Water for a Healthy Country

PROCEEDINGS OF
CLLAMM ECOLOGY RESEARCH CLUSTER
CLLAMM FUTURES WORKSHOP #2

March 4th and 5th 2008,
SAASC, SARDI, West Beach

Rebecca Lester & Peter Fairweather

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The Water for a Healthy Country Flagship is a research partnership between CSIRO, state and Australian governments, private and public industry and other research providers. The Flagship aims to achieve a tenfold increase in the economic, social and environmental benefits from water by 2025.

The Australian Government, through the Collaboration Fund, provides $97M over seven years to the National Research Flagships to further enhance collaboration between CSIRO, Australian universities and other publicly funded research agencies, enabling the skills of the wider research community to be applied to the major national challenges targeted by the Flagships initiative.

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Foreword

The environmental assets of the Coorong, Lower Lakes and Murray Mouth (CLLAMM) region are currently under threat as a result of ongoing changes in the hydrological regime of the Murray-Darling River. While a number of initiatives are underway to halt or reverse this environmental decline, such as the Murray-Darling Basin Commission’s “Living Murray”, rehabilitation efforts are hampered by the lack of knowledge about the links between flows and ecological responses in the system.

The Coorong, Lower Lakes and Murray Mouth program is a collaborative research effort with the aim to produce a decision-support framework for environmental flow management for the CLLAMM region. This involves understanding the links between the key ecosystem drivers for the region (such as water level and salinity) and key ecological processes (maintenance and improvement of bird habitat, fish recruitment, etc). A second step will involve the development of tools to predict how ecological communities will respond to manipulations of the “management levers” for environmental flows in the region. These include flow releases from upstream reservoirs, the Lower Lakes barrages, and the Upper South-East Drainage scheme, and dredging of the Murray Mouth. The framework will attempt to evaluate the social, economic and environmental trade-offs for different scenarios of manipulation of management levers, as well as different future climate scenarios for the Murray-Darling Basin.

One of the most challenging tasks in the development of the framework will be how to predict the response of ecological communities to future changes in environmental conditions in the CLLAMM region. The CLLAMMecology Research Cluster is a partnership between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences that is supported through CSIRO’s Flagship Collaboration Fund. CLLAMMecology brings together a range of skills in theoretical and applied ecology with the aim to produce a new generation of ecological response models for the CLLAMM region.

This report is part of a series summarising the output from the CLLAMMecology Research Cluster. Previous reports and additional information about the program can be found at http://www.csiro.au/partnerships/CLLAMMecologyCluster.html
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1. Introduction and Overview

This document is a report on the CLLAMMecology Workshop held in March 2008 as a part of the CLLAMM Futures project.

CLLAMM Futures aims to integrate the knowledge of the other CLLAMMecology projects with that of past projects by developing a set of ecosystem-level models. These will be used to assess the effects of possible management options and to investigate the likelihood and distribution of a variety of alternative states occurring in the future. This information can then be passed on to the relevant organisations to inform future management of the region.

This workshop was the second of a planned three. Its purpose was to share research findings generated as a part of CLLAMMecology and to develop future scenarios to be used in ecosystem modelling by CLLAMM Futures. It provided an opportunity to share information between CLLAMMecology project members, to relevant stakeholders from management organisations and to gain the input of those stakeholders in developing pertinent, realistic scenarios for modelling.

**Venue:** Conference room, South Australian Aquatic Sciences Centre, SARDI Aquatic Sciences, West Beach
# 2. Agenda

**Day 1 = Tuesday March 4th**

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<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter/Facilitator</th>
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<tbody>
<tr>
<td>8.30</td>
<td>Welcome &amp; introduction to workshop</td>
<td>Justin Brookes</td>
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<tr>
<td>8.45</td>
<td>Introduction to CLLAMM project</td>
<td>Sebastien Lamontagne</td>
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<tr>
<td>9.00</td>
<td>Results presentations</td>
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<td></td>
<td><strong>Productivity and trophodynamics</strong></td>
<td>Brian Deegan</td>
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<td></td>
<td><strong>Fish communities and recruitment in the Coorong</strong></td>
<td>Qifeng Ye</td>
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<td></td>
<td><strong>Bird communities and Ruppia distribution in the Coorong</strong></td>
<td>Dan Rogers</td>
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<tr>
<td>11.00</td>
<td>Morning tea</td>
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<tr>
<td>11.30</td>
<td>Results presentations continued</td>
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<td></td>
<td><strong>Habitat mapping of key study sites</strong></td>
<td>Sunil Sharma</td>
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<td></td>
<td><strong>The changing state of the Lower Murray Lakes</strong></td>
<td>Kane Aldridge</td>
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<tr>
<td>12.50</td>
<td>Lunch</td>
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<tr>
<td>13.30</td>
<td>Project Updates</td>
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<td></td>
<td><strong>Lipid &amp; pigment biomarkers for assessing organic matter sources and fates</strong></td>
<td>John Volkman</td>
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<td></td>
<td><strong>Nutrient sources and sinks in the Coorong</strong></td>
<td>Ralf Haese</td>
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<td><strong>Modelling the states of the Coorong</strong></td>
<td>Rebecca Lester</td>
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<td></td>
<td><strong>Distribution of benthic macroinvertebrates in the Coorong</strong></td>
<td>Alec Rolston</td>
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<tr>
<td>14.50</td>
<td>Results presentations continued</td>
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<tr>
<td></td>
<td><strong>Determining environmental history &amp; movement of fish in the Coorong</strong></td>
<td>Bronwyn Gillanders for Andrew Munro</td>
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<tr>
<td>15.30</td>
<td>Afternoon tea</td>
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<tr>
<td>16.00</td>
<td>Group discussion</td>
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<tr>
<td></td>
<td>- Linking findings between projects, model inputs and outputs</td>
<td>Peter Fairweather</td>
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<td></td>
<td>- Implications of results and directions for further analyses</td>
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<td>17.00</td>
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### Day 2 = Wednesday March 5th

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<tr>
<td>8.00</td>
<td>Introduction to workshop objectives</td>
<td>Peter Fairweather</td>
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<tr>
<td>8.15</td>
<td>Current climate change work &amp; relevance to Coorong</td>
<td>Sebastien Lamontagne</td>
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<tr>
<td></td>
<td><em>Scenarios developed by the Murray-Darling Basin Sustainable Yield project</em></td>
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<tr>
<td></td>
<td><em>The impact of climate change on sea levels and catchment runoff</em></td>
<td>Barry Brook</td>
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<tr>
<td>9.35</td>
<td>Workshop CLLAMM Futures Scenarios</td>
<td>Peter Fairweather</td>
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<tr>
<td></td>
<td>- Which parameters are likely to be affected by climate change?</td>
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<td>- Which of these are important for the CLLAMM ecosystems?</td>
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<td></td>
<td>- How do the SY scenarios apply to CLLAMM Futures?</td>
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<tr>
<td>10.40</td>
<td>Morning tea</td>
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</tr>
<tr>
<td>11.30</td>
<td>Continue to workshop Futures scenarios</td>
<td>Peter Fairweather</td>
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<tr>
<td></td>
<td>- What beyond the SY scenarios do we want to model?</td>
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<tr>
<td></td>
<td>- Which management scenarios are of most interest?</td>
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<td>- What are the rules governing barrage operations?</td>
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<td></td>
<td>- Which other levers will be most important to cover?</td>
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<tr>
<td>12.40</td>
<td>Lunch</td>
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<tr>
<td>13.20</td>
<td>Group discussion</td>
<td>Rebecca Lester &amp; Kane</td>
</tr>
<tr>
<td></td>
<td>- Are CLLAMMecology and CLLAMM Futures on track?</td>
<td>Aldridge</td>
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<tr>
<td></td>
<td>- What are the possible weaknesses and pressure point in the project?</td>
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<td></td>
<td>- What needs to be our next area of focus to make the Cluster work?</td>
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<tr>
<td>14.20</td>
<td>Discussion of impressions and comments on project</td>
<td>Gene Likens</td>
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<tr>
<td>14.30</td>
<td>Finish</td>
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**Contacts:**
- Peter Fairweather (Flinders)  08 8201 5021
- Rebecca Lester (Flinders)  08 8201 3436
3. Proceedings of the workshop

3.1. Day 1

3.1.1. Welcome & introduction to workshop

Justin Brookes, the CLLAMMecology Research Cluster Leader, welcomed the participants, especially the CSIRO Flagship Fellow, Gene Likens, and gave an introduction to the second CLLAMM Futures workshop. Justin commented particularly on the large number of guests and stakeholders attending.

The introduction to the workshop focused on the current state of the CLLAMM region, and the need to develop strategies to firstly rehabilitate the system and for the longer term for ongoing water delivery. Justin drew attention to the need for exchange of ideas and data both between projects in CLLAMMecology, but also from managers. He also saw the workshop as an opportunity to glean what we, as a cluster, should be delivering to managers. He expressed the opinion that for managers to be successful in bidding for water, they needed to have defensible science at their disposal.

3.1.2. Introduction to CLLAMM project

Sebastien Lamontagne presented an introduction to the overall CLLAMM project, including CLLAMMecology Research Cluster.

He introduced a project focused on a region at a crossroads. Key species such as *Ruppia tuberosa*, and various species of fish and wading birds, are in decline in the system and water levels are at record low levels in both quantity and quality. The threats for the future include ongoing water diversions, climate and land-use change and sea level rise. The good news for the system is that nearly all taxa are still found somewhere in the region providing source populations if conditions improve. The challenge is how to improve conditions in the current drought.

CLLAMM takes a whole system approach to studying and managing the region. CLLAMM is made up of CSIRO CLLAMM and the CLLAMMecology Research Cluster. CLLAMMecology is a joint effort by the University of Adelaide, Flinders University, SARDI Aquatic Sciences, the Department for Environment and Heritage, DWLBC and CSIRO Water for a Healthy Country. It consists of four projects: Key Species Responses, led by David Paton; Productivity and Trophodynamics, led by Justin Brookes; Dynamic Habitats, led by Jason Tanner; and CLLAMM Futures, led by Peter Fairweather.

The Cluster aims to develop knowledge at an ecosystem level, including key species of macrophytes, macroinvertebrates, fish and birds. It contends that ecosystem response is a result of climate and management actions interacting with ecosystem drivers which affect key species response, productivity and trophodynamics to determine habitat availability. These can then be used to predict future outcomes under a range of conditions and to assess “water benefits” associated with a variety of management scenarios. The Cluster will used a number of models to predict future outcomes, combining a hydrodynamics model of the region with a biogeochemical model, a dynamic habitat model and an ecosystem model. The objective for the modelling is to predict future outcomes in a 30-50 year timeframe, so the models need to be simple enough to allow long run-lengths. The models will be run with multiple future scenarios including ones that manipulate the “management levers” in the system; that is, the dredging of the Murray Mouth, the operation of the barrages and the other inputs via the Upper South East Drainage Scheme, and various other hypothesised management options. The results of the
modelling will inform managers of the likely long-term outcomes of their management strategies, enabling more informed decision making for the region.

3.1.3. Results presentations

3.1.3.1. Productivity and trophodynamics

A presentation of the results to date from the Productivity and Trophodynamics Project was given by Brian Deegan and Rod Oliver.

Productivity along the length of the Coorong was surveyed in January 2007. The results of that survey showed a change in the phytoplankton composition down the salinity gradient, and a change in the activity of that phytoplankton. Since then, seasonal measurements of pelagic and benthic productivity have been taken at three sites and an investigation has occurred into the nutrient and light influences on productivity.

The investigation into the trophodynamics of the Coorong was designed to determine the structure of the food webs in the system and whether these changed along the length of the Coorong. A substantial amount of energy is required at the primary producer level to support relatively few organisms at the top of the food web. A key question in the functioning of an ecosystem is how the loss of a species will affect the remainder of the food web. Potential food-web diagrams typically contain substantial levels of redundancy, with most species having multiple potential sources of prey. However, as salinity increases in the Coorong, redundancy tends to decrease. This means that, at higher salinities, the loss of a species is likely to have a greater impact on the overall food web, than at lower salinities.

The aims of the trophodynamics investigation were to identify alterations in the food web structure along the length of the Coorong, to characterise the functional roles of organisms and also to quantify the importance of changes in the food webs under various scenarios. In order to characterise the food webs of the Coorong, literature reviews were conducted for the various key species to identify typical diets. These were augmented with field investigations into the species that were present along the Coorong, stomach content or tissue analyses for larger species (fish and birds), and finally stable isotope analyses, focusing on carbon, sulphur and nitrogen isotopes. The field investigations were conducted over two weeks in November 2007. There are several challenges associated with isotope analyses, including a need to understand how the baseline signature is affected by the salinity gradient and by biogeochemical processes.

Rates of photosynthesis and respiration were measured at several scales to indicate the balance of metabolic processes. This enables an analysis of the relative importance of internal and external supplies of organic material that provide the energy to sustain food webs. The types and amount of organic matter produced and respired affects the biomass and diversity of consumers in the system.

Total system metabolism was measured in December 2007 at Mundoo Channel, Pelican Point and Salt Creek. At each location, a number of Sondes were deployed across a depth gradient to measure dissolved oxygen and temperature. Fluorescence and environmental parameters were also measured. Incubations were used to quantify pelagic metabolism. Together, these can also provide an estimate of benthic metabolism, as benthic and pelagic metabolism combine as total system metabolism. While these values can be measured at a given point in time and space, scaling these values for such a large body of water is not trivial. Depth, area, light and biomass all affect metabolic rates and so impact on the accuracy of scaling.

Mundoo Channel and Pelican Point had very similar salinity readings at the time of sampling. Salt Creek was significantly more saline. Significant differences were detected in the diel variation between the sites and sub-sites. At Mundoo Channel and at Pelican Point, significant relationships were detected between metabolic rates and depth, but this was not observed at
Salt Creek. A preliminary interpretation for this pattern may be that pelagic metabolism is unaffected by depth, and that at lower salinities, benthic production increases in the shallows but does not increase at higher salinities.

Fluorescence measurements have been shown to be proportional to photosynthetic rates, particularly in laboratory situations. Monitoring fluorescence over a day can give an understanding of how photosynthesis changes over time. As yet, these data have not been analysed, but will be in the coming months.

3.1.3.1.1. Overview of discussion:

Net total system production was close to zero. Phytoplankton had positive net production but the system totally uses the available resources, so the overall net production is zero. This has also been demonstrated for the Murray River channel. No large allochthonous signal was detected, but no measurements were undertaken in areas with macrophytes (because of the low abundance of macrophytes in the system).

Some questions remain regarding long-term variability in productivity and trophodynamics that were not objectives in the current CLLAMMecology work. The influence of macrophytes is also missing from the data, but is unlikely to be a significant contributor of productivity to the food web. It is likely that microphytobenthos have always been the most important contributor to the system.

Several interesting questions arose, including what changes might occur in the food web further south of Salt Creek (the extent of the survey), and what seasonal fluctuations would be expected in food webs. The ability of the productivity survey design to identify respiration by heterotrophic bacteria was also raised. While small amounts of heterotrophic bacteria can be corrected for using the biomass of phytoplankton in the pelagic measurements, large amounts may be problematic, as it can be difficult to distinguish between the two.

3.1.3.2. Fish communities and recruitment in the Coorong

Results from the CLLAMMecology and FRDC study into fish communities and recruitment in the Coorong were presented by Qifeng Ye.

Within the Coorong, there are fish with a range of life history strategies. The fish species contains both marine and freshwater species, as well as estuarine specialists and diadromous fish that migrate between the marine and freshwater to complete their life cycle.

The objectives of the fish research were to relate fish distributions and abundance to environmental gradients and to investigate how these conditions influenced the reproductive biology and recruitment of the various species. Identifying any influence of freshwater flows on recruitment success was also an objective. Six key species were chosen as biologically or commercially important, or as threatened species in the system.

Laboratory-based salinity tolerance trials have begun, to investigate the lethal and sub-lethal effects of varying salinity and temperature on critical life stage (juveniles). Six species have been included in the study: yellow-eyed mullet, Tamar River goby, black bream, congolli, mulloway and greenback flounder. These lab trials are currently ongoing. Sampling for the reproductive biology of fish species involved monthly sampling and samples of large-bodied fish were collected from commercial fishermen and small-bodied species from targeted research sampling. Samples from commercial fisherman are also forming the basis of work aiming to link flows with recruitment. Using otolith analysis to establish age distribution data, strong cohorts will be identified as indicator of recruitment success, which will be linked to known environmental conditions for those years. Oral histories and historical information on flow/habitat conditions and native fish status collected from local fishers and the Narrindjeri community will also contribute to these analyses.
The fish distribution and abundance sampling has resulted in the capture of around 53,000 individuals. There is a distinct longitudinal gradient in the Coorong, with a decline in diversity from the estuary to the South Lagoon. While total abundance for the estuary and North Lagoon are similar, there is again a decline in the South Lagoon, and most individuals caught in the North Lagoon were the more salt-tolerant hardyhead. Hardyhead was the only species caught in the South Lagoon, and at very low numbers. Throughout the system, there appears to be an increase in the number of marine species.

