ISBN 0-646-46026-9

Recommended citation:

Ward, T.M., Geddes, M.C. & Mayfield, S. (eds). 2006. National Symposium on Ecosystem Research and Management of Fish and Fisheries. Australian Society for Fish Biology Symposium Proceedings, Adelaide, South Australia, September 2004.

Published by:

Australian Society for Fish Biology

Copies are available from:

Dr Mark Lintermans
President, Australian Society for Fish Biology
PO Box 144
Lyneham
ACT 2602
www.asfb.org.au

or

Fisheries Research and Development Corporation
PO Box 222
Deakin West
ACT 2600
www.frdc.gov.au

or

The Librarian
SARDI Aquatic Sciences
PO Box 120
Henley Beach
SA 5022 Australia
www.sardi.sa.gov.au

Proceedings Committee

Editors

Dr Tim Ward
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022

Dr Mike Geddes
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022,
and
Earth and Environmental Sciences
University of Adelaide
Adelaide SA 5005

Dr Stephen Mayfield
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022

Assistant Editors

Dr Simon Goldsworthy
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022

Mr Paul Rogers
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022

Text Editor

Mr Ian Carlson
SARDI Aquatic Sciences
PO Box 120
Henley Beach SA 5022

Graphic Designer

Mrs Melanie Lange
emkay DESIGN
84 Narinna Ave
Cumberland Park SA 5041

Printer

Customer Services
Primary Industries & Resources SA
101 Grenfell St
Adelaide SA 5000

Preface

The 33rd annual Symposium and Conference for the Australian Society for Fish Biology was held in Adelaide, South Australia, in September 2004. The Symposium – National Symposium on Ecosystem Research and the Management of Fish and Fisheries – provided a forum for stakeholders in the Australian fishing industry and the nation's leading fisheries scientists and managers, to identify and discuss options (and constraints) for addressing the increased legislative and social pressures to assess and manage the ecosystem effects of fishing.

Background to the discussions was provided by presentations from members of key stakeholder groups, as well as representatives from Commonwealth and State Government agencies that are responsible for ensuring that fisheries are managed according to the principles of Ecologically Sustainable Development. This was followed with presentations from renowned international scientists outlining their experiences in conducting ecosystem-based research in each of the three broad sub-themes for the workshop: (1) interactions of pelagic fisheries and marine ecosystems; (2) roles of fisheries species in structuring benthic ecosystems; and (3) managing fish and fisheries in rivers and estuaries with limited and variable flows.

The three sub-theme workshops then provided the scope for leading scientists from research agencies throughout Australia to describe the current status of ecosystem-based research and management within their areas of expertise. Thereafter, delegates identified key management needs and research questions, considered options and approaches to ecosystem research and discussed national strategies and approaches. The outcomes from these workshops are documented within these proceedings.

These topics were well received, as agencies throughout Australia are currently working towards addressing these issues. This ensured that the Symposium and Conference were an outstanding success in several respects. Notably, the importance of the Symposium theme was reflected in the significant levels of sponsorship provided by the major sponsors, that included the South Australian Research and Development Institute, the Fisheries Research and Development Corporation, the Natural Heritage Trust and the Murray-Darling Basin Commission.

The Symposium and Conference were attended by more than 170 and 200 delegates, respectively, from throughout Australia. There were also six internationally renowned scientists, representing Canada, South Africa and the USA. Thus, the 2004 National Symposium on Ecosystem Research and the Management of Fish and Fisheries continued the Australian Society for Fish Biology's series of national workshops on key issues in fisheries science and management.

The Australian Society for Fish Biology is indebted to the organising committee. They represented the ideal team with which to ensure the success of the event, committing many hours before, during and after the event. This committee was substantially aided by Carolyn Anderson and Associates, the Symposium and Conference organisers, who did a magnificent job.

These proceedings comprise short summaries of each of the presentations from both plenary and concurrent sessions. Discussions and outcomes of the three sub-theme workshops are also documented.

Many people helped in the production of these proceedings. We are particularly grateful to Shane Penny, Suzanne Bennett and Ian Carlson for their tireless assistance, and especially for their detective work in locating elusive references. Dr Scoresby Shepherd (SARDI Aquatic Sciences), Mr Crispian Ashby (FRDC), Dr Dan Gaughan (WA Department of Fisheries), Mr Gary Jackson (WA Department of Fisheries) and Mr Marcel Green (NSW DPI) provided useful comments on an earlier draft. I am particularly grateful to Mr Ian Carlson (SARDI Aquatic Sciences) and Dr Stephen Mayfield (SARDI Aquatic Sciences) for their efforts to ensure publication of these proceedings. All photographs were provided courtesy of the South Australian Tourism Commission and SARDI Aquatic Sciences.

Dr Tim M. Ward
Chair: ASFB 2004 Symposium and Conference
SARDI Aquatic Sciences

ASFB 2004 Organising Committee

Dr Tim Ward – South Australian Research and Development Institute (Aquatic Sciences) (Convenor)

Mr Roger Edwards – South Australian Rock Lobster Fisherman's Association

Mr Travis Eldson – University of Adelaide

Dr Tony Fowler – South Australian Research and Development Institute (Aquatic Sciences)

Dr Dan Gaughan – Australian Society for Fish Biology President

Dr Mike Geddes – South Australian Research and Development Institute (Aquatic Sciences) and University of Adelaide

Dr Simon Goldsworthy – South Australian Research and Development Institute (Aquatic Sciences)

Mr Neil MacDonald – South Australian Fishing Industry Council

Mr Bryan McDonald – SA Department for Environment and Heritage

Dr Stephen Mayfield – South Australian Research and Development Institute (Aquatic Sciences)

Ms Merilyn Nobes – Primary Industries and Resources South Australia

Dr Jian Qin – Flinders University

Mr Ben Smith – University of Adelaide

Ms Claire van der Geest – Seanet

Mr Trevor Watts – South Australian Recreational Fisherman's Advisory Council

Symposium Sponsors

Major Sponsors

South Australian Research and Development Institute

Fisheries Research and Development Corporation

Natural Heritage Trust

Murray-Darling Basin Commission

Sponsors

New South Wales Department of Primary Industries

Western Australia Department of Fisheries

Department of Primary Industries, Victoria

Supporters

Queensland Department of Primary Industries and Fisheries

Tasmanian Department of Primary Industries, Water and Environment

Fisheries Research and Development Corporation – Ecologically Sustainable Development Reporting and Assessment Subprogram

Australian Fisheries Management Authority

Cooperative Research Centre for Freshwater Ecology

Table of Contents

Definitions

Text Adopted from the FRDC-ESD Reporting and Assessment Subprogram

Ecologically Sustainable Development (ESD) is the overall goal, and covers social and economic outcomes and governance issues. It was formally defined by COAG (1992) as *"Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased"*.

Ecosystem-Based Management (EBM), Ecosystem-Based Fishery Management (EBFM), Integrated Oceans Management (IOM) and Environmental Management Systems (EMS) are strategies that are used to work towards the goal of ESD and form a hierarchy within the overall ESD framework:

Industry EMS » Fishery ESD » EBFM » EBM » IOM» ESD

Industry EMS describe how an individual business or a fishery is attempting to meet ESD principles. An Industry level EMS deals with the management of a corporate group within a fishery or fishing area and describe how an individual/ company/group will meet some, or all, of their requirements as dictated by the relevant management objectives/ community expectations.

Fishery' ESD deals with the management of a fishery and describes how a fisheries agency is implementing their management plan to achieve ESD objectives. Thus each ''ESD'' report being generated for export fisheries to meet EPBC requirements is actually an EMS.

EBFM describes the integrated management of all fishing related activities within an ecosystem or bioregion, while recognising that any fisheries agency can only directly manage "fisheries related" activities (i.e. what is covered by their Act/Legislation). Thus, cumulative impacts and the allocation amongst sectors are adequately managed to assist in achieving ESD for the region.

EBM deals with the aggregate management of all sectors (fishing, shipping, tourism mining etc) operating within a single bioregion to achieve ESD outcomes. IOM extends this to a series of adjacent marine bioregions.

ESD requires a completed IOM strategy that is linked/integrated with a similarly comprehensive strategy for any adjacent terrestrial regions. These could be further expanded from a region to national and international scale ESD assessments; the latter would cover the entire planet.

References

COAG. 1992. 'The National Strategy for Ecologically Sustainable Development.' (AGPS: Canberra, Australia.) 128 pp.

Ecological Sustainable Development

Catching Sustainability

FRDC – Subprogram

Introduction

The National Symposium on Ecosystem Research and the Management of Fish and Fisheries provided a forum for stakeholders in the Australian fishing industry and the nation's leading fisheries scientists and managers, to identify and discuss options (and constraints) for addressing the increased legislative and social pressures to assess and manage the ecosystem effects of fishing in three broad sub-themes: (1) interactions of pelagic fisheries and marine ecosystems; (2) roles of fisheries species in structuring benthic ecosystems; and (3) managing fish and fisheries in rivers and estuaries with limited and variable flows.

Representatives from Commonwealth and State Government agencies provided a background to the discussions. This was followed with presentations from renowned international scientists outlining their experiences in conducting ecosystem-based research.

The three sub-theme workshops then provided the scope for leading scientists from research agencies throughout Australia to describe the current status of ecosystem-based research and management within their areas of expertise. Thereafter, delegates identified key management needs and research questions, considered options and approaches to ecosystem research and discussed national strategies and approaches.

The pelagic theme concentrated on the interactions between pelagic fisheries and marine ecosystems, because pelagic fisheries are presently Australia's largest volume fisheries. These are the fisheries where the impacts of fishing on higher trophic levels and other fisheries may be most apparent. Australia's southern temperate reefs were chosen as the benthic ecosystem around which to base discussions, as they support Australia's most valuable commercial fisheries. As rock lobster and abalone fisheries are the two dominant commercial fisheries operating within this region and are among the most valuable of Australia's fisheries these species formed the basis of discussions on the roles of fished species in structuring benthic ecosystems. The rivers/estuarine theme focused on river flows and channel-floodplain-estuary interactions and their role in the life cycles of native fish, with particular attention paid to the effects of limited and variable flow on the biology and fisheries of freshwater and estuarine fish.

These proceedings comprise short summaries of all presentations and document discussions and outcomes from each of the three workshops. They are divided into five sections that broadly follow the Symposium program (see pgs 154 and 155). Section 1 (Background) provides summaries of the presentations from the broad range of introductory speakers, that set the scene for the Symposium, that included members of key stakeholder groups, as well as representatives from Commonwealth and State Government agencies responsible for ensuring fisheries are managed according to the principles of Ecologically Sustainable Development. Summaries of presentations providing an international perspective by three renowned international scientists, that outline their experiences in conducting ecosystem-based research, are also provided in this Section.

Sections 2 (Interactions of pelagic fisheries and marine ecosystems), 3 (Roles of fisheries species in structuring benthic ecosystems) and 4 (Managing fish and fisheries in rivers and estuaries with limited and variable flows) contain summaries of presentations from a broad cross-section of scientists throughout Australia, outlining the status of ecosystem-based research and management in their jurisdiction, and document the presentations, discussions and outcomes within the focused case-study workshops. Each of the three workshops are similarly structured: presentation summaries follow a brief introduction, with a synopsis of the workshop discussions and outcomes comprising the final component. Brief concluding remarks are provided in the final section, Section 5.

Keynote Speakers

Pelagic:

Professor William Montevecchi

Memorial University of Newfoundland, Canada

Bill obtained his PhD from Rutgers University, and is on the faculty of the Department of Psychology, Memorial University of Newfoundland. Bill's research is focussed on the feeding ecology, energetics and trophic relationships of seabirds, and on the habitat relationships of landbirds.
He conducts research on birds as consumers and bio-indicators in marine and terrestrial ecosystems. The primary emphasis of his work is conservation biology and multispecies interactions in low arctic and boreal ecosystems.

Benthic:

Professor Mark Butler

Old Dominion University, Virginia USA

Mark completed a PhD at Florida State University and is currently a Professor and Assistant Chairman in the Department of Biological Sciences at the Old Dominion University, located in Norfolk, Virginia. His broad scientific interests are focussed around lobsters. Current research interests include evaluation of interactions between octopus and lobster, benthic processes in lobster ecology and the roles of physical refugia

Rivers & Estuaries:

Professor Don Jackson

Mississippi State University, Mississippi USA

Don completed an MSc at the University of Arkansas and a PhD at Auburn University before joining the staff at Mississippi State University in 1986. His primary focus is river fisheries research, management and development. He has worked on international fisheries projects in South East Asia, Latin America, the Caribbean and Europe and is a Fellow of the American Institute of Fisheries Research Biologists.

Professor Reg Watson

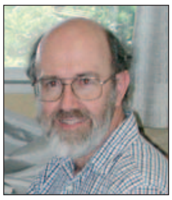
University of British Columbia, Canada

Reg is from the University of Queensland and is currently a Senior Research Fellow at the Fisheries Centre, University of British Columbia. Reg has 28 years of international experience and has expertise in a range of fisheries areas including penaeid biology, trawl fisheries, computer modeling, stock assessment and underwater visual census. He has published extensively on the simulation and optimization of trawl fisheries, and on bias in underwater visual census. An experienced ecological modeler, he was a principal researcher in a study of the impacts of marine protected areas and artificial reefs in Hong Kong. He led a team which developed national marine biodiversity policy for Indonesia.
Reg is currently involved with the 'Sea Around Us' project.

Professor George Branch

University of Cape Town, South Africa

George completed his PhD at the University of Cape Town, at which he is currently a Professor in the Department of Zoology. He has primary interests in two different types of research. The first revolves around the ecology and management of intertidal and shallow subtidal rocky shores. The second is the management of marine fisheries, particularly the role of Marine Protected Areas, and the control of inshore stocks and particularly ecosystem approaches to fisheries management. Together with his students, this work has concentrated on rock lobsters, abalone, urchins, mussels and seaweeds.



Dr Alan Whitfield

South African Institute of Aquatic Biodiversity

Alan completed a PhD at the University of Natal and has worked at Natal University, Rhodes University and now at the South African Institute for Aquatic Biodiversity.
His scientific interests are the importance of estuaries in the life cycles of fish species and on the impacts of development and environmental change on fish communities. His current research includes influences of river flow and ichthyofaunal change and the influence of estuarine type on the structuring of fish assemblages. He has written key international reviews in these areas.

1

Background

1.1 Setting the scene

1.1.1 Ecological assessment of fisheries: creation, evolution and revolution

Tori Wilkinson

In recognition of concerns about the range of impacts of fishing activities on the marine environment, the international and domestic community has actively pushed for improved management of the world's commercial fisheries. A range of international and multilateral agreements stemmed from an evolving realisation that fisheries management practices needed to move beyond target species management to a more holistic approach that explicitly takes into account impacts of fishing on the broader ecosystem and its components. This need for ecosystem-based management (EBM) of fisheries has been explicitly addressed by the Australian Government, which has implemented a forward thinking and world's best practice approach to pursue and achieve EBM of Australia's fisheries.

A national approach to EBM

The release of Australia's Oceans Policy in 1998 clearly defined a way forward and the world's first requirement for large-scale environmental assessment of fisheries. The policy outlined the intention to undertake strategic environmental assessment of all Commonwealth fisheries and the removal of the blanket exemption for marine species from export controls. These two commitments were given effect through the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). In addition, Commonwealth, State and Territory fisheries legislation was changed to incorporate the principles of ESD and State environmental legislation was strengthened.

The EPBC Act fishery assessment process is an independent audit of fisheries management, involving consultation with fishery managers, environment groups, industry and the public as part of the process to push for EBM of all of Australia's fisheries. Assessments of fisheries are conducted in accordance with the wildlife trade, protected species and strategic assessment requirements of the EPBC Act by the Australian Government Department of the Environment and Heritage (DEH). To make assessment against all of the parts of the legislation easier, *Guidelines for the Ecologically Sustainable Management of Fisheries* were developed and endorsed by the whole of government. The Guidelines pull together all of the legislative requirements, provide benchmarks for addressing ecosystem-based management of fisheries and are used to conduct a single assessment for individual fisheries. Details regarding the legislative requirements, Guidelines and the fishery assessment process and progress can be found at http://www.deh.gov.au/coasts/fisheries/index.html.

A crucial part of the process is recognising that there is a spectrum of fisheries – from large to small, complex to simple, well managed to poorly managed - and not all fisheries can or will achieve the same level of EBM as others. The important thing is that each is progressed over time along that spectrum towards true EBM. Also important to the process is recognition that there are real life constraints on fisheries management, like time and resources. DEH seeks to take this into account when preparing reports on fisheries, and in particular in developing recommendations for future improvement, while still seeking improvements required for ecologically sustainable management.

Moving towards EBM

As the assessment process has progressed, and with over two-thirds of the total number of export fisheries assessed, DEH has seen some impressive changes in fisheries management and in the approach and attitude of industry regarding EBM. The most encouraging change has been a noticeable shift in management focus from target species to whole of ecosystem. Increasingly, tools like bycatch action plans, mitigation technologies and spatial management are being introduced to fisheries and used to better manage impacts on the ecosystem.

Another significant advantage of the process has been the documentation and consolidation of information on individual fisheries. Previously, numerous documents, most of which were not publicly available, were needed to get a full 'picture' of a fishery, but now for each fishery assessed there is a single document that is a useful reference and management tool. The consolidation of information has also provided management the opportunity to take a step back and view their fishery holistically. With all the management policies, tools and their effectiveness described they can now look to see where the strengths and weaknesses are and adopt a more strategic longer-term approach to management.

In addition, the assessments have identified a range of issues that are common to particular regions, species and gear types, and many relate to ecosystem impacts. Ecosystem impact management is an issue that affects all types of fisheries. Even large high value fisheries like the Northern Prawn Fishery, which has already spent significant efforts on tackling issues like bycatch and protected species, is still grappling with gaining a better understanding of their impacts on the ecosystem. And while more targeted single species fisheries may not have as many ecosystem impacts as trawling, they are also faced with ecosystem impact questions, such as the impact of removing large quantities of the target species on food webs.

Ecosystem impacts are generally fishery-specific but it is likely that methods to address the issue may be applicable across fisheries and jurisdictions. However, it is unlikely that any single group will be able to address the issue and as we move further towards EBM there will be an increasing need for collaboration and cooperation between groups

The way ahead

The fishery assessment process has identified three main areas that all stakeholder groups need to focus on to help achieve EBM of fisheries and identify and manage fishery impacts. That is, to improve collaboration and cooperation between jurisdictions, managers, industry, scientists, government and non-government agencies (NGOs); to shift the way we think about the issues; and to improve the way we communicate our ideas and share in addressing the issues.

