Review and consolidation of environmental monitoring data collected by industry

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WAMSI Dredging Science Node

Theme 1 Report

Project 1

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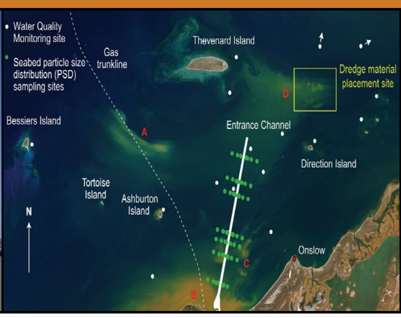

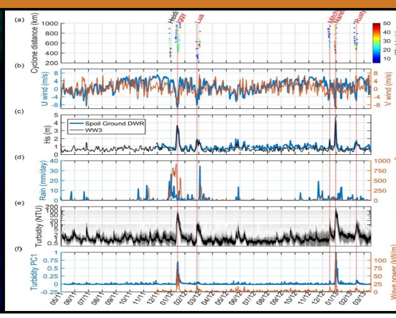

WAMSI Dredging Science Node

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 $20million 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**

woodside | Chevron | WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION | BHP | RioTinto

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Front cover images (L-R)

Image 1: Trailing Suction Hopper Dredge *Gateway* in operation during the Fremantle Port Inner Harbour and Channel Deepening Project. (Source: OEPA).

Image 2: Satellite image of the Onslow area (Wheatstone Dredging project) showing some of the water quality sites. (Source Project 6.3).

Image 3: Dredge Plume at Barrow Island. Image produced with data from the Japan Aerospace Exploration Agency (JAXA) Advanced Land Observing Satellite (ALOS) taken on 29 August 2010.

Image 4: Meteorological, wave forcing, and turbidity in the Onslow area (Wheatstone Dredging project, Source Project 3.3).

Contents

1 Introduction

Over the last decade there have been several large scale capital dredging projects in Western Australia (EPA 2011, Hanley 2011, EPA 2013) associated with port developments and exporting mining products (esp. iron ore), and oil and liquefied natural gas resources to SE Asian markets.

As part of the environmental approval of these projects the dredging proponents have collected considerable amounts of physical and biological environmental monitoring data to support the assessment and implementation of the dredge management plans (Hanley 2011, Styan & Hanley 2013). For the five most recent large projects, in the order of $250 million (AUD) was spent by industry collecting these data sets (Tom Hatton Chair DSAC pers. comm.).

Prior to 2010 these types of data were treated as commercial in confidence and were not made available to the scientific community for analysis. Consequently, it was difficult to learn from successive dredging projects and apply that knowledge to future projects, something that government in particular was criticised for. Since 2010 approval conditions in Western Australia require proponents to make environmental monitoring data publicly available. While that in itself was a major step forward, there were still left two underlying issues: (1) there was no capability within government to collate and analyse these data so the ability to value-add to the existing knowledge base was limited; and, (2) there remained a large amount of valuable data collected pre-2010 that could be of enormous value to help better understand the impacts of dredging on the marine environment.

The potential value of the data was first identified in the early planning stages of the Western Australian Marine Science Institution (WAMSI) Dredging Science Node (DSN), where participants from Woodside, State government agencies, environmental consultancies and scientists from government research organisations and universities were brought together to discuss research priorities for dredging near reefs (see page 15 of Lavery & McMahon 2009). Accessing and evaluating the existing data was considered a high priority in the WAMSI DSN Research Plan (Masini et al. 2011) to better understand the scale of dredging related pressures and the response of affected biota, which in turn enabled the scoping of laboratory and field experiments. Theme 1 (sitting within its own research category '*Review and consolidation'*) was created as a mechanism to: (1) identify and locate various data sets and associated reports; (2) access and review them; and, (3) communicate and disseminate the data to the most relevant of the research themes for subsequent analyses.

This report outlines the approach that was taken to acquire industry monitoring data and describes briefly where and how these data were used and what they enabled. It also gives examples of the types of data provided but without describing the scientific results or the management implications derived from the science. The latter are covered in the Node's individual Theme reports which are listed on the WSMDI DSN Reports website (https://www.wamsi.org.au/dredging-science-node/dsn-reports).

2 Identifying relevant industry data (Phase 1)

The first phase of Theme 1 was to identify environmental monitoring datasets held by Industry. The desk-top fact-finding exercise involved searching for all publically available grey literature material on past, present and future (i.e. pending approval) large scale capital dredging projects in tropical Western Australia, Queensland and the Northern Territory from 2005.

Information was sourced from proponent's websites for ~20 dredging projects including: Cape Lambert A, Cape Lambert B (RioTinto), Pluto (Woodside Energy Ltd), Gorgon (Chevron), Anketell (API), BHPBIO RGP5 - Port Hedland, (BHP Billiton), Dampier Port Upgrade (Hamersley Iron), James Price Point - Browse LNG, (Woodside Energy Ltd), Wheatstone Gas (Chevron), Darwin Harbour (INPEX), Hay Point Apron & Departure Path (BHP BMA), Port Hedland Outer Harbour, (BHP Billiton), South of Embley Project (Rio Tinto Alcan), Port Hedland South West Creek, (Port Hedland Port Authority), Dampier Marine Services Facility, (Dampier Port Authority), Gladstone Port Western Basin Project (Gladstone Port Authority).

The information retrieved included Environmental Impact Statements (EIS) and Environmental Review and Management Programmes (ERMPs) that are required by the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the Western Australian *Environmental Protection Act 1986* (EP Act), as well as the project specific guidelines provided by the Western Australian Environment Protection Authority (EPA) and Commonwealth Department of the Environment, Water, Heritage and the Arts) (DEWHA; now the Department of the Environment and Energy). All technical documents that supported the proponent's submissions were accessed including, where available: dredge management plans; reports describing of baseline data collected; and, pressure field modelling studies. In total, 417 Portable Digital Files (PDFs) reports, amounting to 4.3 Gigabytes, was retrieved.