Preliminary analyses of the data show that the longitudinal gradient is, in fact, shaping the community structure. While there is some seasonal variation, ANOSIM analyses show differences between the sites are significant and BIOENV identifies salinity as the environmental variable that best correlates with the observed patterns. Several species have been identified as significant indicators for the estuarine community and one for the North Lagoon. No significant indicator species were identified for the South Lagoon.

Work to date on the reproductive biology of the various fish species highlights the various reproductive strategies present within the Coorong. Black bream and Tamar River goby appear to have a spring to late summer spawning season, with congolli and greenback flounder spawning during winter. Yellow-eyed mullet may be a mixed population, as two spawning seasons were present, one in winter which is consistent with western Australian populations, and one in summer, consistent with eastern Australian populations. Some of the variability in the data is expected to be due to environmental variables, and histology samples remain to be analysed.

Age and size class structure data from commercial catches of black bream suggest that recruitment is episodic. 2003 and 1997 were both good years for recruitment success. A small environmental allocation of water was released in 2003, which may underlie the recruitment success in that year, but further analysis is needed. Size-age data suggests the species grows most rapidly in the first seven years of life.

Initial results from the laboratory-based salinity trials indicate that all species are quite tolerant to slow changes in salinity. Congolli and mulloway appear to have lower tolerances to high salinity in colder weather. The next round of experiments are intended to link salinity and temperature changes with different habitat elements, but the initial results appear to match the observed distribution of fish species in the Coorong reasonably well, with the exception of the Tamar River goby.

3.1.3.2.1. Overview of discussion:

One of the axes in the NMDS plot was well explained by salinity, but there was also considerable variation along a second axis. This may have described seasonal variation, or variability in the recruitment signal but needs further investigation. One of the options here is to match the distribution data collected during CLLAMMecology to the longer-term commercial fish catch data.

In terms of affecting fish distributions, salinity is not the only factor of importance. While salinity tolerances can preclude a fish from a certain location, a drop in salinity will not necessarily result in an immediate change in fish communities. It is likely that there are linkages through the food web, and habitat availability may also be important.

3.1.3.3. Bird communities and Ruppia distribution in the Coorong

Dan Rogers presented results from the projects focused on bird communities and *Ruppia* distribution in the Coorong.

Investigation into the bird communities of the Coorong involved collation of data from a number of sources. Historical data was sourced from the University of Adelaide, DEH and from the Australian Wader Study Group. Three honours projects have been undertaken as a part of
CLLAMM ecology, and four rounds of ‘baywatch’ sampling have been completed, where bird numbers and activity are monitored at 5 minute intervals at each of the 11 study sites. The first three rounds of ‘baywatch’ sampling occurred between dawn and dusk, with one day per site, but the fourth round involved a three, two-hour blocks of sampling, with no significant differences in the results due to the change in methodology.

Cluster analysis of the bird data reveals distinct communities in the estuary, the North Lagoon and the South Lagoon. Parnka Point appeared to be operating primarily like a South Lagoon site. The response of individual species did vary though. Sharp-tailed sandpiper distribution did not correlate strongly with the salinity gradient. This species may be more constrained by physical habitat, or the pattern may be less distinct because they are able to use a variety of food resources. Fairy terns, however, are likely to be more clear-cut, following food resources in fish distributions, but limited by distance to breeding sites and nests. Black swans occur primarily in the estuary, probably due to the distribution of benthic vegetation, but may also be sensitive to changes in Ruppia distribution.

A number of conceptual models are under construction to identify the key variables driving bird responses in the Coorong. These are being framed in terms of habitat quality, which is being defined using presence/absence and abundance data, along with the behavioural data collected. The models will be validated and quantified using methods such as in the Hyperniche software, classification and regression trees, and Bayesian Belief Networks. A model describing fairy tern habitat, for example, may include fish distribution information, competitor distributions and environmental variables that fairy terns are likely to respond to, albeit indirectly.

The distribution of Ruppia tuberosa in the South Lagoon was surveyed at eight sites in November 2006 and an extension of the survey into the North Lagoon occurred in May 2007, extensive beds recorded at Noonameena and germination recorded as far south as Villa dei Yumpa. Laboratory studies into germination are currently underway, but have been poor to date, as more than 99% of seeds did not germinate. This raises the question of the viability of the seed bank in the Coorong. A predation experiment is also underway, with exclusion plots established to prevent grazing by waterfowl. Up to 84% of shoots surveyed in 2007 were cropped by swans. This figure is likely to be artificially high, due to the current limited distribution of R. tuberosa, but represents a significant pressure on the species.

A number of gaps remain in our understanding of R. tuberosa distribution. The maximum depth at which it may grow is unclear. Previous estimates of 0.8 m seem inaccurate as R. tuberosa has been observed in up to 1 m of water. The maximum depth may, in fact, be determined by the turbidity of the water. The effects of wave energy, sediment size, competition and light on germination, establishment and growth are also poorly understood for the species. It is understood that salinity tends to delay germination (as measured over a 30 day period), but the effects on growth are also unclear.

The tasks for the future for the bird and Ruppia projects are to review the known responses of key species to environmental parameters of interest and to then develop habitat response models for the key bird species and for R. tuberosa. An important part of this process will be to identify knowledge limitations, and to treat each of the key life history stages independently. In order to successfully identify these relationships, similar models will be needed for species lower in the food web. These models can then be used to plot current distributions, and to investigate the effects of future scenarios on the individual key species.

3.1.3.3.1. Overview of discussion:

In Ruppia megacarpa in Western Australia, it is known that there are differences between the peak salinity tolerance for germination and that for growth. Whether there are corresponding differences in not known for R. tuberosa, which may have an impact on the recovery of the species in the Coorong. It was suggested that this question and perhaps others regarding the response of R. tuberosa may be able to be answered by looking at the wetlands surrounding the Coorong, and possibly the Lower Lakes. Another key question regarding R. tuberosa is the
length of time the seeds can survive being buried in the mud without inundation to trigger germination.

The timeframe over which the analyses are being conducted was questioned, with work by Deborah Haines and others suggesting that the recent 'typical' conditions in the South Lagoon may not have been typical over the longer-term. Deborah has offered to provide access to her data and analyses once they are complete.

3.1.3.4. Habitat mapping of key study sites

Progress on the habitat mapping of key study sites was described by Sunil Sharma.

Habitat mapping at the 12 key study sites was undertaken, using a combination of DEH wetland habitat mapping information, aerial photographs taken in 2003, video transects and field observations. The mapping involved a hierarchical classification scheme, using 14 variables to describe various habitat types. Within these 14 habitat types, video transect data was used to identify individual micro-habitats.

For each site, bathymetry layers were created. The presence of macrophytes and other habitat elements were also mapped where applicable. Summary statistics have been calculated for each habitat type across all of the sites, with bare mud and bare sand the most common habitat types. The most challenging aspect of this work has been identifying the transitions between habitat types, and also in the definition of some habitats, such as mudflats.

Additional information has been added to the habitat maps through the incorporation of satellite data. LANDSAT5 and SPOT5 satellite imagery have been used. LANDSAT5 imagery is available since 2004, at a resolution of 25 m, while SPOT5 data is available from around the same time, with a smaller resolution of 2.5 m, but fewer light bands. The data from these satellites were classified using an unsupervised algorithm that was re-classified using the aerial photography. This produced a map showing five habitat types; subtidal, intertidal, open land, vegetation and exposed sand/roads. Marrying the two sets of classifications together using unsupervised classification has been problematic, but this is being resolved. When only the subtidal and intertidal areas are compared, there is good agreement between the two classifications of 93%.

Sediment sampling enabled an extrapolation of sediment size classes to create another layer. Sediment data were extrapolated for the North Lagoon. It was not possible to do a similar extrapolation for the South Lagoon due to the lack of bathymetry data. Samples were taken from each of the 12 sites and the resulting sediment distributions mapped. These were then compared to samples taken by other Projects (such as Key Species) for validation. Prediction of the category of grain size was good.

The most recent focus has been to link the habitat maps with the hydrodynamic model, to create a dynamic habitat model. The model is currently able to accept test values for water depths and calculate the volume of water held in the Coorong. Salinity along the Coorong can also be mapped. Further work with Ian Webster may enable the incorporation of some wind variability.

3.1.3.4.1. Overview of discussion:

At this stage, the video data has not been analysed through the various colour bands, but this may be an option in the future.

There is some anecdotal evidence from GA that sand bars are being created at various points along the Coorong, but there is little data on sedimentation rates. It may be possible to extrapolate sedimentation rates from the Mouth, where some data exists along the system, but, prevalent view is that the sediment is being blown off the sand dunes, rather than washing down the system.
3.1.3.5. The changing state of the Lower Murray Lakes

An update of the LWA-funded work being undertaken in the Lower Murray Lakes was presented by Kane Aldridge.

The Lower Murray Lakes are the largest permanent lakes in South Australia. They have an average depth of 3.4 m with a maximum of 4.1 m. Prior to European settlement, it is likely that the lakes were fresh around 95% of the time, but this would have been variable in space and time. Increasing extraction of water from the River Murray and its tributaries meant the Lakes became increasingly saline until the barrages were constructed in the 1930s. The Lakes are currently used in many different ways, supporting fisheries, as a source of water for townships and agriculture and the ecological significance of the Lakes has been recognised through Ramsar listing. The Lakes also play an important role, as a source of nutrients and water to the Coorong and through the Murray Mouth.

Very little work has been previously undertaken on the Lakes, so there are many unknowns in the system. It is thought to be a eutrophic to hypereutrophic system which is highly turbid and most of the nutrients are in particulate forms. In addition, those nutrients that are in dissolved forms are not very bio-available. Despite this, algal blooms are common.

The barrages are currently operated with the aim of maintaining a lake level of 0.75 m AHD, and are surcharged to 0.85 m AHD during summer months. This operation policy has dramatically altered the flow conditions in the lakes, with the removal of peak flows, increased lake levels, decreased variability in lake level and increased water residence times.

The original objectives of the research into the Lower Lakes included estimating the processing of nutrients within the Lakes, creating a nutrient budget to estimate the effect of outflows to the Coorong and Murray Mouth and the development of a model to predict organic matter and nutrient delivery under various flow regimes.

The current situation in the Lakes, with the dramatic decline of water levels due to the extended drought and the predicted further fall of those water levels to between -1 m and -1.5 m AHD over the coming year, has led to the inclusion of additional objectives. These include monitoring the salt intrusion through the barrages, the impacts of drying and re-flooding on nutrient releases and the impacts of salinity on phytoplankton populations.

The past functioning of the Lower Lakes was described with a nutrient budget created for the years 1979 to 1996, for which the best data was available. Inflows were calculated at Tailem Bend with outflows at Milang. Milang was not an ideal choice, but suitable data for a location closer to the barrages was not available and there is no significant difference between measured nutrient concentrations at Milang and Goolwa. For most of the nutrients and ions measured, increased inflow led to increased loads over the year. For NO₃, total P, FRP and Si, the Lakes tended to act as a sink. The exception was for Si, which acted as a source to the Coorong for one year. Nitrogen retention in the Lakes was more variable, with TKN acting sometimes as a source and sometimes as a sink. Total nitrogen also varied, but the Lakes were usually a sink. Overall, the Lakes appeared to assimilate inorganic nutrients, transforming them to organic forms. This is consistent with autotrophic water bodies, but in contrast to many Australian reservoirs which tend to be deeper than the Lower Lakes. The increased N:P ratio means that water exported to the Coorong and Murray Mouth will be rich in nitrogen, a common limiting element for estuaries and marine systems. This is likely to evoke a response from the first-order consumer and bacterial communities, which would then cascade through the food web.

Field investigations to investigate water quality and primary production were undertaken to gain an understanding of the current situation in the Lakes. These involved measuring patterns in sediment re-suspension due wind and wave action through the day and the effect of this process on dissolved nutrient concentrations. Generally, wind has a distinct diel pattern, increasing through the day resulting in sediment re-suspension and increasing water column particle concentrations through the day. Pulses of FRP were also observed, but it is not yet
clear whether these are a result of wave action forcing porewater from the sediments or the exposure of underlying anoxic sediments, which release phosphorus.

An incubation experiment is currently underway to test the effects of drying and re-flooding on nutrient release from sediment. Exposure is likely to result in the lysis of cells in the sediments, which will then leach nutrients. Measurements of denitrification rates were also measured during the experiments, by labelling nitrate and observing the fate of the labelled N. Preliminary results indicate that dried sediments have very little oxygen below a few millimetres depth, that nitrate remains relatively constant and that ammonia levels increase with depth in the sediment profile.

Routine monitoring of water quality has been carried out since early 2007 at numerous locations in Lake Alexandrina and Lake Albert. Since May 2007, large increases in electrical conductivity and ammonia have been observed, particularly at the barrages and in the ‘arm’ of Lake Alexandrina. Total phosphorus and dissolved organic carbon have also increased significantly, but more recently (November 2007) and more uniformly throughout the Lakes. There are differences in the level of mixing of the water column, with Goolwa showing distinct stratification, but Point McLeay appearing well mixed. Patterns in the concentration of chlorophyll are harder to interpret, as peaks appear to correspond to sampling in windy conditions, rather than increases in background levels. Overall, the pattern emerging from routine monitoring is one of declining water levels, increasing salinity and nutrient concentrations and increasing dissolved organic carbon. There are a number of possible explanations for the increased nutrient concentrations including decomposition of freshwater biota and external inputs (groundwater, Coorong). It is clear that the system is in a transition state.

In order to predict how the system may change in the future, a three-dimensional model is under construction to predict lake levels, temperature, salinity, nutrient concentrations and levels of primary productivity under a range of flow scenarios. This model is current at the validation stage, and will shortly be applied to the various flow scenarios of interest, which will be identified later in the workshop.

3.1.3.5.1. Overview of discussion:

Discussion was focussed on the source of increased nutrient concentrations throughout the Lower Lakes. A number of hypotheses were suggested and discussed, including:

- evapoconcentration, which as the Lakes shrink may account for some of the increase but is not a large enough effect to account for the large spike in total phosphate;
- drying-re-flooding cycles and exposure of acid sulphate soils where the dissolution of iron following drying and re-flooding may result in release of phosphorus;
- salinity-induced dissolution of iron and phosphate, resulting in a release of phosphate into the water column; and
- increased stratification and resultant anoxia in sediments releasing phosphorus into the water column due to the leakage of seawater into the Lakes.

The observed increase in nutrients wasn’t incorporated into the algal community. Very little of the phosphorus was present in bio-available forms. The mechanism causing the increase in nutrient concentrations requires further investigation.

3.1.3.6. Determining environmental history & movement of fish in the Coorong

A presentation of the results to date from work focused on identifying the environmental history and movement of fish within the Coorong was given by Bronwyn Gillanders on behalf of Andrew Munro.

Understanding the environmental history and movement of fish is an important for the management and conservation of those species. It can provide insight into the population and
stock structure, into connectivity between populations and identify dispersal potential. This project aimed to use fish otolith characteristics to determine the environmental history and movement of fish, and to then relate these to the changing environmental conditions within the Coorong.

At various salinity levels, different elements occur at different concentrations within a water body. These elements are taken up by the fish that inhabit them, and are laid down in their otoliths, partially replacing the calcium in the calcium carbonate that comprises the bulk of the otolith. The concentrations of various elements in the otolith can thus give some indication of the environment in which the fish resided, with the annulus structure of the otolith providing a record over time, similar to that obtained by examining rings on a tree. Previous studies have described a significant relationship between barium concentrations, in particular, and salinity.

Fish samples were collected from ten sites along the length of the Coorong, with five in the estuary, three in the North Lagoon and two in the South Lagoon. Water temperatures remained relatively constant along the length of the Coorong in both May and June 2007, but on both occasions, salinity increased dramatically with distance from the Murray Mouth. On these occasions, a strong positive relationship was observed between Ba:Ca ratios and salinity, with a slight positive relationship between Sr:Ca ratios and salinity. The Sr:Ca ratio was more strongly correlated with salinity in the estuary and the North Lagoon than in the South Lagoon.

Samples of yellow-eyed mullet and small-mouthed hardyheads were collected from as many sites as possible. Yellow-eyed mullet occurred across a salinity gradient of 20 to 50 ppt while the small-mouthed hardyheads were caught in water between 3 and 120 ppt. The otoliths were extracted from these fish and were analysed using a Laser Ablation – Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS). Elemental composition at the edge of the otolith was then compared with that of the water from which the fish were caught.

For small-mouthed hardyheads, there was a variable relationship between Ba:Ca ratios and salinity. At low salinities, the relationship appeared to be negative, while it switched to a positive relationship at higher salinities. The corresponding relationship in the water column was non-linear, but generally positive. For Sr:Ca, very little correlations with salinity was observable, either in the otolith or in the water column.

For yellow-eyed mullet, Ba:Ca ratios were non-linearly related to salinity in the otolith, with an apparently negative relationship at low salinities and a positive relationship at high salinities. Ba:Ca ratios in the water appeared more linearly correlated with salinity, with a positive trend across the range of values recorded. The relationship between Sr:Ca ratios and salinity was weak and non-linear in both the fish otoliths and the water column.

