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WAMSI NODE 1 PROJECT 2

FINAL REPORT - OVERVIEW

Coastal ecosystem characterisation, benthic ecology, connectivity and client delivery modules

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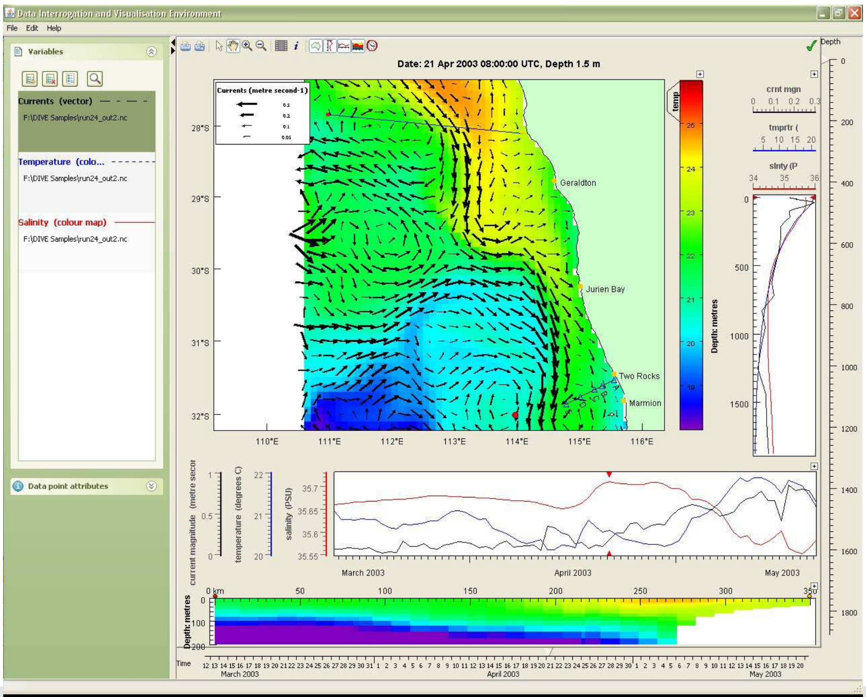

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Important Disclaimer

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Contents

FINAL REPORT

WAMSI NODE 1

Western Australian Marine Ecosystems Research

Node Leader: John Keesing (CSIRO)

PROJECT 2

Coastal ecosystem characterisation, benthic ecology, connectivity and client delivery modules

Project Leader: John Keesing (CSIRO)

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PROJECT DETAILS

Project Start Date:	1 July 2007
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Project Funding:

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CSIRO

Additional In-Kind

Total Funding

1. PROJECT OBJECTIVES

The project objective was as follows:

To better characterise the south west Australian marine coastal and shelf ecosystem structure and function, and enhance our shared capacity to understand, predict and assess ecosystem response to anthropogenic and natural pressures by:

1. An assessment of the importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.
2. An assessment of ecosystem processes with particular relevance to contrasting fished and non-fished areas.
3. An assessment of likely dispersal patterns for marine organisms based on hydrodynamic and population genetic models.
4. Electronic delivery of data and models to management agencies, building on the development of the Data Interrogation and Visualisation Environment (DIVE) in SRFME.

All project objectives have been met. Each component of the project objective had a series of milestones in the form of tasks or timelines which were developed to help plan and track progress of the project. Progress against each of these tasks and timelines was reported in a series of seven Biannual Reports. All of the milestones were met either in original or, in one case, a revised and approved form, and all Biannual Reports were delivered.

In this Final Report, we present the findings of the research in four chapters (see Section 2) which address each of the four components of the project objective above.

A summary of the key findings and components delivered against each objective is given in Section 4 below.

2. RESEARCH CHAPTERS

Please see the attachment Annexure A (Project Final Report – Research Chapters) which comprises four chapters each documenting the research undertaken towards each of the four objectives for this project. The Project Final Report – Research Chapters is the basis for information presented in this overview.

3. METHODOLOGY

This is a large multidisciplinary research project. A wide array of physical, biogeochemical and ecological approaches were taken to collecting data and a similarly wide range of analytical, statistical and modelling approaches were taken to analyse the data. The methodologies used are provided within each of the main chapters which comprise the Project Final Report – Research Chapters (Annexure A).

4. RESULTS

4.1 An assessment of the importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.

Ecologically sustainable management of resources requires the ability to rapidly address the current state of resources as well as key ecological processed which maintain these resources. Increasingly, resource managers also require information on the relative importance of physical versus biological processes in order to predict how ecosystems may respond to environmental variability including a changing climate. In order to better characterise the south west Australian marine coastal and shelf ecosystem structure and function, and enhance our shared capacity to understand, predict and assess ecosystem response to anthropogenic and natural pressures we assessed the relative importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.

