applied re-suspension factors are of unknown accuracy and may be leading to overly conservative estimates of zones of influence;
- Models are required that can more reliably predict the background conditions in environments that are naturally highly variable with respect to turbidity and coral condition. The current models are inadequate;
- Definitive sedimentation and suspended sediment thresholds (for coral health) are required in order to evaluate the risk associated with predicted effects of dredging;
- It would be beneficial to identify and co-ordinate access to a large body of compliance monitoring data that has been collected over time at a large range of sites;
- Efforts undertaken in this case study demonstrate the potential to develop triggers for a variety of stresses, such as sediment deposition. They also highlighted considerable logistical difficulties in implementing management based on these triggers, primarily due to logistical issues, lack of information to support understanding of the risks associated with different levels of stressors (e.g. sediment deposition); and the ability to ascribe breaches of criteria to dredging or other causes in highly variable environments;
- There is a need for universally-accepted protocols for developing site-specific relationships between easily measured water quality parameters (i.e. TSS and turbidity) and other

environmental variables of more direct relevance to biotic responses (e.g. light attenuation coefficients bottom light and sedimentation rate); and

- Improving the capacity to manage the impacts of dredging on coral communities will require well-designed observational or manipulative experimental studies, though compliance data sets may well be a component of, or inform the design of, those studies.

References

Woodside (2006) Woodside Energy Ltd. Pluto LNG Development. Public Environment Report / Public Environmental Review. EPBC Referral 2006/2968. Assessment No. 1632. December 2006

4 REVIEW OF IMPACTS OF DREDGING ON CORAL COMMUNITIES

Presented by Dr Kathryn McMahon (Edith Cowan University)

The literature review of responses of coral communities to dredging-related stresses addressed four main points:

- Physical and chemical changes in the marine environment associated with dredging;
- Known impacts and responses to different biota groups from dredging or stressors associated with dredging, including eco-physiological requirements, sensitivity, resilience, environmental tolerances, cause-effect pathways, impact and recovery, sub-lethal and lethal indicators;
- Comparison and contrast of resilience of different biota to dredging stressors; and
- Identification of key information gaps.

Important physical and chemical variables and processes that can potentially change with dredging include light, turbidity, suspended sediments, sediment deposition and burial, re-suspension, sediment type and particle size distribution, nutrients, organic matter, toxicants, sediment red-ox potential, pH, hydrodynamics, particle transport and particle aggregation.

A variety of tropical biota can be impacted by dredging, including bacteria, primary producers, hard corals, other filter feeders, other macro-invertebrates and fish. Of approximately 80 studies that examined the response of these groups to dredging events, most focusing on the impact to primary producers (50%) and hard corals (25%). Additional experimental studies have examined the effects of different stressors associated with dredging (light reduction, sedimentation, suspended sediments, sediment) on biota.

The types of responses to dredging or dredging stressors were at a number of levels, including:

- Changes in community composition; and
- Changes at the individual level (sexual reproduction, growth, morphology and physiology).

Few studies provide information on the eco-physiological requirements, sensitivity, resilience, environmental tolerances, cause-effect pathways, impact and recovery, sub-lethal and lethal indicators of species in these biota groups. Some of this information was available for some species of corals and seagrass but few studies were specific to the species found in north-western Australia.

Some general trends in the response pathway of biota to dredging were identified, including:

- Photo-autotrophs were likely to be negatively impacted by light reduction and sedimentation, whereas heterotrophs have shown varied responses to increased suspended sediments and sedimentation; and
- Mixotrophs generally declined with light reduction and increased sedimentation but have shown varied responses to suspended sediments.

These variations in responses to dredging stressors highlight the need to target taxa across the trophic groups for a more thorough understanding of dredging impacts in coral communities.

Based on this limited information, the sensitivity of different biota to dredging stressors was proposed. Sensitivity was defined as the combination of the time to respond and the magnitude of dredging-related stress at which a response occurs. The predicted sensitivity of different biota, from most to least sensitive, is considered to be:

- Bacteria
- Phytoplankton / benthic micro-algae
- Sponges, soft corals
- Hard corals, filter feeders, seagrasses
- Motile invertebrates
- Fish

Two models were presented on the susceptibility of hard corals to dredging stressors (Gilmour *et al*. 2007, PIANC in prep). The first was based on the susceptibility of different taxa and growth forms to stressors such as turbidity and sedimentation, ranking them into high, medium and low susceptibility. The second model presented the susceptibility of different growth forms based on their interacting susceptibility to turbidity and sedimentation.

The main information gaps relate to:

- The mechanisms of response (impact and recovery) of different biota to stressors associated with dredging e.g. response pathway;
- The level and duration of pressure for responses to occur;
- The susceptibility and resilience of different components of the coral community to dredging related stressors, and how this varies with intensity, duration, frequency and timing of the pressure; and
- Poor information on many of the biota, especially filter-feeders and macro-invertebrates other than hard corals.