Overall, the data suggested that there was a positive relationship between Sr:Ca ratios and salinity in water, a negative relationship between Ba:Ca ratios and salinity below around 45 ppt and a positive relationship above 45 ppt. Fish otoliths showed no strong positive or negative relationships, or a non-linear relationship between Sr:Ca and salinity, and a non-linear relationship between Ba:Ca ratios and salinity that results in a confounding of freshwater and hypersaline values.

Transects of otolith chemistry have also been analysed for some species. This involves measuring the chemical composition along the growth axis between the otolith nucleus and the edge with LA-ICPMS, to gain an understanding of changes in otolith chemistry over the lifetime of the fish. By examining the changes in Ba:Ca and Sr:Ca, it is hoped that periods can be identified where the fish resided in fresh, saline or hypersaline water. A mechanism for combining the two measures into one parameter that is not confounded between freshwater and hypersaline water is a current focus. Principle component analysis and classification and regression trees are two techniques that are being applied. Once such a measure has been developed, the habitats identified by otolith analysis will be compared to the distribution of habitats within the Coorong to gain an understanding of fish movement within the system.

A final question of interest is the facultative role of the concentration of elements, as there is some evidence that high barium levels facilitate the uptake of strontium.
3.1.3.6.1. Overview of discussion:

The precipitation of carbonate minerals at high salinities in the South Lagoon may be an explanation for the non-linear relationship between barium and calcium concentration in the water column. Calcium is being removed from the system, so the baseline amount changes with salinity. Temperature also affects the uptake of elements, although its impact is smaller than that of salinity.

A challenge will be determining a way to unravel the habitat preferences and active movement of the fish from the passive changes in environmental variables around them. Mobility of fish does vary across species and the likely habitats can be identified on the habitat maps. One species that does not move much is the goby, which may be a useful species to try, since that removes this problem.

The resolution of the analyses may be in the order of a few weeks for fish movement, but will not be shorter.

3.1.4. Project updates

3.1.4.1. Lipid & pigment biomarkers for assessing organic matter sources and fates

The ongoing work in developing lipid and pigment biomarkers for organic matter sources, being undertaken by CSIRO Marine and Atmospheric Research, was introduced by John Volkman.

The aim of the research that is being undertaken is to identify the major sources of organic matter within the Coorong, and then to understand the pathways through which this organic matter is degraded. Possible sources of organic matter include phytoplankton, microphytobenthos, macrophytes, terrestrial inputs, aquatic organisms and organic contaminants.

In order to do this, water and surface sediment samples have been analysed for stable carbon and nitrogen isotopes. They have also been analysed for lipid constituents, and chlorophyll, and carotenoid pigments. Each possible source of organic matter will have a unique combination of these various components, allowing the identification of sources within the samples. For example, most algal classes have diagnostic pigments that allow them to be identified as contributing to organic matter in the system. The amounts of pigments, which expressed as a ratio to organic carbon content, can then be used to give an estimate of biomass of each group.

Sediment sampling was undertaken at five sites along the salinity gradient of the Coorong. Samples of possible source materials were also taken, but further work on this aspect is needed. It was hoped that these data could be used as a reference for studying changes in organic matter sources in sediment cores, but this may be difficult since we are now sampling a degraded system with restricted and atypical biota. Changes in physiology to cope with a stressed condition may also affect lipid compositions.

Initial analyses have revealed quite an unusual signal in the carotenoid and chlorophyll marker pigments in the Coorong waters. Much less diatom-derived pigment was found than is usual for coastal and estuarine settings, and the organic matter seems to be dominated by contributions from green algae. A different picture emerges from analysis of the surface sediments. Here, the organic matter appears mainly derived from diatoms, presumably present in the microphytobenthos, indicating a disconnection from the water column.

Further investigation into the sources of organic carbon can be done by analysing the structural diversity in the sterols detected. The sterols produced by an organism are dependent on the biosynthetic pathways used and various groups have diagnostic sterols. The diversity of these sterols, in combination with other analyses, provide overlapping information that helps to
interpret the source of organic carbon. For example, long-chain alcohols provide a useful
indicator of contributions from higher plants and seagrasses; sterols are good indicators of
microalgal sources and higher plants; fatty acids are good markers for bacteria, microalgae and
fauna.

3.1.4.1.1. Overview of discussion:

More information is required about some additional potential sources. Ruppia, for example, has
not yet been collected, and more information is needed about zooplankton.

According to Evelyn Krull’s work on stable isotopes, there does appear to be a big shift in the
organic matter characteristics that may be coincident with the construction of the barrages. This
may be able to be explored further within this project.

3.1.4.2. Nutrient sources and sinks in the Coorong

Investigation into the nutrient sources and sinks in the Coorong is being undertaken by
Geoscience Australia. Ralf Haese provided an introduction to the work so far.

The objective of the research is to determine the magnitude of nutrient release from the
sediment in winter and in summer and to identify the implications of nutrient availability on
primary productivity in the Coorong. This study will reveal whether sediments act as either a
source or sink of nutrients under hypersaline conditions. As part of this study we will try to
identify minerals containing phosphorus that may precipitate under those conditions. Groundwater discharge is also being investigated as a possible source of nutrients.

Benthic and pelagic coupling is a very important process in determining the nutrient cycling
within a system. Nutrients are imported from the catchment, and exchange with both the ocean
and the atmosphere. Within the estuary, algae and bacteria contribute to the cycling of
nutrients, through nutrient uptake during primary production and nutrient release through
organic matter decomposition. Phosphorous trapping within sediments as opposed to
phosphorous release from sediments can play a major role in determining the amount of
phosphorus available in the system.

Based on thermodynamic calculations and an observed decrease in the ratio of calcium to
magnesium along the salinity gradient Phillip Ford suggested that mineral precipitation is
occurring in the Coorong, in particular towards the southern end of the Coorong. Similarly, the
abundance of algal biomass has indicated that there is an increase in phytoplankton abundance
with distance from the Mouth.

In order to understand the nutrient sources and sinks in the Coorong, samples were taken at
five sites along the salinity gradient in both winter and in summer. Analysis of these samples
revealed a strong increase in total nitrogen along the length of the Coorong, which appears to
be driven by dissolved organic nitrogen. An increase was also observed in phosphorus
concentrations, but there was a major shift in the nitrogen to phosphorus ratio at the southern-
most site, which appears to be due to a large increase in ammonia south of Salt Creek.

Primary production and organic matter decomposition rates in the benthos and water column
were measured under both light and dark conditions. In the dark, the sediment is a net source
of dissolved inorganic carbon, but under light conditions, there were huge rates of primary
productivity and uptake of inorganic carbon. As benthic primary production was much higher
than organic matter decomposition in sediments, re-suspension of surface sediments with
associated microbenthic algae and subsequent organic matter decomposition in the water
column may be important. Primary production in the water column was significantly higher than
at the sediment surface. There appeared to be very little ammonia release and even uptake of
phosphate by sediment under dark conditions suggesting that the sediments are not a major
source of nutrients in the Coorong.
In addition to a loss of phosphorous along the salinity gradient, there was also an observable loss of fluoride with increasing salinity. This suggests that mineral precipitation, possibly in the form of calcium fluorapatite is occurring. Additional analysis is needed to determine whether phosphorus is involved in this precipitation or not.

Groundwater seeps were observable at several sites, particularly in the South Lagoon, along with accreted carbonate mounds suggesting significant groundwater input over prolonged periods in the past. Analysis of groundwater samples for nutrient concentration is ongoing and will reveal whether groundwater is a significant source of nutrients in the Coorong.

3.1.4.3. Modelling the states of the Coorong

An update on the CLLAMM Futures project was given by Rebecca Lester, focussing on modelling the ecosystem states of the Coorong.

The analysis and modelling requirements of CLLAMM Futures are quite challenging. The available data is extremely patchy in both space and time. It contains a mixture of qualitative and quantitative data, and was collected using a myriad of techniques over some years to a few decades. A review of possible techniques that could be applied to give an ecosystem-scale understanding of the system was undertaken. Of the twelve broad approaches assessed, several were identified as being most likely to be useful. State-and-transition modelling would provide a framework in which to assess changes to the ecosystem. Classification and regression tree and multiple regression tree analyses could be used to identify and define alternative states within the dataset, to define the thresholds between these states and to identify indicator species within state. Structural equation modelling would enable the parameterisation of existing conceptual models, further identifying differences between states and requirements for the continuance of indicator species. Finally, Bayesian belief networks would provide an environment in which to build the results of analyses into the state-and-transition model.

Six ecosystem states were hypothesised for the Coorong at the beginning of the project. Analysis has commenced to confirm whether these states exist, are distinct, and are comprehensive within the Coorong. The period for which the greatest coverage of data exists is 1999 to 2007. Within this timeframe, conditions exist that could be considered to fit three of the six states, with possibilities for another two. The final state, a true estuarine condition, falls outside the scope of the available dataset.

Initially, a biological dataset, comprising the distribution of *Ruppia tuberosa*, bird species and commercial fish catches (as catch per unit effort), was constructed. The coincidence of the datasets limited it to the period of 2000 to 2006, for ten of the 12 key CLLAMMecology study sites. Macroinvertebrate distributions were excluded due to the comparatively small number of years in which the data was collected. Cluster analysis revealed the presence of five distinct groups of site years and a similarity profile permutation test confirmed the cut at five groups. Membership within these five biological clusters was then used as a dependent variable in analysis of the environmental data. An environmental dataset comprising water quality measurements, meteorological data and modelled water levels and flow over the barrages was constructed for all twelve sites between 1999 and 2007. Classification and regression tree analysis produced a tree with six terminal nodes, identifying alkalinity, minimum water levels and average daily and annual rainfall as significant variables distinguishing between the groups. One biological cluster was split between two nodes, one was not distinct from the others and the cases that had been missing in the cluster analysis were also split between two nodes. This required further analysis to determine the number of distinct groups in the biological data.

ANOSIM analyses of the biological data confirmed the existence of six distinct communities within the Coorong. Indicator species for each were identified using SIMPER analysis, and all of those comprising the top five driving similarities within groups were bird species. This may be a reflection of the bias in the commercial fish catch data against small-bodied species, which may be more likely to be driving diversity within a community.
The next stages for the analysis are to fill data gaps where possible to simplify the state
definition analyses and to compare the states identified with the original hypothesised states,
and those that result from more detailed analysis of the data collected during CLLAMMecology.
Additional work will then more extensively define the boundaries of each state and the points
of transition between them. The challenge of how to characterise and parameterise states that fall
outside the scope of the currently-available dataset also remains.

3.1.4.3.1. Overview of discussion:

The intention with the state analyses is to link the distribution to the habitat maps and compare
the current (and future) distribution of states with that in the past. The expectation is that at any
one time, there will be a range of states along the full length of the Coorong.

The absence of fish species within the identified indicator species was commented upon, with
the suggestion that data intensity may affect the outcome of the analyses. Further analysis will
be needed to confirm that this is not a problem within the current methodology.

A number of areas that have not yet been covered were also raised. Data from the 1980s and
palaeoecological data are likely to be used for validation of the predictions of the models.
Ecosystem functions, as well as species diversity, has not yet been incorporated, due to a lack
of long-term data, but for short-term analyses on dataset collected during CLLAMMecology,
there is an opportunity to include measures of function.

3.1.4.4. Distribution of benthic macroinvertebrates in the Coorong

An update on the status of work into the distribution of benthic macroinvertebrates in the
Coorong was presented by Alec Rolston.

Surveys of macrobenthic diversity were completed at eleven sites in December 2006, and
January and March 2007. Surveys of juvenile distribution continued through to October 2007
but the number of sites was reduced from 11 to 8 as a result of juvenile distribution patterns
from December ‘06 to March ‘07. A sediment transfer experiment was also conducted from
January 2008. This was designed to test the response of macrobenthos to different levels of
salinity and different tidal exposures.

The distribution of adult macrobenthos in the Coorong is strongly linked to the upper salinity
tolerances of the species. Most species have a salinity tolerance of 50 to 80 ppt (except
chironomid larvae, which can survive to 177 mg/L, approximately 175 ppt). These salinity levels
were reached around Noonameena in each of the surveys, and correspondingly, very few taxa
were present south of this site. A decline in benthos was also observed over time. Community
composition analyses identified significant differences between the macrobenthos in the estuary
and the North Lagoon compared to the South Lagoon. No differences were detected in the
communities at a given site from year to year.

Juvenile distribution varied for different species. Distribution was patchy in both space and time,
but the majority of juveniles were located in the estuary, with some occurring in the North
Lagoon. Only insect larvae were found south of Noonameena.

The sediment transfer experiment was designed to examine how species reacted to changes in
inundation regimes and salinity levels. The study was initially to be conducted across four sites
in the estuary and North Lagoon, but large amounts of filamentous algae made Monument
Road unusable, so the experiment proceeded at three sites. At each site, two tidal elevations
were used, low elevation, where mudflats were usually covered by water, and high elevation,
where inundation was periodic. The experiment involved two types of transfers of sediment
cores: within a site (termed ‘selfs’) and to another site (termed ‘outs’). Controls where no
transfer had occurred and where transfer occurred within a site and a tidal elevation were also
taken. At each site, sediment was transferred between tidal elevations, between sites at the
same tidal elevation and between tidal elevations and sites. Samples were taken prior to
sediment transfers, to establish background community composition, and then one week, two weeks and six weeks after transfer. In all, approximately 600 sediment cores were taken, either as transfers or controls.

Counting and identification of the samples is ongoing, however some preliminary observations can be made. Due to low water levels, high elevation sites at Noonameena and Long Point were not inundated during the study. In these dry conditions, organisms were unable to survive one week without inundation. This indicates that to be useable habitat for macroinvertebrates, mudflats must be inundated more frequently than weekly. Also observed were a general decline in the benthic community at Ewe Island, particularly for Capitella and Simplesetia, high numbers of Capitella at low elevations at Long Point and an absence of fauna other than Chironomid larvae at Noonameena.

During the project, salinities levels were relatively constant, at around 40 ppt at Ewe Island, 60 ppt at Long Point and fluctuating around 100 ppt at Noonameena. Background numbers of juveniles at Ewe Island and Long Point were similar, with Long Point having more individuals than Ewe Island, but a decline over time was observed at Noonameena. All observed numbers of juveniles were low compared with numbers recorded during previous sampling trips.

Other analyses that are continuing are the reproductive status of polychaetes collected, sediment grain size and organic content analyses, and further analyses of the macrobenthos distribution data.

3.1.4.4.1. Overview of discussion:

A question as to the benthos in the remainder (i.e. deep areas) of the system was raised. Very little was found south of Noonameena, but surveys past this point did cease in March 2007 due to a complete lack of taxa.

One major unanswered question is the recruitment source of the species found in the Coorong. If Coorong populations are only recruiting from within the Coorong itself, there are major implications for the recovery of the benthic community and the time over which this is likely to occur. Recruitment from outside the Coorong would likely occur more quickly, but also has implications for the importance of Murray Mouth dredging in keeping that connection open.

3.1.5. Group discussion

- Linking findings between projects, model inputs and outputs
- Implications of results and directions for further analyses Lipid & pigment biomarkers for assessing organic matter sources and fates

3.1.5.1. Overview of discussion:

Primary productivity is one area where the overall story is not yet clear. A number of groups are working on aspects of the how primary productivity functions in the Coorong, and the results that they are obtaining need to be integrated. The stories are not necessarily different and there are similarities, but there are also unexpected results. An investigation in the same units of measurement should be undertaken. One possible explanation for the observed patterns in primary production may be that there is a lack of consumers to take resources from the South Lagoon.

One of the problems associated with integrating the findings related to primary productivity is that most of the surveys have involved spot measurements. These are never going to tell the whole story. A good baseline from which to predict benthic algal activity does not exist,
although Sasi Nayar and Maylene Loo have some data. Seasonal changes are unlikely to be well captured though.

A number of elements are missing from our understanding of the functioning of the CLLAMM region. The role of microbial communities and macroalgal mats is missing from the picture (except for some work being undertaken by Jim Mitchell and Laurent Seuront), as is the effect of these on the mudflats below. We have very little idea of what may be coming through the Murray Mouth, with no water quality data for coastal regions. We also have little idea of the impact of atmospheric deposition. The effect of dredging on the benthic communities is also unknown. It may be contributing to the turbidity of the water and represents a major disturbance. Dredging may be the reason for a lack of seagrasses around the Murray Mouth, however there is a general view that it is necessary to keep the Coorong alive. The impact of dredging may also change with time. It would be good to be able to make some statements about the wider benefits of dredging, and provide justification for keeping the Murray Mouth open, given the financial investment in doing so.

The offshore benefits of river flows are also missing from the project. A project that begins to address this has been submitted to FRDC to look at the dynamics of Goolwa cockles, but it is known that the fishery has not suffered dramatically. However, one species of cockle is not a whole ecosystem and the developing acidic problem in the Lakes may have a significant impact on the coastal ecosystems if it is flushed into Encounter Bay. It would be useful to study the effects of this in the future.

Another element missing from our understanding of the system may be the channel in the centre of the Coorong. The feeling was that there was not much biota in the channel, but that it may be important for fish movement or productivity and fluxes of nutrients from the sediment. Spot work has been done by Milena Fernandes, who found enormous microbial mats at Long Point. Bathymetry for the South Lagoon is also missing, but is due to be flown (although timing is uncertain). Even if it is flown soon, there is a question as to whether we can incorporate it into the habitat maps. Additional focus on the Lower Lakes would have also been useful.