The project focused on the habitat dynamics of temperate algal communities on reefs off Western Australia. These algal communities display a complex mosaic of different algal assemblages, or habitat types, broadly characterised as either canopy or gap habitats. This mosaic structure has a strong influence on the overall biodiversity of rocky reefs in temperate south west Australia. Changes in this pattern and the relative proportion of the two habitat types will therefore have profound implications for the biodiversity and productivity of coastal marine ecosystems in the region. In order to understand the dynamics of this habitat mosaic structure, the project employed three complimentary approaches. First we described natural patterns of habitat variation and correlate these patterns with physical and ecological variables. Second we undertook ecological manipulations to better understand the ecological processes underpinning patterns in habitat mosaics. Finally we developed habitat models of ecosystem dynamics in order to begin developing predictive ability to predict environmental change under varying physical or ecological conditions.

Mosaics of habitat dominated by canopy-forming macroalgae and canopy-free (open-gap) habitat are prominent features of temperate subtidal reefs on the south and west coasts of Australia, with the proportion of reef occupied by canopy forming algae ranging between 40% and 60% based on diver transects. However, the persistence of this mosaic structure and mechanisms underlying this pattern are not well understood. We described patterns in the proportion of reef covered by each of these habitats, and the length of patches of each habitat, at 20 sites encompassing a gradient in wave exposure in south-western Australia. Our aims were to characterise patterns, and the strength of associations with potential influences, in order to develop models of habitat mosaic generation and maintenance. Modelled seabed orbital velocities explained approximately 35% of the variation in the length of open-gap patches with less canopy cover at higher wave exposure sites. This observation supports the hypothesis that waves create open-gaps by dislodging canopy algae. Herbivorous damselfish (*Parma s*pp.) were 5.6 times more likely, and the sea urchin *Heliocidaris erythrogramma* was 20 times more likely, to be encountered at sheltered inshore sites than at exposed sites further from shore. *Parma* were 8.2 times more likely to be found in open-gap habitat. However, there was no relationship between the occurrence of either herbivore and the proportion of open-gap habitat among sites. These observations do not support a hypothesis that grazing by herbivores creates open-gaps. Massive sponges were three times as likely to be found in open-gap habitat, and hard corals were 91 times more likely to be encountered in open-gap habitat. The strength of these associations suggests that canopy algae might negatively influence sessile invertebrates. Further, the large size and likely old age of sessile invertebrates, particularly hard corals, indicates that patches of open-gap habitat can persist for decades. The patterns observed suggest that wave-induced disturbances create open-gaps and that these gaps are persistent features of temperate reefs.

The results of artificial clearance disturbances indicate that open-gap habitat macroalgal assemblages are strong competitors for space and that canopy is slow to establish, with most canopy clearances remaining as open-gap habitat after 3 years. However where returns to canopy habitat were observed, they were more likely to occur when clearances were within or adjacent to canopy habitat. Modelling of habitats using observed probabilities of transitions in habitat state indicated that in undisturbed habitats the average residence time (longevity) of open-gaps was 3.7 yrs and for canopy 2.8yrs, while in disturbed habitats average open-gap residence time was 12 years, of the same order as the average estimated age of coral populations within gaps, while with canopy habitats had much shorter residence times of 2.4 yrs. When canopy habitats were differentiated into *Ecklonia* and *Sargassum*, the two principal canopy forming taxa, the residence times were 6 and 1.6 yrs respectively and open-gap residence times remained unchanged. Projections of proportional composition of the habitat mosaic indicate that, because of the asymmetrical response to disturbance, any increase in the frequency of gap creation is likely to have long term and disproportionate negative impacts on overall canopy cover.

Whether they are observational, experimental or modelling based, studies of the natural environment are characterised by their ‘grain’ and ‘extent’, the smallest and largest scales represented in time and space. These are imposed scales that should be chosen to ensure that the natural scales of the system are captured in the study. We developed a simple cellular automata model of habitat to represent the presence or absence of vegetation, with global and local interactions described by four empirical parameters. Such a model can be formulated as a nonlinear Markov equation for the habitat probability. The equation produces inherent space and time scales that may be considered as transition scales or the scales for recovery from disturbance. However, if the resolution of the model is changed, the empirical parameters must be changed to preserve the properties of the system. Further, changes in the spatial resolution lead to different interpretations of the spatial structure. In particular, as the resolution is reduced, the apparent dominance of one habitat type over the other increases. The model provides an ability to compare both field and model investigations conducted at different resolutions in time and space. The model allows us to better interpret our observations and also forms the basis for ongoing modelling studies.

4.2 An assessment of ecosystem processes with particular relevance to contrasting fished and non-fished areas

One of the processes most likely to change the structure of marine ecosystems on the temperate west coast of Australia is fishing by humans. Our approach to examining this was to conduct a series of surveys designed to contrast management units established to prevent fishing (i.e., sanctuary zones in DEC- and RIA-managed marine parks). Surveys of abundances and sizes of fish, rock lobsters, and large invertebrates were conducted at 28 sites during 2007 and 2008 – 13 in Sanctuary zones, and 15 in ‘General Use’ or ‘Recreation’ zones. These sites encompassed six sanctuaries across three different regions, two each at Rottnest Island, Marmion Lagoon, and Jurien Bay. Sanctuaries included a range of sizes from 5 ha to >1,300 ha, and a range of ages at date of surveys from 4 years to 19 years. Where possible, surveys encompassed reef, and seagrass and bare sand habitats. Analyses focussed on trends in biomass, density, size and species richness as the most frequently-used indicators of the condition of ecological resources.