For industry, there needs to be wider recognition that industry is often one of the real drivers of change in the face of increasing public pressure to protect the environment. While the EBM process has not been accepted by everyone, it is also clear that the knowledge that legislation and public pressure are unlikely to go away has meant that, in general, industry has accepted the new way of doing business. The key message for industry is that without maintaining the system on which commercial fish species rely, their fishing future may be shorter and less certain because ultimately, economic sustainability of the industry relies on the ecosystem being fit enough to support it. What is needed is good communication of this idea and increased ownership of the issue by industry.

For fisheries managers, the assessment process has not been easy, but to their credit they have worked cooperatively through the process, particularly in agreeing to recommendations that are in some cases onerous and unpopular. The challenge will be in delivering on recommendations and this is where collaboration and cooperation within and between jurisdictions will be important. Many issues are similar across different fisheries and a collaborative approach to addressing these could save resources and deliver a better overall result. Better communication can already be seen through the first step of consolidating and making publicly available the diversity of information on individual fisheries.

The next step will be in using that consolidated information as a tool for planning and continuing that shift ever closer to EBM.

For scientists, the challenge is in delivering on the science needed to support all of the requirements coming out of the assessment process. This will require thinking strategically to make the best use of the limited resources available. Given the similarities in some issues raised across different fisheries, there will be opportunity for increased collaboration but also a need for clear communication of results to managers and other stakeholders.

Finally, for conservation NGOs, there needs to be acceptance that some problems cannot be solved quickly and that management operates within constraints, such as time, funds and human resources. The key will be in looking for practical solutions to fisheries issues but also in recognising that often the best people to work out how to achieve what we want are industry, managers and scientists. Communicating issues and ideas in a manner that can be addressed through practical and operationally achievable approaches will be important for future assessments and in continuing to drive EBM across fisheries.

Assessments for the future

1 December 2004 was a major deadline for completion of the first round of assessments, but following this date, the process will continue. Some fisheries are yet to be assessed as they are going through management planning processes and the work on these fisheries will continue. In the medium term DEH will be monitoring how recommendations and conditions have been implemented and, in the interest of seeking continual improvement, DEH will also continue to engage where it can in ongoing fishery management processes and issues.

Reassessment will also commence for a number of fisheries. DEH is holding a workshop with fishery managers in 2005 to map out a process for the second round of assessments. DEH expects that improvements sought in the first round will have been achieved and, with improved information on both target and non-target species and completion of risk assessments, the second round is likely to focus more on the broader impacts of individual fisheries.

This Symposium will be a useful forum to discuss ecosystem impacts of fishing and work towards a more collaborative and cooperative framework through which to approach some of the issues likely to come out of the next assessments.

Wildlife Trade and Sustainable Fisheries Branch
Department of the Environment and Heritage
Australian Capital Territory, Australia
Email: tori.wright@deh.gov.au

1.1.2 Frameworks for assessing the management of marine resources: how do they all fit together?

Rick Fletcher

During the past 4 years there has been considerable progress in implementing the principles of Ecologically Sustainable Development (ESD) across all Australian fisheries and aquaculture sectors. This has been accelerated by the need to meet the requirements of the Australian Governments' Environmental Protection Biodiversity and Conservation (EPBC) legislation, which has resulted in most jurisdictions having completed an assessment against the ecological components of ESD for each of their major commercial fisheries. Many of these assessments utilised some of the tools developed during the first phase of Subprogram activities.

This outcome, whilst significant, is only the first step in the journey. The next phase of implementation will require ESD frameworks that can integrate the individual fishery assessments, explicitly manage the allocation of access amongst stakeholder groups (including the creation of marine reserves), and address the cumulative impacts of fishing activities - all at a bioregional level. One complication to the development and extension of this initiative has been the confusion caused by the plethora of terms, such as 'ecosystem based management' and 'integrated oceans management', which are being used to describe many of these types of activities.

This paper outlines, in an informative manner, how the various 'ecosystem' concepts relate to each other and how they fit within an overall ESD framework. It will also describe the current Subprogram initiatives to extend the single fishery framework to enable the assessment of multiple fisheries within a bioregion, and ultimately cover multiple sectors within a marine planning context.

Department of Fisheries
Western Australia, Australia
Email: rfletcher@fish.wa.gov.au
(Abstract only)

1.1.3 Biodiversity protection in the Great Barrier Reef Marine Park

Leanne Fernandes

The Great Barrier Reef Marine Park has just experienced a significant increase in the protection of its marine environment through a comprehensive review of its zoning. The objective of the rezoning was to increase the protection of the entire spectrum of biodiversity at an ecosystem level through incorporating representative examples of every habitat in no-take zones (therefore called, the Representative Areas Program). Throughout the process, it was recognised that all species, including fish, play an important part in the ecosystem as part of the trophic web. Although the importance of fish in the system was inherent in the design of the new network of no-take areas, no particular fish species or fish population was a key driver in defining the principles. Rather the biophysical operational principles and social, economic and cultural principles were more encompassing of the entire spectrum of ecological and human attributes and values. This included extensive community participation. While it is expected that there will be positive impacts of the new zoning on fisheries resources, the purpose of the Representative Areas Program was biodiversity protection not fisheries management.

Representative Areas Program
Great Barrier Reef Marine Park Authority
Queensland, Australia
Email: l.fernandes@gbrmpa.gov.au
(Abstract only)

1.1.4 The commercial fishing industry and ecological sustainable development

Ted Loveday

Ecologically sustainable development (ESD) is a pre-requisite to the future prosperity and security of the fishing industry. Simply catching more fish is not a solution to maintaining or improving the industry's future economic viability. ESD also requires the external risks to the long-term sustainability of fisheries resources to be addressed, and for the social and economic dimensions of fisheries to be considered in all levels of decision making.

Australia's progress on ESD in fisheries is at the forefront internationally. ESD principles and objectives have been incorporated into most fisheries and resource management legislation. Ecological assessments are now embedded in all export related fisheries. The focus of research has broadened from the traditional biological aspects, to include studies of the ecosystem and quantification of sustainable catch levels. *How to guides* for ESD in commercial fisheries and aquaculture have been prepared under the Fisheries Research and Development Corporation (FRDC) ESD Reporting and Assessment Subprogram.

Significant efforts and resources are being committed towards addressing the ecological dimensions of ESD. However, there remains a paucity of data on the social and economic dimensions of most Australian fisheries, and governance regimes that effectively integrate socio-economic considerations are yet to emerge.

Fisheries-related decisions are commonly made in an environment that is blissfully ignorant of, or in denial about, the associated social and economic consequences. Socio-economic aspects are often considered in a chaotic environment created after the industry has been forced to seek relief through political intervention. Most recent fisheries related socio-economic studies in Australia have been conducted in precisely this type of environment.

A lot of the hard work has already been done and significant progress has been made towards ESD in Australian fisheries. However, impediments, some of them significant, still remain. Integration across biological, economic, social, and cultural disciplines needs to be greatly improved. There is an urgent need to further broaden the scope of fisheries research and development (R&D), and for significant investments to be directed towards socio-economic research, value-adding, quality, post-harvest technology, market research, and in other R&D areas that are critically important to help meet ESD objectives.

Urgent and effective action is needed to mitigate the threats to sustainability of fisheries caused by external environmental impacts. Management regimes need to be more flexible and adaptive to changing environmental, social and economic conditions. Secure property rights are essential to remove disincentives, and to create incentives, to improved environmental performance.

Industry based initiatives such as environmental management systems are helping to break down some of the remaining barriers by ensuring industry takes ownership over its own challenges and becomes increasingly committed to driving the implementation of ESD based solutions in partnership with governments and other stakeholders.

Managing Director
Seafood Services Australia
Australia
Email: ssa@seafoodservices.com.au

1.1.5 Recreational fishing in Australia and ESD

David Hall

Current status of recreational fishing in Australia (based on National Recreational and Indigenous Fishing Survey 2001):

1. 3.36 million participants
2. $1.2 billion p.a. expenditure
3. $3.3 billion investment (replacement value) in boats
4. Estimated catch of 136 million fish, including 108 million finfish
5. 44% of finfish released alive after capture
6. 41% sea, 35% estuary, 20% freshwater
7. Largely non-quantified, but significant social (health and lifestyle) and ecological issues and impacts

External influences on ecosystem-based fisheries management in Australia (fisheries specific):

1. Food and Agriculture Organisation of the United Nations (FAO) Code of conduct for responsible fishing 1992 (International)
2. FAO Agreement on highly migratory species and straddling fish stocks
3. Council of Australian Governments (COAG) Agreement on Ecologically Sustainable Development (ESD) principles and representative Marine Protected Areas (MPAs) 1992
4. National Fisheries ESD reporting framework (ongoing)
5. National Oceans Policy 1998 (ongoing)
6. Environmental Protection Biodiversity and Conservation (EPBC) Act (1999) and assessment process
7. Integrated Coastal Zone and Oceans Management (2004)
8. Commonwealth (1991) and State Fisheries Acts (var.)
9. Offshore Constitutional Settlement agreements
10. Resource sharing and management framework/access rights
11. Fisheries Research and Development Corporation (FRDC) funded program on post release mortality (recreational)

What should the community expect from recreational fishing as a sport and industry?

1. Responsible “stewardship” approach by anglers and angler bodies
2. Sustained campaign to reduce illegal fishing and ecological “footprint” e.g. biodegradable bait bags and “ecologically friendlier” fishing practices and gear
3. Economic as well as lifestyle and health (social) benefits exceeding ecological impact costs
4. Sustainable governance of recreational fisheries

What should recreational fishing as a sport and industry expect from the government?

1. Well defined access rights and transfer mechanisms
2. Sufficient resources (funds and people) to properly address major ESD issues affecting fisheries
3. Informed, communicated and adaptive ESD based fisheries management systems in place
4. Consultation with affected fishers on management decisions
5. Explain need, describe options, inform ALL and involve
6. Proportionate economic and social benefit consideration in government funds allocation and management decisions

How are we going in Australia?

1. A mixed bag
2. Stakeholder involvement variable especially non committee
3. Variable understanding by anglers and some angler bodies of ESD issues
4. Apparent lack of consideration for economic and social impacts of recreational fishing in government decision making (e.g. SA salmon)
5. Ability of both government agencies and angler bodies to handle complexity and volume of work
6. FRDC funded program on post release mortality having a significant impact

What next?

1. Fisheries Ecosystem Plans (FEPs) by "bioregion"
2. Fisheries management plans to address FEPs
3. Decide *what commodity* we are sustaining (i.e. ecosystems not individual species)
4. Healthy ecosystems = maximum socio-economic yield not Maximum Sustainable Yield (MSY) (MSEY = 2/3MSY)
5. Allocate fishing rights (% sustainable harvest) and responsibilities to enable economic transfers
6. Workable national policy agreements on the above
7. Fisheries agency funding consistent with the value and need
8. And finally (to those in authority) .... Consult!

Hallprint Fish Tags
South Australia, Australia
Email: davidhall@hallprint.com.au

1.2 International Perspective

1.2.1 Influences of forage species on pelagic food webs: signs from seabirds

William Montevecchi

Understanding food web dynamics is essential for conceptualizing ecosystem processes. However, the complexity of biological and physical interactions makes the changing conditions of food webs difficult to assess. Research on focal forage species that drive food web dynamics can be used to develop tractable multi-species approaches needed to address ecosystem process and management.

Forage species create avenues of energy transfer between invertebrate and vertebrate assemblages. Biophysical studies of focal forage species and subsets of their key predators and prey reduce ecological complexity while capturing a multi-trophic, oceanographic approach.

Oceanographic and fisheries influences (and their interactions) on focal and keystone forage species can have profound direct and indirect effects that can generate regime-type shifts in pelagic food webs. Such profound shifts are often difficult to predict and even to detect until after a considerable time lag.

Biophysical studies of the ecology and behaviour of seabirds, the most obvious and accessible marine animals, help identify and clarify food web dynamics. Examples of synoptic oceanographic studies needed to effectively probe such processes and to generate management options are presented. Decisions by individual top predators provide mechanisms of pelagic food web interactions and population responses, and the meso-scale processes in which they occur help delineate higher-level mega-scale patterns.

Departments of Psychology, Biology and Ocean Sciences Centre
Memorial University of Newfoundland
Newfoundland, Canada
Email: mont@mun.ca
(Abstract only)

1.2.2 Benthic fisheries ecology in a changing environment: unravelling process to achieve prediction

Mark Butler

"When one tugs at a single thing in nature, one finds it attached to the rest of the world."
John Muir (1838 - 1914), naturalist

Marine fisheries and the ecosystems that sustain them are increasingly beset by environmental deterioration, and the problem is particularly acute in coastal zones where human populations are increasing. Indeed, many of our coastal oceans teeter on the precipice of a dramatic phase shift from ecosystems with diverse benthic communities to biotically depauperate, plankton-dominated systems. The prospect of such a dim future has triggered a surge in international agreements and national initiatives pertaining to ocean management, most espousing an ecosystem-based approach to management. Fishery managers are tasked with determining just what ecosystem-based management really means and how to balance multiple, often conflicting, demands of resource users, politicians and scientists. A further challenge is that management decisions must be made against the shifting backdrop of a deteriorating coastal environment and its effects on ecosystem dynamics. The need for new ecosystem-oriented management tools is ubiquitous and, increasingly, those tools centre on modelling. Yet, in our quest for new modelling approaches to lift us from this dilemma, we must also recognise that we typically lack the necessary empirical data to appropriately parameterise models with vital rates representative of those species reacting to an altered environment. We need both models and data that better reflect the complicated interactions that occur among the environment (i.e. water or habitat features), interacting species, and the fishery influenced dynamics of the species of interest.

Spatially-explicit, individual-based simulation modelling potentially permits this kind of integration, but they have seen limited use in marine resource management, especially with respect to coastal benthic resources. For the past decade or so, my colleagues and I have used and explored the utility of spatially-explicit, individual-based modelling – coupled with targeted experimental work – to explore the impacts of nursery habitat deterioration, coastal freshwater management, and fishery activities on Caribbean spiny lobsters in the Florida Keys, Florida (USA). Those studies have offered managers useful predictions of the minimum impacts that might be expected for lobster and critical biogenic nursery habitat for lobsters (i.e. sponges and octocorals) in coastal regions where impacts from the restoration of the freshwater Everglades hydrology is expected.

I doubt that there is any single "right" way to manage our coastal resources and ecosystems because of the idiosyncrasies of the ecology, the politics, and economics of different regions. Still, we need to be explicit about the goals of ecosystem management and from such goals generate questions about the potential impacts of various strategies formulated to achieve those goals. Modelling must undoubtedly play a role in this process. If so, then there is a place for flexible models that emphasise spatially-explicit, individual-based interactions among organisms and their environment. Although not applicable for all coastal resource management situations, our experiences provide an example of the potential for coupling targeted empirical studies with advanced modelling so as to offer managers "what if" projections of potential changes in benthic ecosystem structure in response to altered dynamics in the coastal environment. The drive toward ecosystem-based management is growing worldwide and in principle it sounds like good management. Like a painting in progress, the form that ecosystem-based management will ultimately take is beginning to materialise in boardrooms, in print, and at meetings like the 2004 Australian Society for Fish Biology Symposium and Conference in Adelaide.

Department of Biological Sciences
Old Dominion University
Virginia, USA
Email: mbutler@odu.edu

1.2.3 Ecosystem connections to river fisheries

Don Jackson

Rivers integrate terrestrial, aquatic and ecotone components of their respective ecosystem upstream to downstream and laterally throughout the catchment/floodplain. Soil characteristics fundamentally determined fish stock characteristics in rivers by influencing water chemistry and subsequently in-channel and extra-channel primary production. Water temperature, scour, fill, erosive processes, depth, current velocity, and substratum characteristics operate synergistically to set the stage for biological events in streams.

Within this framework, heterotrophic processes and secondary production of aquatic invertebrates (forage items for fishes) typically are principal determinants of river ecosystem bio-energetics. When rivers overtop main channel banks they incorporate extra-channel allochthonous organic material and nutrients. The aquatic-terrestrial transition zone is particularly important in this regard because it promotes rapid nutrient exchanges and can stimulate localised plankton production. Flooding also introduces snags (large woody debris) into river channels. In rivers lacking other forms of stable substratum, snags are the principal attachment substratum for invertebrates as well as habitat for fishes. In deeply incised channels, snags are entrapped and can form debris dams that collect coarse particulate organic matter (CPOM). In streams with organically-rich sediment, production of illiophagous (mud-eating) fishes such as catfishes (Ictaluridae) and suckers (Catostomidae) can be very high because while ingesting inert materials, invertebrates as well as organic nutrients become part of the diet.

Fish populations and associated fisheries in rivers exhibit linkages to flow regimes and climatic/weather characteristics. These relationships tend to be strong in lowland rivers because fishes exploit inundated floodplains for spawning and nursery habitat, and for refuge and feeding. Fish yields per unit surface area are considerably greater in rivers with flood pulses and floodplains than in nearby impoundments where flood pulses are reduced or absent. Additionally, fish production in rivers increases exponentially as length of river increases. Because fish from throughout the floodplain concentrate in the main channel and more permanent backwater environments as flood waters recede, floodplain river ecosystems are some of the more productive inland fisheries in the world. Typically, fisheries in floodplain river ecosystems are focused on one to two year old (or older) fish in excess of what the river can support during minimal flow periods. Alterations of main river channel environments through dredging and the removal of snags can harm the carrying capacity of the river channel, especially during minimum flow periods.

Reservoirs above dams, as well as tailraces immediately below dams, can sustain dynamic, productive fisheries. Reservoir fisheries typically are enhanced as temperature, littoral habitat and dissolved nutrients (for plankton production) increase. These influences operate synergistically and also reflect thermal (i.e. latitudinal) effects. Tailrace fisheries respond positively to seston transport, primarily through its influence on secondary production of filter-feeding benthic macroinvertebrates (forage resources for the fishes). Dam design that permits intake of reservoir water from different levels can promote fisheries by targeting strata where plankton are most abundant. In reservoirs having an oxygenated hypolimnion, discharge of cool or cold waters into the downstream tailwater can create environments conducive to establishment and maintenance fisheries targeting exotics such as salmonids in warmer regions beyond their natural range. These artificial fisheries are sometimes viewed as mitigation for fisheries lost as a result of dams. In some cases (e.g. White River, Arkansas, U.S.A.), these fisheries have been tremendously successful in boosting local economies (primarily via tourism).