CLLAMM II would also be our opportunity to put our Coorong understanding into a wider context. The addition of studies on the Lower Lakes, the Lower River Murray, and the oceanic connection would greatly enhance our understanding of the overall system. Other research that could be focussed upon during CLLAMM II includes the functioning of the end of the South Lagoon, beyond Salt Creek, the seasonality of the system, and the biology of *Ruppia megacarpa* and *tuberosa*. Process-based experiments and key knowledge gaps identified during modelling could also be included.

Other interesting questions focus on the effects of drought. There is the potential for surprising changes to occur in the system that may not be predictable yet. For example, new diseases may appear. Groundwater inputs and dry deposition may become more important, even though these have not necessarily been important in the past. It is important to be alert to surprises that may arise in the system, and to do this a good understanding of ecosystem functions is necessary.

Recolonisation is going to be a difficult process to model at the moment. It needs to be linked with water regimes. The timing, extent and duration of flows over the barrages will be important in determining the rate of re-colonisation and need to be considered.

Data sharing is likely to be an issue for the Cluster, with such a large number of people and projects. A list of all datasets available would be useful. A review of what the Coorong used to look like would also be useful. All historical information could be collated into one document. The species of phytoplankton found in the Coorong is an example where additional data sharing would be helpful. Rod Oliver and Sasi Nayar will be identifying species in the coming weeks, and this information is needed by Barbara Robson to incorporate into the biogeochemical model.

Some discussion occurred as to whether the North Lagoon and the South Lagoon should be looked at separately. Palaeoecological information indicates that they may operate as two separate systems. However, a number of project members seemed to think this would be
counter-intuitive for the modern system, given the recent connectivity between the Lagoons, the changes in processes occurring along the salinity gradient, and the wish to maintain a diversity of systems within the region (e.g. for the Ramsar accreditation).

A possible revision of the list of identified key species was raised. For example, the tubeworm *Ficopomatus enigmaticus* was postulated as now being a key species. The general consensus appeared to be that the list would be reviewed prior to any CLLAMM II application.

Another point to be considered is how we translate the information we are gathering to the general community in a manner they can understand. Key questions may include: how much water we require to keep the system going; and whether new paradigms should be considered for the system. We also need to be aware of the social and economic consequences of what we are saying.

### 3.1.5.2. Outcomes of discussion

- A synthesis of findings about primary production is needed to identify the similarities and differences between the findings of groups and find a cohesive story.
- An assessment of the impact of dredging would be useful, including the benefits and disbenefits that are apparent in our dataset. This will provide managers with the justification (or otherwise) to maintain the investment in keeping the Murray Mouth open.
- Additional measure may be necessary to further facilitate data sharing. A list of all available datasets should be created urgently.
- The possibility of creating one document containing all historical information about the Coorong should be explored. Who would undertake this task?
- Rod Oliver and Sasi Nayar to discuss phytoplankton species list with Barbara Robson when it is available.
- Additional ideas for CLLAMM II should be collated so they are of use to the management committee in developing their future plans.

### 3.2. Day 2

#### 3.2.1. Introduction to workshop objectives

Peter Fairweather gave an introduction to the objectives for Day 2 of the second CLLAMM Futures workshop. The intention was that the second day be much more interactive than the first, which was an overview of the work completed to date. The day would include presentations from Sebastien Lamontagne and from Barry Brook that would provide an update on climate change science, how conditions may vary, what was likely to be relevant to CLLAMM Futures and how others were incorporating climate change into their modelling.

From here, there would be discussion about what we were actually able to do to manage the system and identify any additional management levers to be included in modelling. The last goal for the day was to determine what type of scenario modelling to undertake as a part of CLLAMM Futures, including how many scenarios to run. In order to gain an understanding of the future condition of the Coorong, we will be constructing a chain of models through which a number of scenarios will be run. These will include the hydrodynamic model and biogeochemical model being created by CSIRO, the dynamic habitat model and the ecosystem state model being developed by CLLAMMecology.

Peter outlined two broad approaches to scenario modelling. The first option is to begin with a given set of initial conditions, the current state of the system, for example, and to explore the
effect of a given scenario over the run time of the model. The second option was to identify a set of desirable states as an end point for the system and attempt to identify scenarios that result in this endpoint. The second option has the drawback that it may involve striving for impossibilities or closing off options quite early. With the second option, it is also important to be clear what you are aiming to achieve. Is the desirable endpoint for the system embodied in how the Murray Darling Basin is currently operated? Should it reflect the conditions when the region was declared under the Ramsar treaty? Should it be one large true estuary or should some palaeontological reconstruction be designated as the ideal endpoint? Some concerns associated with the second approach of choosing a desirable endpoint are that it may result in a monoculture across the system, that it may be beyond our expertise to identify the consequences of the endpoint (for example, the social implications), and that it may be more political than what we are charged with doing. A decision needs to be taken as to which of these approaches is going to be most useful for CLLAMM Futures.

Key questions to be answered prior to the commencement of modelling are: how many scenarios to include; how disparate these would be; how far ahead we are aiming to manage for; what the starting conditions should be (for example, should we start with the 2008 habitat map?); which future climate conditions do we wish to model; and which management levers are most important to include. In order to answer these questions, we need to consider the scenarios that are going to be most useful to inform managers of what is possible.

3.2.1.1. Overview of discussion:

There are only a couple of examples of other modelling exercises that are considered similar. Port Phillip Bay, in Victoria has been modelled from the perspective of denitrification processes. The approach that was taken here is not possible in the Coorong at this stage.

Feedback loops should also be considered. For example, the consequences of a disease outbreak or changes due to climate change may be important. The effect on human health may be relevant. Are there going to be links between the scenarios and, if not, where does reality lie? Incorporating these will not be straightforward and, while we hope that the behaviour in the system will be captured, we haven’t focussed on this aspect yet.

3.2.2. Current climate change work & relevance to Coorong

3.2.2.1. Scenarios developed by the CSIRO Sustainable Yields project

Sebastien Lamontagne provided an overview of the CSIRO Sustainable Yields project and the scenarios that were developed as a part of that project with a view to incorporating these scenarios in the modelling undertaken by CLLAMM Futures.

The CSIRO Sustainable Yields project arose from a meeting between the Prime Minister and the various state Premiers on Melbourne Cup Day, 2006. There was a reasonably limited brief provided for the project. This was to assess the risks associated with climate change in the Murray Darling Basin, and to integrate, for the first time, the treatment of ground and surface water in the modelling undertaken.

A number of organisations were involved in the project, including the National Water Commission, CSIRO, the various state management agencies, MDBC and several consulting firms.

The aim of the project was not actually to develop figure that represented sustainable yields for the catchments. Instead, the project was designed to assess how much water there is at present in the system and how much there will be in the future. In doing so, it takes the first step towards identifying so-called sustainable yields in the future. The project was set up to allow assessment of the impacts at environmental, socio-economic and stakeholder levels.
The Murray Darling Basin was divided into a series of sub-catchments. In each catchment, rainfall and runoff under a variety of climate change scenarios was modelled. This modelling was then used to predict how much surface and groundwater would be available and involved the use of a wide variety of pre-existing river models. The output from each sub-catchment was then fed into the overall river system models (such as BIGMOD) to develop the surface water and groundwater interactions. So far limited environmental assessments have been carried out, and reporting of the findings is a large and ongoing task. The projected date for the availability of the reports is April 2008 (although this estimate has been extended since the workshop).

Several scenarios were used in the modelling. These included one that modelled the effects of the current level of development in the basin with historical climate conditions. A second scenario modelled the current level of development in the basin under recent climatic conditions (i.e. 1997-2006) to assess how drought conditions would affect the system if they were to persist on the longer-term. The third suite of scenarios involved assessing the current level of development under a range of future climate conditions. These included identifying three levels of warming and obtaining output from 15 global climate models to end up with 45 scenarios of water availability. From these, one of low water availability, one of high water availability and a moderate scenario were chosen to bracket the possibilities. A fourth set of scenarios used these three chosen levels of water availability to assess the effects of future development in the basin, although 'future development' was limited to changes in forestry, farm dams and groundwater extractions. Additional environmental flows, including the water from the Living Murray project and the proposed buy-back of water licenses is outside of the scope of the current study. It is possible that future extensions of the project would also include increased allocation of environmental water.

The river system modelling that was undertaken used more than 40 different river models. Most of these operate at a daily time-step and are link-node models. All of these models have been extended to operate for the full 1895-2006 run-time of the Sustainable Yields project. Groundwater modelling was limited to modelling the recharge of a selection of ‘priority’ aquifers. The alluvial aquifers used for irrigation in northern NSW were an example of a ‘priority’ aquifer. The final stage of the project was to evaluate a water balance for the 600 stretches of river modelled individually in the project. Water accounting was undertaken to identify an errors that may have been propagated through the system, and to determine how accurate the modelling was. Additional work will now begin on areas where modelling was thought to be poor, such as the interaction between surface and groundwater.

An example of the output was provided for the Border Rivers in Queensland and NSW. The catchment occupies 4% of the Murray Darling Basin and accounts for approximately 4.4% of the surface water and 2% of the groundwater used in the MDB, primarily for cotton irrigation and grazing. The catchment contains one important wetland, where some assessments of environmental impact were conducted. The key findings for this catchment were that there was a high level of surface water diversion and a high level of groundwater development. In this region, the previous 10 years’ climate was not particularly different from the long term average, so the second scenario was not modelled for this catchment. As a result of climate change, there is likely to be a 10% reduction in the amount of available water in that catchment. This would mean that the projected use of groundwater in that catchment in 2030 is likely to be unsustainable. However, projections indicate that there is only likely to be 2% less water available for extraction, with environmental flows decreasing to absorb the remaining deficit. If the driest estimates arising from the project are true, then there will have to be changes to the rules governing water sharing between the states and for the environment.

While it is not necessary that CLLAMM Futures uses the scenarios developed by Sustainable Yields, there is a good opportunity here. Over the long term, there are good estimates of daily river flows under a variety of climatic conditions. There is also some simulated climatic data for the region already and the National Water Commission has given permission to use the data for CLLAMM Futures.

A number of lessons arising from the CSIRO Sustainable Yields project are applicable to CLLAMM Futures. Even a relatively simple set of initial scenarios resulted in the generation of a massive amount of data. Reporting was a significant component of the analysis and more time...
consuming than expected. The project has been a learning process and areas of weakness in system understanding have come to light over the course of the modelling exercise.

3.2.2.1. Overview of discussion:

Joe Davis highlighted the benefit of the available river-flow modelling for CLLAMM Futures as this could be directly translated into flows over the barrages. He also clarified the process through which MDB Icon Sites will bid for water in the future, focusing on developing resilience and healthy systems. In the future, there will be an attempt to juggle system operations to get additional water to the end of the system, but as a general rule, the environment is often the user that absorbs any shortfalls.

There was agreement that it would be useful to know what is necessary to keep the Coorong going. It should also be considered, however, that there are physical limitations associated with putting water across the barrages, and that with the current level in the Lower Lakes, it is not physically possible to spill water to the Coorong.

It was felt that the current situation tended to focus attention on the pessimistic options for the system, but that it was also important to include some optimistic scenarios as well. However, a survival strategy for the coming few years while the Lower Lakes were below operating range was also thought to be useful.

3.2.2.2. The impact of climate change on sea levels and catchment runoff

An update into the latest climate change science and, specifically, how this was likely to affect the CLLAMM region was presented by Barry Brook. His presentation was focused on the effects of climate change on catchment runoff and sea level rise.

In the past, there have been clear peaks and troughs in both greenhouse gases and global temperatures. Large fluctuations have been observed at numerous times in the past 400,000 years. During this time, the Coorong has been transient, existing and not existing due to changes in sea level tracking the temperature fluctuations quite closely.

Sea level is very dynamic and has varied over a massive scale historically. The changes in sea level can also be very rapid once an initial inertia is overcome, and rates of a metre every 20 years have been observed under levels of forcing much smaller than what is currently occurring.

The current rate of change in temperature is increasing. An increase of approximately 0.2 to 0.3°C per decade has been observed. The rate of change, however, is not uniform across the globe. The observational record shows substantially higher levels of warming at the poles, and at the North Pole in particular.

Locally, more variability in the climate record is apparent. A strong trend towards warming can still be detected, with the last 20 years consistently showing positive anomalies relative to the long-term average. With this warming, there have been shifts in the pattern of rainfall across Australia. The north-west of the country has become wetter since 1950, and there has been a drying of the south-east. It is thought that Indonesian forest fires may have contributed to this pattern of wetting and drying by affecting weather patterns.

The trend in sea level is also one of accelerating increase. In the period from 1880 to around 2005 there has been a rise of approximately 20 cm. In addition to the actual amount that the average sea level rises, storm surges are an important consideration. Increases in temperature tend to produce more intense tropical cyclones and the current concentration of people living near the coast increases our vulnerability to future risk from such storm events.

There has been an expansion of tropical weather patterns by about 2° latitude. This represents a current expansion of 3%, which is more than was predicted for the entire 21st century. This expansion of tropical weather systems pushes temperate weather systems further south, and there is already an increase in the number of rain-bearing systems that are now missing the southern coast of Australia and raining over the ocean instead of over land.
Water vapour is the most powerful greenhouse gas. It is responsible for around 70% of the warming due to greenhouse gases. Increased water vapour is, however, largely an effect of the other greenhouse gases in the atmosphere. If all these other gases were removed, the water would simply rain out of the atmosphere. The other gases act to trap it in the atmosphere instead. The additional ability of the atmosphere to hold water may, however, lead to more rain.

The current IPCC projections for climate change indicate that we are already committed to 0.3 to 1°C of additional warming, with no further addition of greenhouse gases to the atmosphere. A range of scenarios have been developed for projected future warming, with the worst of these predicting further increases of up to 6.4°C this century. As for previous warming trends, there will also be significant polar amplification of these warming patterns, with possible increases of more than 7°C for the North Pole. The Garnaut report is investigating the impact that this warming would have on the Australian economy, but current measurements indicate that we are already tracking beyond the scenarios used in that report in terms of emission increases.

The IPCC use a variety of possible warming scenarios. The outcomes for this range of scenarios in terms of mean surface temperature is very similar in 2030. The differences, however, are stark by 2090. With increasing levels of warming, and greater timeframes, however, the uncertainty associated with the predictions also increase dramatically. Current projections suggest that Australia is likely to be 1 – 2°C warmer by 2030, and 4°C warmer by 2070, although this may be as much as 7°C. There is also likely to be a significant increase in evapotranspiration, leading to a net decrease in runoff.

Available models do quite a reasonable job of describing current rainfall patterns. They capture all of the major weather systems. Analysis of the anomalies suggests that Australia is going to continue to get drier, with decreases in average annual rainfall in the order of 5 – 10%. While these models do not suggest a big decline in rainfall, they do suggest an increase in variability and a large increase in evapotranspiration, so the 5 – 10% decline in average annual rainfall is likely to result in a significant decline in runoff. In particular, the number of days where rainfall is sufficient to cause runoff declines significantly.

Sea level has already risen 10 cm in the last 60 years. Current predictions for future rises suggest that increases of 20 - 60 cm in the next century are realistic. These are derived from models of thermal expansion and contribution of land based glacial ice melt. However, the models exclude uncertainties in icesheet dynamics (which may cause an additional 20 – 40 cm of sea level rise) and more rapid ice melt and ice sheet disintegration, because these can’t be modelled, so larger increases of the scale of 1 – 4 m cannot be confidently ruled out.

At this time, measurements of atmospheric carbon dioxide are above the most extreme scenarios contained in the IPCC report. Growth in emissions was at 1% in 2000 and is now 3% in 2006. The current temperature record matches the upper bound of the predicted increases. Sea level rise is also above the 95% confidence interval for predictions and there are many fossil fuels left, so exhausting supplies is not going to solve the problem.

The rate of retreat of arctic sea ice has been a warning to the scientific community. Although it doesn’t contribute to sea level rise on its own, as it was floating ice, it has consequences in terms of the albedo of the region. The level of change observed in the last year was completely outside the previous experience. Scientists are concerned that it represents a step-change and a regime shift. The icecap is unlikely to survive by 2040 and may be lost as early as 2020. Greenland is another vulnerable icesheet. There has been an exponential rise in ice-quakes suggesting that there is increased movement in that iceshelf. This rise is not correlated with a rise in earthquakes. The Larson B iceshelf in Antarctica is another example. It was predicted to break up over 50 years, but suddenly broke up over a couple of weeks in 2002. Since its disappearance, the discharge rate from land-based glaciers behind it has tripled. If the Greenland and Antarctic iceshelves are lost, we could be looking at up to 14 m of sea level rise. The important question will then be the rate at which this change occurs.

Only a small change in global temperature is required to have a dramatic effect on the amount of sea level rise. Massive changes in the frequency of periodic inundation due to storm surge events are likely. At the moment, we appear committed to actual sea level rises of between 5 and 30 m. Again the important question is how long this will take to occur. In comparison to
previous conditions, the current changes are at the upper bounds of the total amount of change, but also at the upper end of the rate at which that change is occurring. This effectively makes it a massive instantaneous change that is going to be very difficult for many ecosystems to respond to.