Results of the surveys were generally consistent with the expectation of higher abundance and biomass inside Sanctuary Zones (SZs) where fishing is prohibited, although we did not find a ubiquitously higher biomass or density inside SZ for all the metrics evaluated. An important finding was evidence that for several of the metrics large SZs better achieved the goals of higher biomass and density than small SZs, with a trend for higher density inside large SZs of western rock lobsters, and higher biomass of targeted species on reef habitat. This pattern is consistent with the pattern expected if individuals inside small SZs are more susceptible to fishing mortality, and with expectations arising from the fact that both groups are heavily fished in Western Australia. In the case of western rock lobsters, a higher biomass and density was found in both small and large SZs than adjacent fished areas, but the magnitude of the difference in density was much greater for large SZs. In the case of targeted fish, the difference in biomass between SZs and adjacent fished areas was only detected in large SZs, and was not detected in small SZs.

4.3 An assessment of likely dispersal patterns for marine organisms based on hydrodynamic and population genetic models

Gaining an understanding of patterns of dispersal within marine systems is fundamental to the identification of fishery stocks and the design of effective management strategies such as marine protected areas, but in practice is difficult to achieve. Hydrodynamic modelling is a rapidly developing and increasingly sophisticated application that has the potential to predict patterns of connectivity among marine populations in great detail. However, without empirical validation it is difficult to determine how well particle modelling is able to realistically represent biological processes. Genetic analysis has the potential to provide such empirical validation in a timely manner. This project employed a multidisciplinary approach incorporating analysis of DNA genotypes and hydrodynamic modelling to characterise dispersal during the larval stages of development in multiple sea urchin species. Sea urchins are useful model organisms for investigating connectivity in marine systems because whilst adults have similar sedentary life-histories, there is extensive variation in the larval life-history of different species allowing the contribution of passive, current-driven larval dispersal to be assessed.

Sea urchins were sampled at Jurien, Perth, Albany and Esperance for assessment of population structure using DNA sequence variation. This phylogeographic analysis was compared with hydrodynamic dispersal modelling to determine biological connectivity under the influence of the Leeuwin Current system.

A deterministic particle tracking model was implemented in Matlab for the BLUELink Re-analysis (BRAN) model outputs during 1997-2002. Particle tracking experiments were carried out to quantify the fate of the Leeuwin Current waters and the modelled larval dispersal patterns among the four urchin sample sites.

Results show that a significant portion of the Leeuwin Current particles, representing more than one third of the Leeuwin Current southward volume transport, were advected around Cape Leeuwin and eastward into the Great Australian Bight. The rest of the particles were dispersed by the Leeuwin Current eddies and interaction with the continental shelf. Particle dispersal from sampling sites was generally southward on the west coast and eastward on the south coast, however, substantial northward dispersal was also observed in summer from the west coast sites when the Leeuwin Current flow is weakest and eddy activity is greatest. Dispersal distances were greater in winter when Leeuwin Current activity is greatest. Areas of higher retention or lower flushing rates were visible at several points along the coast indicating potential for the accumulation of larvae. The ecological implications of this result invite further investigation.

Three genes in *H. erythrogramma* and two genes in *P. irregularis* were sequenced in individuals from all four localities, revealing substantial levels of variation among individuals. Sequence diversity at nuclear genes was higher than for the mitochondrial gene COI. Substantial diversity exists within sites and most of the variation is partitioned among individuals rather than among sites as reflected in Φst values close to or below zero in most genes.

Genetic differentiation among sites (two west and two south coast sites spanning 1130 km of coastline) was observed in nuclear but not mitochondrial genes, consistent with faster rates of intron evolution. Stronger structure and isolation by distance was apparent in *H. erythrogramma* compared to *Phyllocanthus irregularis*, suggesting the latter may have a longer lived larva than the 3-4 day duration measured in *H. erythrogramma* or some other adaptation counteracting population differentiation over the scale of this study.

Coalescent-based directional estimates of genetic exchange rates were consistent with overall predictions from hydrodynamic particle models that incorporated spawning time and larval duration in *H. erythrogramma* where northward gene flow from Perth predominated. Similar findings in *P. irregularis* imply a similar spawning time and this needs experimental investigation.

4.4 Electronic delivery of data and models to management agencies, building on the development of the Data Interrogation and Visualisation Environment (DIVE) in SRFME

DIVE is a data access and visualisation package that has been developed through CSIRO's partnership with the WA Government. DIVE enables scientists and managers to view the diverse data sets that have been generated in WAMSI. The data are multidisciplinary and multidimensional, and range from relatively small numbers of field samples through to 4d model output occupying gigabytes of computer storage. DIVE can be installed onto all platforms supporting Java. It is functional on Windows, Linux and Mac OSX computers.