Dams can impact movement of migratory fishes. Unless provisions are made to allow fishes opportunity to bypass dams, riverine fish stocks (and their dependent fisheries) will diminish primarily through failure of fish to access spawning sites, or through mortality as fishes move downstream through or across the barriers. Understanding the biology of individual fish species is imperative because passageways around the dams must be specific to each species needs, biological capabilities, and behavioural characteristics.

Reduced or unnaturally variable streamflow is common below dams, particularly during dry seasons or in arid/semi-arid environments. This can negatively affect basic biological activities of fishes (e.g. reproduction) and their forage bases, standing stock of fishery resources (via reduced or unstable environments), and access by fishers (if flows are too high, fishers not using boats are impacted; if flows are too low, fishers using boats are impacted).

Placement of dams in lower reaches of rivers has greater impact on river fisheries per unit of stream length (i.e. it is harder for a reservoir to replace the amount of fish lost in the inundated section of the river) than if the dams are further upstream. However, the cumulative impact of dams in headwaters can be devastating to river fisheries because the reservoirs tend to trap nutrients and organic materials essential to productivity in the streams lower reaches. In severe cases, these impacts extend to coastal zone fisheries.

River ecosystems and their fisheries have had major influences on human history, culture and tradition. People living in close association with rivers, and especially those who fish in these rivers, develop an identity as a river people, often engaging in activities that resonate cultural values and tradition more clearly than economic interests. Because these connections are with non-mobile, non-transportable resources (i.e. the rivers), degradation of these resources leaves such persons without alternative connections to the source of their identities. When this happens, their status and stature within their respective communities erode.

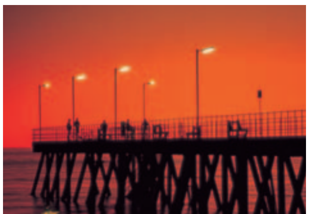
Fisheries and aquatic resources professions are founded on science and technology. Yet, when we work with rivers we actually assume the role of artists. Through our efforts we compose a picture on the landscape. We are in many ways perhaps the perfect artists because we are able to become components of our own art…a part of the picture.

If we work long enough with rivers, and if we listen carefully, we also may start to hear the river's song. When we begin to sing the rivers song, we need to begin softly, gently, and in persuasive ways in order to reassure those who look to us for guidance that we have not abandoned science but rather are using science as a platform, perhaps as a springboard, from which we can move toward higher realms in understanding humankinds relationships with the rhythms of the earth. In these endeavours, we must help others recognise that stability as a working paradigm for the management of rivers is appropriate only if spatial and temporal resolutions are of sufficient scale, and that there is music in variance… that variance is not necessarily a noise and that the power of variance is oftentimes expressed in organism responses to abiotic forces sculpturing the landscape that are beyond human control. Finally, we must have great courage as we lead others to realise that rather than adjusting river ecosystems, perhaps *we must adjust ourselves.*

Department of Wildlife and Fisheries
Mississippi State University, Mississippi, USA
Email: djackson@cfr.msstate.edu

2

Interactions of pelagic fisheries and marine ecosystems




2.1 National and International case studies to provide a conceptual framework

2.1.1 Mapping global fisheries' indicators and potential conflicts

Reg Watson and Kristin Kaschner

Managing fisheries has always been challenging, but the realisation that we must consider the wider ecological context makes new demands on the data we collect. Single species fisheries do not operate in isolation from their supporting ecosystems. We present an approach that allows the relatively coarse statistics available for many fisheries to be placed in a wider, yet relatively fine-scale framework.

This approach relies on assembling a global database, collated and harmonised from a variety of sources such as the Food and Agriculture Organization and its regional bodies, regional fisheries organizations in the North and South Atlantic, statistics from national authorities and those gathered through collaborations and consultations. These data are then processed to mitigate problems such as taxonomic misidentifications, the prevalent use of highly aggregated taxon items such as 'miscellaneous marine fishes' for reporting, and the misrepresentation of the fishing country through the practice of 'flags of convenience'.

We developed significant supporting databases describing the global distribution of commercial species, and of the fishing patterns and access agreements of reporting countries which allowed a rule-based model to allocate the crudely defined global catches available to a system of 30-minute by 30-minute spatial grid cells. Such a fine-scale representation of global fisheries catches since 1950 supported a range of analyses revealing gross over-reporting by China, reductions in the trophic level and mean size of landed taxa, spatial patterns of fisheries collapses, the global consumption of fuel for fishing, increases in the use of destructive fishing gears such as bottom trawl, and spatial overlaps in consumption between fisheries and marine mammals.

We described the relative distribution of 115 marine mammal species by relating information about species-specific habitat preferences to local, average oceanographic conditions. Using these distributions combined with biological characteristics such as population abundances, sex-specific mean weights, standardised diet compositions, and weight-specific feeding rates it was possible to produce food consumption maps for each species, as well as maps of the resource overlap between marine mammals and fisheries using a modified niche overlap index. Spatial overlap and exploitation of the same food types was relatively low, suggesting that actual competition between fisheries and marine mammals may be quite low. The highest overlap predicted was in the temperate to sub-polar shelf regions of the northern hemisphere. Overall, < 1% of all estimated marine mammal food consumption stemmed from areas of high overlap. Nevertheless, overlap between marine mammals and fisheries may be an issue on smaller scales (especially for species with small feeding distributions) where more detailed local investigations are required.

Much of the information described here is available from our website www.seaaroundus.org where the catch taken from each nation's exclusive economic zone is also presented in detail.

Fisheries Centre
University of British Columbia
British Columbia, Canada
Email: r.watson@fisheries.ubc.ca

2.1.2 Large predator assessments of forage species in marine food webs

William Montevecchi

Complex biological and oceanographic interactions make it difficult to assess food web dynamics. Within food webs, focal forage species often have pervasive influences by creating avenues of energy transfer between invertebrate and vertebrate assemblages and by driving large predator production. Forage species, in turn, are often profoundly affected both directly and indirectly by fisheries and oceanographic events (and their interactions). Examples of anthropogenic and oceanographic influences on forage species are globally evident.

Biophysical studies involving top predators can reduce biological complexity and capture information about the distributions, movements, availability and conditions of forage species' sexes and age-classes. Data from top predators provide inexpensive, catch-independent, natural assays of forage species that can complement and enhance conventional fisheries research.

Different predators have different foraging constraints (e.g. body size, surface-feeders vs. divers) and intersect prey using different tactics at varying depths and distances from breeding sites where they are easily accessed by researchers. Measurements from predators include behavioural, dietary, reproductive and population responses. Fluctuations in the populations of long-lived vertebrates are buffered from bottom-up environmental perturbations by behavioural and life history features that cope with transient variation in prey conditions. Yet over decades and centuries changes in predator populations integrate and reflect large scale influences of prey and ocean climate. Intra-annual responses of predators include breeding success and body condition that often reflect prey conditions over months and weeks. On finer scales involving days, measurements of diet and foraging behaviour can provide rapid feedback about prey conditions. Advances in micro-technologies (e.g. archival data loggers, telemeters) and chemical analyses (e.g. isotopic, fatty acid and steroid assays) are rapidly improving the means to assess predator responses to changing prey conditions over a large range of temporal and spatial scales.

Research directed at top predators and centred on focal forage species can be used to develop the tractable multi-disciplinary programs that are needed to investigate ecosystem processes and to engage effective long-term management. Research power to enhance predator-derived information can be maximized by 1) inter-area and inter-annual comparisons, 2) large multi-disciplinary research approaches that involve synoptic assessments of prey distributions and densities within predator foraging ranges, and 3) long-term, multi-species studies that sample focal prey across many scales and oceanographic processes. Mechanisms of predator responses can be probed, using predator-borne devices, to assess foraging behaviour and decision-making by individuals. The integration of these types of research with conventional fisheries studies can be very informative.

An ecosystem-based fisheries management research program involving the growing South Australian pilchard *(Sardinops sagax)* fishery is being designed. Objectives include assessment of potential effects on top predators and the development of fishery-independent assays of pilchard conditions. Fish quota allotments for large predators and spatial allocations will be investigated. Given the current state of increasing fishing pressure (i.e. annual doubling of quotas), viral outbreaks and stock collapses, these tools appear necessary and could be very useful. Other precautionary approaches could involve social and economic scientists and fishers in the establishment of an independent observer program and the production of a code of conservation-oriented fishing practices.

Departments of Psychology, Biology and Ocean Sciences Centre
Memorial University of Newfoundland
Newfoundland, Canada
Email: mont@mun.ca

2.1.3 Ecosystem approaches to examining seal-fishery trophodynamics: a comparison of a single and multi-species fishery in Australia

Simon Goldsworthy

Globally, the extent of ecological or trophic interactions between marine mammals and fisheries is becoming increasingly important in light of increasing requirements for Ecologically Sustainable Development (ESD.) In Australia, harvesting of seal populations in the early 1800s resulted in severe reductions in numbers from which species have yet to recover. As a consequence, commercial fisheries in Australia have largely developed during a period of minimal competition from seal populations. However, in recent years fur seal populations have increased rapidly and there is now concern about the impact that these recovering populations may have on fisheries production, and/or how fisheries may impede the recovery and status of seal populations. The use of trophodynamic models to examine the trophic interactions between seals and fisheries is examined here for two different fisheries in Australian Territory. A multi-species fisheries in south-eastern Australia (part of the Commonwealth South East Fishery) where seals consume few of the commercially targeted species, and the mackerel icefish fishery at Heard Island in the southern Indian Ocean (part of the Commonwealth Heard Island and McDonald Island Fishery), where icefish also form a major component of diet of Antarctic fur seals. Results from both studies highlight the role of seals as major consumers of marine resources, and in structuring key trophic interactions between predator and prey species, including those commercially fished.

SARDI Aquatic Sciences
South Australia, Australia
Email: goldsworthy.simon@saugov.sa.gov.au
(Abstract only)

2.1.4 Fishery-predator competition and the effects of predator depletions: insights from trophic models that incorporate benthic-pelagic coupling

Tom Okey

Humans and other high trophic level predators remove large quantities of living organisms from marine ecosystems, but the degree of competition for these resources is controversial. Indeed, there are as many perspectives on the strength of competition between fisheries and other marine predators as there are interests in marine resources. Competition, whether exploitation or interference, varies in space and time. We evaluated whether exploitation competition between fisheries and high trophic level predators is weak or strong in three coastal marine ecosystems—Prince William Sound, Alaska, the West Florida Shelf, and a Galápagos Rocky Reef—by presenting preliminary results of dynamic simulations using whole food-web *(Ecopath)* trophic models (Okey *et al.* 2004a, Okey *et al.* 2004b, Okey and Wright 2004). The *Ecopath with Ecosim* modelling approach in general is explained by its developers (Polovina 1984, Walters *et al.* 1997, Pauly *et al.* 2000, Christensen and Walters 2004) (also see www.ecopath.org). We also explored the potential whole-food-web effects of removing high trophic level predator groups - in this case shark groups - from these marine ecosystems. These models were not constructed specifically for addressing these questions, nor were they modified for this purpose (except for dis-aggregating a general shark group from one of the models). We chose these three models for this evaluation because these are the three most refined models that the lead author has direct experience in constructing.

We conducted virtual manipulative experiments using *Ecosim* with these *Ecopath* models by removing all fishing and recording the predicted relative change in the biomasses of all functional groups after 100 years. Likewise, we evaluated the ecological role of sharks by removing sharks and recording the relative changes in the other functional groups in the model. Finally, a full series of functional group removal simulations indicated a broad range of trophic interaction strengths among functional groups, but with the strongest interactors tending to be at the highest trophic levels or at the apex of their own sub-webs. These preliminary simulations, in general, indicated moderate to high competition for food between fisheries and certain marine mammals and birds as well as strong community effects of removing sharks and certain other high trophic level predators.

A clear cluster of the highest trophic level groups increased notably after all fishing was removed from the Prince William Sound and Galápagos rocky reef models (e.g. Figure 1). The effects of removing fishing were also strong in the West Florida Shelf model, but resulting increases were not clustered at the very top of the food web in that model. Of all the mammal and bird functional groups above trophic level 3.5 from all three models, eleven increased after the removal of fishing, while only one decreased after removal of fishing. Sea lions decreased in the Galápagos rocky reef model because sharks increased four fold, also raising the possibility that adjustments to dietary parameters could change the results for a setting like Prince William Sound, Alaska. Most of the increases of mammals and birds in these fishery removal simulations were reasonably large.

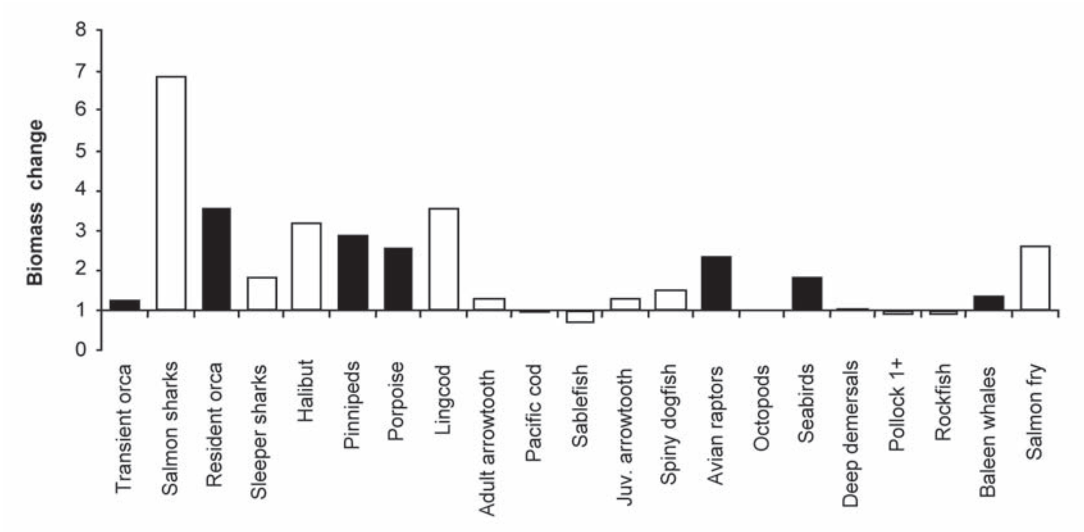


Figure 1. Simulated changes in top predators (arranged by descending trophic levels (TL) from 5.3 on left to 3.5 on right) in the Prince William Sound, Alaska *Ecopath* model 50 years after the simulated removal of all fishing. Black bars represent mammal and bird groups. Adult salmon (TL= 4.2) are too trophically transient in PWS for the result to be displayed usefully.

These preliminary findings are not inconsistent with those from a recent global analysis of first-order resource overlap between marine mammals and fisheries (Kaschner 2004) because that analysis indicates high first-order resource overlap in some coastal settings (though *much* lower resource overlap in most of the world's oceans). The present analysis of direct and indirect trophic effects indicates potentially strong exploitation competition between marine mammals and fisheries in the coastal/continental shelf ecosystems examined here, which range from sub-arctic to tropical settings. The relatively strong community effects of removing sharks from these models is inconsistent with recent results from shark depletion analyses conducted by Kitchell *et al.* (2002) using an *Ecopath* model of the pelagic food web of the Central Pacific, perhaps because coastal marine ecosystems have higher connectivity and lower redundancy related to stronger benthic-pelagic coupling.

These analyses are somewhat preliminary because these models need to be refined and calibrated further (for example by fitting predicted trajectories to observational time-series data) before being used to generate quantitative policy advice. Compared with many other *Ecopath* models, however, the present models have high overall data pedigrees and have been refined iteratively. In their present form, these models are useful for gaining insights into potential mechanisms and relationships that are strong and consistent.

Concluding that competition between fisheries and other high trophic level predators is strong does not automatically mean that competitors should be eliminated, though it probably means that they have been in the past, thereby explaining some cases of apparently low competition where intensive fisheries occur. Depletion or elimination of top predators is indeed likely to be reckless and unwise in terms of likely changes to the structure and function of the ecosystems that support human populations.

Decisions regarding the protection or depletion of top predators ought to be precautionary and based primarily on overall societal values that are well informed by science in addition to ethical and other considerations.

CSIRO Marine Research
Queensland, Australia
Email: tom.okey@csiro.au

References

Christensen, V., Walters, C. J. 2004. Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling* 172:109-139.

Kaschner, K. 2004. Modelling and mapping of resource overlap between marine mammals and fisheries on a global scale. PhD Thesis, University of British Columbia, Canada.

Kitchell, J. F., Essington, T. E., Boggs, C. H., Schinder, D. E., Walters, C. J. 2002. The role of sharks and longline fisheries in a pelagic ecosystem of the Central Pacific. *Ecosystems* 5:202-216.

Okey, T. A., Banks, S., Born, A. R., Bustamante, R. H., Calvopina, M., Edgar, G. J., Espinoza, E., Farina, J. M., Garske, L. E., Reck, G. K., Salazar, S., Shepherd, S., Toral-Granda, V., Wallem, P. 2004a. A trophic model of a Galápagos subtidal rocky reef for evaluating fisheries and conservation strategies. *Ecological Modelling* 172:383-401.

Okey, T. A., Vargo, G. A., Mackinson, S., Vasconcellos, M., Mahmoudi, B., Meyer, C. A. 2004b. Simulating community effects of sea floor shading by plankton blooms over the West Florida Shelf. *Ecological Modelling* 172:339-359.

Okey, T. A., Wright, B. A. 2004. Toward ecosystem-based extraction policies for Prince William Sound, Alaska: integrating conflicting objectives and rebuilding pinnipeds. *Bulletin of Marine Science* 74:727-747.

Pauly, D., Christensen, V., Walters, C. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57:697-706.

Polovina, J. J. 1984. Model of a coral reef ecosystem 1. The Ecopath model and its application to French Frigate Shoals. *Coral Reef* 3:1-12.

Walters, C., Christensen, V., Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Reviews in Fish Biology and Fisheries* 7:139-172.