An initial review was conducted of whether the projects had collected, or were likely to have collected, information that was relevant to the three broad research categories of the WAMSI DSN Research Plan: (1) *Pressure[1] field Prediction and Characterization*; (2) *Ecological Response Prediction;* and, (3) *Critical Ecological Processes and Windows*. A summary table of the key details of each project was produced such as: location; proponent(s); environmental consultancy companies involved; volume to be dredged; proximity of key habitat;, size and scale of monitoring programs; and, if available, baseline habitat and physico-chemical environmental information (i.e. water quality data and turbidity thresholds used to predict zones of impact).

All documents (PDFs) were entered into a database, which was provided to scientists across the DSN at the start of the research programme. An example of the material collated for the API Management Pty Limited, Anketell Point Proposed development is shown in Figure 1.

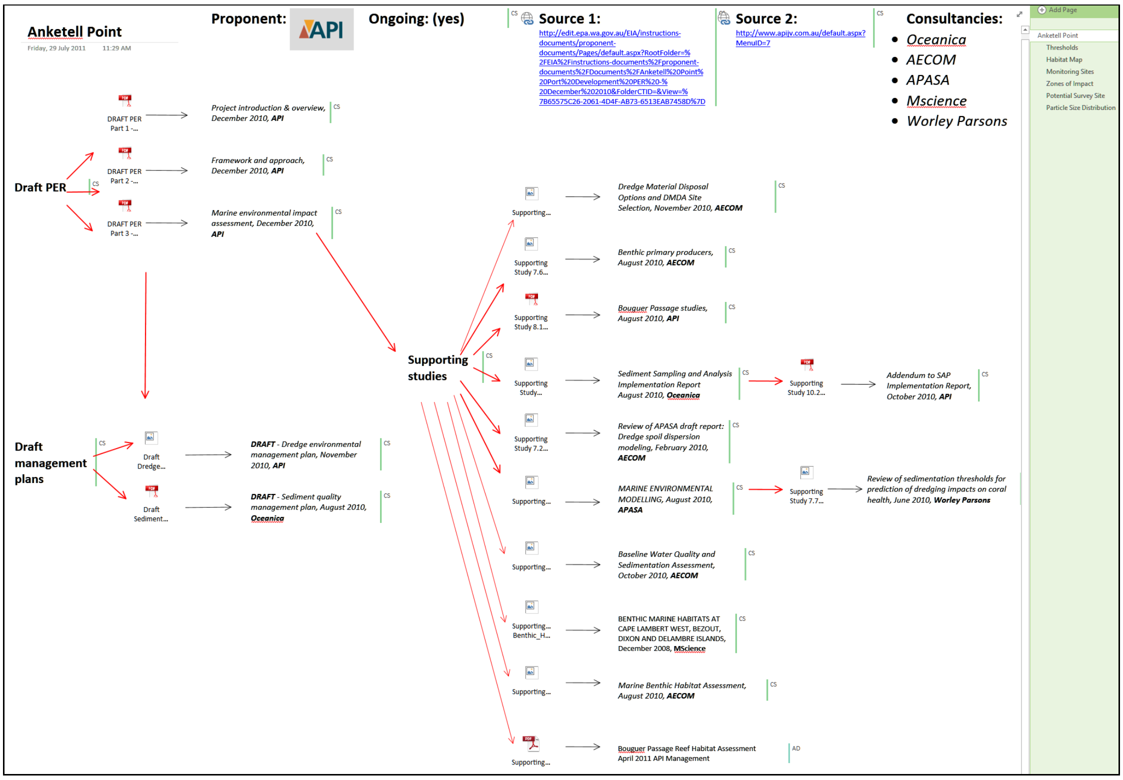

Figure 1. Screen shot of the Microsoft OneNote database page of the API Management Pty Limited Anketell Point Port Development proposal showing the information that was identified in the initial review process.

Four large-scale capital dredging projects in the Pilbara region of North West of WA were identified as most relevant and useful for capturing large scale capital dredging data, including: Woodside Energy Ltd.'s Burrup Peninsula (Pluto) project (Ministerial Statement No. 757); Rio Tinto's Cape Lambert B project (Ministerial

[1] In this context a *pressure* is a physical, chemical or biological change that has the potential to cause environmental change. In terms of dredging activities the term is synonymous with elevated SSCs, sediment deposition, or reduced light availability from increased turbidity.

Statement 840); and Chevron's Barrow Island (Gorgon) project (Ministerial Statement No. 800); and Chevron's Onslow (Wheatstone) project (Ministerial Statement No. 873) (Figure 2). Ministerial Statements are available on the WA EPA website (http://www.epa.wa.gov.au/all-ministerial-statements).