DIVE supports the display of spatial maps, time-series plots, vertical profiles and cross-section plots. The spatial data are represented as coloured maps, contoured plots, vector maps or as habitat maps. The full functionality of DIVE is described in the user manual. DIVE's features include:

- Selection and display of arbitrarily directed cross-section plots
- Display of data from multiple sample points through the use of distinguishing colour and line styles
- Display of scalar and vector variables
- Expansion of individual panels by utilising a "lift-out" function to assist with examination of the data: the lift-out option is invoked by clicking on the small plus sign at the top-right of each plot, to make the panels appear in their own windows
- User–selection of the time-zone in which the data are displayed: most commonly, this will be UTC, or the local time-zone of the user.
- Single-step viewing through the time-series or vertical layers: that is, the time-slide and depth-slide can be clicked through individual time or depth intervals in the data file.
- Output of animations, over either the whole time-range or user-defined subsets: animations can be saved in AVI, Flash and animated gif formats.
- Ability to read folder-based datasets: if data are held in multiple files within a single folder/directory (as is common with output from large model runs), DIVE can interpret the files as a single data source, enabling, for example, faster access and continuous plots (rather than a new plot for each separate file).
- Display of underway datasets including high-resolution glider data, in which hovering the cursor over the track produces detail of the data

DIVE accepts data in self-describing format, in particular NetCDF, which is the standard for oceanographic data and model output. For model results, it has been tailored to handle:

- box-model output, for example from CSIRO's ecosystem model (Atlantis)
- z-coordinate models, such as CSIRO's SHOC,.

- sigma-coordinate models, such as Rutger's University's ROMS. (ROMS is one of the hydrodynamic models used in WAMSI, in Nodes 1, 3 and 6. The vertical sigma coordinate varies in time with the surface elevation.)

DIVE can also read:

- HTF (Hydrographic Transfer Format), see www.hydro.gov.au/tools/htf/htf.htm
- CFF (Column File Format Files) an in-house CMAR text-based spreadsheet-like format. This format is described in an appendix to the DIVE manual.

DIVE can connect to MEST (Metadata Entry and Search Tool) servers, select from available on-line datasets, and download and plot these datasets. MEST servers are based on OGC (Open Geospatial Consortium) Catalogue Services standards to access data sets across the web. This capability will enable DIVE to access data sets archived by the Australian Oceanographic Data Network (AODN), and the Australian Integrated Marine Observation System (IMOS), which have both adopted OGC standards. The capability will be available in DIVE when the national MEST servers are fully functional.

The DIVE installer can be freely downloaded from the WAMSI website http://www.wamsi.org.au/category/region/research/data-management which links to http://software.cmar.csiro.au/

The DIVE Manual is available on the web site.

5. DISCUSSION

5.1 An assessment of the importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.

5.1.1 Implications for Management and Advancement of the Field

We characterised the proportion and size of canopy and open-gap states at multiple sites along a gradient in wave exposure, and found open-gap patch lengths were positively correlated with modelled seabed water velocities. We also found open-gap patches are naturally persistent features, which likely become even more long-lived in the face of severe disturbance. Given the potential for increasing levels of disturbance from urbanization, climatic factors such as increasing sea temperatures and changing wave intensity regimes, it may be predicted that the relative balance of habitat types on southwest Australian temperate reef ecosystems will change in the future. While this may not necessarily have dire immediate consequences for biodiversity, there may be negative implications for secondary production on temperate reefs, where food webs appear to be disproportionately reliant on brown algae as a food source. The ability of open-gap habitat to occupy space indicates that such changes may be very difficult to reverse, and that we should ensure that we make efforts to manage any processes that may exacerbate the transitions from kelp canopy to open-gap habitats.

5.1.2 Problems encountered

Limitations with SWAN wave model, which could only be run using a 30m grid, could potentially be overcome by making the scale of the model more congruent with the average dimensions of open-gap patches. Also, we were unable to derive instantaneous maximum wave velocities from the SWAN model which would have the potential to further improve our understanding of the relationship between wave climate and algal patch dynamics. Ultimately it would be most desirable to make direct measurements of wave dynamics within multiple replicated canopy and open-gap habitats, however the costs and logistical complexity of this approach were beyond the scope of this project.

5.1.3 New Research Directions

As the dynamics of algal patch dynamics appear to play out over timescales longer than the life of WAMSI projects it was not possible to follow clearances for as long as would be desirable, however we will seek other opportunities to pursue this work. Nevertheless the approach has proved useful as a means of parameterising habitat models. Such models promise to provide a useful predictive tool, particularly when combined with environmental models of variability and change in temperature and wave climate associated with climate change and variability. Currently, downscaled models of this kind for marine environments do not occur for the southern west coast of Australia. A valuable complimentary approach to the study of habitats we have recently completed would be to construct similar models of coral and sponge populations which would provide an independent means of evaluating the time scales of patch persistence, as well as having obvious importance for understanding and predicting the response of sessile invertebrates such as corals to changing marine climates.

5.2 An assessment of ecosystem processes with particular relevance to contrasting fished and non-fished areas.

5.2.1 Implications for Management and Advancement of the Field

Probably the most compelling result from this study is that, where SZs are established with the aim of increasing the biomass and/or density of species targeted by fishers, larger reserves will be most likely to achieve this aim. It also showed that these patterns were strongest for the two most heavily fished groups of species. Although we found some evidence that small reserves did show responses for some metrics, the difference was smaller than that yielded by large reserves, and was present for fewer metrics. One inference from this is that, while small reserves might achieve aims of increasing biomass or density, they are less likely to do so, or will lead to smaller increases seen in fewer species.