4.1 Workshop Feedback

The following points emerged from discussions following the presentation:

- Workshop participants re-iterated the point that modelling of predicted dredge plumes does not always model variables that might directly impact biota, such as light reduction or sediment deposition;

- There would be benefit in examining dredging-related impacts on taxa that covered the range of trophic groups (autotrophs, heterotrophs, mixotrophs), as they are likely to respond differently to dredging pressures and at different timescales.

  It was agreed that most of the knowledge on the impacts and response of biota to stressors associated with dredging were for hard corals and primary producers and that this is limiting our understanding of the cause-effect pathways. Other sessions discussed in more detail the issue of which biota should be the focus of research effort (see Sections 1 and 9 of this Appendix);

- Population dynamics and demographics of coral species were important to understand to be able to predict longer-term impacts of dredging activities;

- There is a need for taxa-specific research to clarify the response pathways of biota to light- and sediment-related stress;

  While the review highlighted presumed response pathways of biota to light and sediment stress, there is generally inadequate evidence to support these models. The response pathways are a synthesis of the general patterns observed across a variety of studies on a variety of taxa. Therefore, they provide a framework and guide to test pressure- response relationships of individual taxa and highlight the need for further studies required to refine these to a taxa-specific level. This was considered to be equally true of many hard coral genera taxa in north-western Australia as it was for other taxa.

- There is a need for genera- and morphology-specific research to clarify the response pathways of hard corals to sediment deposition;

  There was some uncertainty about the models of susceptibility of coral genera and sensitivity to sedimentation and turbidity of coral morphologies. Not all species within a genera conformed to the predictions in the model, especially species in the Dampier region.

- Light quality was suggested as another parameter that may be affected by dredging and could impact photosynthesising biota. Few studies were found in the literature on the impact of this variable.

4.2 Implications for Research Priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Section 2 and 3 of the main report:

- To improve predictions of the impact of dredging on biota the modelling of pressure fields needs to target variables that directly cause stress to the biota. This was also raised in other sessions (Sections 2 and 8 of this Appendix);

- The research priorities should include improving our understanding of how a variety of biota respond to dredging impacts, encompassing a range of trophic modes and taxonomic groups (this point was also addressed in Sections 1 and 9 of this Appendix; and

- Existing published studies and data in unpublished literature may be limited in providing threshold values or defining pressure-response relationships for biota, but can provide guidance on the most appropriate taxa to focus research on. A review of this the literature and data should be underpin any decision on which taxa are used in the research program.

References

Gilmour JP, Coper TF, Fabricius KE and Smith LD (2007) Early warning indicators of change in the condition of corals and coral communities in response to key anthropogenic stresses in the Pilbara, Western Australia. Australian Institute of Marine Science; Commonwealth Government of Australia, National Heritage Trust.

PIANC The World Association for Waterborne Transport. Dredging and Port Construction around Coral Reefs. Unpublished Report of working group 15 of the Environmental Commission.

5 PERSPECTIVE ON CORAL MONITORING IN NORTH-WESTERN AUSTRALIA

Presented by Dr Jim Stoddart (MScience Pty Ltd)

The perspectives on monitoring of corals related to compliance monitoring programs that formed part of environmental management programs for dredging projects. The following observations were made:

- Setting water quality triggers that can provide protection is difficult due to a number of uncertainties, including which component(s) / value(s) of the system is/are being protected;

- Interpreting breaches of trigger values can be difficult since the contribution of dredging may be difficult to separate from other activities or from re-suspension;

- Coral mortality has inherent problems as an indicator of coral condition in reactive monitoring programs because:
    - It can be unclear whether the mortality refers to habitat, to whole colonies or to proportions of individual colonies;
    - It can be hard to assign a cause to mortality, with significant natural mortality frequently occurring within monitoring plots;
    - Effects of dredging may not act primarily on the mortality of adult corals; and
    - It (and associated water quality data) is a long lag indicator, often taking days to weeks to assess, while incidents occur within hours.

- There are logistical issues associated with monitoring of coral mortality. To date, this form of monitoring has required divers to be in the water. Weather conditions can limit diver access and often monitoring cannot occur at regular, scheduled times, or at times of interest due to weather. Visibility is often a constraint, since much of the monitoring is performed using photography. Frequently, corals will have a layers of sediment on them and it can be unclear whether the underlying tissue is healthy or not;

- Despite the above concerns, monitoring has revealed quite predictable changes in hard coral assemblages in response to dredging-related environmental changes. Susceptibility can vary with growth form, size of the colony and taxonomic grouping. Some of these relationships have been summarized in publications, for example by Stoddart and co-workers and a review by Gilmour and others (2006);

- There is a need to improve the ability to predict coral community responses to ambient dredging pressures super-imposed on ambient conditions in order to drive an alternative approach to management; and

  Management should be based less on reactive monitoring and more on leading indicators, such as weather or tide and the predictions of their effects on turbidity. This will require a sound understanding of how those conditions will affect the coral community and will require before, during and after-dredging monitoring to confirm the accuracy of predictions.