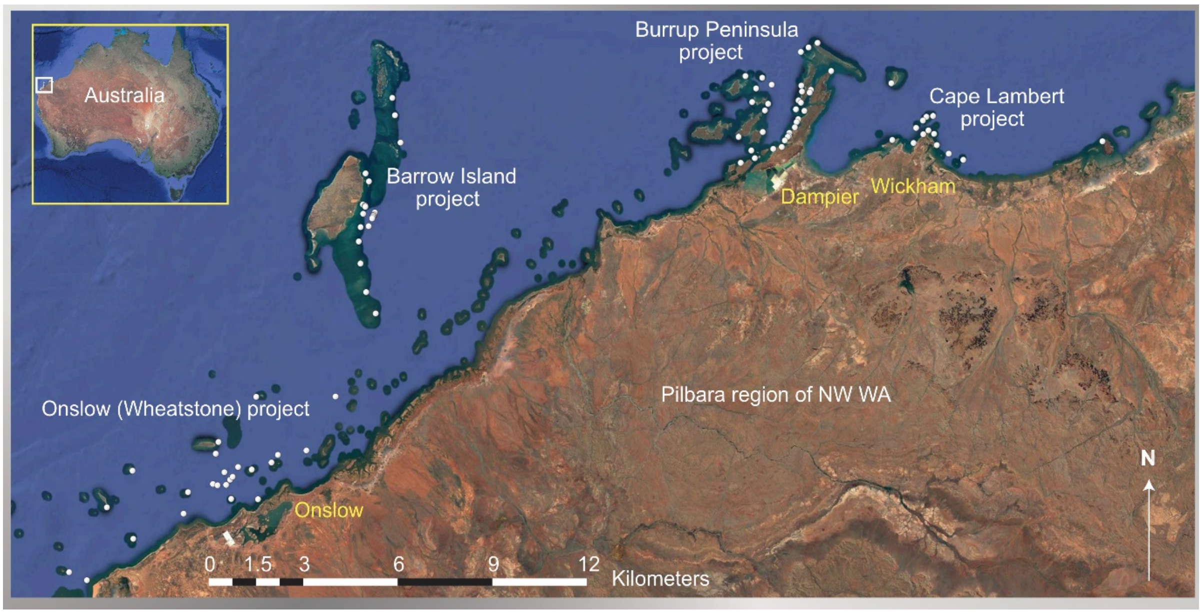

Figure 2. Environmental monitoring sites for four capital dredging projects in the Pilbara region of NW Western Australia since 2009 including from left to right, the Onslow (Wheatstone) project, Barrow Island (Gorgon) project), Burrup Peninsula (Pluto) project and Cape Lambert A and B projects.

3 Accessing the relevant Industry data (Phase 2)

The second phase of Theme 1 involved brokering access to environmental monitoring datasets held by Industry. The scale of the combined dredging projects was enormous by any global standard and the marine environmental monitoring required for compliance against environmental approval was larger than anything experienced previously in WA. Similarly, industry had never made environmental monitoring data of this detail and scale publicly available before in WA. Individual companies were approached for access to those datasets that were not available to WAMSI as a requirement of a Ministerial condition. Representatives from the Dredging Science Advisory Committee (DSAC) played a key role in negotiating access to data from dredging proponents of the 4 projects (see Figure 2). The DSAC, was comprised of key funding contributors to the DSN, end-user beneficiaries of the research outputs from state government, the two Node Leaders (Science and Policy), the WAMSI CEO and a representative from the Environmental Consultants Association (WA). Meetings were chaired by the Head of the WA EPA. The key purpose of this committee was to ensure science-management linkages were embedded from the outset and reinforced during execution of the research program.

Not surprisingly, negotiations were complex and protracted, requiring multiple levels of approval within each company. After several months of negotiation, data sharing agreement were developed between WAMSI and the respective companies – in most cases this was a single page that included a statement on what was and wasn't transferrable.

Data acquired from industry were stored centrally at the Pawsey Supercomputing Centre (https://pawsey.org.au/) which, subject to authorisation, was accessible to scientists across the DSN. Data management protocols were developed to ensure that the use of data by WAMSI complied with the data access agreements. Each project leader signed a *Data Acknowledgement Agreement*, endorsed by the DSN Leader for Science, acknowledging the conditions. Relevant datasets were then transferred to respective scientists through the WAMSI Data Manager.

4 Nature of the data

4.1 Physical data

The physical data included wave, wind and current measurements, conductivity, temperature and depth (CTD) measurements, turbidity (water cloudiness), underwater light measurements from bottom mounted sensor platforms, and sediment composition at multiple locations in and around the dredging activities (Figure 2). Measurements were taken at typically 10–30 minute intervals and at locations that varied from a few hundred metres away from the dredging (and so heavily influenced by plumes) to more distantly located control (reference) sites tens of kilometres away and unlikely to be influenced by plumes (Figure 2, Figure 3, Figure 4). The data usually included measurements taken before (pre) dredging (i.e. a baseline period) and during dredging, and so captured both natural turbidity events associated with storms and cyclones as well as dredging related events.

Although the majority of the physical data made available by the proponents came from compliance monitoring (i.e. data collected to prove their activities were compliant with EPA regulatory conditions as specified in project Dredge Management Plans), some data were made available from a number of ancillary, supplemental more targeted studies initiated by the proponents to improve management of the projects.

Notable additional data provided were the daily dredge logs from the 2 year Wheatstone project (Figure 3) which contained a summary of the daily activity for each piece of operating dredging equipment as well as records of the overall progress of the excavation and placement.

4.2 Biological data

Biological data that were identified and made available to the DSN included information on the abundance and health of corals, seagrasses and filter feeders before, during and after dredging at multiple locations at various distances from dredging (including reference sites). Information on the reproductive status of corals was also made available.

The biological data also comprised a remarkable ‘tagged coral’ monitoring program dataset from the Barrow Island project. In this survey technique individual coral colonies were marked (‘tagged’ with an identification marker) and photographed and then re-photographed at frequent intervals over the duration of dredging. Any evidence of mortality and partial mortality or signs of stress from the photographs was used by the dredging proponents to provide a rapid feedback on the consequences of the dredging.

The tagged colony technique, which originated in dredging projects on the Great Barrier Reef was first introduced to WA during the Cape Lambert A project (Hanley 2011). To our knowledge the Barrow Island project tagged colony surveys was the largest tagged coral study of its kind anywhere in the world, with 50–70 coral colonies (considered representative of the local reef community) photographed approximately every 2 weeks for the duration of the 2 year dredging project at each of the 26 water quality monitoring sites (Figure 2).

5 Where and how the data was used

The main focus of Theme 1 was to identify, access and collate existing dredging data sets. Data were captured and categorised into three main groups: modelling data, physical data and biological data.

Modelling data were collated from technical reports and included information on the generation, transport and fate of sediments from dredging and spoil disposal activities. These data provided an invaluable and immediate initial source of information for the review articles in Themes 2 and 3 where *Project 2.2* examined contemporary practices of estimating the primary source terms for trailing suction hopper dredgers and cutter suction dredgers and *Project 3.3* synthesized the current knowledge on several key processes relevant to sediment transport modelling and assessed factors that contribute to the accuracy of model predictions.

Description of the physical and biological data attributes and application is provided in the following sections.