5.2.2 Problems encountered

No major problems were encountered. One constraint imposed by the comparison of small versus large SZs was that less area was available for surveys in small SZs.

5.2.3 New Research Directions

None.

5.3 An assessment of likely dispersal patterns for marine organisms based on hydrodynamic and population genetic models.

5.3.1 Implications for Management and Advancement of the Field

The main implication for management is that population connectivity has been shown to exist over very large spatial scales indicating west and south coast parts of some species ranges can be linked genetically by Leeuwin Current-mediated larval dispersal. In widely dispersing species, the south west coast of WA potentially spans a single evolutionarily significant unit. This has implications for how spatial management units such as those used in zoning marine parks are designed and for how species may change their distribution in response to climate change induced modifications to marine environments and oceanography.

5.3.2 Problems encountered

Staff movement interstate resulted in a delay in obtaining the DNA sequence data.

5.3.3 New Research Directions

None.

5.4 Electronic delivery of data and models to management agencies, building on the development of the Data Interrogation and Visualisation Environment (DIVE) in SRFME.

5.4.1 Implications for Management and Advancement of the Field

DIVE has advanced considerably over the WAMSI project. It is a versatile, intuitive data access and visualisation tool, developed to assist both researchers and managers in their interpretation of field data and model output

5.4.2 Problems encountered

Unlike physical oceanographic data, there is no standard format for biological data. Further, oceanographic data are stored in 'self-describing format', that allows a data-access program to interpret the content without user intervention. We have established an ascii column-file format to enable data to be read by DIVE. However, in reality, the tool is presently most suited to physical, and some biological, oceanographic data, and to model output. While DIVE has now been set up to interrogate MEST servers, neither WAMSI nor the national servers have yet been established with databases that allow the actual data sets to be accessed. This means that this DIVE capability has cannot, to date, be fully tested.

5.4.3 New Research Directions

At the start of WAMSI, the adoption of MEST standards by national data agencies had not been anticipated. The ability to connect to MEST servers is a response to the establishment of the Australian Oceanographic Data Network (AODN) and the Integrated Marine Observing System (IMOS)

6. OVERALL PROJECT ACCOMPLISHMENTS

6.1 Students supported

David Rivers (UWA) was awarded a WAMSI PhD top up scholarship and will complete his PhD in 2011. His project was entitled: The role of seedling recruitment in maintaining seagrass diversity which is linked to the first project objective. David was supervised By Professor Di Walker (UWA).

Eloise Brown (UWA) was awarded a CSIRO Wealth from Oceans National Research Flagship PhD top up scholarship. She is undertaking a project entitled "Hydrodynamics of submerged *Ecklonia radiata* kelp canopy in a sub0tidal reef ecosystem" which is linked to the first project objective in this project and also to the other Node 1 project. Eloise is co-supervised by Carolyn Oldham (UWA), Graham Symonds (CSIRO) and Euan Harvey (UWA).

6.2 PhD theses, Dissertations and Student Placement

David O. Rivers
School of Plant Biology, School of Environmental Systems Engineering, University of Western Australia

Draft Thesis Abstract

Seagrass colonization into gaps in meadows – the role of seedling recruitment

Gaps – openings in structured biotic environments – play an important role in maintaining community diversity by providing space for species to recruit. In seagrass ecosystems, recolonization of gaps occurs through two processes: vegetative propagation of seagrass shoots from the gap margin or seedling recruitment. In many seagrass systems seedling recruitment contributes only a minor amount towards gap recolonization compared to vegetative propagation, yet seedling recruitment is nonetheless a critical process for maintaining species diversity in seagrass communities. This thesis investigated the persistence and fate of gaps in a *Posidonia-Amphibolis* seagrass community and examined the influence of gaps on vegetative and sexual recolonization, while emphasising the implications of seedling recruitment to gaps for seagrass diversity.

The persistence and fate of meadow gaps was determined through analysis of eight years (2002 – 2009) of aerial photography of seagrass coverage in Owen Anchorage, Fremantle, Western Australia. Gap size frequency showed a Poisson distribution at all four meadows analysed, with the greatest number of gaps falling into the small size class (30 – 50 m^2). The predominance of small gaps, which have high edge to area ratios, highlight the potential for edge effects to have a strong influence on

recolonization. 500 randomly selected gaps were tracked over time and gap fates fell into four categories: persistent but with changes to size and shape (4.8%); merging with another gap (5.9%); completely recolonized (18.3%); and merging with the background sand matrix (71.0%). Within meadows, the gap size distribution was consistent over time, regardless of changes in seagrass cover at the meadow scale. The continuous presence of gaps, coupled with changes in gap position as gaps evolve, indicates that the influence of gaps on recolonization is persistent in this system.