3.2.2.2.1. Overview of discussion:

For the Coorong, we would expect that storm surges would regularly breach the mouth within the next decade or two. Within 50 years, it is possible that the whole system will be underwater. Developing a better handle on local variability will help to calibrate the predictions for local effects. At small scales, for the next 10 to 30 years, changes are likely to be largely driven by local variability. At time scales greater than this, change can be crudely estimated by the IPCC models. At this stage, we are not likely to have enough information to come up with a time series for the sea level in Encounter Bay.

There is not strong agreement in the scientific community as to how ENSO (El Niño and La Niña) cycles will be affected by climate change. Some models predict that La Niña will completely disappear. Others predict an increase in the amplitude of the system, or a semi-persistent El Niño to be established. Feedbacks to the global system may also make the outlook worse than suggested here. These would include the potential breakdown of circulation in the ocean, the melting of tundra and subsequent decay to release methane.

Most models do predict an intensification of the hydrological cycle. There is not an insubstantial level of risk in the next 10 to 30 years. We should be managing for the current drought to be a much more frequent event. The overall message may also be more pessimistic because of the political and social climate of denial.

3.2.3. Workshop CLLAMM Futures Scenarios

- Which parameters are likely to be affected by climate change?
- Which of these are important for the CLLAMM ecosystems?
- How do the SY scenarios apply to CLLAMM Futures?
- What beyond the SY scenarios do we want to model?
- Which management scenarios are of most interest?
- What are the rules governing barrage operations?
- Which other levers will be most important to cover?

3.2.3.1. Overview of discussion:

The purpose of this workshop was to determine which types of variables should be considered for use in the scenario modelling undertaken by CLLAMM Futures.

There has previously been little work done considering the effects of climate change on Australian marine life. Hobday et al. (2006) have undertaken one of the few analyses on how marine life is likely to be affected. From their work, changes in the ocean surrounding the CLLAMM region include an increase in sea surface temperature of 1 to 1.2°C, an increase in mean surface ocean currents of 2 cm/s in an easterly direction, a decrease in mean zonal winds of between 1 and 2 m/s, and a lowering of the mixed layer in the ocean of 0 to 10 cm. Other changes include a decline in pH or 0.15 to 0.16, a change in the aragonite saturation state (important for formation of calcium carbonate) of 1.0 to 1.1, an increase in downward solar radiation at the surface of 40 to 60 W/m² and a decline in precipitation minus evaporation of 0.5 to 1.0 mm/d. Sea-level height anomaly due to stratification is also likely to increase between 16
and 18 cm relative to the height in 2000. Realistically, the effects of climate change are likely to mean that floods such as that seen in 1956 are possible, as are even more extreme floods, but are less likely than previously.

A number of variations to management operations are being investigated for the Lower Lakes and Coorong. These are being driven by the extremely low water levels and are focused on addressing some of the issues associated with drying of sediments, including acid sulphate soils, increasing salinity and a lack of connectivity. The management options include assessing the impact of marine water on the lakes, increasing the connectivity between the North and South Lagoons of the Coorong, or possibly adding marine water to the South Lagoon.

Questions that managers raised as being critical to be answered were: what is required in terms of flow over the barrages?; and what is the level of resilience in the system? Knowledge of the types of flows needed to rehabilitate the system was also important, without necessarily considering how these flows were to occur, and an assessment of the number of years that the system can continue before it is likely to be irreversibly altered. By having information about what is required, there is a greater likelihood of attracting water from the Living Murray allocation. The key questions were what benefits would arise from a given volume of water. Other managers expressed a preference for learning what options are realistic now, what the short-term targets should be, how we stop the system from collapsing in the short term (i.e. what should the recovery strategy be?) and what the effect of climate change was likely to be. It was observed that, in the short term, the only source of water available is marine water, but that the Ramsar listing for the region was based on the benefits of receiving freshwater inputs. Management options that removed the option of future freshwater inputs were seen to be less desirable than those that maintained the option.

Connecting the South Lagoon to the ocean and disconnecting it from the North Lagoon has been suggested as a management option for the Coorong. There were seen to be inherent benefits of having the river run to the sea, which was reflected by the investment of $4.5 million per annum on dredging the Murray Mouth. It was also recognised that after some period of time, the addition of fresh water to the Coorong would lead to a different recovery trajectory from that seen during the decline and that we may not achieve the same ecosystem back.

An overview of the barrage operating rules was provided by Mike Geddes. Traditionally, the Lakes have had an operating level of 0.75 m AHD. More recently, they have been surcharged to 0.85 m AHD in spring and allowed to spill only when additional water was forecast to enter the system. From heights of around 0.5 m AHD, it is no longer possible to allow water to spill across the barrages because of intrusion of salt water back into the Lakes. The maintenance of the Lakes at 0.75 m or 0.85 m AHD has implications for the fringing wetlands, which are continuously full. Releasing water when the Lakes are at 0.75 m AHD has benefits to the Coorong and fish communities and restrict sand ingress through the Murray Mouth. Automated water gates have been or are being installed in each of the barrages to allow operation with tides to reduce the inflows of salt water to the Lakes.

For the Lower Lakes, questions of interest included what the effect of salt intrusion was likely to be and what flows would be needed to flush the Lakes to return them to a fresh condition. In order to maintain the current water level, flows of 500 to 700ML per day are required, and further modelling work is being done to assess how much water is needed to fill them. Under the possible management option of opening the barrages and allowing marine water to enter the Lakes, it would be important to understand whether these would also become hypersaline, like the Coorong, or estuarine. An estuarine condition, however, is unlikely due to the lack of freshwater. In this situation, the Lakes would most likely be marine in character. If this option was adopted, it would be important to realise that it involves losing the option to add fresh water to the Coorong, but perhaps there would be scope for the Lakes to act as a ‘new’ Coorong from the perspective of ecological value. Ralf Haese highlighted an example of a lake in the Netherlands that was kept artificially fresh and then re-connected to the sea and allowed to become marine. There may be learnings from this example that would apply to the Lakes situation. There are also some Australian examples, on a smaller scale, including the Peel-Harvey estuary in WA.
Interest was expressed in the ‘do nothing’ scenario, and in the possibility of recovery for the Lakes should they become marine and the option arose to resume a freshwater system. Debate occurred over whether salt water intrusion was likely in the River Murray past Mannum. Some modelling has been undertaken external to the Cluster that suggested it was unlikely to occur, but within the Cluster there was hesitation to accept that that would actually be the case, and caution was advised against relying on a ‘virtual weir’ based on freshwater head. The question of dredging to allow the Lakes to become marine was also raised, including the possibility of having to dredge through some of the islands between the Murray Mouth and the Lakes. Timing was also felt to be an issue, with the construction of a weir taking 10 months, which was felt to be too long a lead time to prevent the problems associated with acid sulphate soils. However, if there is not a very wet winter this year, some action will need to be taken, and opening the barrages is one.

The likelihood of acid sulphate soils being a problem in the Lower Lakes was also discussed. The possibility of simply accepting that it was going to occur and dealing with the effects was raised. As yet, no work on acid sulphate soils has been done in the Coorong. It was generally felt that more modelling needed to be done regarding the effects of acid sulphate soils on the Lakes. Lake Albert was seen as particularly vulnerable, so the option of dredging to improve connectivity there was raised. Thinking in terms of linkages and consequences was seen as important. The question of how to address acid sulphate soils if ocean water did not solve the problem was raised. Other consequences of allowing salt water into the Lakes were also raised, such as increased stratification and socio-economic consequences.

In terms of fisheries, the effects of any management options on the recruitment, growth and habitat would be important to understand. It would be useful to investigate how fisheries should be managed under the various scenarios. It was postulated that changing the Lower Lakes to a marine system would have impacts on callop, carp and other freshwater species. While the fishery is already for multiple species, a change in salinity would lead to a change in which species were available. The survival of the freshwater species would depend on connectivity with the river. There was also some discussion about how fisheries models should be constructed; using either a bottom-up or a top-down approach and whether this would need to be altered due to the effects of climate change. However, given that CLLAMMecology has not developed a model to manage fisheries, it was felt to be premature to advocate major alterations to the existing management practices.

Questions were raised about the effects of climate change and sea level rise on the barrages. The structures are currently operated to have a 100 year lifespan, but the suggestion that they may be over-topped within 20 years means that this may need to be re-assessed. Barry Brook suggested that coastal managers were going to need to make some difficult decisions in the next few years. For example, in the Netherlands, it has been recognised that sea level rise of 1 m will mean that their dyke system is not sustainable and result in a loss of 30% of the country. A decision will need to be made at some point in the future about whether we manage with the expectation of having more fresh water in the future or whether we manage with the expectation that conditions will remain similar to the current situation. The management options that are available under each situation are not the same, and we are not able to manage for both simultaneously. This should be addressed explicitly at some stage. There will also be costs associated with delaying this decision, should it need to be taken. We need to weigh up the costs associated with the delay and the risk that an early decision may prove unnecessary.

The likelihood of having freshwater in the next five years, based on historic records, would be nearly certain, but, the effect of climate change on this is unknown. The Living Murray water, to this stage, has not been released, and even when it is, there are six icon sites which all need it. It was recognised that there will be a deficit in storage that will need to be redressed before water reaches the CLLAMM region, as MDB will want to refill storages before allocating environmental flows. This raised questions about whether irrigation allocations would rise or whether additional water would be stored following the next rain. There may be a decision to keep allocations low to allow water storages to fill, but it is unlikely that the environment would be prioritised first. There was some hope, however, that if a strong case for water can be made for the Coorong and Lower Lakes, that water will be available before dams like Hume are full.
While it was recognised that the environment is not the top priority for management of the Murray Darling Basin, the connection of the river to the sea and the fact that it is the only major estuary in the Basin mean that the CLLAMM region is still important. For each of the modelled scenarios, it was deemed important to have a list of risks that accompany the predictions to allow for informed decisions. A broader, more long-term focus was also seen to be desirable, with the drought conditions tending to encourage micro-management of the system which may not be beneficial in the long run.

Discussion was then concentrated on developing a short list of scenarios (to be modelled) that would be most useful to managers. During this discussion, participants were reminded of the resources available to the Cluster and the limitations of the data and models available.

The Sustainable Yields project was seen as an opportunity to link CLLAMMecology with other high-profile research. While not all the variables that we require to run CLLAMM Futures models was generated as a part of SY, the future climate and future development scenario as seen to be a scenario of interest.

Other scenarios of interest that were identified for the Coorong were

- The effects of the Living Murray outputs (500GL for environmental flows)
- Larger average flows (i.e. Living Murray plus additional environmental water)
  - 1500GL
  - 4000+ GL
- Using the ‘Natural’ BIGMOD run to get an idea of the distribution of states without diversions and infrastructure
- A current conditions run
- The effects of climate change on the current conditions and on the natural run
- A worst-case scenario with no flows
  - and no dredging
  - and the effect of the current dredging
  - and additional dredging
  - and dredging between the North and South Lagoons
- An estimate of how much water the system needs
  - This could be based on salinity
  - Identify what the key number of gigalitres is
- A change in the Lake level at which spilling occurs to 0.35
- A run based on predictions from the Icon Site management plan of effects of flows of 50ML and 1GL to assess which barrage these should be released through.
- Upper South East Drainage scheme releases
  - 10GL
  - 40GL
  - 60GL

For the Lakes, scenarios of interest were

- Differences in Lake operating level
- Developing a range of options for the operating strategy
  - What do they achieve?
  - Start with the Icon Site Management plan and Ramsar plan
The effects of acid sulphate soils

Scenarios that were identified as being of interest, but falling outside the scope and ability of CLLAMM Futures included the effect of a South Lagoon connection to the ocean, the ecological benefits of an even lower operating level for the Lakes, and trading off of benefits between the Lakes and the Coorong.

Outputs of interest included the salinity in the South Lagoon under the various scenarios and how often the targets in the Icon Site Management Plan (and other management documents) were being met. The development of an envelope of conditions to capture the range of possible outcomes was also seen to be desirable.

It was also suggested that the Cluster would be wise to have a prepared 10 minute spiel ready in case of an opportunity to speak with a relevant minister. This would need to provide an overview of the situation in the CLLAMM region and the current challenges in a nutshell, along with some suggestions for improvement.

3.2.3.2. Outcomes of discussion

3.2.3.2.1. Questions of most interest to managers

Coorong

- What is a survival strategy for the Coorong? How do we stop the system collapsing in the short term?
- What kinds of flows are needed to rehabilitate the system? What is the recovery strategy?
- How much water does the Coorong need to keep going? What is needed in terms of flow over the barrages?
- What is the resilience in the system? How many years can it go before it is irreversibly altered?
- What benefits would there be from a given volume of water?
- What options are realistic now? What should the short term targets be?
- What will the effect of climate change be?
- What are the risks associated with each scenario?

It was seen as important to include both optimistic and pessimistic scenarios in the modelling.

Lower Lakes

- What are the expected impacts of salt water intrusion?
- What flows are needed to put it back to a fresh system?
- What would the conditions in the Lakes be if the barrages were opened? Would they go hypersaline, would they be estuarine?
- What is the ‘do nothing’ scenario?
- What are the effects of acid sulphate soils likely to be?
- Would dredging the Narrows help the situation in Lake Albert?
3.2.3.2. Most useful scenarios for the Coorong (in order)

Coorong

- Worst-case of no additional flows
- How much water does the system need?
- What happens if the Lakes operating level is lowered to 0.35 m.

Other scenarios were not given a priority.

From these options, a list of initial scenarios to be run by CLLAMM Futures will be compiled. An additional list of scenarios to be run should time permit will also be developed. These will be circulated to relevant managers for final comment and then adopted.

3.2.4. Group discussion

- Are CLLAMMecology and CLLAMM Futures on track?
- What are the possible weaknesses and pressure point in the project?
- What needs to be our next area of focus to make the Cluster work?

3.2.4.1. Overview of discussion:

The level of discussion in the previous session (before afternoon tea) was such that time did not permit this session to be held. From the perspective of CLLAMM Futures researchers, the most value from the discussions was to be gained in prolonging the previous session than to cut that discussion short.

3.2.5. Insights into the program

The CSIRO Flagship Fellow, Gene Likens, provided a summary of his insights into the Cluster, based on the proceedings of the workshop.

Gene believed that the Cluster was tackling a very difficult, but most important set of multidisciplinary, environmental issues, and that most of the key components of the system had been covered, especially within the Coorong. The major challenge will be in the integration and synthesis of these into a meaningful whole. The scenarios should be quite helpful in this regard but should be driven by an ecosystem perspective, which is more than just a collection of key species. The short time remaining in the project will also be a challenge in successfully finding ecosystem-scale insights. It is important to remember that models are simply a tool. They do not provide real answers to a problem in themselves.

The idea of a short spiel (the “elevator speech” or one-pager) ready for an opportunity to inform and influence the public and ministers is a good one. The input of CLLAMMecology into the management direction of the region is critical as no one else is in the same informed position to speak about current conditions in the region. This document should be prepared now. It will have the added benefit of forcing the projects to synthesise their information early, highlighting priorities and identifying points of disagreement. It may also identify any small gaps in CLLAMM that are still possible to address during the first phase.

The treatment of intellectual property within the Cluster is unclear. Is the Cluster speaking with one voice, or are there competing opinions? A book may also be a good way to communicate the overall findings of the project. It would provide a point of integration and synthesis and may have a bigger impact than any number of scientific articles, particularly in the public arena.
Gene also commented on the intellectual strength and diversity added to the project by the excellent group of post-docs. He raised a concern about the amount of trampling occurring at the relatively-small number of study sites with so many research activities occurring there. Finally, he suggested that a web cam focused on the Murray Mouth, or some other site on the Coorong or Lakes (like a bird breeding colony) streamed to the internet or for use by local television may be an excellent way to raise awareness as to the current and changing state of the system.

4. Conclusion

From the perspective of the CLLAMM Futures project team, the workshop was a success. It provided the opportunity for the Cluster members and stakeholders to liaise with one another and to update everyone on the progress that has been made so far.

The discussion into the management options and scenarios for CLLAMM Futures was comprehensive, interesting and engaging. The options that were presented were wide-ranging and numerous, indicating a willingness for all involved to think beyond previous management actions and attempt to find innovative solutions to a new challenge. The list of scenarios of interest developed both for the Coorong (to be modelled under CLLAMM Futures) and for the Lower Lakes (to be modelled as the LWA part of Productivity and Trophodynamics) represent a wide range of options in response to a range of potential future conditions. Limiting that list to a manageable number to be modelled during this first phase of CLLAMMecology will be challenging, and additional input will be sought from managers in making the final decisions. The CLLAMM Futures project team are looking forward to beginning work on the scenario development and applying these scenarios to the ecosystem model. We expect the process of predicting the outcome of each scenario to be illuminating and will provide ongoing information to other Cluster members and stakeholders during this process. Work is expected to be complete by April 2009 and additional results-based workshops will be held between now and then.
Acknowledgements

This research was supported by the CSIRO Flagship Collaboration Fund and represents a collaboration between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences.