2.1.5 Improving fisheries sustainably: using seabirds to manage marine resources

Ashley Bunce

Overexploitation of commercial fisheries is widespread with an increasing proportion of the world's catches originating from stocks that are overfished. Seabirds are often highly visible, wide-ranging upper trophic level consumers that aggregate in area of increased ocean productivity and therefore have been reported to be natural monitors of marine environmental conditions. South-eastern Australia supports large populations of breeding seabirds which feed on commercially exploited prey such as pilchards (*Sardinops sagax*). To improve the sustainability of this fishery a model has been developed using seabird breeding and feeding data together with information on oceanographic conditions. The parameters used include: the reproductive success of Australasian gannets (*Morus serrator*) and little penguins (*Eudyptula minor*), both major local marine predators; the proportion of pilchard in the diet of Australasian gannets; sea surface temperature; and the Southern Oscillation Index (SOI). The predictive accuracy of the model in terms of local catch and catch per unit effort (CPUE) for pilchards in Victoria and the implications of the model for improving long-term sustainability of Australia's fisheries will be discussed.

School of Ecology and Environment
Deakin University
Victoria, Australia
Email: ashley.bunce@deakin.edu.au
(Abstract only)

2.1.6 Blue whales in the Bonney Upwelling and adjacent waters

Peter Gill and Margie Morrice

Endangered blue whales (*Balaenoptera musculus*), most likely pygmy blue whales (*B.m.brevicauda*), form seasonal feeding aggregations in the Bonney Upwelling and adjacent waters off western Victoria and south-east South Australia. Their primary prey is the neritic euphausiid *Nyctiphanes australis.* This previously unreported feeding area is one of few known worldwide. Since 1998 this study has used a combination of aerial surveys, boat-based fieldwork, deployed instrumentation and satellite remote sensing imagery to examine dynamic aspects of the upwelling system, the distribution of surface productivity and krill, and the distribution and behaviour of blue whales in relation to these key elements of their feeding ground. The main study area extends along the shelf from Cape Otway (Victoria) to Robe (South Australia), with a fine-scale survey area near Cape Nelson (Victoria).

During late spring each year, high pressure systems move south into the Great Australian Bight, so that prevailing winds blow from the south-east quadrant along this coast. These winds are most prevalent during November to February, and because of the relative narrowness of the continental shelf in the study area and the orientation of the coastline, they force classical Ekman upwelling in shelf waters. Timing of upwelling was determined from Sea Surface Temperature (SST) imagery and weather charts. The mean onset of upwelling was on 13th November over five seasons, with mean last day of upwelling on 29th April. Within each season, the temporal pattern of upwelling was determined by the longitudinal passage of weather systems. Mean number of upwelling events was 20.4, with mean duration of upwelling events was 3.8 dd, and mean duration of intervening 'relaxation periods' was 4.8 dd.

Previous studies of the upwelling had focused on the narrow-shelf surface plume region along the Bonney Coast of South Australia, in the study area's western half (or zone), west of Portland. Temperature loggers deployed both in this zone and to the east of Portland showed identical temporal patterns of stratification and mixing, strongly suggesting that upwelling occurred simultaneously across the study area, even where surface upwelling was not evident. The oceanographic division (defined at 141º40'E) between surface and non-surface upwelling 'zones' (narrower versus broader shelf width) has been a major feature of the study. In the surface upwelling western zone, a number of predictable upwelling centres or jets were identified. During intense upwelling these jets merged to form a single surface plume of cool (<17ºC) water, which was advected to the northwest by upwelling winds, and was usually shoreward of the 200 m isobath. There was often a strong (~5ºC) thermal front at the seaward edge of the plume, which could sometimes be detected in SST imagery for several weeks after upwelling ceased, until mixing was initiated by autumn gales.

'Ocean colour' satellite imagery provided a convenient indicator of primary production. Comparison with SST images showed that in the western zone, chl-*a* levels were very low within cold surface upwelling centres, while chl-*a* levels 40-50 times greater than ambient levels occurred in 'downstream' fronts between cold and adjacent warmer water. In the eastern zone, with no predictable surface fronts, elevated primary production was frequently widely dispersed across the shelf, with higher chl-*a* levels being associated with warmer surface water.

Nyctiphanes australis occurred in shelf water throughout most of the study area, and was noted in every month except September (when no surveys were conducted). It is one of few krill species worldwide, which habitually form surface swarms in daytime, enabling visual detection from aerial surveys. Swarms appear to grow larger and more numerous as the season progresses, and are generally few, small and scattered during the non-upwelling season. In the western zone, krill surface swarm distribution was strongly correlated with chl-*a* fronts, occurring in a relatively narrow alongshore band. In the eastern zone, krill surface swarms were often much more widely dispersed across the shelf. Chl-*a* values (from ocean colour images) underlying krill sightings were significantly higher in the western zone than in the eastern zone. Surface swarms were generally larger in the western zone, with swarms longer than 1000 m regularly seen, much larger than has been reported for this species elsewhere. Hydroacoustic surveys showed that *N. australis* could occur at all depths between the surface and the seafloor in shelf waters. Most surface swarms were sighted in water with depths of 160 m or less.

Blue whales are specialist krill feeders, occurring in few areas worldwide where krill is locally abundant. They arrive in the Bonney Upwelling feeding area from unknown wintering grounds around the onset of upwelling, with the earliest sighting on 13th November (2003), and the latest sighting on 19th May (1999). Prior to the study there had been 45 blue whale sightings in the region since 1865, but since 1998, 658 sightings were recorded from air, sea and land. The encounter rate during aerial surveys was three times higher in the western than the eastern zone. The mean group size was 1.5, with nearly 2/3 of sightings consisting of single whales; group size did not differ significantly between eastern and western zones. A maximum of 50 blue whales were seen in a single aerial survey. All size classes were represented, with a majority of sightings recorded as 'large' whales. Cows with well-developed calves were seen on 21 occasions, but calving is thought to occur in tropical waters during winter.

'Typical' blue whale occurrence in the study area was in shelf waters with mean depth of 86 m, gentle shelf slope (<10 $m.km^{-1}$), and in areas where elevated chl-*a* levels were associated with fronts between cool upwelled water and adjacent warmer water masses. Mean chl-*a* levels underlying blue whale sightings in the western zone were not significantly higher than in the eastern zone, in contrast with chl-*a* values underlying krill sightings, which were significantly higher in the western zone. Blue whale sightings were correlated with chl-*a* values an order of magnitude lower than the maximum chl-*a* values associated with fronts in SeaWiFs images, suggesting that blue whales feed on krill swarms which aggregate in areas 'downstream' from centres of the highest primary production. Blue whales and krill surface swarms were very rarely sighted offshore of the 200 m shelf break.

Evidence of feeding was observed in ~30% of all sightings. Confirmation of feeding on *N. australis* was obtained by net sampling in swarms where blue whales had fed, and by blue whale faecal DNA analysis; this species is undoubtedly the blue whales' main prey item. Other zooplankton taxa have been obtained in net samples, but the diversity of their diet in this region is still unknown. Most whales appeared to feed alone, with surface lunge feeding frequently observed. There was also evidence of feeding at depth, with fluke-up dives of several minutes duration associated with strong backscatter at various depths.

During December 2003, a previously unreported blue whale feeding area was identified along the shelf break to the west and south of Kangaroo Island. Here, blue whales (up to 47 in one survey) and the surface krill swarms on which they were feeding were distributed within 15 km inshore and offshore of the 200 m shelf break, in significantly deeper water than in the Bonney Upwelling study area. These sightings occurred in waters of elevated chl-*a*, probably resulting from shelf-break upwelling. During this period there were no blue whales sighted in the Bonney Upwelling. This suggested that these highly mobile, enormous predators forage along the shelf between upwelling centres of localised prey aggregation, of which the Bonney Upwelling is the most prominent. This is consistent with increasing knowledge of the Flinders Current, the northern boundary current, which flows west along the shelf throughout the year.

Whale Ecology Group – Southern Ocean
School of Ecology and Environment
Deakin University
Victoria, Australia
Email: petegill@bigpond.com

2.1.7 Trophodynamic models in the South East Fishery

Catherine Bulman, Scott Condie, Dianne Furlani, Madeleine Cahill, Neil Klaer, Chris Rathbone

Trophic and circulation models for the East Bass Strait (EBS) are being developed to investigate management issues such as the impact of increasing seal populations, changing discarding practices and environmental variability on fisheries production. Goldsworthy *et al.* (2004) simulated the impact of increasing seal populations and suggested that the consumption of resources by seals was greater than the consumption by the fishery, so the growing population of seals is of great concern to the fishery. Discarded fish catches are beneficial to scavenging species such as the dogfishes, seals and even seabirds (Bulman *et al.* 2001, Goldsworthy *et al.* 2004) and reduction of discarded fish might necessitate a switching of prey or even a population decline. The trophic models, constructed using the *Ecopath* with *Ecosim* software (Christensen and Pauly 1992, Walters *et al.* 1997, 1999, 2000, Christensen and Walters 2003), will be used to assess the sensitivity of components of the model to food-chain effects. These investigations will be completed over the next six months so here we present the methodology of building the models and some early findings.

The EBS study area is situated on the southeast corner of mainland Australia. The trophic model being developed covers the shelf and the slope to about 700 m, where there is a major change in fish community composition (CSIRO Marine Research 2001). The water influences are from the cool low-nutrient Bass Strait waters, the warm low-nutrient East Australian Current (EAC) intruding in summer and the cool nutrient-rich sub-Antarctic waters upwelling onto the outer shelf and slope areas more or less continually (Newell 1961, Bax and Williams 2000, Condie and Dunn in prep.). A northward flowing counter-current along the shelf-break brings slope water onto the shelf (Cresswell 1994). Nutrient enrichment of shelf waters is primarily by cool sub-Antarctic water uplifted from the slope, driven by EAC eddies, topography and wind, resulting in intermittent and seasonal events (Bax and Williams 2000).

The shelf consists of soft and hard grounds interspersed with reef outcrops (Bax and Williams 2000, 2001, Williams and Bax 2001). The invertebrate communities are highly diverse and show high endemism (Williams *et al.* 2000, National Oceans Office 2002). However, *Maoricolpus roseus*, the New Zealand screw shell, now dominates the biomass of several of the inshore habitats.

The fisheries of the South East Fishery (SEF) have been operating since the early 1900s. Up to the 1970s, the fishery operated on the shelf of New South Wales and north-eastern Victoria with little formal management or co-ordinated research (Tilzey and Rowling 2001). Steam trawlers and Danish seiners were the main fishing methods used and tiger flathead was the main target species. During late 1960s and early 1970s, diesel-powered otter trawlers allowed the rapid expansion of the fishery into the upper- and mid-slopes and further afield. To establish a possible state of the pre-fished shelf ecosystem, historical fishery data have been used to calculate virgin biomasses of the major commercial species and to parameterise a simple trophic model. We shall determine the feasibility of simulating the fishery trends over the past half-century or more based on the validity of the outcome.

The SEF shelf ecosystem study (Bax and Williams 2000) concluded that demersal fisheries are strongly dependent on pelagic prey, the source of which is from primary production. Hydrodynamic models of average seasonal circulation indicated that primary production in Bass Strait is transported into the study area (Bruce *et al.* 2001). A new circulation model based on satellite altimetry and modelled wind has been developed and the historical circulation was computed for the period over which satellite estimates of phytoplankton concentration and primary productivity were available (1997-2001). Primary productivity was estimated from ocean colour data for years 1998 through to 2001. The goal is to combine the circulation and ocean colour datasets to estimate the average annual standing stock biomass to input into the trophic model, and to estimate the net migration of phytoplankton into the shelf system and compare it to that estimated from the trophic model.

Satellite chlorophyll estimates for the 4-year period show autumn and spring blooms in most years. In 1999, two anomalously large blooms occurred: one in February and one in September. The summer upwelling was probably a result of anomalously strong north-easterly winds causing the cool subsurface waters to move up to replace them (Edwards 1990, Cresswell 1994). The spring bloom in early September was the most prolonged and widespread of the 4-year period.

While anecdotal evidence of fishers suggested that catches were higher when plankton is abundant (i.e. "dirty water"), correlations between catches and satellite chlorophyll data were low. Three trophic models have been constructed. Two historical models representing the shelf of the NSW-Victorian ecosystem in 1915 and in 1961 were constructed to establish the fishery effects over the 46-year period when fishing became more intense. This model differs from the more complex EBS model (see below) because its range extended to north of Sydney and was designed to investigate only the four major commercial species of that period: tiger flathead, latchet, Chinaman's leatherjacket and banded morwong. Abundances for these species were reconstructed from historical catch records and used to parameterise the model and will be used to parameterise a version of the more complex model. The abundance data showed that fish stocks have been greatly depleted since 1915, particularly flathead which in 1961 was probably less than 10% of 1915 biomass (Klaer 2001). Latchet and Chinaman's leatherjacket were probably at about 40% of 1915 biomass and redfish at probably 50%. We have yet to determine whether the 1915 model can be driven, using the time series of fishery catches, to the 1961 model state.

The third model was built for the EBS ecosystem for 1994. The EBS initial biomasses were based largely on CSIRO surveys conducted during 1994-96. Fisheries statistics for the SEF from Commonwealth and State fisheries agencies were collated and used to construct time series to drive the models although the time series have not yet been incorporated into the model. Data from the integrated scientific monitoring program (ISMP) were used to estimate the discarded catch not recorded in the fishers' logs. The dietary information for the model was derived primarily from a trophic study of over 70 species available for the EBS area (Bulman *et al.* 2001), while several other large studies in the SEF provided data for the other species (Coleman and Mobley 1984, Blaber and Bulman 1987, Bulman and Blaber 1986, Parry and Hobday 1990). Production and consumption parameters, and some dietary data, were mostly derived from Fishbase values (Froese and Pauly 2003) but wherever possible data applicable to the local populations were used.

The structure of a model depends on the purpose for which the model is to be used. A fishery-oriented investigation requires explicit groupings for exploited species, diet and style of feeding (e.g. fishes that were either largely piscivorous or invertebrate feeders or invertebrates which were planktivorous or filter- feeding), the size of the species, depth preferences (i.e. shelf, slope-dwelling or pelagic), ecological importance of a species (e.g. very abundant species which were presumed to be important prey or predators).

The resulting model was structurally more complex than the previous historical ones, with 58 groups covering the shelf and slope. The scientific surveys identified more than 200 species of fish in the EBS, which were allocated into the model groups. The majority of the SEF quota species were identified explicitly. All other fishes were aggregated into shelf, slope or pelagic groups, further subdivided into 3 size groups based on average standard length (SL) (<30 cm, 30-50 cm and >50 cm), and 2 feeding types based on more than or less than 40% fish in the diet. The lower trophic groups were far more aggregated, since less was known about them and the emphasis was on higher trophic levels. The model was balanced by adjusting diet composition and biomasses where justifiable.

Although the model is at an early stage of development, results have pointed to two interesting outcomes. Firstly, while the EBS area is reputed to have relatively low primary production compared to other temperate shelf waters (Bax and Williams 2000), the model estimated that a standing stock biomass of mesopelagic fish exceeding that found off eastern Tasmania (May and Blaber 1989) was required to support the consumption by slope fishes. This result supports the conclusion of Bax and Williams (2001) that production (in this case, mesopelagic fish but also other lower trophic groups) is advected from the deeper water. Based on Maria Island estimates of mesopelagic fish biomass, we will estimate a migration rate for the mesopelagic fishes, and its feasibility, onto the shelf from outside the study area. The flux of lower trophic groups will be modelled similarly.

Secondly, the model estimated the biomass for the small pelagic fish, redbait (*Emmelichthys nitidus*), because no accurate abundance data were input. Because seals, seabirds and tuna eat significant amounts of redbait (Goldsworthy *et al.* 2004, Welsford and Lyle 2003, Young *et al.* 1997), the relative changes in their abundances were sensitive to the initial redbait abundance estimates. Expansion of the fishery for redbait could impact the predators, the first of which is a potential threat to fisheries, and the last, a lucrative commercial fish. However, a more rigorous investigation would require modifications to the model to suit the area of interest and accurate abundance information.

CSIRO Marine Research
Tasmania, Australia
cathy.bulman@csiro.au

References

Bax, N. J., Williams, A. W. (Eds). 2000. Habitat and fisheries production in the South East Fishery Ecosystem. Final Report to the Fisheries Research and Development Corporation, Project No. 94/040. CSIRO Marine Research, Hobart, Australia. 490 pp.

Bax, N. J., Williams, A. W. 2001. Seabed habitat on the south-eastern Australian continental shelf: context, vulnerability and monitoring. *Marine and Freshwater Research* 52:491-512.

Blaber, S. J. M., Bulman, C. M. 1987. Diets of fishes of the upper continental slope of eastern Tasmania: content, calorific values, dietary overlap and trophic relationships. *Marine Biology* 95:345–56.

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

Bulman, C. M., Blaber, S. J. M. 1986. Feeding ecology of *Macruronus novaezelandiae* (Hector) (Teleostei: Merluciidae) in south-eastern Australia. *Australian Journal of Marine and Freshwater Research* 37:621–639.

Bulman, C. M., Althaus, F., He, X., Bax, N. J., Williams, A. W. 2001. Diets and trophic guilds of demersal fishes of the south-eastern Australian shelf. *Marine and Freshwater Research* 52:537–548.

Christensen, V., Pauly, D. 1992. Ecopath II-a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling* 61:169–185.

Christensen, V., Walters, C. J. 2003. Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling* 172:109–139.

Coleman, N., Mobley, M. 1984. Diets of commercially exploited fish from Bass Strait and adjacent Victorian waters, south-eastern Australia. *Australian Journal of Marine and Freshwater Research* 35:549-560.

Cresswell, G. 1994. Nutrient enrichment of the Sydney continental shelf. *Australian Journal of Marine and Freshwater Research* 45:677-691.

CSIRO Marine Research. 2001. Rapid assembly of ecological fish data (community composition and distribution) for the South East Marine Region. Report to the National Oceans Office. CSIRO Marine Research, Hobart, Australia. 52 pp.

Condie, S. A., Dunn, J. R. in prep. Seasonal characteristics of the surface mixed layer in the Australasian region: Implications for primary production regimes and biogeography.

Edwards, R. J. 1990. Upwelling could hold clues to fish patterns. *Australian Fisheries* 49:18-20.

Froese, R., Pauly, D. (Eds). 2003. FishBase. World Wide Web electronic publication. www.fishbase.org, version 26 November 2003.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J., Littnan, C. 2003. Trophic Interactions between Marine Mammals and Australian Fisheries: An Ecosystem Approach. In 'Marine Mammals: Fisheries Tourism and Management Issues'. (Eds N. Gales, M. Hindell and R. Kirkwood). pp. 62-99. (CSIRO Publishing: Melbourne, Australia.)

Klaer, N. 2001. Steam trawl catches from south-eastern Australia from 1918 to 1957: trends in catch rates and species composition. *Marine and Freshwater Research* 52:399-410.