5.1 Workshop Feedback

The following points emerged from discussions following the presentation:

- There are a variety of mechanisms through which dredging might affect hard corals

  The principal mechanism of impact on adults is likely to be through smothering (sediment deposition), blocking or interference with feeding (suspended sediments) and reduced productivity (through reduced light availability). Corals may also experience reduced immune system function and increased levels of disease associated with lower available energy, if they have to expend energy on sediment clearance. These effects may depend on the nature of the sediments since this could affect settling and re-suspension rates, capacity for clearance and light attenuation. It may also depend on the reproductive status of the coral if energy required to clear sediments is diverted to reproductive processes. Conversely, reproduction may be affected as a consequence of energy diverted to clearance of sediments. Finally, the timing, frequency and intensity of dredging-related impacts will be crucial in determining the capacity of corals to tolerate these impacts, since many of the impacts are likely to relate to energy expenditure in clearing sediments or reproductive status.

- Coral mortality is not an ideal indicator for reactive management;

  There was a strong sense of agreement that defining mortality was not as simple as it first seemed. An example put forward was the timescale over which effects are being considered; are corals surviving but their reproductive fitness is being reduced so that they are unable to sustain a viable population in the longer-term, and if so, over what period should 'mortality' be assessed.

- The problem with the time-lag in mortality responses highlights the need for alternative indicators of coral community condition that can be used as management triggers;

  What these are remains unclear, but they may not necessarily be coral variables; other components of the system may respond more rapidly and provide useful indicators of condition or potential change in condition. However, this requires an improved understanding of the relationship between dredging-related pressures and community responses (i.e. the cause-effect pathway).

- The difficulty in ascribing cause to coral mortality also suggests that multiple indicators may be required in order to confirm the cause of community responses, and therefore determine whether dredging activities need to be managed;

  This again, requires a better understanding of the cause-effect pathways of dredging-related impacts on coral communities in order to identify the range of indicators that respond at appropriate timescales and can be ascribed to specific types of impact.

- Insufficient information currently exists to confidently suggest alternative indicators that could be used to either predict impacts or provide indicators and associated trigger values for management;

  Potential alternatives to coral mortality include a range of physiological, reproductive, population and assemblage-level indicators. Work on these has been reviewed by Gilmour *et al*. (undated) who also conclude that developing alternative indicators would require identifying a range of species with different levels of susceptibility that could be calibrated against the magnitude of stress. Primary producers, sponges, foraminifera and amphipods have all shown potential.

- There is a need to understand the impact of dredging on vulnerable life-stages of corals, especially spawning;

  Dredging may affect vulnerable life-stages of corals as well as adults. Sediment plumes may interfere with reproductive process such as spawning and fertilisation. This has led to strict controls of dredging during spawning periods as a precautionary approach. Furthermore, deposited sediment may prevent or impede coral larval settlement, while the negative consequences of sediment deposition and light reduction noted for adults may have more severe consequences for new recruits, which have less energy stores and a lower physical profile. Industry identified the need to better understand coral spawning and the impacts of suspended sediment plumes as a priority for managing dredging activities in the lead up to, during and after coral spawning events. In particular, the question was raised as to whether the precautionary approach was justified.

- There is a need to understand how dredging may interact with coral bleaching or thermal stress.

  The workshop participants felt there was considerable uncertainty over how dredging impacts interact with other environmental factors, especially temperature. On the positive side, temperature-stressed coral may benefits from turbidity and nutrients. Alternatively, thermally stressed corals may lack the resources to clear deposited sediments or cope with light reductions.

  Subsequent discussion indicated that the priority need was to understand the primary response pathway of corals to light reduction and sediment deposition and any interaction with typical seasonal or bleaching events. Interactive effects related to long-term climate change were seen as lower priority.

5.2 Implications for Research Priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Sections 3 and 4 of the main report:

- There is a need to undertake research into the response of taxa other than hard corals to dredging-related stresses. The justification for this is as follows:

  - Hard coral mortality is unlikely to provide the basis for ongoing management programs based on reactive monitoring, which require indicators that respond rapidly and early to changes in environmental quality. What these additional indictors should be remains unclear but could include either other aspects of hard coral condition at the individual, population or assemblage level, or alternative taxa. The research should investigate responses of individual, population variables to dredging-related changes in the environment;

  - Ascribing cause to any coral mortality is difficult when the only measure of effect is coral mortality. Multiple indicators are required to provide multiple lines of evidence of cause and effect; and

  - Improved understanding of the cause-effect pathway of dredging impacts on coral communities requires studies of taxa other than hard corals;

- There is also a need to improve understanding of hard coral mortality in responses to dredging. The justification for this is two-fold:

  - If it were determined that management should be based around leading indicators rather than lagging indicators, then there is a need to identify variables that can be quickly measured and to understand the relationship between those variables and coral mortality. In other words, a thorough understanding of the cause-effect pathway of dredging impacts on corals is required; and

  -Interpretation of coral mortality data is currently made difficult by an inability to disentangle dredging-related mortality from other sources of mortality.