We also acknowledge the contribution of several other funding agencies to the CLLAMM program and the CLLAMMecology Research Cluster, including Land & Water Australia, the Fisheries Research and Development Corporation, SA Water, the Murray Darling Basin Commission Living Murray program and the SA Murray-Darling Basin NRM Board. Other research partners include Geoscience Australia, the WA Centre for Water Research, and the Flinders Research Centre for Coastal and Catchment Environments. The objectives of this program have been endorsed by the SA Department of Environment and Heritage, SA Department of Water, Land and Biodiversity Conservation, SA Murray-Darling Basin NRM Board and Murray-Darling Basin Commission.

References

Appendix A: Participants

Attendees:
Kane Aldridge, Adelaide University
Michelle Bald, DWLBC
Simon Benger, Flinders University
Elisa Bone, Adelaide University
Corey Bradshaw, Adelaide University & SARDI
Barry Brook, Adelaide University
Justin Brookes, Adelaide University
Stacee Brouwers, DWLBC
Anthony Cheshire, SMU
Joseph Davis, Murray Darling Basin Commission
Brian Deegan, Adelaide University
Sabine Dittman, Flinders University
Peter Fairweather, Flinders University
Milena Fernandes, SARDI
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Apologies:
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Brenton Grear, DEH
Tom Hatton, CSIRO
Jason Higham, PIRSA
Justine Keuning, Flinders University
Coby Matthews, Adelaide University
Ian Prosser, CSIRO
Nick Souter, DWLBC
Stephanie Williams, DWLBC
Tim Wilson, DEH
Appendix B: Presentations

Introduction to CLLAMM project – Sebastien Lamontagne

Overview of the Coorong, Lower Lakes and Murray Mouth Program

Sebastien Lamontagne

OLLAMMecology workshop
4 March 2008

The Coorong, Lower Lakes and Murray Mouth

- Irrigation agriculture
- Tourism and fisheries
- Ramsar-listed wetland
- Living Murray river

- Spiritual home of the Ngaritjadjil

Flow regime of the Coorong

- Rising salinity in the Lower Lakes
- Decline in water birds and estuarine fish
- Sedimentation of the Murray Mouth
- Hypersalination of the Coorong

Ruppa – Key food sources

- Ruppa megacarpa
  - Perennial
  - Perennial
  - Thalentic species

- Ruppa tuberosa
  - Amphibious/semi-perennial
  - Tolerant
  - Perennial
  - Thalentic species
Current and future threats to the water supply of the region:

- Water diversions
- Continued high surface water extraction
- More groundwater use

Climate change:
- Projected increased temperatures
- More forest fires
- More evaporation

Land use change:
- Forest clearances
- Farm fires

Sea level rise

A "system" vision for the region:

The Coorong

Ecosystem Drivers

- Climate
- Land use changes
- Other factors

Management Levers

- Irrigation
- Water levels
- Sediment

Ecosystem Responses

- Wetland habitat
- Freshwater flows
- Water levels

Who is doing what?

Stakeholders

- WWCRC
- CSIRO
- Geoscience

Other funding and research partners

- PFCC, Living Murray, IPCC

CSIRO

- Hydromod
- Water dynamics
- Other research

Geoscience

- Aquatic dynamics
- Sediment

Properties of the linked model:

- Simple enough to enable long-term (30 years+) scenario analysis
- Can be integrated to current and future hydrological model of the Murray
- Built-in ecological response

Alternative ecological status analysis?

- Freshwater fish
- Saltwater fish
- Marine turtles
- Birds

Current Status:

- Fish numbers
- Salinity levels

Projected status:

- Fish numbers
- Salinity levels

Model output

Link hydrodynamic-biogeochemical model

- Sediment
- Nutrient balance
- Biodiversity status

Cleaning bed and banks (wetlands)
**Key Events**

- **June 05**: CLAMMecology begins
- **January 06**: Delivery of 1-D hydrodynamic model to the Cluster
- **March 06**: CLAMMecology “Futures” Workshop
- **April 06**: CLAMMecology Open Day in Goolwa
- **December 08**: Scenario analyses completed: end of field activities
- **June 09**: End of CLAMM and CLAMMecology

**Scenario analyses**

- Use flow scenarios from the MUdg Sustainable Yield project
- Add local management levers (UEE drainage scheme, Murray Mouth dredging, etc)
- Impact of sea level rise on Coorong?
Trophodynamics – Brian Deegan

**Overview**
- **Productivity**
  - Extensive productivity survey conducted January '07
  - Seasonal measurements of pelagic and benthic productivity in the Coorong
  - Modeling of Coorong marine base
- **Food Webs**
  - Determine if different food webs exist
  - Determine the structure of these food webs
  - Identify keystone/keystone species

**The trophic pyramid**
- Tertiary consumers
- Secondary consumers
- Primary producers

**Food webs**

**Alternative ecological states analysis**
- Territorial
- Territorial
- Territorial
How does the food web structure change along the Coorong and Murray Mouth salinity gradient?

How we will do this?

- Literature Review of the diet of key species
- Field investigation of diet of key species of fish and birds
  - What food sources are present
  - Fish stomach content analysis
  - Field observation of bird foraging
- Stable isotope analysis

Murray Estuary

Moving down into the Northern lagoon – salinity increases

South lagoon
Salinity: 105+ ppt
<table>
<thead>
<tr>
<th>Species</th>
<th>Zone A</th>
<th>Zone B</th>
<th>Zone C</th>
<th>Zone D</th>
<th>Zone E</th>
<th>Zone F</th>
<th>Zone G</th>
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<td>2</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

**Food web Summary**

- Identifies alterations in food web structure along the salinity gradient in the Coorong.
- Identifies the functional roles of the different organisms present.
- Identifies the ecological significance of alterations in the Coorong food webs under different scenarios.
Productivity – Rod Oliver

Collaborative CLLAMMecology Cluster Project
- Adelaide University
- Judith Brooks, Brian Deggan and Kane Liddle
- Wisconsin, University
- Paul Harvey (GLEON Global Lake Ecological Observatory Network)
- CSIRO Land and Water
- Rod Oliver and Zelfon Lenora

Ecosystem metabolism
- Ecosystems require an energy supply to maintain structure and function.
- Measurements of aquatic metabolism (photosynthesis and respiration) estimate the formation and breakdown of organic material in order to:
  - assess the magnitude of energy (food) supplies
  - identify sources of organic material (algae, bacteria, autochthonous)
  - identify energy pathways (e.g., benthic, planktonic)

Ecosystem responses to energy supplies
- The quality of available organic material determines the potential biomass of secondary producers.
- Variations in the type of organic material influence the density and community structure of secondary producers.
- Both the quality and type of organic material influence the significance of the microbial loop in cycling energy.

Metabolism and dissolved O₂ concentrations

\[ \frac{dO_2}{dt} = P + R \pm E \]
- If R then \( O_2 \) is \( +VE \)
- If P then \( O_2 \) is \( -VE \)

Metabolism measurements
- DOC (dissolved organic carbon)
- DD (dissolved oxygen)
- System metabolism
- Planktonic metabolism
- Benthic + Total - Planktonic
Ecosystem metabolism

- Seven sponges distributed at each of the three locations to monitor representative areas of different depths - system metabolism
- Plankton samples incubated in chambers at different light intensities
- Other metabolism measurements included:
  - Active fluorescence of phytoplankton
  - Active phytoplankton incubated in chambers
- Environmental and water quality measurements:
  - Conductivity
  - pH
  - Temperatures
  - Incident light and attenuation
  - Chlorophyll concentration
Fish communities and recruitment in the Coorong – Qifeng Ye

Objectives
- Fish distribution and abundance along the Coorong - how these relate to habitat environmental conditions.
- Reproductive biology and recruitment of key species* - potential influence of environmental conditions.
- Relationship between freshwater flow and recruitment success and fitness and production of key commercial species.

*Key species include Black Bream, greenback salmon, yellow-eye mullet, angelfish and various trout salmons.

Methodology - Reproductive Biology
- Monthly sampling of key species from various sites:
  - Commercial fishery
  - Research sampling
- Fish processed:
  - Sex, gonad stages, SS, and histology etc.
Methodology - salinity tolerances

Lab, tran, lekan and sub-rectal effect or salinity on early life stages at winter temperature (14°C) and summer (25°C).
- Yellow eye flounder, horse red goby, black turbot, angelfish, triggerfish

Expose fish to gradual change of salinity (0.5% per day) to establish upper/lower salinity tolerance.

Stressed trials at salinities within these limits, duration of 2 months exposure - impact on growth and condition.

Methodology - linking flow and fishery

- Commercial catch and effort data - envir. variables (flow)
- Year class strengths (stock analysis) - envir. variables (flow)
- Historical fishery data - historical flow conditions?
- Include collection of info (qualitative anecdotal/ literature) into model.
- River fisheries in the Cormorant, e.g. European eel and eelgrass conditions.

Results - fish sampled in the Cormorant (Oct-Dec-Dec)

<table>
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<tr>
<th>Species Name</th>
<th>Occurrence</th>
<th>Size</th>
<th>Age</th>
<th>Total</th>
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<td>Rudd</td>
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<td>7.5</td>
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</tbody>
</table>

Results - cluster analysis based on salinity data

Indicator species analysis comparing the relative abundance of fish species between the regions

- Species | Region | Relative Abundance |
- Bream | Region A | 0.001 |
- Roach  | Region B | 0.002 |
- Perch  | Region C | 0.003 |
- Rudd   | Region D | 0.004 |
- Tench  | Region E | 0.005 |
- Dace   | Region F | 0.006 |

*Data analysis was conducted using R and JASP. Rel. Abundance values were normalized to 1 for each region. A p-value of 0.05 or lower was considered statistically significant.
Proceedings of CLLAMM Futures Workshop #2, March 4-5 2008, Page 48
Bird communities and Ruppia distribution in the Coorong – Dan Rogers

Summary to date: Birds

- 4 baywatch surveys of 11 sites completed
  - Oct Feb 08, Jan 07, Nov Apr 07, Jan 08
  - 35% methods changed - no impact on key parameters
- 3 honours projects
  - Le Bonne, wader diet: foraging ecology completed
  - Phyla Wilson, estuary manipulation of shoreline food: completed
  - Kim Naka, influence of tidal cycle on food and foraging
- Correlation of historic data
  - Univ. Adelaide, WWF-Australia
  - Document declines, global significance
  - Used for "baseline" (whole-Coorong) habitat models
**Summary to date - Boids**

- Definitions of habitat quality
  - PL / abundance
  - habitat area
- Habitat forage NDZ (for fine-scale discrimination)
- Concept models
  - define key explanatory variables, & relationship to bird response
- Model development
  - Populate models with data
  - Techniques = NPMR (Nonparametric), CART, SOM

---

**Fairy Tern response model**

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**Summary of R fassina work**

- Nov 06: survey conducted at 8 sites
  - 20 cores each @ tree regns / site
  - shoots, turions (2 & 3), and seeds counted
- May 07: further qualitative surveys
  - germination recorded as far south as VCT
  - beds recorded south of Portsserum
- historical data collated & analysed

---

R fassina seeds (total seeds recorded in 15 cores) values range from 0 to 17%
**What do we know?**

- can deduce environmental responses correlatively from historic data
- experimentally:
  - salinity:
    - delays & reduces germination
    - growth experiments currently underway
  - salinity:
    - impact plant – does not do well at salinity > 0
  - wave energy:
    - wave energy – unclear impact - ???
  - predation:
    - currently high predation pressures (90% of adults removed – n = 192 cores)
    - predation experiment currently underway
  - sediment size, competition, light - ???
### Two tasks for the future

1. Review known responses of key species to key environmental parameters:
   - responses at all life history stages
   - identify knowledge limitations
   - apply testbed and other models
2. Develop habitat response models for key bird species and R. fusiforme
   - construct models for lower trophic species
   - state of play + future models

### Model-building strategies

- survey data: NPvR (Hypoxia), CART
  - includes real-time
  - includes overlapping datasets, in space and time
  - current
- Bayesian Belief Networks (BBN):
  - combination of datasets – in situ, ex situ, other
  - R, tolerance experiments
  - published literature – salinity tolerance in A. microstoma
- Results used for:
  - predicting responses of key species to scenarios
  - predicting and current distribution of habitat
  - identifying important explanatory variables for future models
Habitat mapping of key study sites – Sunil Sharma

Outline
- Habitat mapping in the reference sites
- Imagery classification
- Sediment analysis and mapping
- Habitat and water volume prediction at different water levels

Sources of data/information
- DEH Wetland habitat mapping layer
- Interpretation of the Aerial Photographs (2003)
- Video transects in the reference sites
- Field observations
  - Hydrological classification scheme was 14 categories in total of 4 physical and biological attributes were used in the 3D longitudinal mapping
  - The video survey data in the reference sites in conjunction with the classic aerial photographs were the basis of the inputs to the classification of the segmenting.

Proceedings of CLLAMM Futures Workshop #2, March 4-5 2008, Page 53
Area distribution in % for the Micro-habitat in the reference sites

Conclusions

- Sometimes it is difficult to identify the transition between two micro-habitats (eg. P公司将 Point) based on the video transect survey and the Aerial photos.
- Problem in defining Mud Flat.

Total Micro-habitat distribution in the reference sites

Imagery Classification
LANDSAT5 & SPOT5 Imagery

- Source: LANDSAT (1994)
- Resolution: 25 m (LANDSAT)
- Resolution: 2.5 m (SPOT5)
- Imagery Year: 1994
- Imagery Year: 2004
- Bands (1 to 7)
  - Band 1
  - Band 2
  - Band 3
  - Band 4
  - Band 5
  - Band 6
  - Band 7
- Bands (1 to 5)
  - Band 1: Vegetation
  - Band 2: Water
  - Band 3: Built area
  - Band 4: Water
  - Band 5: Water

Classification Processes

- Unsupervised classification of both LANDSAT and SPOT5 images into 60 classes.
- Supervised classification of the LANDSAT images into 60 classes.
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Habitat and Volume Prediction with the change in the water level in the Coorong

Model for the Subtidal & Intertidal Area and Volume Prediction at different Water level in the North Lagoon

Water level interpolation based on the hydrological model (an example)
Future works

- GIS habitat model for the key species and communities.
- Incorporate outputs from the hydrodynamic model (water level and salinity levels) into the habitat model.
The changing state of the Lower Murray Lakes – Kane Aldridge

Acknowledgements

Authors
- Brian Deegan
- Justin Brookes
- Sebastian Lamontagne
- Parran Cook
- Ian Webster
- Matt Hissey
- Andrew Disset

DVLBC, EPA, MDBC, AWQC

The Lower Murray Lakes

- Largest remnant lakes (55 and 56 km²)
- Station: average depth approx 18 m at minimum depth -1.5 m
- Floodplain lakes and wetlands, high productivity ecosystems
- Important for waterbirds, high percentage native species
- Significant commercial fishery
- Significant commercial and recreational importance
- Major irrigation water source

Multi-purpose - fisheries, agriculture, residence, water supply, recreation,...

Biot...
... and a supply of resources to downstream ecosystems

- Water, nutrients, organic material is supplied to Coorong, Murray Mouth and near-shore environment

The Lower Murray Lakes – a turbid, eutrophic environment

- Eutrophic-hypereutrophic (classes 1994, 1986)
- Marginal heterotrophic-phosphate limitation growth
- Right turbid, nutrients are primarily fixing nutrients not available for algae growth
- Algal blooms common, particularly during periods of low-flow (low turbidity)
- Impact fisheries, water supply and tourism
- This paper really talks about the functioning of the Lower Murray Lakes

Barrage operations

- Barra operations from the Coorong and the Murray Mouth and its effects on lakes
- Opened
- Closed
- Marginal water level (2000-2010)

Original project objectives

- Examine the processing of resources (nutrients, organic matter) within the Lower Murray Lakes
- Develop historical nutrient and algal budgets for the Lower Murray Lakes
- Examine how resource delivery from the Lower Lakes could impact primary and secondary production in the Coorong and Murray Mouth region
- Develop a model capable of predicting nutrient and algal delivery from the Lower Lakes for the Coorong and Murray Mouth under various flow regimes

The current situation – Murray inflows

- The current situation – falling water levels
**The current and future situation**

**Additional objectives**
- Monitoring salt intrusions
- Impacts of drying-reflooding on nutrient release and bacterial activity
- Impacts of salinity on phytoplankton communities

**Steps involved**
- How have the Lower Murray Lakes functioned in the past?
  - Analysis of historical data
- How are the Lower Murray Lakes currently functioning?
  - Monitoring and field/laboratory experiments
- How will the Lower Murray Lakes function in the future?
  - 3D hydrodynamic-ecological model

**How have the Lower Murray Lakes functioned in the past?**
- Nutrient and ion budget
  - Water quality data from AWQ, EPA and MDBC
  - HCO₃, K, Mg, Na, SO₄, Cl, NO₃, pCO₂, TN, TP and TP
  - Only 1973-1988 were considered, most comprehensive
  - Collection of the data from SWSWQ and SWSB
- Inflow = rain on land
- Outflow = Q
- Close to average
- Nutrients concentrations do not significantly affect chlorine, pH, etc.
- Monthly data were obtained at the inflow and outflow points
- Average monthly concentrations vs. month

**Annual inflow v nutrient & ion inputs**
Retention in the Lower Murray Lakes

The nutrient budget 1979-1996

How are the Lower Murray Lakes currently functioning?
- Field and laboratory experiments
- Sediment characterization
  - Water column: chlorophyll, DOM, PoD, PO4, NH4, in situ temperature profiles
  - Water column: nutrients, chlorophyll, PO4, NH4
  - Wind-driven sediment resuspension: P release
  - Influence of drying-reflooding on sediment/nutrient release
  - Thermistor chains
    - 10 km x 60 km area, every 10 km in rows (summer 2006)
    - Routine monitoring: all 20 sites
  - Hydrologists: MODIS, MODIS
  - In situ 2006: Secchi disk, turbidity, and light profiles
  - Phytoplankton diversity

Drying-reflooding – nutrient release
- Impacts of sediment exposure (drying) and reflooding on nutrient release
  - Sedimentation – self-rack-and-nutrient leaching
  - Incubation experiment
  - Nutrient release of sediments vs. sediment-laden
  - Changes in water column nutrient concentrations through time
  - Microsensor profiles for CO2, NO3, N2H
  - Blank integration by water column through profiles
  - Injection of labelled N for calculation of denitrification rates
  - Add to water column (NO3) – sample from the N

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How are the Lower Murray Lakes currently functioning?