May, J. L., Blaber, S. J. M. 1989. Benthic and pelagic fish biomass of the upper continental slope off eastern Tasmania. *Marine Biology* 101:11-25.

National Oceans Office. 2002. Ecosystems - Nature's diversity. The South - East Regional Marine Plan Assessment Report. National Oceans Office, Hobart, Australia. 224 pp.

Newell, B. S. 1961. Hydrology of south-east Australian waters: Bass Strait and New South Wales tuna fishing area. CSIRO Division of Fisheries and Oceanography Technical Paper No. 10, Hobart, Australia. 22 pp.

Parry, G. D., Campbell, S. J., Hobday, D. K. 1990 Marine resources off east Gippsland, south-eastern Australia. Marine Science Laboratories Technical Report No. 72, Queenscliff, Australia. 166 pp.

Tilzey, R. D. J., Rowling, K. R. 2001. History of Australia's South East Fishery: a scientist's perspective. *Marine and Freshwater Research* 52:361-376.

Walters, C., Christensen, V., Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Reviews in Fish Biology and Fisheries* 7:139-172.

Walters, C., Pauly, D., Christensen, V. 1999. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *Ecosystems* 2:539-554.

Walters, C., Pauly, D., Christensen, V. and Kitchell, J. F. 2000. Representing density dependent consequences of life history strategies in aquatic ecosystems: Ecosim II. *Ecosystems* 3:70-83.

Welsford, D. C., Lyle, J. M. 2003. Redbait (Emmelichthys nitidus): a synopsis of fishery and biological data. Tasmanian Aquaculture and Fisheries Institute Technical Report No. 20, Hobart, Australia. 32 pp.

Williams, A. W., Bax, N. J. 2001. Delineating fish-habitat associations for spatially based management: and example from the south-eastern Australian continental shelf. *Marine and Freshwater Research* 52:313-336.

Williams, A. W., Bax, N. J., Gowlett-Holmes, K. 2000. Biological Communities. In 'Habitat and fisheries production in the South East Fishery Ecosystem', Final Report to the Fisheries Research and Development Corporation, Project NO. 94/040. (Eds N.J. Bax and A.W. Williams.) pp. 187-269. (CSIRO Marine Research: Hobart, Australia.)

Young, J. W., Lamb, T. D., Le, D., Bradford, R. W., Whitelaw, A. W. 1997. Feeding ecology and interannual variation in diet of southern bluefin tuna, *Thunnus maccoyii,* in relation to coastal and oceanic waters off eastern Tasmania, Australia. *Environmental Biology of Fishes* 50:275-291.

2.1.8 Determining ecological effects of longline fishing off eastern Australia

Barry Bruce

The domestic longline fishery in eastern Australia operates year round and ranges over various habitats from tropical Coral Sea waters to the southern limits of the East Australia Current, and eastward past the limits of the Australian Fishing Zone (AFZ). Each habitat may represent a unique ecosystem with a different food chain and ecological composition. The fishing impacts on these ecosystems are unknown. The fishery targets several apex predator groups - tunas, swordfish and marlins, and although other apex species groups such as sharks are not targeted they are still caught in large numbers. A growing body of literature on pelagic and coastal ecosystems suggests that removal of apex predators via fishing can have a greater impact on the ecosystem dynamics than removal via fishing of lower trophic level species. Potential effects of removing apex predators through fishing include dramatic increases in the biomass of prey (smaller-sized) or competitor species and loss of ecosystem stability, all of which impact the economic viability of a fishery. We present here preliminary results from a Fisheries Research and Development Corporation (FRDC) funded study that has the objectives of (1) identifying key ecosystems of the eastern tuna and billfish fishery, (2) defining trophic structure within these ecosystems with emphasis on relationships between target, bycatch and threatened and protected species and, (3) developing an ecosystem model for the fishery incorporating data on the relative abundance of species, trophic linkages and physical environment. These data will be used to investigate impacts of longline fishing on the ecosystem and evaluate alternative harvest strategies.

CSIRO Marine Research
Tasmania, Australia
Email: barry.bruce@csiro.au
(Abstract only)

2.2 Focused case study: ecosystem-based management of southern Australian pelagic fisheries

2.2.1 Introduction

There has already been years of effort on establishing ecosystem-based fishing management (EBFM) as an alternative or adjunct to traditional fisheries management (TFM), including various other symposia in recent years: this Symposium was not about re-inventing EBFM, but rather was about providing clarification and direction so as to ensure that the approaches taken towards implementing EBFM suit Australian conditions. The Symposium thus aimed to promote the most appropriate approaches to implement EBFM in a useable and defendable manner that suits the community, sectoral and legislative arenas of Australia. Given this background, the case study began with a series of presentations comprising:

1. James Scandol (Planning: the keystone species within ecosystem-based fisheries management);
2. Jeremy Lyle and Dirk Welsford (Small pelagic fishery: meeting the challenges of fishery and ecosystem assessment);
3. Dan Gaughan (EBFM for small scale purse seine fisheries: layout the basics, don't reinvent food–webs, provide defendable scientific advice);
4. Tim Ward (South Australian sardine fishery);
5. Sam McClatchie and Tim Ward (Alongshore variation in upwelling intensity in the eastern Great Australian Bight); and
6. Simon Goldsworthy (GAB ecosystem project).

Thereafter, the Workshop proposed the following high-level aim, which had also been promoted at the start of the symposium on the previous day.

Regarding EBFM, the Workshop aimed to determine:

1. where we are at (Current Status);
2. where we want to be (Goals); and
3. how best to get there (Defining the path).

A series of more specific issues relevant to implementing EBFM were then suggested as an agenda for the session. These were:

1. Australia's strategic directions.
2. The framework.
3. Research (e.g. data requirements, modelling approaches, ecosystem indicators, use of proxies).
4. Development of scientific advice.
5. Communication with stakeholders (at grass-roots and committee levels).
6. Social/economic aspects.

However, the session group felt that there had been insufficient "general" discussion and as such there was still a considerable level of misunderstanding about where the Australian fisheries community was going with EBFM. To work through the agenda was deemed premature at this time. Thus, rather than adopt a structured approach to discuss the preceding case studies, the participants in the final session decided to pursue an open-forum discussion of ecosystem research and management of fisheries. The discussion was much broader than just the pelagic theme; much of the discussion was therefore applicable to fisheries research and management in general.

2.2.2 Planning: the keystone species within ecosystem-based fisheries management

James Scandol

Ecosystem-based fishery management (EBFM) is a relatively new concept that is gathering momentum in non-government organisations and natural resource management agencies. This extended abstract argues that the issues associated with EBFM are similar to those faced by environmental managers of terrestrial systems. In particular, the ramifications of the complex and overlapping value systems of stakeholders can already be observed in terrestrial environmental management. Given the historical development of institutions such as environmental planning and assessment, and the legal importance of precedent, it was (and is) inevitable that the existing machinery developed for terrestrial environmental management has been (and will continue to be) applied to aquatic systems.

EBFM is a complex concept with a definition that is still evolving (FAO 2001, Brodziak and Link 2002, Ward *et al.* 2002, FAO 2003). The Food and Agriculture Organisation of the United Nations (FAO) recently presented a summary of current directions in EBFM and noted (FAO 2001 at para. 42): "It should be well understood that the broadening of the fisheries management approach does not call for any revolution. Adding ecosystems considerations to present methods can be done gradually". Ward *et al.* (2002) developed guidelines for implementing ecosystem-based management in a hypothetical coastal fishery that included the need to: identify the stakeholder community; prepare maps of eco-regions and habitats; identify partners and their interests/responsibilities; establish ecosystem values; determine major factors influencing ecosystem values; conduct ecological risk assessment; establish objectives and targets; establish strategies for achieving targets; design information systems, including monitoring; establish research and information needs and priorities; design performance assessment and review processes; prepare education and training packages.

There must be recognition that many of the operational guidelines of EBFM described by Ward *et al.* (2002) are the same types of issues that have to be considered within the strategic environmental assessments completed to meet Part 13 and Part 13A of the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. The significant areas of difference are the social issues (such as 'identify stakeholder community', and 'establish ecosystem values'). These types of issues are either captured (with varying degrees of success) within the consultative provisions of the EPBC Act (e.g. s 303FR) or the Commonwealth Fisheries Management Act 1991 (e.g. s 17), or reflected in the broader scope of environmental laws such as those provisions regarding biodiversity (within Part 13). Ward *et al.* (2002) also put emphasis upon 'prepare maps of eco-regions and habitats', an issue addressed in less detail for most fisheries.

The most pertinent lesson to be taken from this (far too) brief comparison of EBFM with strategic assessment is how readily laws developed to regulate international movement of wildlife (primarily legislation to capture Australia's ratification of the Convention on International Trade in Endangered Species, CITES) could be applied, with significant consequences, to commercial fisheries. Application of existing environmental laws to progress fisheries management has also occurred in NSW; when certain actions undertaken by the then NSW Fisheries, were found in breach of provisions within the NSW Environmental Planning and Assessment Act 1979 (Hurrell and Jardim 2000).

Fisheries scientists and managers should not underestimate the scope and importance of existing environmental law and policy. In particular, environmental planning was defined by Gilpin (1996) as "The identification of desirable objectives for the physical environment, including social and economic objectives, and the creation of administrative procedures and programmes to meet these objectives. Matters embraced include: national, regional, and local environmental policies; living-resource conservation; landscape conservation; wilderness; national and marine parks; pollution-control strategies; environmental impact statements and assessments; public hearings and inquiries; appeal mechanisms and procedures; and the application of international conventions and agreements (+ 18 other matters)". Application of the existing tools of environmental planning will inevitably play a critical role in any developments towards a more ecosystem-based fisheries management. We must recognise that "ecological values" are part of the complex value systems held by members of our society - that is why they are so important.

Natural resource managers of terrestrial systems have had to deal with the social, economic and ecological complexities of environmental management for decades (if not centuries). There exists ample policy, legislation and case law to help structure the path of decision makers though these issues. Terrestrial environmental management is not, of course, perfect (nor even satisfactory by many accounts); but it does present a future scenario for aquatic resource management. This is because the tools already exist, and minor legislative amendments or well-targeted legal actions are likely to have significant effects. The role of aquatic ecological science within such a scenario should not be over-simplified (Harding 1988).

Department of Primary Industries
New South Wales, Australia
Email: james.scandol@dpi.nsw.gov.au

References

Brodziak, J., Link, J. 2002. Ecosystem-based fishery management: What is it and how can we do it? *Bulletin of Marine Science* 70:589-611.

FAO. 2001. 'Towards Ecosystem-Based Fisheries Management: A Background Paper Prepared by FAO for the Reykjavik Conference on Responsible Fisheries in the Marine System.' (Food and Agriculture Organization of the United Nations: Rome, Italy.) 11 pp.

FAO. 2003. 'FAO Technical Guidelines For Responsible Fisheries: 4 Fisheries Management (2) The ecosystem approach to fisheries.' (Food and Agriculture Organization of the United Nations: Rome, Italy.) 112 pp.

Gilpin, A. 1996. 'Dictionary of Environment and Sustainable Development.' (John Wiley and Sons: Chichester, U.K.)

Harding, R. (Ed.) 1998. 'Environmental Decision-making: The Roles of Scientists, Engineers and the Public.' (The Federation Press: Sydney, Australia.)

Hurrell, J., Jardim, J. 2000. Part 5 of the EPandA Act Nets Another Big Fish. *Local Government Law Journal* 5:230-238.

Ward, T., Tarte, D., Hegerl, E., Short, K. 2002. Policy Proposals and Operational Guidance for Ecosystem-Based Management of Marine Capture Fisheries. World Wide Fund for Nature, Sydney, Australia. 80 pp.

2.2.3 Small pelagic fishery: meeting the challenges of fishery and ecosystem assessment

Jeremy Lyle and Dirk Welsford

Introduction

The Commonwealth Small Pelagic Fishery (SPF) extends southward from the New South Wales/Queensland border around to southern Western Australia, and includes waters surrounding Tasmania. The fishery is divided into four management zones (A to D), with Zone A (around Tasmania) managed cooperatively with the Tasmanian Government and progressing toward a Joint Authority arrangement. In the other zones the Australian Fisheries Management Authority (AFMA) is responsible for managing the fishery in Commonwealth waters with the States managing adjacent inshore waters.

Five species are defined as small pelagics within the context of the SPF. They are jack mackerel (*Trachurus declivis*), peruvian jack mackerel (*T. symmetricus*), yellowtail scad (*T. novaezelandiae*), blue mackerel (*Scomber australasicus*) and redbait (*Emmelichthys nitidus*).

Fishery background

Large-scale commercial fisheries for small pelagics have operated sporadically off Tasmania (Zone A) over a number of years. Initial fishing trials during the mid-1970s produced catches of jack mackerel in the order of 5,000 tonnes and during the 1980s and 1990s an industrial purse-seine fishery, primarily targeting jack mackerel, took catches in excess of 40,000 tonnes in a single season. The fishery was characterised by large inter-annual fluctuation in catches, linked in part to interactions between schooling behaviour, prey availability and local oceanography. Purse seining was replaced by mid-water trawling in 2002, with a shift to redbait as the dominant species in the catch. In addition, moderate quantities of blue mackerel and yellowtail scad are taken by purse seine off southern NSW (Zone D) and there is growing interest in expanding the fishery into western Bass Strait (Zone C) and the Great Australian Bight (Zone B).

Catches are generally frozen for use as fodder in the aquaculture industry or for bait or processed into fishmeal or pet food. Only small quantities are used for human consumption. Unit value tends to be low and thus fishery profitability is dependent on achieving high catch volumes.

Small pelagics are also taken for bait in commercial tuna fisheries and as by-catch in trawl fisheries and other inshore net fisheries and are utilised by recreational fishers for bait (game fish) and for consumption.

Species characteristics

The target species exhibit parallels with other small pelagics (e.g. sardines (*Sardinops sagax*) and anchovies (*Engraulis australis*)) in that they are schooling zooplanktivores, and are major prey species for many large pelagic fish species, including tunas, as well as birds and marine mammals. However, they differ due to their higher maximum ages (generally > 10 years) and longer time to reach maturity, factors which are likely to impact on productivity and resilience to fishing pressure.

Management framework

Management of the SPF is under review. Currently, however, management of Zones B-D is based on limited entry and gear restrictions (mid-water trawl and purse seine methods), along with Trigger Catch Limits that are species specific, competitive and subject to review if reached within a fishing season. A statutory management plan is being developed between the Commonwealth and Tasmania for Zone A and will involve fishing rights in the form of ITQs along with a series of performance indicators. Present management is developed around total allowable commercial catches (combined species) for the different licence categories.

Draft Strategic Assessment, By-catch Action Plan and Ecological Risk Assessment reports have been developed for the SPF. The draft Ecological Risk Assessment identified that there was moderate or higher ecological risks associated with fishing, specifically in relation to impacts on target species, by-catch/by-product, and the pelagic ecosystem

Research – past and present

Previous research has focused largely on the biology and fisheries for the target species, with particular attention on jack mackerel and to a lesser extent blue mackerel and yellowtail scad. Research has included early life history studies (Jordan 1994), age and growth studies (Lyle *et al.* 2000, Stewart and Ferrel 2001), biological characteristics of the commercial catch (Williams and Pullen 1993) and predator-prey interactions (Young *et al.* 1993). Methods to estimate biomass have not been successfully developed or applied.

Following concerns about possible expansion of the blue mackerel fishery in Zone D (Ward *et al.* 2001), a major study of blue mackerel, including evaluation of the daily egg production method for estimating spawner biomass was recently initiated. The introduction of mid-water trawling in Zone A and development of the fishery for redbait also prompted a concerted research effort to describe key biological parameters for the species and characterise the catch (including by-catch) (Welsford and Lyle 2003), as well as to evaluate the suitability of the egg production method for redbait off Tasmania.

The challenge

Robust quantitative assessments for small pelagic fish stocks are notoriously difficult and generally expensive to achieve. This is due in part to the highly dynamic environment in which they live, resulting in considerable inter-annual variability in distribution, abundance and behaviour. Furthermore, fishery dependent information is generally unreliable as an indicator of stock status (due to the schooling behaviour) and fishery independent surveys generally produce results with a high degree of imprecision.

The SPF represents a data-limited situation. There is no time-series of data available to track or monitor change in the populations and in fact, due to structuring within populations (linked to schooling behaviour), representative information is very difficult to obtain. If current studies of egg production prove successful in providing conservative spawner biomass estimates for key small pelagic species, in the sense of the South Australian pilchard fishery (Ward *et al.* 2002), this will represent a significant step towards the sustainable management of the fishery. However, in an ecosystem context, the impact of harvesting large quantities of lower-level trophic groups may be significant and thus, while the economic value of the fishery may be low, ecological costs may be high and need to be assessed. Pragmatically, implementing large-scale ecological studies would prove expensive and take some time to complete, time that may not be available given the capacity of the fishing industry to rapidly expand. At this stage, a realistic approach would be to make the best use of available information, including studies on known predators (tunas, sea birds and seals), available oceanographic data, along with conceptual trophodynamic models available for similar systems. Ultimately such conceptual models may be largely qualitative or at best semi-quantitative, but linked with population information for potential indicator species (for example sea birds and seals), and on-going assessment of the target species, it should be possible to adopt a more ecosystem based approach to the management of the small pelagics fishery.

Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Tasmania, Australia
Email: jeremy.lyle@utas.edu.au

References

Jordan, A. R. 1994. Age, growth and back-calculated birthdate distributions of larval Jack mackerel, *Trachurus declivis* (Pisces: Carangidae), from eastern Tasmanian coastal waters. *Australian Journal of Marine and Freshwater Research* 45:19-33.

Lyle, J. M., Krusic-Golub, K., Morison, A. K. 2000. Age and growth of jack mackerel and the age structure of the jack mackerel purse seine catch. Final report to the Fisheries Research and Development Corporation, Project No. 1995/034. Tasmanian Aquaculture and Fisheries Institute, Hobart, Australia. 49 pp.

Stewart, J., Ferrel, D. J. 2001. Age, growth and commercial landings of yellowtail scad (*Trachurus novaezealandiae*) and blue mackerel (*Scomber australisicus*) off the east coast of New South Wales, Australia. *New Zealand Journal of Marine and Freshwater Research* 35:541-551.

Ward, P., Timmiss, T., Wise, B. 2001. A review of the biology and fisheries for mackerel. Bureau of Rural Sciences, Canberra, Australia. 120 pp.