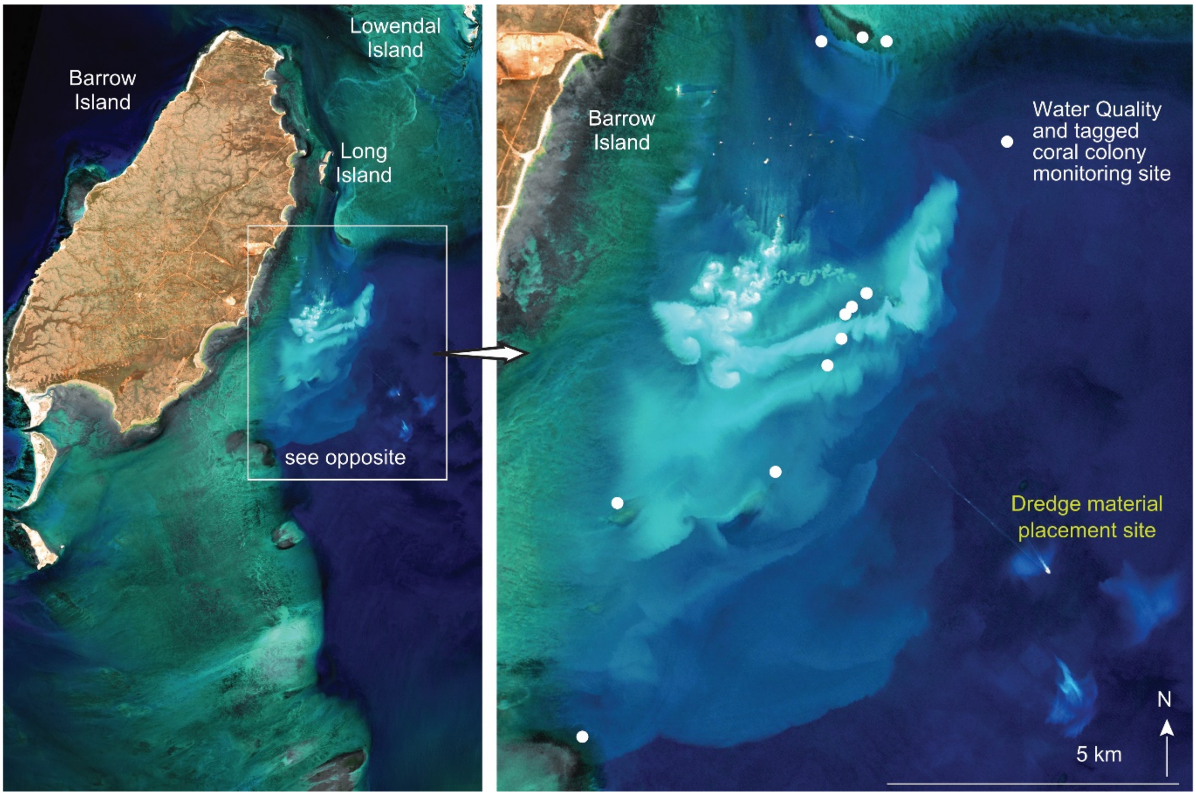

Figure 3. Satellite images showing a dredging plume passing over several water quality and coral health monitoring sites (white symbols) during the Barrow Island (Gorgon) dredging program. Datasets from this project proved very useful in many of the research themes of the DSN (source: Japan Aerospace Exploration Agency (JAXA) Advanced Land Observing Satellite (ALOS) Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) satellite image (10 m pixel resolution) taken in 29 August 2010)

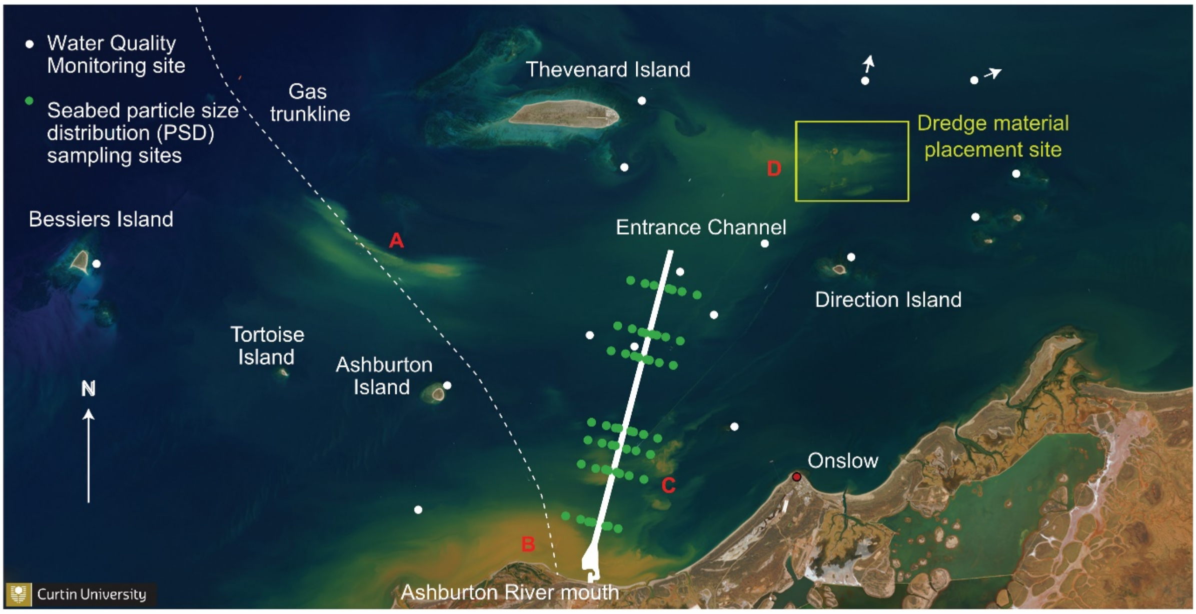

Figure 4. The Onslow (Wheatstone) dredging program (Pilbara Region of NW WA) was the largest dredging project to have occurred in WA. The image shows some of the complexity of large scale dredging projects with turbidity (plume) generation from dredging of the gas trunk line (dashed line), (B) the Ashburton river discharge (C) dredging the main access channel and (D) dredge material placement at the 'spoil ground'. Source: Atmospherically and colour corrected, pan sharpened Landsat image from the United States Geological Survey (USGS) Operational Land Imager (OLI) US Geological Survey provided by Peter Fearns (Remote Sensing and Satellite Research Group, Curtin University).

5.1 Physical data

A total of 8.5 million individual readings of water column turbidity and benthic light collected over a combined total of 85,433 days of observation from 111 sites were made available for analysis from the 4 large scale capital dredging projects (Figure 2). A typical example of what the data shows is provided below (Figure 5).