- Reducing water levels and increasing salinity
- Increasing nutrient concentrations (NH₄, NO₂)
- Decreasing DO
- Eutrophication?
- Increasing DOC
- Phytoplankton
- Decreasing macrophyte
- Reduced diversity of benthic community
- A transition state

How will the Lower Murray Lakes function in the future?

- Develop predictive model of Lower Lakes water quality
- 3D hydrodynamic-ecological model (ELCOM-CAEDYM)
- Quantity, biogeochemical dynamics of Lower Lakes (i.e. fluxes, phytoplankton groups)
- Predict physical, chemical and biological parameters under various flow scenarios
- Predict resource (nutrients, organic matter) delivery loads to Coorong under different flow conditions

ELCOM
Estuary, Lake & Coastal Ocean Model

- Hydrodynamics
- Sediment transport
- Temperature
- Salinity

CAEDYM
Computational Aquatic Ecosystem Dynamics Model

- Integrated sediment (flux)
- Organic matter (POC, DOC)
- Inorganic nutrients (NH₄, NO₂, NO₃, PO₄, SiO₂, DIC)
- Nitrification-denitrification (flux)
- Phytoplankton (Chl a, C, nitrate, nutrients, metabolism)
- Higher biology (zooplankton, fish, energy)
- Benthic biology (microalgae, seagrass)
- Pathogens & internal indicators (organic, pathogens, viruses)
- Oceanography (pH, oxygen, wave, mesoscale winds)
- Sediment dynamics
Required data
- Bathymetry
- Water quality
- Sediment
- Chlorophyll
- Microbial data
- Water temperature
- Light intensity
- Water chemistry
- Sediment data
- Water chemistry
- Water temperature
- Light intensity

Chlorophyll a - capabilities

Next steps
- Analyze results
- Complete routine monitoring – March 2008
- Modeling
  - Include or incorporate any existing
  - Increase of algal ratio
  - Identify scenarios
  - Run scenarios
- Assess the use of satellite imagery to estimate water quality parameters within the Lower Murray Lakes
- Sediment
  - Spatial data
  - Use for larger scale measurements from grab samples
- Meteorological data

Conclusions & project outcomes
- Lower Murray Lakes are a modulator of resources
  - Nutrients and on Coorong, Murray Mouth and seaward
- Lower Murray Lakes are in a transition state
  - Current drivers are hard to identify
- More complications ahead
  - Shallow, warm, reducing nutrient fluxes, acid sulfate soils, saltwater
- Model will provide a decision tool for management
  - Impacts of various scenarios
  - Impacts of controls on the new pumpworks
  - Environmental flows and resources to the Coorong
Lipid and pigment biomarkers for assessing organic matter sources and fate

John K. Volkman, Andy Revill, Rhys Leeming and Lesley Clement

CSIRO Marine and Atmospheric Research, 6700 Box 1529, Hobart, Tasmania

**Aims of our Research**
- Identify and, if possible quantify, the main sources of organic matter in coastal marine sediments and identify the pathways by which they are degraded as part of studies of carbon and nutrient cycles.
- Use the lipid composition in sediment cores to reconstruct changes in the paleoecology of that area.
  - pelagic phytoplankton (diatoms, dinoflagellates, haptophytes etc.)
  - microphytobenthos (benthic microalgae) if present
  - terrigenous organic material (higher plants and soil)
  - aquatic animals including zooplankton and benthic fauna
  - phototrophic, sulfate-reducing, and other bacteria
  - microalgae and diatoms
  - organic contaminants

**Methodology**

Analyze bulk sediment for stable carbon and nitrogen isotopes: $^{13}$C, $^{15}$N

Extract sediment with organic solvents and analyze lipid concentrations by TLC, GC, GC-MS and irnm

GC-MS and analyze chlorophyll and carotenoid pigments by HPLC. Amino acid and sugars can also be analysed by HPLC.

Carry out laboratory incubations of sediment cores to determine nutrient fluxes, oxygen consumption, etc.

**Typical Extraction Scheme for Lipid Analysis**

1. Cell extract
2. Dry weight
3. Stable isotopes

**Diagnostic Marker Pigments for Algal Classes**

- Dinoflagellate: $^{13}$C, $^{15}$N
- Happonedale: $^{13}$C, $^{15}$N
- Chlorophyta: $^{13}$C, $^{15}$N
- Cyanobacteria: $^{13}$C, $^{15}$N

*Annual group of diatom genera have fucosterol ester from polar lipids as their marker pigment.*

**Distribution of Pigments in Algal Classes**

- Chrysophyceae
- Centrales
- Phaeophyceae
- Dinophyceae
- Chlorellaceae

Proceedings of CLLAMM Futures Workshop #2, March 4-5 2008,
Proceedings of CLLAMM Futures Workshop #2, March 4-5 2008,
Some Examples of Lipids with Known Biological Sources

- Carotenoids of anoxygenic photosynthetic green sulfur bacteria
- Lipidbioreactors of past dairy waste treatment systems in hot springs
- Chloroplasts Isonicotinohydrazide

Long-chain (C20-C40) hydrocarbons
- Sources of algal lipids in the surface layer of open ocean (SSL)
- Temperature-related:

Fatty Acids in Marine Animals and Microalgae

- HHTA Structures
- EPA [22:5n-3]
- DHA [22:6n-3]

Fatty acids are labeled by a number of carbon atoms, a letter
- the number of double bonds, and a position of the double bond closest to the methyl
- end of the molecule; all double bonds are geometrical for simplicity and non-enumerated.

Typical Sterol Structures

- Cholesterol
- Diastereol
- Diazastereol

Structural Diversity in Sterols

- Double Bonds
- Methyl groups
- Methyl or propyl groups
- Double bonds
- Additional hydroxyl groups
- Methyl groups on the stereotopic:

Characteristic Sterols in Microalgae

<table>
<thead>
<tr>
<th>Microalgae</th>
<th>Major or Common Sterols</th>
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<tbody>
<tr>
<td>Chlorella</td>
<td>C_{35}H_{59}O_{6}, C_{37}H_{60}O_{7}, C_{38}H_{60}O_{6}</td>
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<tr>
<td>Rhodomonas</td>
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Wilson Inlet Sample Sites
Stable Isotope and Carbon Contents of Wilson Inlet Samples

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<thead>
<tr>
<th>Sample</th>
<th>δ13C</th>
<th>δ18O</th>
<th>Nδ</th>
<th>C</th>
<th>E</th>
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<tbody>
<tr>
<td>Wilson Inlet</td>
<td>-29.6</td>
<td>-1.2</td>
<td>1.3</td>
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Wilson Inlet Sediment Wi-33

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<th>Ethanol</th>
<th>Toluene</th>
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<td>Actual</td>
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<td>5.0</td>
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<tr>
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<tr>
<td>300</td>
<td>Standard</td>
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Denmark River Sediment

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<tr>
<td>300</td>
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<td>30.0</td>
<td>15.0</td>
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Coorong Sediment Site 3

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<td>300</td>
<td>Standard</td>
<td>30.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Lipid and Pigment Markers for Cyanobacteria in Coorong Waters and Sediments

<table>
<thead>
<tr>
<th>Marker</th>
<th>Concentration</th>
<th>Water Column Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desaminob</td>
<td>C32-Hepesin</td>
<td>Water Column Samples</td>
</tr>
</tbody>
</table>

Concluding Remarks

- Biomarker ratios and stable isotope data can be used to provide reasonable, semi-quantitative estimates of the sources of organic carbon in coastal sediments and each provides a unique check on the other.
- This approach relies critically on the choice of end-members and assumes limited effects due to degradation.
- Highly branched alkanes provide a useful baseline for contributions from higher plants and algae, whereas short-chain alkanes and very short-chain alkanes are good indicators of microbial sources and higher plant fatty acids are good markers for bacteria.
- Freshwater algal material due to microphytobacteria can be a significant source of organic carbon in shallow sediments as revealed by high cyanobacterial biomarkers.
Ultimate biomarkers: rRNA encoding genes

Identification of microorganisms in contemporary environments at the species level based on variations in the nucleotide positions.
-16S rRNA (prokaryotes) and chloroplast 16S-like rRNA (eukaryotes)

-16S rRNA (prokaryotes) 2,000 nucleotides

But is fossil cDNA a suitable biomarker for the identification of ancient water-column-dwelling species? Yes, but fragmentation of fossil DNA can be a problem.

E.g. Holocene Meloney Lake sediments (Coombs and Overmann)

HBI Alkenes as Diatom Markers

Long-chain Alkyl Diols in Nannochloropsis

HBI alkenes occur widely in marine sediments and can be used as biomarkers for organic matter derived from diatoms.
HBI alkenes are also found in few other oils of very young ages.
Nutrient sources and sinks in the Coorong – Ralf Haese
Conclusions

In August:
- Higher nile tilapia in primary productivity (PP) increase from Capt. 1 to Capt 4.
- Water column productivity increased. Surface water and bottom water productivity.
- Based on DP, water column PP was similar between Capt 1 to Capt 4, with Capt 1, Capt 2, Capt 3, and Capt 4.

Results are in good agreement with PP and nile tilapia PP.

Temporal (7) groundwater discharge is widespread in the South Lagoon; mechanism behind major source of nile tilapia remains unknown, yet.
Modelling the states of the Coorong – Rebecca Lester

Outline
- Review of modelling techniques
  - Re-cap
  - Alternative states
  - Original hypothesised states
  - Developing states from data
    - Clustering causes by biological characteristics
    - CART on environmental characteristics
    - Confirming distinct states
    - Indicator species
  - Next steps

Review of modelling techniques

CLLAMM Futures requirements
- Ecosystem scale
- Highly multivariate
- Spatially & temporally explicit
- Disparate collection techniques
- Mixture of quantitative, semi-quantitative & qualitative data
- Data & values are patchy in both space and time

Techniques & concepts reviewed
- Alternative stable states
- Heterarchy
- Bifurcation
- State & transition modeling (ST)
- Classification & regression trees (CART)
- Multiple regression trees (MRT)
- Structural equation modeling (SEM)
- Bayesian belief networks (BBN)
- Gaussian error propagation
- Individual-based modeling
- Levels of evidence
- Ecospace

Most useful techniques
- CART & MRT
  - Parameterise alternative states
  - Identity transitions between states
  - Investigate key species and community distributions
- SEM
  - Parameterise conceptual models
  - Further information on transitions between states
- S&T modeling
  - Temporal information
  - CART, MRT & SEM
  - Predict state of given location under given elements
- BBN
  - Environment in which S&T modelling occurs
Alternative states

Hypothesised states

- **Bream Dream**
  - Hypoxia conditions
  - *H. macrosoma* & estuarine fish
- **Seagrass Meadow**
  - Storm events
  - Seagrass present
- **Wader’s Delight**
  - Characterised by *R. fischeri*, invertebrates, small fish

- **Algal Bowl**
  - High turbidity & nutrients
  - Large *Rupplea* seagrass
- **Brine Shrimp Paradise**
  - Hypoxia
  - *N. exupereza* & fish
  - Brine shrimp and banded shrimp
- **Dead Sea Downunder**
  - Hypo-hypoxia
  - Few organisms

Biological data set

- Input data set included
  - Commercial fish catch data 02-06 (SARDI)
  - Bird count data 02-07 (UoA)
  - *Rupplea* distribution data 00-06 (UoA)
- Used data from
  - 10 study sites
  - 2000-2000

Cluster analysis

Environmental data set

- Meteorological data (BoM)
- Water quality (DEH)
- Modelled water depths (CSIRO)
- Modelled flow over barrages (MDBC)

CART analysis

- Used 4 clusters identified from biological data as dependent variables
- Environmental variables
- Also included cases with missing values (<30 cases)
  - Sites where *Rupplea* was not surveyed
  - 1999 – no bird data
  - 2007 – no commercial fish catch data
**Initial alternative states**

- Average density: 572 m
- Misclassification rate: 14%

<table>
<thead>
<tr>
<th>Min. Current Level</th>
<th>Max. Current Level</th>
<th>Annual rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.34 m</td>
<td>&gt; 0.34 m</td>
<td>&gt; 32 mm</td>
</tr>
</tbody>
</table>

**Confirmation of distinct states**

- Used one-way ANOSIM
- Not including factors for year and site
- Categories 3a and 3b are different
- Categories 3b & 9b are different
- No information about 99a due to missing values
- Using only bird data, 99a is different from 1

**Distinct alternative states**

- Average density: 572 m
- Misclassification rate: 14%

<table>
<thead>
<tr>
<th>Min. Current Level</th>
<th>Max. Current Level</th>
<th>Annual rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.34 m</td>
<td>&gt; 0.34 m</td>
<td>&gt; 32 mm</td>
</tr>
</tbody>
</table>

**Species driving similarity within states**

<table>
<thead>
<tr>
<th>Species</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabian oystercatcher</td>
<td>++</td>
<td></td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Arabian sandpiper</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Black drongo</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Black stork</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Cattle egret</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>City duck</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Common shelduck</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Coral-banded plover</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Great white pelican</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red-footed booby</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Silver gull</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Yellow-eyed plover</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

**Definition of new states**

<table>
<thead>
<tr>
<th>Trait</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average density</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Annual rainfall</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Minimum current level</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Maximum current level</td>
<td>High</td>
<td>Common</td>
<td>Common</td>
<td>Common</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Minimum only current level</td>
<td>High</td>
<td>Few</td>
<td>Few</td>
<td>Few</td>
<td>Some</td>
<td>Few</td>
</tr>
<tr>
<td>Maximum only current level</td>
<td>High</td>
<td>Few</td>
<td>Few</td>
<td>Few</td>
<td>Few</td>
<td>Few</td>
</tr>
<tr>
<td>Odor</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**Questions to address**

- How do these relate to the original hypothesised states?
- How do we capture and parameterise states that fall outside the dataset?
- Brian’s dream:
  - Dead Sea Downunder
  - Beyond the Dead Sea?
Next steps

- Fill data gaps where possible
  - Add Rupala & commercial fish data for 2007
- Re-run state definition analyses
- More analyses to define states
  - e.g. indicator species
- More analyses to define transitions
  - e.g. response rates of indicator species to environmental variables to incorporate into scenario modelling

Questions?

Species driving dissimilarity between states

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian whiskers</td>
<td>++</td>
<td></td>
<td>++</td>
</tr>
<tr>
<td>Backswim</td>
<td>++</td>
<td></td>
<td>++</td>
</tr>
<tr>
<td>Coastal landbridge</td>
<td>++</td>
<td></td>
<td>++</td>
</tr>
<tr>
<td>Restored wetland</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Definition of new states

- **State A**
  - High average alkalinity & [CH b]
  - Very low minimum water levels
  - Good numbers of duck, waders & mullet, few fishers
- **State B**
  - Very similar to State A but moderately high minimum water levels
  - Average numbers of waders, few duck &-commoners
- **State C**
  - Moderate to low alkalinity & [CH b]
  - Moderately high rainfall but very low minimum water levels
  - Average numbers of common waders, few other species

Definition of new states cont...