Ward, T. M., McLeay, L. J., Rogers, P. J., Dimmlich, W. F., Schmarr, D., Deakin, S. 2002. Spawning biomass of pilchards *(Sardinops sagax*) in South Australia in 2002. South Australian Research and Development Institute (Aquatic Sciences) Report No. 01/16, Adelaide, Australia. 33 pp.

Welsford, D. C., and Lyle, J. M. 2003. Redbait (*Emmelichthys nitidus*): a synopsis of fishery and biological data. Tasmanian Aquaculture and Fisheries Institute Technical Report No. 20, Hobart, Australia. 32 pp.

Williams, H., Pullen, G. 1993. Schooling behaviour of jack mackerel, *Trachurus declivis* (Jenyns), observed in the Tasmanian purse seine fishery. *Australian Journal of Marine and Freshwater Research* 44:577-587.

Young, J. W., Jordan, A. R., Bobbi, C., Johannes, R. E., Haskard, K., Pullen, G. 1993. Seasonal and interannual variability in krill (*Nyctiphanes australis*) stocks and their relationship to the fishery for jack mackerel (*Trachurus declivis*) off eastern Tasmania. *Marine Biology* 116:9-18.

2.2.4 EBFM for small scale purse seine fisheries: layout the basics, don't reinvent food–webs, provide defendable scientific advice

Dan Gaughan

Australia has many small-scale fisheries: most cannot attract research funds to undertake ecosystem-based research. Nonetheless, these fisheries can implement ecosystem-based fishery management (EBFM). While the national reporting framework for fisheries performance (Ecologically Sustainable Development) can highlight ecosystem issues and possibly assist in obtaining funds to address specific issues, this does not necessarily imply that EBFM is being applied. A simple approach can be used to apply EBFM for those fisheries lacking directed research on, for example, trophic relationships. The first step is to place the exploited/target species within an ecosystem context, starting with graphical construction of text-book level food-webs; using available literature will enable many exploited species to be placed within functional groups. Then, assimilate whatever data may be relevant to building up a picture of the ecosystem that the fishery operates within. This simple approach provides a basic communication tool, a critical factor for introducing an EBFM philosophy to the fishing and non-extractive sectors. From this point, the base-level productivity of systems can be placed in a local, national or global context so as to assess in relative terms the carrying capacity of the functional group of interest. Communicating these corner-stones of fisheries production can provide a defendable impetus to assist in affecting the change in focus of fisheries management philosophy from single species to EBFM. For the Western Australian purse seine fishery this approach has been investigated as a means of reconciling the expectations of purse seine fishermen, anglers and conservationists.

Department of Fisheries
Western Australia, Australia
Email: dgaughan@fish.wa.gov.au

2.2.5 South Australian sardine fishery

Tim Ward

Waters off southern Australia between Cape Otway and Head of Great Australian Bight (GAB) form part of the world's only northern boundary current system (Middleton and Cirano 2002) and support levels of primary, secondary and fish production that are higher than elsewhere in Australia and within the lower portion of ranges recorded in the productive eastern boundary current systems off the west coasts of Africa and the Americas (Ward *et al.* 2005). As well as supporting Australia's largest fishery by weight (i.e. the South Australian sardine (pilchard) (*Sardinops sagax*) Fishery with a total allowable catch (TAC) for 2005 of 51,100 t, this region supports the majority of Australia's New Zealand fur seal (*Arctocephalus forsteri*) and Australian sea lion (*Neophoca cinerea*) populations (Goldsworthy *et al.* 2003) and globally-important feeding and/or breeding grounds for mobile marine predators, including southern bluefin tuna (*Thunnus maccoyii*) and seabirds such as shearwaters (*Puffinis* spp.), terns (*Sterna* spp.) and little penguins (*Eudyptula minor*) (Ward *et al.* 1998, Ward *et al.* 2006). Small pelagic fishes, including sardine and Australian anchovy (*Engraulis australis*), form key components of the diets of many of these predators.

In 1995 and 1998, mass mortalities of sardine began in waters off South Australia and spread like a wave throughout the Australasian population (Griffin *et al.* 1997, Hyatt *et al.* 1997, Jones 2000, Jones *et al.* 1997, Whittington *et al.* 1997, Gaughan *et al.* 2000, Ward *et al.* 2001a). Each event eventually killed more fish over a larger area than any other mono-specific fish-kill ever recorded. Herpesvirus was identified as the likely disease agent on both occasions (Hyatt *et al.* 1997, Whittington *et al.* 1997). In the main fishing area off southern Australia, over 70% of the spawning biomass was killed in each event (Ward *et al.* 2001a). In 1995, only adult fish were killed, but in 1998/99 juveniles were also affected in some areas (Ward *et al.* 2001a). The mortality events had significant effects on other components of the ecosystem. Ward *et al.* (2001b) provided evidence that suggested the events facilitated an increase in the distribution and abundance of Australian anchovy (*Engraulis australis*). Several studies described changes in the diets and reductions in the reproductive success of seabirds, including Australasian gannets (*Morus serrator)*, little penguins and little terns (*Sterna albifrons sinensis)* (Dann *et al.* 2000, Bunce and Norman 2000, Taylor and Roe 2004). The mass mortality events highlighted the potential ecological impacts of large declines in sardine abundance in southern Australia.

Numerous scientific papers and advisory panels have identified the need to establish ecosystem-based fishery management (EBFM) systems which avoid degradation of ecosystems, prevent irreversible changes in species assemblages and ecosystem processes, maintain long-term socioeconomic benefits, and generate knowledge of ecosystem function and the consequences of fishing (see Nicol 1991, 1993, Pikitch *et al.* 2004). However, there are relatively few published examples of fisheries that have implemented EBFM (but see Nicol 1999). It is widely recognized that where knowledge is insufficient, robust and precautionary measures should be adopted, yet few examples exist that demonstrate how precautionary management measures have been implemented in fisheries for which scientific data are incomplete. A key element of EBFM is the involvement of stakeholders in decision-making processes. Several studies have shown that decision-making by stakeholders groups can be enhanced by establishing decision rules for fisheries management (Cochrane *et al.* 1998, Hall and Mainprize 2004).

A dedicated purse-seine fishery for sardine was established in South Australia in 1991. To support this fishery, a stakeholder-based management committee was established to provide advice to the South Australian Minister for Fisheries. The development of the fishery was directly affected by the mass mortality events in 1995 and 1998, with the TACs restricted in the years immediately following the events to allow the recovery of the stock. The fishery was also affected indirectly by the mortality events, as the impacts of declines in sardine abundance on other components of the ecosystem highlighted the need to explicitly consider the potential ecological effects of the fishery. Management arrangements that have been developed for the fishery since the mortality events reflect the management committee's recognition of the importance of these ecological issues. The fishery is managed under a regime of input and output controls that involve entry limitations, gear restrictions, an annual TAC and individual transferable quotas (ITQs). The fishery comprises 14 licence holders, some of which are amalgamated and up to 11 vessels operate at any given time. Throughout the 1990s, purse-seine vessels in the fishery typically ranged from 10 to 23 metres in length. Larger, more efficient vessels entered the fishery after 2000. Purse-seine nets cannot exceed 1000 m in length or a depth of 200 m and the permitted mesh sizes are 14 to 22 mm.

The TAC was held at or below 3,500 t up until 1998, whilst the population recovered from the first mortality event in 1995. Following the second mortality event in 1998, the working group for the South Australian Sardine Fishery agreed that decision rules should be established to act as guidelines for using estimates of spawning biomass to establish future TACs. Prior to development of the decision rules, it was agreed that the major weakness with the Daily Egg Production Method (DEPM) was the high degree of uncertainty associated with estimates of spawning biomass, (i.e. the technique is imprecise) (Cochrane 1999). Furthermore, it was agreed that estimates tended to be too high rather than too low because of two factors: (i) effects of samples with large numbers of eggs on estimates of egg production (Gaughan *et al.* 2004) and (ii) the confounding effect of egg dispersal on estimates of egg mortality and initial egg production (Dr Rick McGarvey, SARDI Aquatic Sciences, personal communication). To address these issues, it was agreed that a conservative method for estimating spawning biomass should be adopted. The method agreed upon involved adjusting the bias correction factor that is applied when the linear version of the exponential mortality model is used to estimate egg production. Simulations show that incorporating this negative bias into the standard model for the DEPM results in an ~30% reduction in the estimate of spawning biomass. The working group agreed that estimates obtained using this method would be sufficiently conservative to be used in the management of a fishery for this ecologically important species.

The following rationale was used to develop decision rules for establishing TACs from conservative estimates of spawning biomass. Members of the management committee agreed that (1) Available international scientific literature (presented by TMW) suggested that exploitation rates (i.e. catch/spawning biomass) of up to 30% were generally considered to be biologically sustainable for small pelagic fisheries. (2) Although this exploitation rate was biologically conservative, it did not take into account the implications of harvesting large quantities of sardine on other components of the ecosystem, and that the upper exploitation rate for the South Australian Sardine Fishery should be lower than 30%. (3) Higher exploitation rates would be acceptable in periods when the spawning biomass was large, than would be acceptable when the biomass was smaller. (4) The strength of 2-3 year old age classes recently recruited to the fishery should be considered when TACs were being established. Based on this reasoning, the decision rules shown in Table 1 were established for the fishery (Shanks 2005). The working group agreed that the decision rules in Table 1 should provide guidelines for establishing TACs but should not be applied prescriptively and could be amended to reflect other issues.

Table 1. Decision rules and exploitation rates established for the South Australian sardine fishery.

Decision rule	Conservative spawning biomass estimate (CSBE, (tonnes))	Exploitation rate (% and tonnes)
1	<100,000	10% of CSBE or 5,000 tonnes (whichever is largest)
2	100,000-150,000	10 or 12.5% of CSBE if 2 & 3 yr olds represented < or > 40% of catch samples, respectively
3	150,000-250,000	12.5 or 15% of CSBE if 2 & 3 yr olds represented < or > 40% of catch samples, respectively
4	>250,000	15 or 17.5% of CSBE if 2 & 3 yr olds represented < or > 40% of catch samples, respectively

The recovery of the biomass while these precautionary decision rules have been in place does not necessarily suggest that the existing stock assessment procedure or decision rules should be altered (i.e. made less precautionary) to reflect internationally accepted levels of fishing mortality, and to “maximise the yield”. Recent studies have shown that attempts to maximise yields almost inevitably result in overexploitation through random errors or inherent statistical biases (Pikitch *et al.* 2004). Furthermore, there is a long history of rapid expansions in major clupeoid fisheries being followed by crashes and there is no evidence to suggest that the apparently optimal conditions for sardine recruitment that have occurred in South Australia in recent years will continue into the future. Although small pelagic fish are adapted to fluctuating environments and clearly have a strong capacity to recover rapidly from major declines in abundance, it is not clear what response the South Australian sardine population may have to a combination of increased fishing pressure, extended periods of unsuitable meteorological conditions or another mass mortality event.

Despite the success of the management arrangements in facilitating the recovery of the biomass and development of the fishery, their effectiveness in mitigating impacts on the other components of the ecosystem are unknown. This issue is particularly significant in southern Spencer Gulf, where large aggregations of key predators are known to occur and where most sardine fishing is undertaken. The management committee for the fishery has identified the potential effects of localised depletion of sardine abundance on the diets and breeding success of predatory species in this area as a key issue. In response to these concerns, licence holders have contributed ~$A1M to support a research project that is examining the role of sardine in the diets of key predators.

SARDI Aquatic Sciences
South Australia, Australia
Email: ward.tim@saugov.sa.gov.au

References

Bunce, A., Norman, F. I. 2000. Changes in the diet of the Australasian gannet (*Morus serrator*) in response to the 1998 mortality of pilchards (Sardinops sagax). *Marine and Freshwater Research* 51:349-353.

Cochrane, K. L. 1999. Review of the Western Australian Pilchard Fishery 12-16-April 1999. Fisheries Resource Division Food and Agricultural Organisation of the United Nations Fisheries Management Paper No. 129, Rome, Italy. 28 pp.

Cochrane, K. L., Butterworth, D. S., De. Oleveira, J. A., Roel, B. A. 1998. Management procedures in the fishery based on highly variable stocks and with conflicting objectives: Experience in the South African pelagic fishery. *Reviews in Fish Biology and Fisheries* 8:177-214.

Dann, P., Norman, F. I., Cullen, J. M., Neira, F. J., Chiaradia, A. 2000. Mortality and breeding failure of little penguins (*Eudyptula minor*) in Victoria, 1995-96, following a widespread mortality of pilchard (*Sardinops sagax*). *Marine and Freshwater Research* 51:355-362.

Gaughan, D. J., Mitchell, R. W., Blight, S. J. 2000. Impact of mortality due to herpesvirus on pilchard *Sardinops sagax* along the south coast of Western Australia in 1998-1999. *Marine and Freshwater Research* 51:1-29.

Gaughan, D. J., Leary, T. I., Mitchell, R. W., Wright, I. W. 2004. A sudden collapse in distribution of Pacific sardine (*Sardinops sagax*) off south western Australia enables an objective reassessment of biomass estimates. *Fisheries Bulletin* 102:617-633.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J., Littnan, C. 2003. Trophic Interactions between Marine Mammals and Australian Fisheries: An Ecosystem Approach. In 'Marine Mammals: Fisheries Tourism and Management Issues'. (Eds N. Gales, M. Hindell and R. Kirkwood). pp. 62-99. (CSIRO Publishing: Melbourne, Australia.)

Griffin, D. A., Thompson, P. A., Bax, N. J., Hallegraeff, G. M. 1997. The 1995 mass mortality of pilchards: no role found for physical or biological oceanographic factors in Australia. *Marine and Freshwater Research* 48:27-58.

Hall, S.J., Mainprize, B. 2004. Towards ecosystem based fishery management. *Fish Fisher* 5:1-20.

Hyatt, A. D., Hine, P. M., Whittington, D. A., Griffin, D. A., Bax, N. J. 1997. Epizootic mortality in the pilchard (*Sardinops sagax neopilchardus*) in Australia and New Zealand in 1995. II. Identification of the herpesvirus in the gill epithelium. *Diseases of Aquatic Organisms* 28:17-29.

Jones, J. B. 2000. Baitfish and Quantitative Risk Assessment Issues. In 'Proceedings of the OIE International Conference on Risk Analysis in Aquatic Animal Health, Paris, France, 8-10 February, 2000'. (Ed. C.J. Rodgers.) (Office International des Epizooties: Paris, France.)

Jones, J. B., Hyatt, A .D., Hine, P. M., Whittington, D. A., Griffin, D. A., Bax, N.J. 1997. Special Topic Review: Australasian Pilchard Mortalities. *World Journal of Microbiology and Biotechnology* 3:383-392.

Middleton, J. F., Cirano, M. 2002. A northern boundary current along Australia's southern shelves: the Flinders Current. *Journal of Geophysics Research* 107:3129-3143.

Nicol, S. 1991. The CCAMLR and its approaches to management of the krill fishery. *Polar Record* 27:229-236.

Nicol, S. 1993. Ecosystem management and the Antarctic krill. *American Scientist* 81:36-47.

Nicol, S. 1999. Krill fisheries, development, management and ecosystem implications. *Aquatic Living Resources* 12:105-120.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J., Sainsbury, K. J. 2004. Ecosystem based fisheries management. *Science* 305:346-347.

Shanks, S. 2005. Management Plan for the South Australian Pilchard Fishery. South Australian Fisheries Management Series No. 47, Adelaide, Australia. 54 pp.

Taylor, I. R., Roe, E. L. 2004. Feeding ecology of little terns (*Sterna albifrons sinensis*) in south-eastern Australia and the effects of pilchard mass mortalities on breeding success and population size. *Marine and Freshwater Research* 55:799-808.

Ward, T.M., Hoedt, F., McLeay, L.J., Dimmlich, W.F., Jackson, G., Rogers, P.J., Jones, K. 2001b. Have recent mass mortalities of the sardine *Sardinops sagax* facilitated an expansion in the distribution and abundance of the anchovy *Engraulis australis* in South Australia? *Marine Ecology Progress Series* 220:241-251.

Ward, T. M., Hoedt, F., McLeay, L., Dimmlich, W. F., Kinloch, M., Jackson, G., McGarvey, R., Rogers, P. J., Jones, G. K. 2001a. Effects of the 1995 and 1998 mass mortality events on the spawning biomass of sardine, *Sardinops sagax*, in South Australian waters. *ICES Journal of Marine Science* 58:865-875.

Ward, T. M., Kinloch, M., Jones, G. K., Neira, F. J. 1998. A collaborative investigation of the usage and stock assessment of bait-fish in southern and eastern Australian waters, with special reference to pilchards (*Sardinops sagax*). Final Report to the Fisheries Research and Development Institute, Project No. 1994/029. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 324 pp.

Ward, T.M., McLeay, L.J., Dimmlich, W.F., Rogers, P.J., McClatchie, S., Matthews, R., Kämpf, J., Van Ruth, P.D. 2006. Pelagic ecology of a northern boundary current system: effects of upwelling on the production and distribution of sardine (*Sardinops sagax*), anchovy (*Engraulis australis*) and southern bluefin tuna (*Tunnus maccoyii*) in the Great Australian Bight. *Fisheries Oceanography* 15:191-207.

Ward, T. M., Rogers, P. J., Stephenson, P., Schmarr, D. W., Strong, N., McLeay, L. J. 2005. Implementation of the Age Structured Stock Assessment Model for Sardine (*Sardinops sagax*) in South Australia. Final Report to the Fisheries Research and Development Corporation, Project No. 2000/125. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 130 pp.

Whittington, R. J., Jones, J. B., Hine, P. M., Hyatt, A. D. 1997. Epizootic mortality in the pilchard (*Sardinops sagax neopilchardus*) in Australia and New Zealand in 1995. I. Pathology and Epizoology. *Diseases of Aquatic Organisms* 28:1-15.