6 RESEARCH ON EFFECTS OF DREDING-INDUCED LIGHT REDUCTION ON SEAGRASSES

Presented by Professor Paul Lavery (Edith Cowan University)

Research has been undertaken recently in Western Australia to improve the capacity to predict and manage dredging impacts on seagrass ecosystems. That research was structured around answering the key information gaps outlined in Table A1 (see Section 2 of this Appendix). The study outcomes are reported in McMahon and Lavery (2008) and are available in full at <http://cmer.ecu.edu.au/seagrass/amphibolis-seagreass-light-reduction.php >.

A number of key lessons from the above work are relevant to building capacity for predicting and managing impacts of dredging on coral communities, including:

- A combination of manipulative experiments and observations of real dredging events was valuable in establishing seagrass responses to dredging impacts. Manipulative field experiments removed the often-significant confounding factors that make observational studies difficult to interpret. Nonetheless, concurrent field studies on the recovery of seagrasses to real dredging operations in nearby regions provided valuable validation of the experimental studies;

- Determining cause-effect pathways required a large number of variables in the seagrass community to be measured. While this was time-consuming, it ultimately allowed identification of physiological and morphological indicators of change that have potential to serve as early, sub-lethal indicators of impact in management plans, some of which were completely unanticipated;

- Constructing experiments to follow the recovery of the seagrass was important in identifying thresholds of impact (duration and intensity of light reduction) from which the seagrass community could or could not recover and the timescales of that recovery;

- By structuring the research design around the presumed cause-effect pathway, the outcomes provided information on three sets of information gaps: 1) the general model of response to stress; 2) the prediction of impacts; and 3) the identification of indicators for management of impacts. This aligns strongly with the set of key information gaps identified in Table A1 (see Section 2 of this Appendix);

- The appropriate descriptor of the stress field only became apparent towards the end of the project. Due a complex interaction between ambient light conditions, temperature and the imposed shading % light reduction was not the most useful descriptor of stress. Instead, change in the hours of saturating light intensities received by plants was a strong predictor of impact;

- High quality, long-term data sets for key environmental variables, such as light attenuation coefficients are essential to guiding this type of research and interpreting the outcomes;

- The experimental approach, while logistically feasible, requires constant access by personnel for maintenance. This has implications for remote locations or areas that may have restricted access due to occupational health and safety or other considerations.

6.1 Workshop Feedback

The following points emerged from discussions following the presentation:

- There was a general agreement that where manipulative field experiments are feasible, the improved inferential power is worth the effort of establishing and maintaining the experiments;

  At the same time, it was noted that a number of logistical constraints might influence the feasibility of large-scale field experiments in north-western Australia, including visibility, crocodiles, poor access and lack of land-based support infrastructure.

- The combination of experimental data and comparable observational data from commercial dredging operations is desirable;

  In the case of coral communities, this emphasizes the value of compliance monitoring data or other historical that have been collected and the desirability of those data being available to inform research.

- Lack of regional data sets for key environmental parameters is a major gap that needs to be addressed;

  Some key variables of interest are TSS, sedimentation rates and light attenuation. Strategic impact assessments or coordinated industry-government programs might provide a mechanism to collect these key data sets at a regional scale.

- The need to determine the appropriate descriptor of stress was reiterated to allow the appropriate stress fields to be generated as model outputs;

  The appropriate description of stress will vary for different organisms. For hard corals, it could include amount and rates of sediment deposition, reduction in light availability and less obvious parameters, such as microbial activity, which relates to infection and disease. For filter-feeders, concentrations of particles of particular sizes could be relevant, relating to clogging of filtering apparatus.

- The ability to predict recovery and the associated timescales is important in evaluating impacts.

  Understanding the potential for recovery provides insights into critical thresholds that should be avoided (i.e. those that result in lack of recovery) and also allows evaluation of interim loss of ecological function. It may also permit greater tolerance of impacts if there is certainty that recovery will occur within an acceptable timeframe. There was a range of views on how interim loss of ecological function should be considered in impact assessment. On the one hand, some participants felt that a significant period of reduced ecological function should be considered in the evaluation of dredging management options, while others felt that evidence that the system would recover in an acceptable period of time should be taken as indicating no permanent loss of function and therefore no effective impact;

6.2 Implications for the research priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Sections 3 and 4 of the main report:

- Where practicable, the use of manipulative, controlled experiments should be included in the research;

- The research should address a sufficient range of taxa or variables in coral reef communities to provide insights into the cause-effect pathways of dredging activity. This will require a range of physiological, morphological and assemblage level data to be collected. This is reflected in the High Priority research areas which incorporating several key taxa;

- Compliance and other data collected as part of historical and ongoing dredging projects should be identified and, where possible under established data sharing protocols, be made available to inform the design of any research and validate experimental research outcomes;

- Effort should be made to acquire regional data sets of key environmental parameters, such as TSS and light, to characterise ambient variability and to inform the design of research projects and interpretation of research outcomes.

- The focus around the three sets of key information gaps (Table A1; see Section 2 of this Appendix) was endorsed as appropriate. This is reflected in the set of sub-questions embedded within the research priorities for determination of thresholds of tolerance to dredging-related stresses among key taxa.