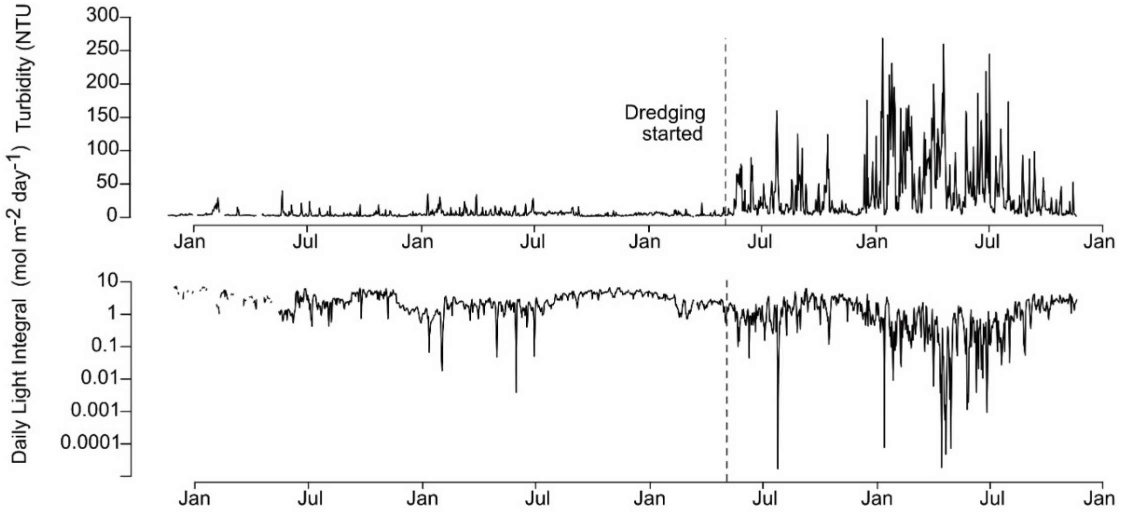

Figure 5. Dredging activities can profoundly change turbidity (water cloudiness) and benthic light availability. Data provided by industry for analysis in the Node included extended baseline pre-dredging periods for some projects, allowing detailed study of how the intensity, duration and frequency of turbidity events caused by dredging differs from natural turbidity event associated with storms and wind/wave events. Shown above is daily average turbidity (NTU) and photosynthetically active radiation) expressed as a daily light integral (DLI, µmol photons m-2 d-1) during the pre-dredging and dredging phase of the Barrow Island dredging project measured every 10 min at sites <1 km from the main excavation activities (see *Projects 4.1 and 4.2*).

Information from the analyses clearly showed the profound effects of dredging on turbidity and benthic light levels (Figure 5) and also highlighted the ephemeral nature of turbidity (see *Projects 4.1, 4.2*)**.** The information derived from the data was important because it clearly demonstrated the physical changes experienced by benthic primary producers *in situ* as a result of dredging. Scattering and light attenuation by suspended sediments is well known, but close to dredging complete loss of light at moderately elevated SSCs occurred quite regularly, especially at deeper sites and during winter (see *Project 4.2*)***.***

More commonly observed phenomena were semi-dark, caliginous or diurnal 'twilight' periods of extremely low light, in some cases for extended periods. These conditions present physiological challenges for benthic primary producer habitat which usually only experience such events over much shorter time periods associated with storms and natural turbidity events (see *Projects 4.2, 4.6*)***.***

Analysis of temporal patterns showed high variability in environmental quality both during dredging and natural resuspension events, which highlighted the need to use appropriate metrics (means as opposed to median values) and multiple time scales (days to weeks) otherwise key events with significant physiological consequences could be missed (see *Theme 4, Project 4.9*).

This variability was examined more closely in the studies with seagrasses. It was hypothesized that the capacity of seagrasses to cope with episodes of light deprivation (from overlying turbid waters) may not only depend on the absolute quantity of light they receive during that episode, but also on how the light deprivation varies through time. The effects of constant light reduction versus effects of pulsed turbidity events (i.e. changes in the pattern of the delivery of light) using a suite of sublethal bioindicators was investigated in *Projects 5.5.1* and *5.5.3.*

These concepts, as well as explicit inclusion of natural (storm-related) turbidity events when measuring cumulative exposure, were developed further to operationalise the results of laboratory studies on corals and augment the knowledge gained from the industry-supplied data (see *Project 4.9*).

When summarised as the 80th percentile of a 14 d running mean period and arranged spatially with distance to the nearest dredging activity, the industry-supplied compliance monitoring data showed clear evidence of an exponential decay relationship and an improvement of water quality with increasing distance from the dredging activities (Figure 6; see *Project 4.2, 4.9*).

Although intuitive, this information has not been shown previously, and clearly supports the use of spatially-based zonation schemes to manage dredging projects as introduced by the WA EPA (EPA 2016), and adopted in other locations in Australia.

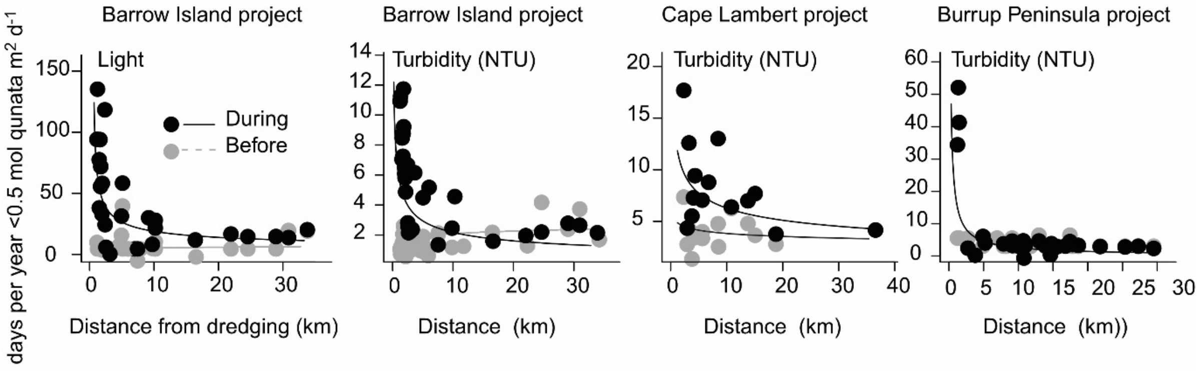

Figure 6. Industry-supplied water quality monitoring data was used to describe distance-decay relationships. The data shows how profoundly dredging activities can change turbidity and benthic light availability but also the extent of the spatial effects which supports the use of the spatially-based zonation scheme to manage dredging projects introduced by the WA EPA (EPA 2016). Shown above is underwater light data (expressed as the number of days ,normalized to a year, where the daily light integral is very low, <0.5 mol quanta m^{-2}, and turbidity (NTU) data based on the 80th percentile over a 14 d running mean period (adapted from *Project 4.9*).