2.2.6 Alongshore variation in upwelling intensity in the eastern Great Australian Bight

Sam McClatchie and Tim Ward

South Australian shelf waters form part of a unique Northern Boundary Current, support a large biomass of sardines, and include a series of regional coastal upwelling centres driven by south-easterly, summertime wind forcing. Both bottom temperature records and conductivity, temperature and depth (CTD) profiles (Figure 1) indicate diminishing intensity of the upwelling signal from east to west along the Eyre Peninsula. Relatively cool (<17°C), fresh (<35.6), dense (sigma-t > 26 kg. m^{-3}) upwelled water associated with a fluorescence plume was present at the surface up to 20 km offshore of Cape Finnis (134.8°E) on the western Eyre Peninsula between 16-26 March, 2004 (Figure 2). Further west at Point Bell (133.1°E), upwelled water (indicated by the 17° C isotherm) was only detectable on the bottom at depths of ~45 m at 18-30 km offshore (Figure 3). Unlike further east, the upwelling plume did not reach the surface, indicating diminished alongshore intensity of upwelling to the northwest along the western Eyre Peninsula. The east-west trend is overlain by two distinct patches of surface upwelling, centred on Brown Point (separating Streaky Bay and Denial Bay), and the southern side of Cape Finnis and Flinders Island. The upwelled water could be traced to ~70 m depths on the shelf ~100 km offshore of Cape Finnis and ~150 km off Point Bell, but the origin has not been located. Mixed layer depths on the shelf off the western Eyre Peninsula were much shallower than the euphotic depth in March, even in the presence of upwelling.

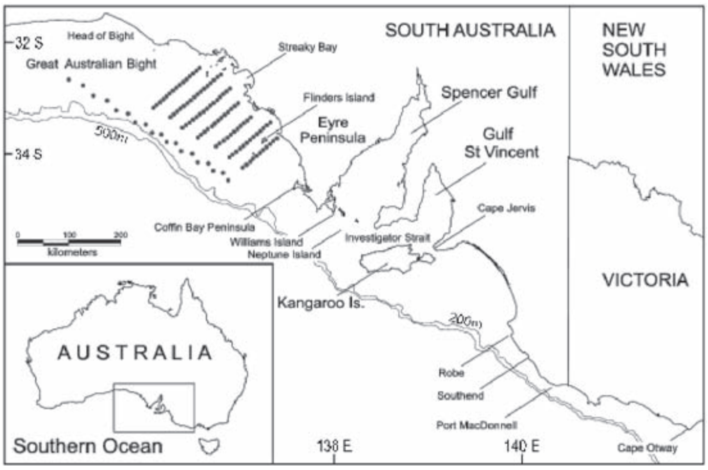


Figure 1: Map of the survey area showing stations sampled during the 10-26 March, 2004 sardine survey. Locations referred to in the text are marked. A CTD profile was collected at each of the stations (marked by dots).

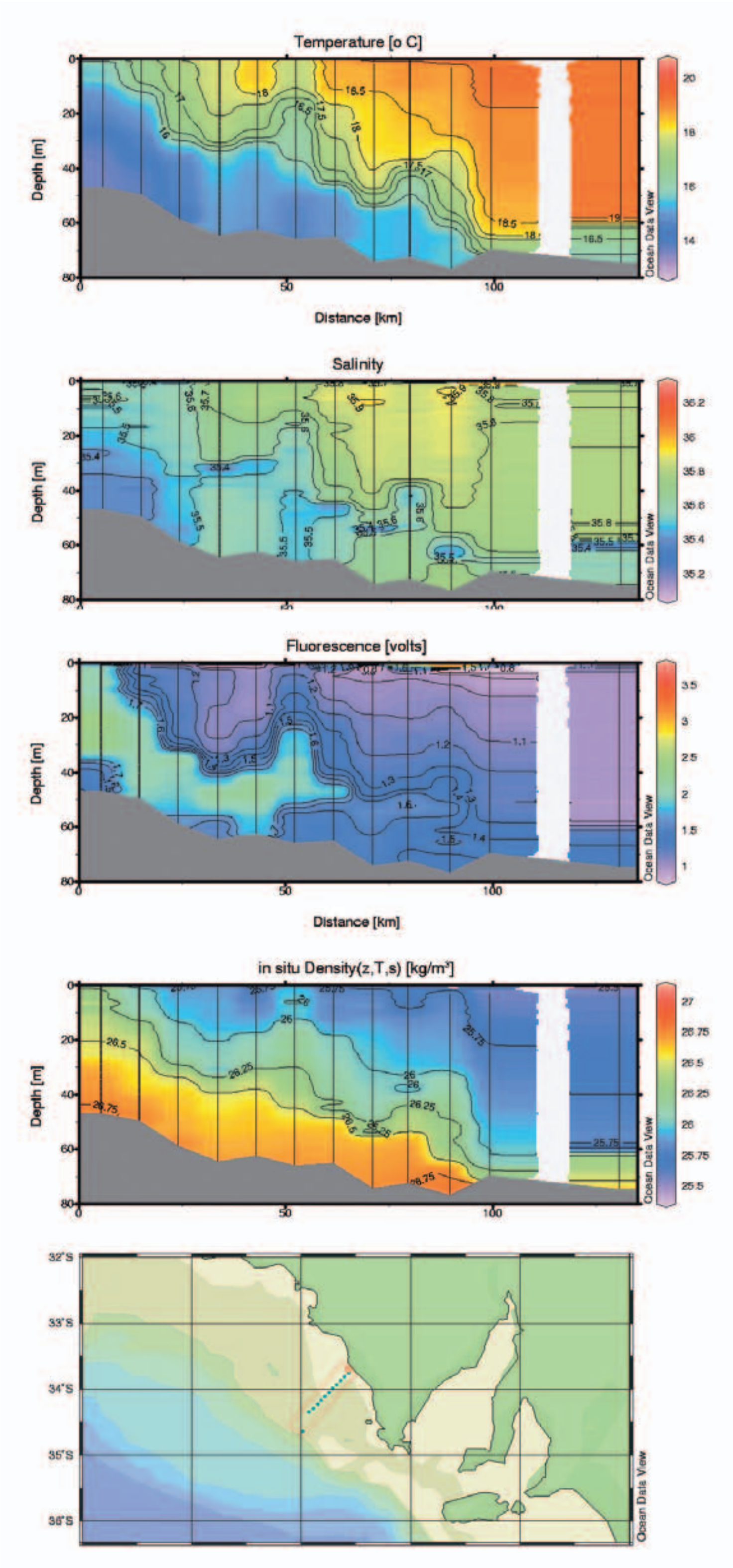


Figure 2: Section constructed from CTD profiles along a transect off Cape Finnis marked by the red box on the map. Upwelled cool (<17oC), relatively fresh (<35.6) water reaches the surface up to 20 km from the coast. The dense upwelling plume is associated with high fluorescence

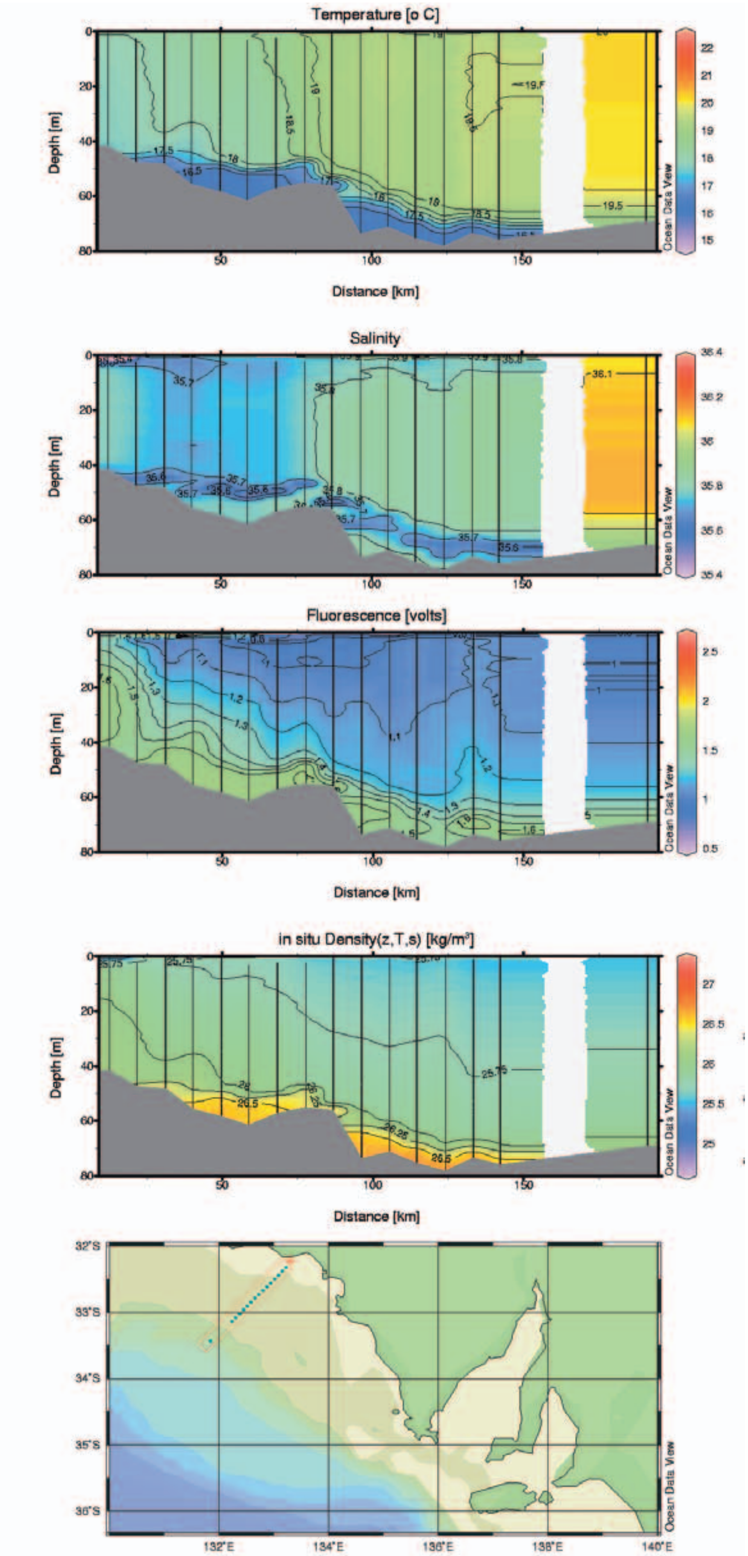


Figure 3: Section constructed from CTD profiles along a transect off Point Bell marked by the red box on the map. Upwelled cool (<17oC), relatively fresh (<35.6) water does not reach the surface, but is detectable on the bottom at ~20 km from the coast.

SARDI Aquatic Sciences
South Australia, Australia
Email: mcclatchie.sam@saugov.sa.gov.au

2.2.7 GAB ecosystem project

Simon Goldsworthy

The South Australian sardine fishery has expanded rapidly over the last 5 years and is now the largest fishery (by weight) in Australia, with the total allowable catch (TAC) for 2005 being set at 55,100 t. Prices currently paid to fishers are $500-700/t for tuna fodder and ~$1,000/t to factories servicing markets for bait and human consumption. The predicted GVP for the fishery in 2004 was ~$24M.

Annual stock assessments undertaken since 1995 show that sardine spawning biomass is continuing to recover from the mass mortality events in 1995 and 1998 (Ward *et al.* 1998, 2001, 2004). The strength of this recovery, in conjunction with the rapidly growing demand for local sardine by the tuna mariculture industry, suggests that the sardine quota may continue to increase over the next few years.

As a result of the rapid growth of the fishery, and in acknowledgment of the important roles that small pelagic fishes, such as sardine, have in pelagic ecosystems (e.g. Ward *et al.* 1998), the fishery working group, which includes representatives of recreational fishing and conservation groups, as well as PIRSA Fisheries and the SA sardine industry, has identified the need to acquire information and establish systems that will ensure that the SA Sardine Fishery is managed according to the principles of Ecologically Sustainable Development (ESD, Fletcher *et al.* 2002). This study will address these needs by developing ecological performance indicators and reference points that could be used to assess the need for ecological and/or spatial allocations in the SA Sardine Fishery.

Ecological performance indicators to be assessed in this study include population parameters, such as measures of foraging and reproductive success, for predatory species that consume large quantities of sardine, such as little penguins (*Eudyptula minor*), New Zealand fur seals (*Arctocephalus forsteri*) and southern bluefin tuna (*Thunnus maccoyii)*. For the purposes of this study, an ecological allocation is defined as the proportion of the potential TAC that is not allocated to fishers but reserved in consideration of the role of sardine in the ecosystem, particularly as fodder for key predatory species. Similarly, a spatial allocation is defined as the portion of the potential fishery that is temporarily or permanently closed to fishing in recognition of the importance of that area for foraging by key predators.

The eastern Great Australian Bight (GAB) and southern Spencer Gulf, where the SA Sardine Fishery is located, form part of the world's only northern boundary current system (Middleton and Cirano 2002). Upwelling that occurs between Cape Otway (Victoria) and the Head of Bight (SA) during each summer-autumn boosts primary, secondary and fish production in the region to levels that are significantly higher than those recorded in other parts of Australia, and within the lower portion of ranges recorded in the productive eastern boundary current systems of the west coast of Africa and the Americas (Ward *et al.* 2006). These oceanographic phenomena explain why the region between Cape Otway and the Head of the Bight supports Australia's richest pelagic ecosystem, and has global significance for marine conservation. Not only does the region support the largest population and fishery for sardine in Australasia, but it also includes the world's most important feeding ground for juvenile southern bluefin tuna (SBT, *Thunnus maccoyii*, Ward *et al.* 2006); Australia's highest concentration of pinneped colonies, including >75% of the global population of the Australian sea lion (*Neophoca cinerea*) and almost 80% of the Australian population of New Zealand fur seal (*Arctocephalus forsteri*, Goldsworthy *et al.* 2003); ~1.3 million pairs of short-tailed shearwaters (*Puffinus tenuirostris*), white-faced storm petrels (*Pelagodroma marina*) and the little penguin (*Eudyptula minor*) collectively (Ward *et al.* 1998); and significant feeding grounds for pygmy blue whales (*Balaenoptera musculus brevicauda*).

In response to the need to establish ecosystem-based management of the fishery, sardine licence holders and the FRDC funded a pilot study entitled *"Trophodynamics of the GAB: assessing the need for an ecological allocation in the SA pilchard fishery"* (2003/072, Ward *et al.* 2004). The objectives of that project (which was completed in November 2004) were to develop: (1) methods for estimating primary and secondary production; (2) methods for assessing the role of sardine in the diets of key predators; (3) methods to monitor the status and health of key predators within and outside the fishery; (4) conceptual and preliminary trophodynamic models for the eastern GAB; and a proposal for a comprehensive study to assess the need for an ecological allocation in the SA sardine Fishery.

SARDI Aquatic Sciences
South Australia, Australia
Email: goldsworthy.simon@saugov.sa.gov.au

References

Fletcher, W. J., Chesson, J., Sainsbury, K. J., Hundloe, T., Smith, A. D. M., Whitworth, B. 2002. National ESD reporting Framework for Australian Fisheries: The "How to Guide for Wild Capture Fisheries". Final report to the Fisheries Research and Development Corporation, Project No. 2000/145. Western Australia Department of Fisheries, Perth, Australia. 120 pp.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J., Littnan, C. 2003. Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In 'Marine Mammals and Humans: Fisheries, tourism and management'. (Eds N. Gales, M. Hindell and R. Kirkwood.) pp. 62-99. (CSIRO Publications: Melbourne, Australia.)

Middleton, J. F., Cirano, M. 2002. A northern boundary current along Australia's southern shelves: the Flinders Current. *Journal of Geophysics Research* 107:3129-3143.

Ward T.M., Goldsworthy, S.D., Page, B. 2004. Trophodynamics of the GAB: assessing the need for an ecological and spatial allocation in the SA pilchard Fishery. Final report to the Fisheries Research and Development Corporation, Project No. 2003/072. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 188 pp.

Ward, T. M., Kinloch, M., Jones G. K., Neira, F. J. 1998. A Collaborative Investigation of the Usage and Stock Assessment of Baitfish in Southern and Eastern Australian Waters, with Special Reference to Pilchards *(Sardinops sagax*). Final report to the Fisheries Research and Development Corporation, Project No. 1994/029. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 324 pp.

Ward, T. M., Hoedt, F., McLeay, L. J., Dimmlich, W. F., Kinloch, M., Jackson, G., McGarvey, R., Rogers, P. J., Jones, K. 2001. Effects of the 1995 and 1998 mass mortality events on the spawning biomass of pilchard, *Sardinops sagax*, in South Australian waters. *ICES Journal of Marine Science* 58: 865-875.

Ward, T.M., McLeay, L.J., Dimmlich, W.F., Rogers, P.J., McClatchie, S., Matthews, R., Kämpf, J., Van Ruth, P.D. 2006. Pelagic ecology of a northern boundary current system: effects of upwelling on the production and distribution of sardine (*Sardinops sagax*), anchovy (*Engraulis australis*) and southern bluefin tuna (*Tunnus maccoyii*) in the Great Australian Bight. *Fisheries Oceanography* 15:191-207.

2.2.8 workshop discussions and summary

The wide-ranging discussion in the Workshop touched on a wide variety of issues relevant to progressing the move toward ecosystem-based fishery management (EBFM), of which the following were particularly pertinent.

Coming to grips with what EBFM really means was again discussed. The key high-level questions that were put forward were:

1. What is it?
2. What does it include?
3. How to do it?

The group recognized that ecologically sustainable development (ESD) provides the framework for placing fisheries management within an ecosystem context. The view was put forward that, in one sense, having ESD assessments are akin to EBFM.

Another generally agreed-to view was that EBFM should equate to encompassing all aspects of the fishery and how the fishery fits within the ecosystem. However, there was not agreement that such knowledge (at a level adequate for a fishery to be considered as being managed according to EBFM principles) was automatically achieved simply because a fishery has undergone an ESD assessment.

A large part of the session discussion was devoted to the question of how we might go about implementing an EBFM approach. A central theme to this discussion was the need for the best available information. Key points on this topic were:

Gap Analysis. The group felt that the diversity of problems or issues yet to be sorted out for EBFM need to be clearly identified through a formal process. Gaps in our current approach could then be identified.

Research Priorities need to be carefully assessed to ensure that work leads to data that is useful for implementing EBFM. That is, research needs to be focused on the gaps identified, and the intended data should underpin management changes.

Adaptive Management. Given the diversity with which EBFM is interpreted and how it means different things for different fisheries, the process of implementing EBFM must remain dynamic. As such, the development of EBFM, as a replacement or adjunct to traditional fishery management (TFM), will rely on fisheries management systems that can expect to change as our knowledge of both ecosystems and fisheries management systems increase. Any changes in management structure need to retain or build-in flexibility sufficient to allow adoption of, and/or response to, new knowledge relevant to either the science or policy streams of fisheries management.