7 EXPERIMENTAL RESEARCH ON EFFECTS OF SEDIMENT DEPOSITION ON HARD CORALS

Presented by Dr Andrew Negri (Australian Institute of Marine Science)

Experimental research is currently being undertaken to determine the effects of sediment deposition on hard corals. As the research was still work in progress and subject to confidentiality restrictions, the presentation focussed on the methods being used and some of the variables being examined rather than the research outcomes.

The following points are highlighted:

- The research aimed to characterised the responses of selected hard corals to different sediment deposition regimes in order to develop sediment deposition and turbidity thresholds over significant time periods (up to 3 months);

- A major effort of the research project was devoted to establishing a facility that could create the sorts of treatments required to answer the research questions;

- The experimental facility requires significant maintenance during experiments, with 1-2 staff required to ensure the correct treatment conditions are achieved;

- Large corals are not practical for these types of experiments unless much larger treatment tanks are used. Either small (5 cm) sections of flat coral (*Montipora*) or 1-2 digits of branched coral (*Acropora*) were used;

- Translocation of corals is a significant issue. Many of the north-western Australian species, which were the focus of the research, did not cope with relocation to the facility in QLD (relocation may be possible using other methods). Consequently, identical species from similar reefs in QLD were used as surrogates for the WA species;

- Species of coral with flat morphologies were more susceptible to sediment deposition that branching corals;

- Under the sediment loading regimes used in the study, full mortality was recorded after 4-12 weeks (*Montipora*) with some decline continuing the recovery periods for some taxa (Acropora); and

- The experimental system closely controlled all environmental variables, enabling the clear identification of cause-effect relationships and derivation of threshold values;

- A number of potential sub-lethal indicators have been identified, including PAM fluorescence variables, pigment and lipid composition, calcification rates and gene expression responses.

7.1 Workshop Feedback

The following points emerged from discussions following the presentation:

- Effort required to establish and maintain infrastructure;

The participants acknowledged the significant effort required to establish the facility and the staffing requirements to maintain an experiment.

- Characterising sediment deposition regimes under dredging scenarios;

  There was considerable discussion on how well tank-style experiments replicated real field sediment deposition regimes. The absence of good quality data on field sediment deposition regimes makes this difficult to assess. While, the experimental facility would allow different deposition regimes to be mimicked, it is not clear how complex these might be and therefore how feasible it would be to replicate them. The first step would be to obtain appropriate field data and calibrate the laboratory treatments against these. Anecdotal accounts indicated that sediments might persist on corals for 2-3 weeks but that this may change under continuous versus pulsed loading regimes.

- Need to understand the factors that influence the effect of deposited sediment;

  There was discussion as to whether the effects of sediment deposition on corals were due to the period of sediment accumulation on the coral surface or the nature of the sediment. Other work has suggested that organic content of the sediment can be an important determinant of the condition of the underlying coral, with higher organic content associated with greater incidence of disease.

- Up-scaling the experiments;

  The potential to upscale the experiments to whole coral colonies was queried. At this stage it is not clear that the system could cope with whole colonies and trials would be required. The feasibility is likely to depend on the size of the colonies, their ability to cope with transportation, overcoming problems of sediment accumulation on the colonies and approvals for removal of significant numbers of whole colonies from donor sites.

- Definition of tolerance thresholds;

  The laboratory experiments focused on a narrow range of loading regimes. A broader range of experiments would be required to determine lethal, chronic and no effect thresholds. It would also be desirable to develop recovery trajectories. While the experience to date indicates that this is possible, the infrastructure and time required would be significant.

- Determining effects of sediment deposition on reproductive processes.

  The possibility of using these types of experiments to examine long-term effects, such as impacts on reproductive capacity, was raised. This would appear to be very species-dependent. Some species are much more adaptable to the relocation required to establish them in the experimental system, the requirement to use surrogates in this experiment being a good example. This may well affect any research in north-western Australia and suggests that minimising transportation is desirable.

7.2 Implications for the research priorities

The following points from the workshop discussion influenced the identification of information needs and research priorities described in Sections 3 and 4 of the main report:

- The use of manipulative, controlled experiments to test the effects of sediment deposition on corals (and other biota) appears to be feasible, but requires considerable investment in infrastructure and staff to maintain the experiments. This approach offers the possibility to manipulate key aspects of sediment deposition, including the type of sediment, load and the frequency of re-suspension. These factors would be extremely difficult to manipulate in field experiments, suggesting a role for laboratory-based experiments to determine coral thresholds to sediment deposition;

- Similar approaches could be applied to other taxa, including filter-feeders to determine the effects of TSS on filtration capacity;

- The approach needs to take into account the likely sediment deposition regimes that will be experienced in dredging operations and differing ambient conditions. This may require acquisition of field data to determine the regimes to be applied in experiments;

- Given the difficulties experienced in transporting corals, it is desirable to undertake these types of experiments in facilities located as close as possible to point of collection of the corals, though these facilities do not currently exist outside Queensland;

- It remains unclear whether small coral fragments are representative of whole corals and this would need to be determined in future experiments.