Perhaps the most significant outcome from the temporal and spatial analyses of the industry-supplied physical data was generation of an information matrix describing the likely pressure fields over multiple different temporal scales and at different distances from dredging. This information effectively defined the 'hazard' associated with dredging activities and was critically important for not only contextualizing the results of past studies but also for developing environmentally relevant and realistic exposure regimes in the laboratory based studies for the Themes that examines the physiological response of benthic communities (Figure 7). The matrix was used in multiple themes and projects where laboratory based test were conducted e.g. *Projects 4.6, 4.8, Projects 5.5.1, 5.5.3, Projects 6.4* and *Projects 7.3, 7.4 and 7.5.*

Figure 7. Industry-supplied water quality monitoring data collected during dredging project were directly used to develop environmentally realistic and relevant exposure scenarios for the laboratory based studies of Theme 4, 5, 6, 7, where physiological effects of suspended sediment and/or light attenuation were examined alone and in combination on corals, sponges and seagrasses.

Several of the dredging projects included supplemental studies involving the collection of physical data to assist in dredge management planning. The studies that were identified as potentially useful in the review included investigations of changes in light quality and quantity underneath plumes, suspended sediment size (particle size distribution, PSD) and changes in the seabed (PSD) before and after dredging (see *Projects 4.1* and *4.9*).

Analysis of the PSD data generated information that was used in the laboratory based studies (principally *Themes 4, 5, 6 and 7*) for preparing the sediments for study. Analyses of the underwater light data identified decreases in quantity but also changes in light quality to less photosynthetically useful yellow/green light (*Project 4.1*). This spectral shift was considered significant and so examining PSDs and spectral shifts in plumes was specifically built into the DSN and examined in plume characterization studies in the Wheatstone Project (see *Project 3.1.1*).

Figure 8. A trailer suction hopper dredge (TSHD) *Cornelis Zanen* dredging during the Pluto dredging project. Ancillary, supplementary studies conducted during some of the projects provided information on sediment particle size distributions (PSDs) in the water column, changes in light quality and quantity and changes in seabed PSDs before and after dredging and this industry-supplied data was made available to the DSN for re-analysis (see *Projects 4.1* and *4.9*). Perhaps, one of the most significant aspect of these ancillary, supplementary studies was the ability to sample very close to dredging activities, whereas during the DSN's research sampling typically could not occur within a 500 m exclusion zone around working dredges.

Because of the complexity involved in designing controllable full spectrum LED aquarium lights the effects of light quality were not examined in the main laboratory based studies of *Themes 4, 5, 6* and *7*. However, over the last few years controllable full spectrum LED lights have been designed at the Australian Institute of Marine Science (AIMS) aquarium facilities (National SeaSim facilities) and experiments are currently underway to examine the physiological significance in the changes in light quality under plumes to corals as a direct consequence of the analysis of the industry-supplied data.

The seabed sampling in each of the studies revealed a very consistent story between projects of an increase in the silt and clay content of the seabed following dredging. These changes were interpreted in terms of the release of sediments (spillage) into the water column advection away from the site of dredging and subsequent settling, creating an area (halo) of enhanced deposition around the dredging activity.

Elevated sediment deposition is a key cause-effect pathway for some taxa (notably some corals), these measurements, coupled to observations of sediment smothering of corals during dredging programs (see below), contributed significantly to the development of a model of how coral mortality occurs in some growth forms, and hence the size of coral impact zones in dredging projects (see *Project 4.9*).

Sediment deposition is particularly hard to measure at the appropriate scales (i.e. mg cm^2 day^{-1}). As a follow on from these observations, the DSN made considerable effort to address sediment deposition as a key cause-effect pathway. This included attempts to model sediment deposition and identify periods where deposition was likely using: a statistical turbidity model (*Project 4.3*); redesign and testing of an *in situ* sediment deposition sensor (*Project 4.4*); as well as a suite of laboratory based studies examining the tolerance of ability of different corals, sponges and seagrasses in response to different deposition rates of different particle sizes and shapes and organic content (see *Projects 4.6*, *5.5.2, 5.5.4*, *6.4.4* and *7.3*).

One of the most significant uses of Industry-supplied data was in the *Pressure Field Prediction and Characterization* research category and in the numerical modelling project (*Project 3.4*). Bathymetry data, multibeam, wind, wave and current data and turbidity and benthic light data were made available from the Wheatstone project. The dredge logs were also made available describing what volume was dredged and where. This was collectively the largest block of information handed to the DSN and it allowed the development of a hind cast model for the entire Wheatstone dredging (*Project 3.4*).

Using the data and the hindcast model, *Project 3.4* focused on identifying the most important processes and model parameters, in particular, the bed schematization and cohesive sediment transport model parameters (Figure 9).