- **State D**
  - Moderate to low alkalinity & [CH b]
  - Moderate to high annual rainfall & moderate to high minimum water levels
  - Good numbers of eel, commoners & whiskered terns
- **State E**
  - Moderate to low alkalinity & [CH b]
  - Very low annual rainfall & very low average daily rainfall
  - Good numbers of common waders, few other species
- **State F**
  - Very similar to State E but moderate to high average daily rainfall
  - Very high numbers of ducks & banded plovers, good numbers of mullet, no commoners
**Invertebrate Key Species Update**

**Talk Content**
- Brief reminder of work completed to date
- Reminder of key results
- Description of sediment transfer experiment
- Preliminary results from sediment transfer experiment and other observations

**Work Completed**
- Macrobrachia monitoring surveys
  - 11 sites
  - Dec '06, Jan '07, March '07
- Juvenile brachia monitoring surveys
  - 11 sites from 7 sites
  - Simultaneous from Dec '06 – Oct '07
- Sediment transfer experiment
  - Transfer of sediment cores within and between sites of differing salinities and tidal exposures

**Key Results**

<table>
<thead>
<tr>
<th>Species</th>
<th>Upper Salinity Tolerance (ppt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. lutea</td>
<td>62</td>
</tr>
<tr>
<td>S. slateri</td>
<td>72</td>
</tr>
<tr>
<td>N. pugilis</td>
<td>54</td>
</tr>
<tr>
<td>A. listeri</td>
<td>-55</td>
</tr>
<tr>
<td>C. elongata</td>
<td>177g L</td>
</tr>
</tbody>
</table>

**Key Results**
- Most brachia absent from Site 8 southwards
- Decrease in brachia with time (except Site 5)
Sediment Transfer Experiment

- Preliminary Observations:
  - Reduced benthic diversity at Eve Island than previously observed – C. fiordale and Simplesia
  - C. fiordale in high abundance at Long Point Low Elevation
  - Nonameria – Only Insect larvae
  - Water levels varied at LP and N – High Elevation dry for most of deployment
    - Organisms went dead after 1 week in dry conditions
    - Has implications for available mudflat habitat with regards to decreasing water levels in the Coorong

- Salinity
  - Graph showing salinity levels over time for different locations:
    - Site 1
    - Site 2
    - Site 3

- Mean Abundance (LP & N) Recruitment
  - Bar graph showing mean abundance at LP and N:
    - Bar heights indicate recruitment levels

- Abundance (LP & N) Recruitment
  - Bar graph showing abundance levels at LP and N:
    - Bar heights indicate abundance levels

- Large decrease in juvenile recruitment at Eve Island

- Changes between Oct 07 and Jul 08 also observed between Dec 06 and Jul 07 but on smaller scale
Key Points

- Lack of macrobenthos from Hoobartrenna (Site 3) Southwards
- Reduced benthos diversity observed at Eve Island
- Reduced juvenile recruitment at Eve Island
- Benthic organisms could not survive for one week in dry microsat
  - Large implications with regard to decreasing water levels

Data still to collect
- Macro benthos to be identified and counted
- Polythyla size and ovigarity
- Sediment grain size analysis
- Sediment organic content
- Statistical analyses
Determining environmental history & movement of fish in the Coorong – Bronwyn Gillanders and Andrew Munro

Determining environmental history of fish in a hyper-saline estuary using natural otolith elemental signatures

Andrew R. Munro and Bronwyn M. Gillanders

Understanding Fish Populations

Important for management and conservation
- population/stock structure
- connectivity & dispersal
- contributions to population

The Coorong

- Estuary to the Murray-Darling Basin
- Environmentally degraded
- Low flows
- Rising salinity

Objectives

- Characterize otolith composition of key fish species
- Can we estimate environmental history and movement of fish within the Coorong?
- What are the responses of fish to changing conditions?
  - Response models

Otolith Chemistry

Element vs. Salinity

Past studies

Distributions & Gillanders (2005)
Conclusions

- Complex relationship between oolith composition and salinity
- Difficult to distinguish trend from hyper-saline
- Combination of methods (e.g., isotope analysis – PIQ)
- Multivariate methods (e.g., PCA or CART analysis)
- Quantify post-environmental history
- Multi-species comparisons
  - Similar patterns in Sr and Ba, but ratio values different

By understanding past environmental history of key fish species
- Better understanding of life-history
- Predict response to different management scenarios

Acknowledgements

- Funding:
  - CSIRO-CLAMM

- Ships/Support
  - David Heron, Del Whelan, & Gilling Yi (SIO)
  - Patrick McKeown (CSC)
  - CSIMarine

- Otolith preparation and analysis
  -жалкий ROV and Thomas Barnes (SIO)
  - Bangarra

- Water Analysis
  - Natural Resource Institute, INW
Introduction to workshop – Peter Fairweather

Objectives

- Update on climate change science
  - How might it vary?
  - How are others incorporating it?
- Focus on management levers
  - Relationships between Coorong & LL
  - Current barrage operating rules
  - What else could we include?

Objectives cont...

- Confirm type of scenario modelling to be done
- Detailed CLLAMM Futures scenarios
  - What parameters to incorporate?
  - How many scenarios to model?
  - Which combinations of climate change/management levers to include?
- Sign off on which scenarios to model

2 types of scenarios possible?

1. set future climate/management/starting conditions
   - Let run to predict likelihood of various states & their coverage
   - Explores options for managers & stakeholders
2. pick a set of desirable states
   - Model to see how to get there
   - But closes off options or might strive for impossibilities?

What to aim at?

- E.g.
  - As the MDB is operated now?
  - When Ramsar status was declared?
  - As a complete, true estuary?
  - Much easier from paleo-reconstructions?
  - Such a prescriptive stance would
    - Close off other options?
    - Result in a monoculture?
  - Be beyond our expertise?
  - Be more political than the task we were charged with?
2 types of scenarios possible?
1. Set future climate/management/starting conditions
   - Let run to predict likelihood of various states & their coverage
   - Explores options for managers & stakeholders
2. Pick a set of desirable states
   - Model to see how to get there
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Chain of models
- Range of models being developed
  - MDCC “DynOO”
  - CLLAMM Hydrodynamic model
  - CLLAMM Biogeochemical model
  - CLLAMMecology Response models for individual projects & sub-projects
  - Key apps: food web, production, dynamic habitat
  - CLLAMM Futures Ecosystem modeling
- We chain these models together & run agreed scenarios through the entire chain

So, key questions include:
- How many scenarios to try to model?
- How disparate should they be?
- How far ahead to model?
- What starting conditions?
  - e.g. 2008 habitat map + environmental conditions
  - What future climate?
  - Which management levers pulled? (drivers)

Sustainable Yields project

SY scenarios
- 15 IPCC GCMs x 3 levels of global warming = 45 climate scenarios
- Investigate changes in available water at 2030
- 112 years historical rain scaled by
  - estimated mean increase
  - seasonal variability
  - different amounts for different-sized events

Inputs & outputs
- Rainfall/runoff modelling
  - Inputs
    - Rainfall
    - Evapotranspiration
  - Outputs
    - Runoff
    - Groundwater recharge
- River system modelling
  - Inputs
    - Runoff
    - Groundwater recharge
  - Outputs
    - Flow estimates
Other sources of data

- Output of GCAMs is available
  - Includes variables such as air temperature, air moisture content, precipitation, cloud cover, sea level
  - Also includes changes in extremes like frost, large rainfall events, heat waves
  - Requires significant processing to generate time series

Potentially important climate variables

Potential variables to incorporate

Parameters
- Rainfall
- Flow over the barrages
- Wind speed
- Evaporation
- Storminess
- Tidal height
- Sea level
- Acidification

Characteristics
- Total
- Timing
- Variability
- Extreme events

Climate change predictions for Australia

Climate change & Australian marine life

- Review by Poloczanska et al. (2007)
- Few studies on the effect of climate change in the S Hemisphere
- N-Hemisphere results may not be transferrable to our:
  - Oligotrophic waters
  - Low & variable average annual rainfall
  - May be more vulnerable to stress
Summary for Coorong 2070
- Sea surface temperature +1.0 to 1.2°C
- Mean surface ocean currents +2 cm/s easterly
- Mean zonal winds -1 to -2 m/s
- Mixed layer depth -10 to 0 m
- Mean pH -0.15 to 0.10
- Aragonite saturation state -1.0 to -1.1
- Downward solar radiation at surface -40 to 60 W/m²
- Precipitation minus evaporation -0.5 to 1.0 mm/d
- Sea level height anomaly due to stratification +18 to 18 cm (relative to 2000)
- Extracted from Poloczanska et al. (2007)

Hypothesised effects on ecosystems
- Level of prediction will not be sufficient
- Need additional detail

Barrage operating policy
- Current barrage operating strategy
  - Fill to 0.85 m AHD & then spill
- Under Icon: Site Man Plan 2006/07
  - Release water when level reaches 0.75 m AHD if flows over SA border are forecast
  - Allows for more extended release
  - Sand ingrowth better managed with longer flow
**New opportunities**

- Automated gates at Taunton Vale, Ewe Is & Mundroo; planned for Goolwa
- Fishways at Taunton Vale & Goolwa
- Allows fine scale management of small volumes
- Consideration given to which barrages to open
  - Small volumes (10-100GL) fishways & small estuaries
  - Boundary; Mundroo; Goolwa
  - Modest volumes (100s GL) Taunton Vale & Ewe Is
- Large volumes (1000sGL): need to “balance” barrage flows for benefit of the mouth

**Flow over barrages**

- Median is 27% of natural conditions
- 3x reduction in frequency & duration of small/mid flows
- MM now ceases to flow in 2 years on average (c. 1 in 20 naturally)
- Due to a combination of climate & diversions

**Natural v current flows**

**Coorong**

- **Dredging**
  - Mouth
  - Between lagoons
  - Other places as needed
- **USED**
  - Current flows
  - Future flows
  - But upper limit to volumes?

**Other management levers**

- **Other**
  - Closures (e.g. at Pamplin Point)
  - Antithesis of dredging
  - Artificial mouth in S
  - Canal to water-basin transfers from other water bodies
  - Quite separate management goals for different portions...
Lakes
- Wet at Porannda Island
- Channel to Coorong (Lake Alber)
- Pumping water from Coorong - to at least wet sediments of ASS
- Removing barrages to expand estuary
- Others?

Can we agree on some scenarios?

Scenario Climate Management

Planning for extremes not averages

Extremes in ecology
- Many problems of biological interest concern the extremes of parameters
  - e.g. highest temp, longest drought
- Not adequately addressed by standard biostatistics
  - Focused on the mean & variance
- Statistics of extreme values
  - e.g. use of return times with CIs (routinely used in hydrology)

Return times
- Estimated from relatively short data sets
  - e.g. 6 years for sea surface temp
- Can speculate beyond that time interval for only some variables
  - Sampling interval longer than time interval b/w independent samples (no autocorrelation)
  - Standardised to remove trends
- Obtain return times using ML estimation
- Can compare estimates between sites

(Gaines & Denny 1993)
Scenarios developed by the Murray-Darling Basin Sustainable Yield project – Sebastien Lamontagne

Terms of Reference

- Water Summit: PM and First Ministers, Nov 2005
- CSIRO to report progressively by end 2007 on sustainable yields of surface and groundwater systems within the NCP
- Estimate current and likely future (~2030) water availability in each catchment in the Murray-Darling Basin
- Climate change and other risks
- Surface-groundwater interactions
- Compare the estimated current and future water availability to that required to meet the current levels of extractive use

Who was involved?

- National Water Commission
- CSIRO
- State management agencies
- MDBWC
- Consulting firms

Project Context

- The Project
  - Assessments of current & future water availability
  - Socio-economic impacts of alternate allocation regimes
  - Environmental impacts of alternate allocation regimes
  - Sustainability and community consultation

- Water resource planning, management and investment

Overview of methods

- Event study
- Post-crop water availability
- Sustainable water use
- Relative risk
- Optimal water policies
- Environmental thresholds
- Focusing

Scenarios

- Current development & historic (1895-2005) climate
- Current development & recent (1997-2006) climate
- Current development & future climate
- Future development & future climate

- Future climate
  - 2001 climate based on AIP IPCC results
  - 3 global warming levels (low, mid, high)
  - 15 global climate models
Development

- Economic/variability fluctuations
- Indicators for MERI regions
- Water quality projections in areas suitable for pantanal
- Tempertures
- Current levels, trends, analyses, policy controls
- Groundwater extractions
  - Groundwater in sustainable use: State advice

Rainfall-runoff modelling

- GIMHYD and Sacramento models on 5 x 5 km grids
  - Run for scenarios A and B (single runs)
  - Run for Scenario C (15-50yr x 1 global warming levels)
  - From C select dry, mid, wet future: modify for Scenario D
- Groundwater
  - Modify 3 runoff series from C for local evaporation
  - Adjust daily flows using "Forest/Forest Floor Change" model
  - Modify 3 runoff series from C for local dam
  - Adjust daily flows using a dam water balance model
  - Groundwater recharges, evaporation, demand, inflows and outflows

River system modelling

- Many different river models (MDM) in use in DAM
  - Monthly, daily, some daily, link-model integrations
  - These are being extended to 1895-2008
  - Groundwater exchanges being quantified
  - Models being refined and automated
  - Sacramento model runoff series transformed into inflows
  - Some new models being developed

Groundwater recharge

- Diffuse recharge
  - WAVE: considers plant physiology and soil physics
  - Runoff, QDI point locations across USDA rain gradient
  - Groundwater recharge of floodplain and water types
  - Analyse results to obtain recharge scaling factors
  - Apply across all groundwater management units on 5 km grid

- Impingement recharge
  - 1-D modelling for key impingement areas plus literature values

Groundwater modelling

- Prioritize groundwater management units (GMUs)
  - Porosity level of development level, salinity and stream impact
  - 12 large, medium, small GMUs (~10% of area)
  - Existing and new numerical groundwater models
  - Run models with scenario recharge series and current step-down flux for 111 years (no equilibration) and further 111 years
  - Provide equilibrium flux back to river models
  - Simple assessments for low priority GMUs
  - Connectivity mapping across all regions

Water accounts

- For many 100 km reaches across the Mba, independently assessed
  - Inflows
  - Outflows
  - Demand
  - Floodplain losses
  - Direct evaporation
  - Exchanges with groundwater
  - Storages (reservoirs, receiving)
  - Assess river model performance
The Paroo:
- 12,000 km², 3% of MDB
- 100,000 people
- Mixed agricultural, pastoral, grazing, fruit, and beef production
- Irrigation, very little drainage
- No major dams, very little irrigation
- Commercial forestry and dryland farming
- Numerous wetlands of national and international significance:
  - Camooweal Lakes
  - Paroo River wetlands
  - Paroo Savanna Country
  - Paroo Basin Wetlands

Key findings – by investigation scenario:
- Current average annual rainfall is 450 mm less than 0.1% is currently diverted for use. Groundwater use is low and does not support extensive irrigation.
- The recent climate has been similar to the long-term historical average climate.
- The best estimate of climate change by 2050 is for a 5% reduction in average annual rainfall availability. There is a wide range in potential climate change scenarios. A 10% reduction in average annual rainfall availability is a 1% increase. Climate change is likely to boost the economy of some industries in the region.
- Future development of commercial forestry and farming is unlikely. Groundwater extraction is not expected to increase significantly into the future and will not pose a threat to future water availability.

Current development & historic climate:
- Long-term average annual rainfall: 311 mm
- Modified average annual rainfall: 37 mm, 2% of MDB
- Average annual surface water availability: 444 GL
- Water usage very low: 0% of available water is diverted
- Groundwater is the region’s main source of water
- 3% of the groundwater used is from the confined GWIS aquifers
- Current ground water use has no impact on shallow groundwater
- Current low level of water resource development in the region has had no significant effect on the environment or stream flow in the Cooper River or the Paroo River.

Current development & recent climate:
- The average annual rainfall and total over the ten-year period 1997 to 2006 are within 1 percent of the long-term (1895 to 2006) average values
- The last ten years was therefore not unusual for this region.

Current development & future climate
- Scenarios more likely to depress than to increase by 2050:
  - The best estimate (median) 2050 climate would see a 2% reduction in water availability
  - The uncertainty range is from a 1% reduction to a 40% increase

- Future scenario 2050 climate would see a 2% increase in water availability
- No change in surface water availability
- Environmental impacts
  - Only minor changes to the frequency and volumes of beneficial flooding to Lake Norman and the Paroo River: 2050 levels
  - Increases of extreme events increases average frequency of floods to, on average, over 35 years
  - Dry climate would be detrimental
    - Average period between floods would increase by 50%.
  - Total inflow volumes would decrease
    - 1% Lake Norman, 1% Lake Wyola and Paroo River.
B: Current development & recent climate

- The average annual rainfall and runoff over the ten-year period 1997 to 2006 are within 1 percent of the long-term (1950 to 2006) average values.
- A scenario based on the last ten years was therefore not modelled for this region.

C: Current development & future climate

- Future climate projections suggest the possibility of increased rainfall and higher runoff.
- The uncertainty range is from a 20% reduction to a 20% increase.

D: Future development & future climate

- Population growth is projected to increase by 10%.
- The water supply will need to be increased by 10%.
- Climate change could alter the frequency of extreme drought events.
- The uncertainty range is from a 20% reduction to a 20% increase.
- Extreme droughts could alter the water supply.
- The uncertainty range is from a 20% reduction to a 20% increase.

Water sharing summary by scenario

- 100 year times series of daily river flows at the locations for the four scenarios and sub-scenarios.
- Water input, water level and salinity in the Lower Lakes.
- Simulated climatic data for the region.
- Permission in principle from the NWC to use results as soon as available.
Lessons for CLAMMecology?

- Even a relatively simple set of “scenarios” generated a massive amount of data.
- Reporting component a significant component of the overall analysis.
- A learning experience: Where are the “weaknesses” in our ability to understand future behaviour for the “system”.

Murray-Darling Basin Sustainable Yields Project

Raising National Water Standards Program of the National Water Commission

www.csiro.au/mdbsy