8 PREDICTING AND MODELLING STRESS FIELDS

Presented by Dr Des Mills (Marine Environmental Reviews)

The experience gained from the application and evaluation of a range of hydrodynamic and sediment transport models was summarised, with a focus on the key information needs required to improve these models.

The following points are highlighted:

- Hydrodynamic circulation and ocean wave models are relatively well-developed and can provide bottom shear stress for sediment re-suspension and deposition modelling and currents for modelling the advection of the dredged sediment plumes, provided;
  - The important processes, drivers and the temporal and spatial scales of the local and regional oceanography are understood and incorporated;
  - The models are implemented for the dredging project and surrounding region, with appropriate coverage, spatial resolution, boundary conditions, bathymetry and forcing data; and
  - Each model implementation is calibrated and validated against representative, high quality field data sets encompassing the relevant temporal and spatial scales.
- Less well-developed are:
  - Sediment source models, including models to predict the rate (and particle size distribution) of sediment released from the various types of dredging plant working on different soil and rock materials;
  - Sediment transport and fate models; and
  - Water quality models that translate the suspended sediment fields into relevant descriptors of stress for the biotic community (e.g. benthic light fields).
- The inadequacy of these models relates primarily to uncertainties in:
  - Dredging project definition (i.e. preliminary dredging plans and assumptions, which are subject to change, are often incorporated into model simulations for the purposes of environmental impact assessment);
  - Geo-technical information needed as input for modelling (e.g. sediment types. grain sizes and likely behaviour under dredging conditions);
  - Dredge-induced sediment mass release:
    - Often the estimation methods are not transparent; and
    - A detailed international review of published reports on sediment release from dredging operations revealed that field measurement methods were often inconsistent and frequently failed to result in the collection of all the data required to assess releases from different types of plant working in different soil and rock materials. Protocols have recently been developed to provide guidance on standard methods of measuring sediment release from dredging plant (HR Wallingford Ltd and Dredging Research Ltd, 2003);
  - Understanding is required of how sediment release rates and characteristics in the near- field varies with respect to the interactions of:
    - Dredge type;
    - Dimensions and operating characteristics;
    - In-situ sediment properties; and
    - Marine operating conditions;

- Understanding is required of key sediment transport processes, primarily:
    - Particle sinking rates, accounting where necessary for size-class interactions and enhanced settlement due to flocculation if concentrations within a sediment suspension exceed certain thresholds;
    - Parameterisation of the critical shear stress and sediment flux rates for erosion and deposition, including consideration of sediment cohesion, consolidation and armouring of the seabed; and
    - TSS vertical profiles under different physical conditions;
- The predictive capabilities of model applications in WA, due to lack of comprehensive data sets of dredging operations, sediment characteristics, suspended sediment and sediment deposition fields and metocean data that would enable the models to be calibrated and validated;
- Drivers of variability in background sediment loads and characteristics; and
- The relationships between sediment dynamics and the stressors for biota (a point made in several earlier presentations). For example:
    - The relationship between TSS and light attenuation and TSS and sediment deposition rates.

- Two fundamental approaches to modelling sediment dynamics can be taken, both with significant knowledge requirements:
    1. Superimpose transported dredge sediments onto a static ambient sediment background estimate derived from field data
        - Most dredge plume models deal only with the transport and fate of those sediments that are initially suspended by dredging and dumping operations. As a consequence the model predicts levels of suspended sediment concentrations, deposition and resuspension rates that are “above background levels”; and
        - This approach may be difficult to justify in a dynamically variable marine environment and if used then a review of background data, field validation data sets and estimates of error should be provided.
    2. Superimpose transported dredge sediments onto a dynamic (ambient sediment dynamics) background:
        - Consideration should be given to an alternative modelling strategy, which deals both with the dynamic simulation of background sediment transport, and with the dredge-induced sediment fate and transport fields within the one model. Within such a modelling framework parallel runs could be made of a base case (background without dredging) and a case which also includes dredging;
        - This may be a technically preferred approach but requires broader knowledge of sediment fluxes and budgets and more detailed calibration. (NB: this suggestion should also be viewed in light of the earlier comments that the ability to model ambient sediment characteristics is currently weak but has been identified as a major need by industry if the impact of dredging is to be accurately predicted); and
        - This would provide a much better basis for estimating the contribution of the dredging to variable water quality conditions.
- The absence of information in many of these key areas stems from the lack of in-field plume characterisation through measurements during dredging events, particularly the near-field plume dynamics. Consequently, there is a lack of strong statistical relationships between a number of water quality parameters and measured release rates of sediment from dredges. This hinders the ability to reliably estimate dredge-induced sediment release rates and characteristics and this, in turn, compromises far-field sediment plume

modelling. These data need to be collected at appropriate spatial scales to use as validation data in future modelling exercises; and

- There is a need for agreed protocols for the development and assessment of models, to provide both industry and Government with confidence in the models outputs.
- There is a need for both industry and Government to agree on and establish a common user data base (which documents dredging operations, associated sediment dispersion and fate, and resultant changes in water quality) for the purpose of testing and improving confidence in the application of sediment source models, sediment transport models and water quality models.