The effect of gaps on recolonization was examined by quantifying seagrass loss, vegetative propagation and seedling recruitment at three gaps at a *Posidonia-Amphibolis* meadow. Of the total recolonization, 1 – 17% was due to seedling recruitment while 83 – 99% was from propagation of shoots from the gap margin. *Posidonia* species were responsible for most of the vegetative recolonization, while *Amphibolis* species were more successful at seedling recruitment. The different strategies by which these genera recolonize gaps enable their co-existence in areas where gaps are present. Stochastic processes appeared to drive gap evolution, measured as change in gap size and position, in this system. Although recolonization occurred throughout the 18 month study there were no consistent spatial or temporal patterns among gaps. Likewise, disturbance events resulting in the loss of shoots or seedlings occurred through the study, but without consistent patterns among gaps. Yet for the combined set of gaps, recolonization and disturbance both occurred during every sampling period. The stochastic interplay between recolonization and disturbance was reflected by the varied evolution of gaps after 18 months; one gap expanded by 11.2 m^2, one reduced by 4.8 m^2, and one reduced by 1.7 m^2.

A spatial analysis of seedling recruitment at the three gaps investigated whether gaps influenced recruitment for *Amphibolis* and *Posidonia*, and to identify potential mechanisms. *Amphibolis* seedlings settled most frequently on matte – exposed roots and rhizomes – within gaps while *Posidonia* settlement showed no consistent spatial pattens with regard to gaps. Odds of survival for *A. griffithii* increased with proximity to the gap margin (Wald statistic -2.39; $p > 0.05$), corresponding to the location of matte. This study demonstrated that gaps positively influence seedling recruitment for the *Amphibolis* species while having comparatively little influence for *Posidonia*. A field experiment was conducted to explore the role of matte in influencing recruitment success of *Amphibolis* seedlings. *A. antarctica* seedlings were transplanted onto meadow, matte and sand at six gaps and survival tracked over two months. Seedling survival was greatest on the matte, and more force was required to dislodge seedlings from matte than from sand, where all seedlings were lost. The ability of *Amphibolis* seedlings to anchor to matte was identified as the mechanism by which gaps increase recruitment success for this genus. *Amphibolis* recruitment to gaps was limited by the availability of matte, not by seed production.

This thesis demonstrates that *Amphibolis* species can persist in *Posidonia* meadows that contain gaps by colonizing via seedling recruitment. The matte located along the gap margin improved recruitment success of *Amphibolis* seedlings. Disturbance events removed existing seagrass shoots and created new matte. Although disturbance events were stochastic at individual gaps, in a meadow containing many gaps disturbances continuously create new matte which is available for *Amphibolis* recruitment. Small gaps with high edge to area ratio were most predominant, and the high proportion of gap edge increases the likelihood of matte availability. The fate of individual gaps and the availability of matte within them were unpredictable over time, yet gaps were abundant features of within meadows over an eight year period. The long-term persistence of gaps allows *Amphibolis* species to co-exist in meadows dominated by *Posidonia*.

Eloise Brown
School of Plant Biology, School of Environmental Systems Engineering, University of Western Australia

Abstract for PhD Thesis defence

Hydrodynamics of submerged *Ecklonia radiata* kelp canopy in a subtidal reef ecosystem

Boundary layer dynamics in submerged canopies and complex reef habitat are generally not well understood, yet have the potential to shape benthic ecology by controlling the fate of suspended matter and nutrients in these systems. This research examined wave-driven hydrodynamics and turbulence in Western Australian fringing limestone reefs with *Ecklonia radiata* kelp canopy. The experimental approach involved a field study and a physical model of reef with 1:10 scaled-down kelp. Using an array of 4 acoustic Doppler velocimeters (ADV) sampling at 8 Hz and an acoustic wave and current profiler, water velocities were measured in the field at fixed heights through the kelp canopy and on bare reef over a 3 week period spanning several winter storms. Spectral analysis showed a wave peak at 12.5 Hz and a clear inertial subrange between 0.5 - 3 Hz, indicating that there was a fully developed turbulent boundary layer. A significant vertical intensification of turbulent kinetic energy (TKE) dissipation rate (ε) occurred within the kelp canopy. However, comparisons between bare reef and kelp canopy suggest that the removal of kelp canopy had no impact on ε. This was further examined in the laboratory, where TKE was parameterized as a function of reef roughness, canopy density and distance from the canopy edge. Profiles of the flow field were measured with paired ADVs sampling at 25 Hz over bare reef, over five densities of model kelp canopy, and at five distances away from the edge of the model canopy. TKE decreased with canopy density and with distance away from the canopy edge, suggesting that, even at significant distances away from the canopy edge, kelp canopy in the presence of wave-orbital velocities exerts a strong influence on local hydrodynamics. This has important implications for the ecology of understory algal

and invertebrate communities in these kelp forest ecosystems.

6.3 Publications

Copies of Journal Publications listed below are given in Annexure B (WAMSI Node 1 Publications and Presentations). Published and Unpublished Reports have previously been provided to WAMSI.

Journal Publications

Babcock, R.C., N.T. Shears, A.C. Alcala, N.S. Barrett, G.J. Edgar, K.D. Lafferty, T.R. McClanahan and G.R. Russ (2010). Decadal Trends in Marine Reserves: differential rates of change for direct and indirect effects. Proceedings of the National Academy of Science (USA). 107(43): 18256–18261.doi:10.1073/pnas.0908012107

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6.4 Presentations

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Rivers, D.O., G.A. Kendrick and D.I. Walker (2011). Microsites play an important role for seedling survival in the seagrass *Amphibolis antarctica. Journal of Experimental Marine Biology and Ecology* 401: 29-35.