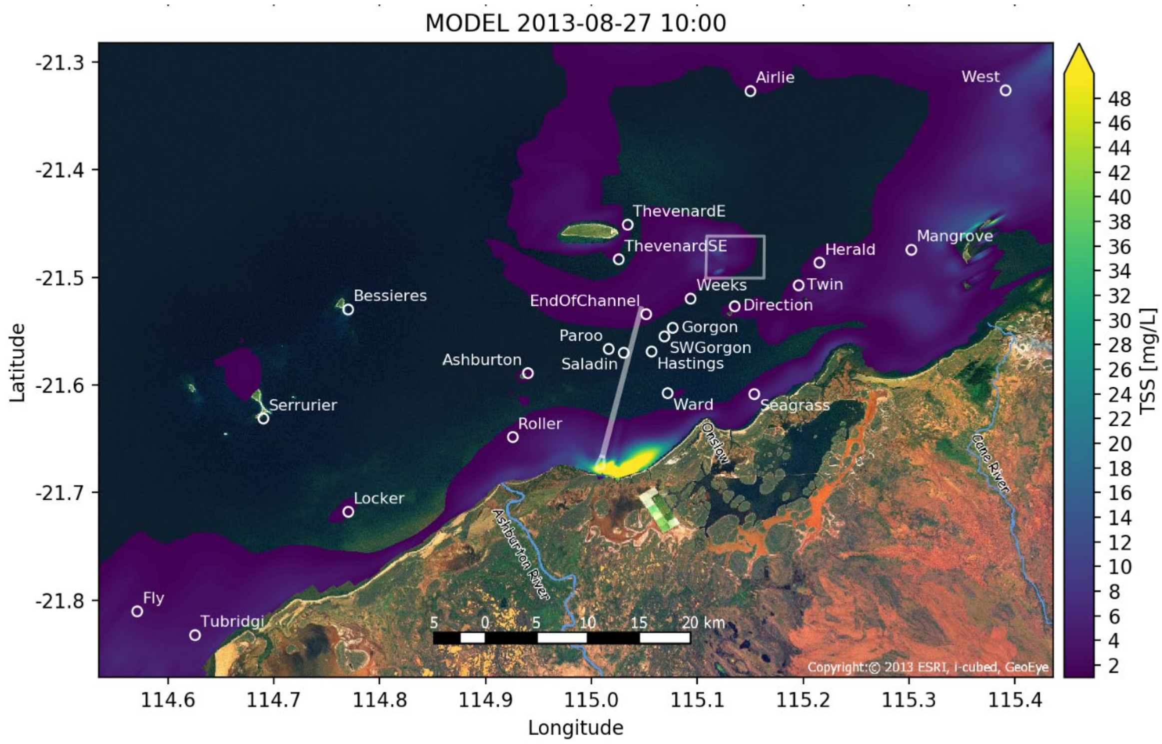

Figure 9. In the Wheatstone dredging project all current, conductivity, temperature depth (CTD) measurements, as well as turbidity and underwater light data at multiple sampling sites together with bathymetry and daily dredge log activity (indicating what was being dredge and where) was provided to the DSN, allowing a hindcast model to be created of the Wheatstone dredging program in *Theme 3, Project 3.4*.

5.2 Biological data

One of the most significant of the industry-supplied datasets was the time series of photographic images taken of the tagged coral colonies during the Barrow Island dredging project. These images were particular useful for Theme 4 (Corals) and used as part of a ‘forensic’ investigation of cause-effect pathways and the susceptibility of different coral growth forms (*Project 4.9*).

An example of the type of data available is provided below (Figure 10). The photographs are of a branching *Acropora* spp. overlying a massive hemispherical shaped *Porites* spp. coral colony taken at roughly fortnightly intervals over a 2 year period.