8.1 Workshop Feedback

There was general agreement that the current models are inadequate at describing ambient suspended sediment characteristics of areas surrounding dredging operations. It was also agreed that key processes were poorly understood, and that this became more obvious in the far-field estimates of suspended sediments. The physical modellers in the workshop stressed that this emanated from the lack of information on near-field dynamics.

Several participants referred to extensive compliance monitoring programs that occurred over dredging periods and were capable of providing the sorts of information referred to above. Overwhelmingly, however, the view was that the compliance monitoring data are collected for different purposes and generally do not have the appropriate spatial and temporal designs needed to provide adequate descriptions of near-field conditions.

Issues of workplace safety may hinder access to near-field sediment plumes during dredging operations, though ti was also felt that these problems could be overcome.

Translating sediment fields into stress fields will require clear communication between the ecologists and the sediment modellers. It was suggested that stress surfaces could offer a means of representing the dredge-generated stress fields.

8.2 Implications for the research priorities

The presentation and discussion added further weight to earlier conclusions that there is a significant inadequacy in the current sediment transport models, in their ability to accurately predict sediment distribution and to translate that into appropriate descriptors of stress fields.

Research is needed across a range of physical processes to provide the information or understanding necessary to improve the transport modelling. This will require a focus on:

- Settling velocity;
- Aggregation/disaggregation of particles;
- Sedimentation and re-suspension as functions of shear stress;
- Suspended sediment profiles under different physical conditions;
- Bottom boundary layers (e.g. very fine suspensions); and
- Plume dispersion under different physical conditions.

The relationships between TSS and other key water quality parameters that represent stresses to biota, as a priority TSS versus light attenuation and turbidity versus other water quality parameters.

Three approaches are required to gain the above understanding:

- Detailed field collection of data from near- and far-field sediment plumes during either commercial or experimental dredging events and under a variety of physical conditions to calibrate/validate models and to provide the fundamental understanding of sediment dynamics under a variety of conditions;

- In the near-field, the focus of predictions should be on quantifying sediment release and its settlement over scales of metres to kilometres; and
- In the far-field, the focus should be on the role of re-suspension in adding dredge-derived sediments into the water column.

- Best-practice protocols for the collection of those field data and for establishing relationships between water quality parameters; and
- Simulation and calibration of these processes in models.

References

HR Wallingford Ltd and Dredging Research Ltd (2003). Protocol for the Field Measurement of Sediment Release from Dredgers. Issue 1. Report produced for VBKO TASS Project by HR Wallingford Ltd and Dredging Research Ltd. Published by Vereniging van Waterbouwers in Bagger- Kust en Oeverwerken (VBKO).

9 PERSPECTIVES ON MODELLING BIOTIC RESPONSES TO DREDGING

Discussion facilitated by Professor Paul Lavery (Edith Cowan University)

Initial workshop discussions (see Section 1 of this Appendix) were ambiguous regarding the need to examine effects of dredging on biota other than hard corals. Subsequent discussions (see Section 5 of this Appendix) produced a stronger consensus that a range of biota should be considered in the term ‘coral community’, since hard corals were unlikely to be a useful indicator of dredging impacts around which management triggers could be based; other taxa were likely to respond more rapidly and provide potential sub-lethal indicators. Even at this stage, the consensus was not unanimous; some participants felt that reactive monitoring triggers were inappropriate and that the focus should be on leading indicators. However, the majority view was that even a leading indicator approach requires a better understanding of cause-effect pathways, which can only be achieved by examining the response of a range of the community’s biota to dredging.

Participants held extended discussions on which taxa should be considered as priorities for research into responses of biota to dredging-related stresses. Participants were asked to confirm which groups should be prioritised, to justify the choices and to summarise the key information gaps in relation to those taxa. The workshop sessions highlighted the following relevant points:

9.1 Priority taxa

- There is a poor understanding of the cause-effect pathways of dredging impacts on many components of coral communities;
- Current (unpublished) studies in Queensland (Katharina Fabricius, pers. comm.) suggest that some components of the community respond earlier than hard corals and in a predictable fashion, especially some sponge taxa;
- There is very little understanding of the impacts of dredging-related pressures on filter-feeders and macro-invertebrates (see also Section 4 of this Appendix);
- The capacity for systems to recover is poorly understood and whether there are dependencies, or ‘successional sequences’ among different biotic assemblages for recovery to occur; and
- While it may not be possible at this time to identify the specific priority taxa, those ultimately chosen as the focus for research should be those with the potential to act as indicators of community condition, dictated by their: Sensitivity, Importance, Robustness, and Commonness; as well as the Predictability of their response; Transferability among different coral communities; the Depth of existing knowledge of the organisms; and Ease of measurement.

The taxa considered most relevant to focus research on were:

Hard corals,

They are iconic, a key value, a focus area for management and an appropriate indicator of impact. However, research is required to clarify many aspects of the responses of hard corals to dredging-related pressures (see Section 5 of this Appendix).