Thomson, D., R. Babcock and M.V. Vanderklift (2010). Kelp Patch dynamics; patch size, wave exposure, herbivores and patch age. *Australasian Society for Phycology and Aquatic Botany*. Rottnest Island, Australia, November 15 -18, 2010.

Thomson, D., R. Babcock and M.V. Vanderklift (2010). Kelp Patch dynamics; patch size, wave exposure, herbivores and patch age. Invited speaker at workshop entitled Management, conservation, and scientific Challenges on Subtropical Reefs under Climate Change. *Australian Coral Reef Society (ACRS) conference*. Coffs Harbour NSW, Australia, September 10, 2010.

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7. OVERALL PROJECT BENEFITS

7.1 An assessment of the importance of physical forcing and ecological interactions among key functional groups in determining patterns of spatial mosaics in benthic habitats.

7.1.1 Discovery and Application of New Products and Processes

No new applications or products

7.1.2 Tools, Technologies and Information for Improved Ecosystem Management

The relationships between a key environmental parameter, wave intensity, and the dynamics of kelp forest habitat mosaics can now be modelled in ways that, when combined with appropriate climate models, will enable us order to provide general predictions of changes to the productivity, and biodiversity of coastal reefs in south western Australia.

7.2 An assessment of ecosystem processes with particular relevance to contrasting fished and non-fished areas.

7.2.1 Discovery and Application of New Products and Processes

No new applications or products

7.2.2 Tools, Technologies and Information for Improved Ecosystem Management

The results of the SZ comparisons will be important for marine conservation planning in Western Australia. No new tools *per se* have been developed, because conclusions about the benefits of SZs of different sizes are necessarily qualitative - that is, that larger SZs are more effective than smaller SZs. This information is being provided to DEC and to the MPRA, as the two main bodies responsible for marine conservation management in Western Australia. We envisage that the information will be used to support decisions when planning new marine parks, or when assessing the management plans in place for existing marine parks. The findings are particularly relevant for the revision of the Marmion Marine Park Management Plan currently being undertaken by the MPRA.

7.3 An assessment of likely dispersal patterns for marine organisms based on hydrodynamic and population genetic models.

7.3.1 Discovery and Application of New Products and Processes

No new applications or products

7.3.2 Tools, Technologies and Information for Improved Ecosystem Management

This work demonstrates the value of combining two sophisticated technologies, hydrodynamic modelling and molecular ecology to elucidate the cryptic but important spatial dimension in marine ecology of which dispersal is a central determinant. Understanding the spatial extent of populations and species is crucial to spatial ecosystem management and our project has yielded information on an important benthic invertebrate but also demonstrated the potential to apply the same approach in other marine taxa reliant upon passive dispersal under the influence of oceanographic processes.

7.4 Electronic delivery of data and models to management agencies, building on the development of the Data Interrogation and Visualisation Environment (DIVE) in SRFME.

7.4.1 Discovery and Application of New Products and Processes

DIVE development was begun during the SRFME project, so it is not strictly a new product. However, it is a major enhancement of the tool that was available at the start of WAMSI.

7.4.2 Tools, Technologies and Information for Improved Ecosystem Management

The intention of DIVE was that it be a tool to enable environmental managers to access, look at, and compare the diverse range of data sets collected across WAMSI. It can access data across the web, and should be particularly suitable for interrogating the WAMSI central database. This gives managers access to the actual data, so that they do not have to rely on the subsets and interpretation provided in research reports. DIVE handles data in up to 4 dimensions, from across the marine disciplines. However, as noted above, its universality is limited by the lack of standards for formatting of biological data. It can read geospatial biological data so long as they are in a standard format. DIVE and its manual are available for download from the WAMSI website.

8. PROJECT METADATA AND DATA GENERATED

The WAMSI program has generated data from a wide range of sources, disciplines and organisations that has resulted in the assembly of a multitude of data formats and data types.

To manage these datasets, a version controlled data repository was established that served as a central data distribution point and is supported by a repository website (http://www.marine.csiro.au/datacentre/SRFMEandWAMSI/) and a publicly accessible metadata tool called MarLIN (http://www.marine.csiro.au/marlin). MarLIN is linked to both the Australian Spatial Data Directory and the Australian Ocean Data Network (AODN). Both these external metadata search services provide international online access to WAMSI metadata records.

Metadata records are published in the public domain, while access to datasets in the data repository is provided via the data repository website.