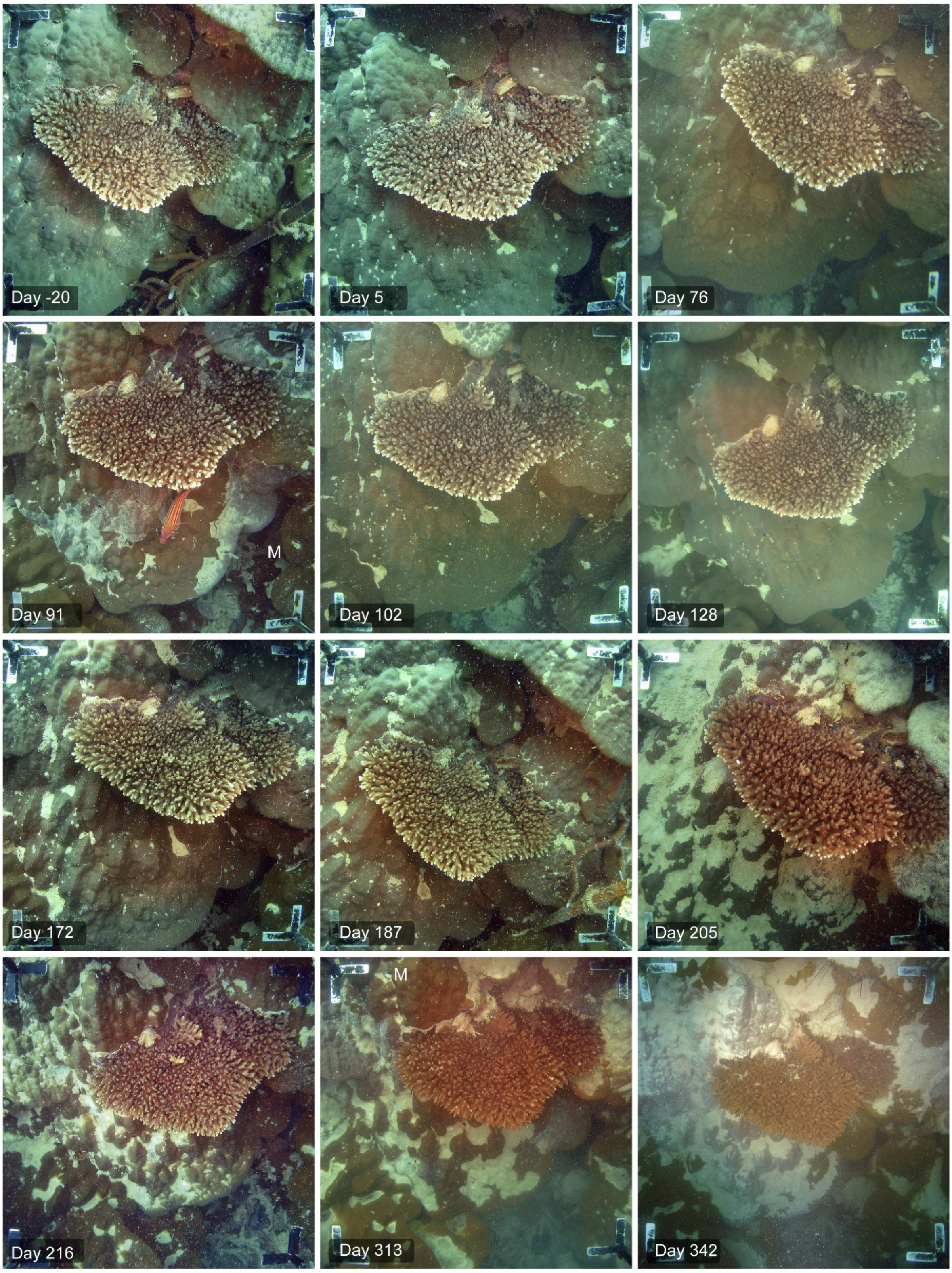

Figure 10. Barrow Island dataset. Time series of images taken 1.4 km away from a large scale capital dredging project showing the superior sediment clearing abilities of branching (tabulate) morphology of the *Acropora* species compared to underlying massive, hemispherical morphology of the *Porites* spp. which becomes smothered with fine sediments. Legends on the images indicate days from the start of dredging (20 May 2010).

Approximately 17,700 such images were made available and re-analysed within Theme 4 and a forensic assessment made of the likely cause of any partial or whole colony mortality.

When coupled to the water quality data collected at the tagged coral monitoring sites, derivation of field based water quality thresholds were possible (see *Project 4.9*) and complimented the laboratory based studies (see *Project 4.6*).

The study revealed the significance of sediment deposition as a primary cause-effect pathway associated with mortality in some morphologies and the comparative resilience of branching species to deposition (although not to the light reduction caused by elevated suspended sediment concentrations, see *Project 4.9*).

During the forensic investigation it was noticed that there appeared to be an association between the production of thick sheets of mucus by massive *Porites* species and proximity to the dredging activities (Figure 11). This was formally analysed and confirmed statistically. These results were further supported by laboratory-based manipulative experiments under aquarium conditions where the same species exposed to fine sediments also developed mucous sheets (Figure 11). This ultimately resulted in the development of mucous sheet production as a potential bioindicator of sediment exposure for massive *Porites* spp. (*Project 4.8*)

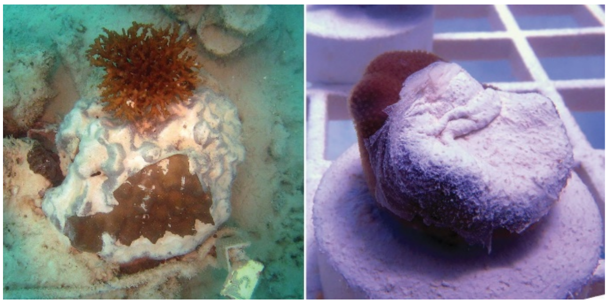

Figure 11. Examples of mucous sheet production on a *Porites* spp. colony during the Barrow Island dredging project and mucus sheet formation induced in a laboratory based investigation. Multiple lines of field and laboratory based evidence suggest a close association between mucous sheet formation and sediment load, and that sheet formation (and subsequent sloughing) is an additional mechanism used by massive *Porites* spp. to clear their surfaces when sediment loads become too high. These results suggest that mucous sheet formation is an effective bioindicator of sediment exposure.

The initial review of the data identified other useful information including seagrass abundance data collected during the Wheatstone project. These data were combined with data from five other locations visited in *Project 5.3*, and used to improve our understanding of the spatial and temporal patterns in seagrass composition, abundance and reproductive phenology in the Pilbara.

Lastly, data on the reproductive status of hard corals was regularly collected during dredging projects to identify the coral spawning period(s) when dredging may need to cease (see Figure 12). Similar to the seagrass study above, these data were accessed and used in *Project 7.2* to compliment data from many other locations (from published literature and grey literature) and describe the coral mass spawning reproductive pattern over a 20° latitude span in Western Australia.

Figure 12. In situ examination of eggs is the most common and useful means of determining times of spawning. The technique involved snapping the apical portions of branching species and looking for large pigmented oocytes which appear prior to spawning. Data reports from 15+ surveys from 3 different dredging projects were used in *Project 7.2* to complement existing literature and expand knowledge of coral mass spawning reproductive patterns over a 20° latitude span of WA.

6 Conclusions

Theme 1 was designed to identify data from past large scale dredging projects that could contribute to the WAMSI DSN science goal '*to enhance capacity within government and the private sector to predict and manage the environmental impacts of dredging in Western Australia*', and then to disseminate the data to the relevant WAMSI researchers.

Ultimately most data was sourced from 4 capital dredging projects and from 3 proponents, Woodside Energy Limited, Chevron Australia and Rio Tinto Iron Ore. The information had been collected for the purpose of environmental impact assessment and environmental compliance against State and Commonwealth conditions of approval.

In some cases negotiating release of commercially sensitive and confidential information was complex and protracted, based on fear of misuse of the data in the public arena. This was resolved through careful development of DSN data sharing agreements and involvement of the Dredging Science Advisory Committee which was chaired by the Head of the WA EPA and included representatives from the data owners. Perhaps this was further augmented by the WAMSI governance structure which was comprised of each of the Joint Venture partners that were ultimately accountable for the DSN objectives deliverables, and performance of their scientists.

The data had little or no intrinsic value once the purpose for which they had been collected had been served. However, when reconsidered and repurposed by the WAMSI DSN, the latent value hiding within the enormous quantities of complex data was unlocked. The creation of the WAMSI DSN, with over 50 scientists from 9 institutions committed to dredging-specific research provided the mechanism to unlock the value and then to value add. Scientists were given access to data that they would otherwise never have had permission to use, or never had the resources to collect on such an enormous scale. This led to significant co-investment from WAMSI DSN partners as the value of the data became realised. After the repurposing the data were transformed into information and from there knowledge along the information hierarchy (Ackoff 1989), increasing scientific capacity, and providing substantial benefits for government and industry with an enormous return on the initial investment.

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