Research should focus on:

- The cause-effect pathway of dredging impacts on adult coral mortality, taking into account physiological, population and assemblage-level responses, in order to improve the ability to predict impacts and to identify indicators of coral mortality;
- The effects on vulnerable life-history stages and reproductive processes, in order to improve understanding of key ‘environmental windows’ and the timescales over which impacts may be realised; and
- The effects of suspended sediment plumes on coral spawning events, in order to assess the current requirement to avoid dredging during spawning periods.

<u>Primary producers</u>

Primary producers are a key component of coral communities and include macro-algae, benthic micro-algae, turfing species and endo-lithic and endo-symbiotic algae. They typically respond rapidly to change in light availability, but may also respond to smothering through reduced settlement and growth. Other studies have shown primary producers in other systems to have predictable response to the intensity, duration and timing of light reduction and have potential as indicators of the magnitude and duration of sub-lethal stress (see Section 6 of this Appendix). Key uncertainties regarding primary producers in coral communities relate to the basic eco-physiological requirements of the organisms, their sensitivity to burial/sediment deposition and which components of the primary producer assemblage are more likely to demonstrate response early on the cause-effect pathway.

Discussion highlighted a general concern that the fundamental trophic relationships in coral communities of the north-western were not well understood. In particular, the relationship between primary production and the condition of other, heterotrophic components of the community is poorly understood, reflecting a lack of fundamental food web studies compared to many temperate ecosystems.

<u>Filter-feeders</u>

Filter-feeders are an abundant, diverse component of marine habitats throughout north-western Australia. Paradoxically, knowledge of these organisms is scant. Preliminary surveys of north-western Australia have revealed extensive areas dominated by high biomass assemblages of filter-feeders, from as shallow as 5 m depth. In these areas, they are likely to be ecologically important components of coral communities, either as a direct component of the community or through trophic connectivity among filter-feeding habitat and adjacent coral communities.

Dredging has the potential to significantly affect these assemblages through a variety of mechanisms, including: the capacity for sediments to reduce feeding efficiency through clogging; smothering of adult or juvenile organisms; and inhibition of settlement. The nature of the sediment particles is likely to have a significant influence on any impact, particularly the sediment grain size. Some components of the assemblage could also be affected by reduced light availability, specifically those sponges with endo-symbiotic algae.

While some individual species have received some research attention, the group as a whole is poorly studied. There is a lack of information on their basic biology, ecology and distribution. There is a profound lack of understanding of sensitive biota and thresholds of key organisms. Known or presumed responses to dredging impacts include change in the morphology (size) of sponges, and gorgonian corals, increased sensitivity to bio-erosion, and changes to the timing of reproductive events. The response can be quite fast, particularly in the heterotrophic sponges. Other components of the assemblage, such as sea whips tend to be quite resilient, though the basis for this is not understood.

While the fundamental information needs are identical to those of corals and primary producers, any research is starting from a much lower knowledge base and so more fundamental information also needs to be collected. With this in mind, it may be appropriate to develop a ‘health index’ that reflects stress at the whole assemblage level, rather than focussing on specific species. Alternatively, it may be useful to develop dose-duration response relationships for a set of appropriate species. What constitutes 'appropriate' species remains unclear and so any efforts in this area need to be proceeded by screening research to identify those components of the filter-feeder assemblage likely to respond to dredging impacts. This screening data might be obtained through experimental procedures, but given the low knowledge base, it may be more useful to use natural gradients in turbidity to develop correlative relationships between species sensitivity and turbidity, as a first guide.

Other taxa

It was also felt that some groups offered exciting possibilities, particularly bacterial genotypic variability under different environmental conditions. However, our understanding of bacterial diversity was considered so rudimentary at this point that it was inappropriate to pursue this line of inquiry. Further discussion in small working groups refined the key biotic groups to which should receive research priority: to three:

1. Hard corals (including adult and larval life-history stages)
2. Primary producers; and
3. Filter-feeding organisms.

9.2 Guiding research questions for biotic responses to dredging

The research questions outlined in Table 6.1 (Appendix 2) were considered appropriate in focusing research for improving the definition of thresholds of response of biota to dredging-related impacts.

9.3 Sediment characteristics as a modifier of biotic response

On several occasions participants raised the topic of sediment type as a determinant of the potential to impact coral communities. It was felt that the sediment type could strongly influence the resulting stress, and that this should be recognised in any prediction of impact and the design of research programs. The important sediment-related variables were considered to be:

- Mineralogy: carbonate versus non-carbonate sediments, which are the two dominant forms of sediment in the region;
- Size fraction: which may influence the ability of coral to clear settled sediment, light attenuation and may influence the degree of clogging of the coral's filtering apparatus; and
- Organic content: this has been shown to affect the degree of mortality resulting from sediment deposition, presumably through its influence on bacterial growth and subsequent infection of corals.

The workshop participants' views in relation to research on the tolerance of biota to suspended sediments was that the research should clarify any effect of different types of sediments, at least with respect to the type (carbonate and non-carbonate) and (for filter-feeders) grain size of sediments.