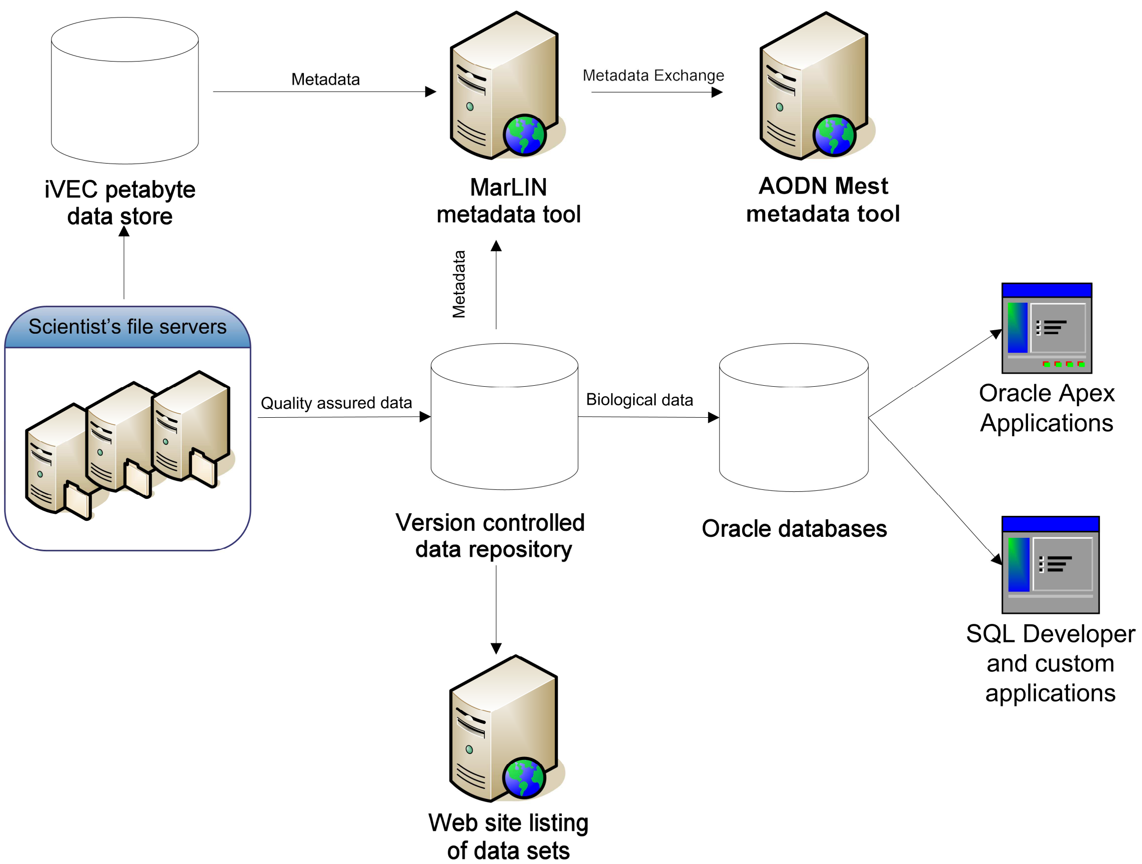

Figure 8.1. WAMSI Data Repository architecture

The data repository is mounted on a CSIRO computer with appropriate file restrictions to limit access to CSIRO WAMSI participants only. The repository consists of a directory structure that mirrors the major project components of the WAMSI program.

To maintain the integrity of data, only data that has been quality assured by scientific staff is included in the repository. Quality standards are maintained by, and are the responsibility of individual projects.

8.1 Version control

To maintain the currency of data exposed via the WAMSI data repository website, the data repository was placed under an "Apache Subversion" (SVN) version control system. SVN was chosen because of its simplicity and ability to support the needs of a wide variety of users and projects.

8.2 Biological data

Most biological data was provided in the form of Microsoft Excel® spreadsheets, the format of which reflected a wide range of datasets, experiments and data manipulation processes. These spreadsheets have been placed directly into the data repository.

Quality assured raw data was also entered into an Oracle database so that common attributes such as temporal and spatial information could be merged for different datasets, such as algae, invertebrate, fish species, coral, habitat and substrate datasets. A variety of tools were then used by scientists to further process data. At the time of writing, the data base contained 39,160 biological data items in 1,018 data sets and 11,973 transect images.

8.3 Large data sets

Where large data sets of terabyte size would have placed an excessive burden on the data repository and its associated infrastructure, this data was placed in the iVEC petabyte data store.

9. LINKAGES TO ASSOCIATED PROJECTS

The multidisciplinary approach employed in this project, which involved high-resolution genetic analysis and hydrodynamic modelling of larval transport, has been extended to two applied projects involving exploited demersal fishes in Western Australia and a study of the potential connectivity among Areas for Further Assesment as part of the establishment of a national Marine Protected Area network. The first, (WAMSI Project 4.4.2-2a in collaboration with Fisheries WA) evaluated the appropriateness of existing spatial management for the west Australian Dhufish, *Glaucosoma hebraicum*. The second, (CSIRO and Rangelands NRM funded and in collaboration with Fisheries WA), characterised the extent of dispersal in adult, juvenile, and larval spangled emperor (*Lethrinus nebulosus*). This project also evaluated the suitability of existing spatial management for this species. In addition, the hydrodynamic predictions of connectivity made for the dhufish are currently being incorporated into ELFSim models of population dynamics of this species within the West Coast Bioregion as part of WAMSI project 4.4-3. , Hydrodynamic simulations have also been conducted for the baldchin groper (SPP) within the West Coast Bioregion as part of the WAMSI project 4.4.2-2b, which incorporates research by a PhD student enrolled at Murdoch University.

DIVE is a visualisation tool that is available for all WAMSI projects and data sets, subject to the formatting requirements described above.

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