A key issue for EBFM is dealing with multi-species - ecosystem indicators. While we are familiar (and hence comfortable) with single-species management, in that we have tangible indicators of what is good (a large stock) and what is bad (a small stock), and, have developed over many decades means of ascertaining what is and what is not acceptable for a stock, the relatively short history of EBFM leaves us with a limited history of what to do and, importantly, what is practical. Thus, not only does the move to EFBM away from TFM leave us without our array of familiar quantitative tools, it also leaves us wondering what in fact we should be attempting to quantify.

Some key questions or points relating to the fact that we are still at a pioneering stage with EBFM were:

1. What can we tractably deal with?
2. What constitutes acceptable levels of ecosystem impacts, given that some level of impact is inevitable? (e.g. is 10% mortality of seals OK?).
3. What are the reference points (RPs) and indicators that will/can be used?
4. How much knowledge is required to develop such indicators and how will they be used?
5. Reference points can be used for managing marine parks, but must be measurable and therefore need data.
6. How do we set reference points, risk-levels and time-frames?
7. How do we optimize the balance between ecological and social values? (While models to do this are "on their way", the need for data remains.)

The direction taken in the session reflected the earlier comments regarding the diversity of views on EBFM and eventually the group reached the point where it was obvious that different fisheries have different problems and there was no all-encompassing solution. Rather, implementation of EBFM may well be reliant, at least in the short term, on first considering individual fisheries, whether these be for single- or multi-species. At this point the discussion turned towards the practicalities of undertaking research with an ecosystem focus. Given the conclusion that different fisheries may well need different approaches, the discussion then returned to the case studies.

The group was highly cognisant of the need for cost-effective data (i.e. in a competitive funding environment) that was able to provide defensible scientific advice (i.e. decision makers/politicians need concise advice that is scientifically robust).

Similar to that for TFM, research for EBFM must aim to provide robust data that will help managers to better balance uncertainty and risk. With regard to the practicalities of progressing EBFM, the balance between uncertainty and risk must be considered with respect to the levels of available or potential funding. Most, if not all, fishery problems can be thought of in terms of the uncertainty-risk-funding model; the considerable effort that all management jurisdictions, research facilities and a host of committees at all levels in Australia put into prioritising research highlights that the uncertainty-risk-funding model forms a dynamic continuum, with trade-offs between:

1. Need for certainty of an outcome;
2. Risk of not achieving outcomes;
3. Investment required to reduce uncertainty.

The group considered that although there may be a continuum, the case studies showed clearly that fisheries of different size can (and should?) be dealt with differently. Further discussion raised some general principles, which may be considered as generally holding true, but should not be considered as holding true in all cases. These included:

1. Small fisheries represent smaller ecosystem risks.
2. Small fisheries may be amenable to qualitative assessments.
3. Larger fisheries will more likely represent greater risks to the ecosystem.
4. Larger fisheries will more likely need quantitative assessments.

These points essentially represent either end of the uncertainty-risk-funding continuum, with "medium" sized fisheries perhaps needing a mix of qualitative and quantitative assessments (see Table 1). It is not intended that every fishery can be classified as small, medium or large; the intention is that by referring to this table a researcher or manager can ascertain what avenues might best apply when attempting to implement EBFM for a particular fishery. In an ideal world it would be satisfying to have highly quantitative assessments for all fisheries, even those that are small, but in practical terms this will never be the case.

Table 1. Continuum of assessment levels required for fisheries of different size.

Class 1	Class 2	Class 3
High risk (large)	Medium risk (intermediate size fisheries)	Low risk (small)
Highly quantitative assessments. *E.g. Biomass estimates.* *Predator prey interactions.* *Trophic model.* *Oceanography.* *Spatial aspects.*	Mix of quantitative and qualitative *E.g. Data mining (use of available data).* *Proxies (Ecosystem productivity).* *Model transferability.*	Qualitative assessment. *E.g. Strategic assessment.* *Case study transferability.*

The model portrayed here suggests that larger fisheries will continue to be those that attract (and need) more research funds, leaving small-scale fisheries to make-do the best they can. This does indeed appear to be the reality of fisheries research in Australia. However, small-scale fisheries nonetheless retain the need to be managed in the ecosystem framework. The challenge in terms of the underlying management philosophy may be in convincing decision-makers that qualitative assessments do in fact provide an adequate basis for managing fisheries. In turn, the challenge for those who work on small-scale fisheries is to develop a repertoire of scientific advice that will stand up to scrutiny, yet not be reliant upon extensive data sets. The challenge for those working on large fisheries is to justify the expected higher level of research investment by competently collecting and analysing relevant data that feeds into EBFM and that can be seen to be an advance over what would have been available if a TFM approach had been followed.

Further to the model outlined in Table 1, the group agreed that the starting point would be to develop reference case-studies that could provide the basis for researchers and managers to put their particular fishery or problem into the appropriate context. Case studies should start with desk-top study of the literature and current work to provide a comprehensive list of what approaches are being adopted and which of these are working (i.e. practical and achievable): this approach is applicable to fisheries of all sizes. This would include an assessment of which approaches are suitable for the social, political and funding environment in Australia.

A desk-top study should also consider how to best use currently available data, and examine the benefits of maintaining (or extending) long-term data-sets. Alternative data sets (e.g. multi-species length frequencies, guano deposits) should also be investigated as these may provide insights that were simply not deemed relevant, or widely used, in the era of single-species assessments.

On a final note, one of the international speakers, Professor Bill Montevecchi, highlighted a significant gap that was evident over the course of the Symposium – the lack of social scientists integrated with fisheries research and management appears to be a significant risk for the success of EBFM in Australia.

This summary for the Pelagic Theme Workshop attempts to capture the important elements. The participants in the session appreciate the difficulty in summarizing the broad array of comments and opinions that were aired. Nonetheless, this summary of the discussion that was held amongst a diverse range of fisheries workers from around Australia (about 60 participants) represents a positive step towards how the Australian fisheries community might implement EBFM. This Workshop represents a work-in-progress; the "answer" to EBFM was not an outcome of this session and many of the problems or issues raised remain to be solved. However, the outcomes of this session are certainly components of the progress towards better fisheries research and management in Australia.

Presentation and workshop summaries provided by Dan Gaughan and Tim Ward in association with speakers and workshop participants.

3

Roles of fisheries species in structuring benthic ecosystems

3.1 National and international case studies to provide a conceptual framework

3.1.1 Abalone and rock lobsters in the context of their ecosystems

George Branch

Ecosystem effects of fishing require consideration of four main elements: (1) bycatch species, (2) effects of fishing gear on both the physical composition of the ecosystem and on other species, (3) indirect effects of removal of the target species on other species, including prey and competitors that may benefit from its removal, predators that suffer, and species that are in turn connected to these organisms, and (4) environmental alterations caused by or affecting fishing. Not all of these elements will appear in every fishery, but all need to be considered and evaluated before being dismissed as being of little significance.

In this overview, I focus on the ecosystem effects of fishing for the South African West Coast rock lobster *Jasus lalandii*, particularly in terms of its interactions with another commercially important species, the abalone *Haliotis midae*. *J. lalandii* supports a lucrative commercial fishery worth about US$22 million per annum, based on hoopnets in shallow waters and traps further offshore. The entire fishery takes place in relatively shallow, near-shore waters and is concentrated on the south-west section of the coast. *J. lalandii* was the first marine resource to be commercialised in South Africa, with canning beginning as early as 1874. From about 1915, unsustainable 'mining' ate into the accumulated reserves, with peak catches reaching 18,500 tons in 1950. Subsequently the resource declined steadily, until a total allowable catch (TAC) was introduced in 1979, and the harvest stabilised at about 3,800 tons for a decade. Thereafter, an unexplained decline in growth rate set in, diminishing productivity and compelling further reductions in TAC and a deliberate stock-building policy. Finally, in the last three years, there has been an upturn in the stocks, which has led to gradually increased TACs (Griffiths and Branch 1997; Pollock *et al.* 2000).

An abundant and aggressive predator, *J. lalandii* has the potential to transform benthic communities. The full extent of this potential became evident in studies by Barkai and Branch (1988a,b), comparing two adjacent islands with apparently similar physical conditions: Malgas Island with abundant rock lobsters and nearby Marcus Island with virtually none. Where rock lobsters were abundant, the benthos comprised mainly kelp, seaweeds and a few inedible species, whereas in their absence dense and species-rich beds of mussels formed, accompanied by large numbers of urchins and grazers that restricted algal growth. Experiments demonstrated that exclusion cages allowed a typically 'Marcus community' to develop at Malgas if lobsters were excluded. The most intriguing part of this comparison is that the two conditions appear to be an example of alternative stable states. When lobsters were experimentally introduced to Marcus Island, they were almost immediately eliminated by dense populations of the whelk *Burnupena papyracea*, which overpowered and consumed the lobsters. Barkai and McQuaid (1988) argue that where lobsters are abundant they prevent whelks' from building up their numbers, but where the whelks have achieved high densities, they will continue to exclude lobsters in a reversal of the normal predator-prey relationship. In part, the dominance of whelks at Marcus Island is maintained because their shells are coated with a symbiotic bryozoan, *Alcyonidium nodosum*, that secures the whelks' protection against lobster predation.

A second player that is important in benthic interactions is the urchin *Parechinus angulosus*, which provides protection for juveniles of the abalone *Haliotis midae* (Tarr *et al.* 1996). Experimental elimination of urchins results in rapid declines in juvenile abalone, as well as less expected results including accumulation of sediment, a decline in drift algae and a reduction of the settlement (or survival) of abalone settlers. Also unexpected was the fact that removal of urchins has no effects on macroalgal growth. Although unanticipated, this observation explains much about the urchin-abalone association, for *P. angulosus* traps drift seaweeds rather than grazing, and urchins concealed beneath urchins gain not only protection against predators but a source of food in the form of trapped kelp (Day and Branch 2002).

Returning to the rock lobsters, there have been four striking changes in their population dynamics. First, their overall abundance has declined due to fishing, with catches now hovering around 3,000 $t.yr^{-1}$ compared with peak values of over 18,000 $t.yr^{-1}$. Second, in parallel with this, modal sizes have declined. Third, growth rates have inexplicably declined drastically, reducing productivity, particularly in the north-west. Finally, a south-easterly shift has taken place in their distribution, with high densities now being recorded in areas that comprise the heartland of the abalone industry, whereas lobsters were previously virtually absent there (Mayfield and Branch 2000). The consequences are of immense importance, because the invasion of lobsters has depleted urchins, and abalone juveniles have declined in concert. Abalone are thus hit by a double whammy: natural increases in lobsters indirectly depleting their juveniles while extensive poaching targets adults (Hauck and Sweijd 1999). It is not just the density of lobsters that matters: size also counts. Mayfield and Branch (2000) showed that small lobsters (<68 mm carapace length) are incapable of consuming adult urchins, so urchin densities are inversely correlated with densities of large lobsters.

The south-easterly expansion of lobsters has not only affected urchins and juvenile abalone: depletion of grazers such as winkles has led to a proliferation of seaweeds. Thus, the whole subtidal benthic community has been transformed. Although it is possible that these changes reflect background environmental shifts, lobsters remain the most likely cause: changes have taken place in invaded areas, with localities just beyond the present range of lobsters remaining unaltered.

One is left with the inescapable conclusion that rock lobsters play an important (some would say 'keystone') role in modifying benthic community composition, and that changes in abundance and size of lobsters, caused by fishing and/or alteration of environmental conditions will have powerful repercussions, including the future viability of the abalone industry. If this web is not complex enough, periodic red tides cause local and massive depletions of lobsters, the most ferocious of which was a 2,000-t 'walk-out' that mass-stranded lobsters after a single red-tide event (Cockcroft 2001).

The role of fishing in altering community composition may extend even further than the benthic participants discussed above. Pollock and Shannon (1987) have gone so far as to hypothesise that fishing on pelagic fish has reduced consumption of phytoplankton, leading to increased frequencies and intensities of oxygen depletion because of decay, and that the shoreward concentration of lobsters during certain seasons is a reflection of this. Decreased growth rate and intensified effects on the benthos may flow from this.

Returning to the opening 'checklist' of four possible ways that fishing may affect ecosystems, (1) it seems likely fishing for rock lobsters has no adverse bycatch effects because traps and hoops are relatively selective, and none of the species that are caught as bycatch are threatened or endangered as a result. (2) It is also probable (though still untested) that the methods used inflict relatively little damage on the benthic habitat. However, (3) the effects of removing large numbers of rock lobsters will have profound effects on benthic structure and functioning, including interactions with other commercial species. Moreover, (4) environmental changes have clearly had an effect on the distribution, growth and probably size composition of lobsters, in turn influencing their impacts on the benthos and the availability to the fishery. It is even possible that fishing directed at pelagic resources has played a role in environmental change.

Planning the way forward in terms of sensible management strategies that incorporate these ecosystem effects will not be easy, especially given the rapid social transformation that has taken place in the South African fishing industry and the magnitude of poaching on abalone. A multi-species ecosystem approach is clearly needed to embrace the complexities of the ecosystem, together with innovative ways of managing the diverse range of fisher themselves, who span the full gamut of industrial, small-scale commercial, subsistence and recreational fishers. Both co-management and strategically positioned marine protected areas are likely to become increasingly important complementary approaches to single-species management (Branch and Clark 2005, Mayfield *et al.* 2005, van Sittert *et al.* 2005).

Marine Biology Research Institute
University of Cape Town
Western Cape, South Africa
Email: gmbranch@botzoo.uct.ac.za

References

Barkai, A., Branch, G. M. 1988a. Contrasts between the benthic communities of subtidal hard substrata at Marcus and Malgas islands: a case of alternative stable states? *South African Journal of Marine Science* 7:117-137.

Barkai, A., Branch, G. M. 1988b. The influence of predation and substratal complexity on recruitment to settlement plates: a test of the theory of alternative stable states. *Journal of Experimental Marine Biology and Ecology* 124:215-237.

Barkai A, McQuaid CD. 1988. Predator-prey role reversal in a marine benthic ecosystem. *Science* 242:62-64.

Branch, G. M., Clark, B. 2006. Fish stocks and their management: the changing face of fisheries in South Africa. *Marine Policy* 30:3-17.

Cockcroft, A. C. 2001. *Jasus lalandii* 'walkouts' or mass strandings in South Africa during the 1990s: an overview. *Marine and Freshwater Research* 52:1085-1094.

Day, E., Branch, G. M. 2002. Effects of sea urchins (*Parechinus angulosus*) on recruits and juveniles of abalone (*Haliotis midae*). *Ecology* 72:133-149.

Griffiths, C. L., Branch, G. M. 1997. The exploitation of coastal invertebrates and seaweeds in South Africa: historical trends, ecological impacts and implications for management. *Transactions of the Royal Society of South Africa* 52:121-148.

Hauck, M., Sweijd, N. A. 1999. A case study of abalone poaching in South Africa and its impact on fisheries management. *ICES Journal of Marine Science* 56:1024-1032.

Mayfield, S., Branch, G. M. 2000. Interrelations among rock lobsters, sea urchins and juvenile abalone: implications for community management. *Canadian Journal of Fisheries and Aquatic Science* 57:2175-2185.

Mayfield, S., Branch, G. M., Cockcroft, A. 2005. Role and efficacy of Marine Protected Areas for the South African rock lobster, *Jasus lalandii. Marine and Freshwater Research* 56:913-924.

Pollock, D. E., Shannon, L. V. 1987. Responses of rock-lobster populations in the Benguela ecosystem to environmental change—a hypothesis. *South African Journal of Marine Science* 5:887-899.

Pollock, D. E., Cockcroft, A. C., Groeneveld, J. C., Schoeman, D. S. 2000. The commercial fisheries for *Jasus* and *Palinurus* species in the South-East Atlantic and South-West Indian oceans. In: 'Spiny Lobsters: Fisheries and Culture'. (Eds B. F. Phillips and J. Kittaka.) pp. 105-120. (Blackwell Scientific: Oxford, UK.)

Tarr, R. J. P., Williams, P. V. G., MacKenzie, A. J. 1996. Abalone, sea urchins and rock lobsters: a possible ecological shift may affect traditional fisheries. *South African Journal of Marine Science* 17:319-323.

Van Sittert, L., Branch, G. M., Hauck, M., Sowman, M. 2006. Benchmarking the first decade of post-apartheid fisheries reform in South Africa. *Marine Policy* 30:96-110.

3.1.2 The ecological consequences of catching the big ones

Mark Butler

Among the most rapid and universal effects of fishing is the depletion of large individuals within exploited populations. The ecological consequences of human-induced alterations of the size structure of higher trophic level marine species are manifold and cascading with extraordinary examples, both historical and contemporary. Much of the recent emphasis in this area has been on changes in ecosystem trophodynamics via alterations in top-down regulation of prey communities. Most of what we know about top-down impacts comes from situations where strong interactions dominate (e.g. keystone predation), although weak interactions among multiple species and trophic levels may be more common. The most dramatic examples of the fishing-induced loss of top-down control occur where apex predators or herbivores have disappeared entirely.

An obvious and related issue is the fact that fishing nearly always acts to reduce the mean size of individuals in the exploited population, and these effects are nearly always manifested first before changes in total abundance or biomass ensue. In fact, a basic premise of fishery management is that by targeting large individuals, fisheries can increase biomass production via greater turnover of small, faster growing individuals. More often than not, fisheries have been quite effective at this. The end result is that the size structure of nearly all fished populations has been drastically altered: truncated in the upper portion of the size distribution and devoid of large individuals. What are the effects of this on the population dynamics and community interactions of benthic marine communities? We know little about such effects. Therefore, I note a suite of possible consequences, drawing largely from information on a geographically widespread group of benthic marine animals that are highly prized for their flesh, and thus subject to intense fishing wherever they occur – spiny lobsters (Palinuridae; Decapoda; Crustacea).

Population Effects: Theoretically, reducing individual size should have many effects on population dynamics and this is true for spiny lobster, although biogeography modifies the conclusions. Potential population effects include those on: egg production, egg and larval provisioning, fertilisation success, disease, mortality, and emigration/immigration. In general, large females produce more eggs per gram of biomass than do smaller females, and tropical spiny lobsters produce many more eggs per female than do temperate species. A related issue is the impact that the removal of large females has on egg size, larval size, and larval survival. For example, large female southern rock lobster (*Jasus edwardsii*), a temperate species, produce larger eggs and larvae than do smaller conspecifics, and large larvae swim faster and survive starvation longer than larvae produced by small females. In contrast, there is no relationship between female size and any measured attribute of their young (i.e. egg size, egg nutrition, larval size, larval swimming speed, or larval survival of starvation) in the tropical species, *Panulirus argus*, the Caribbean spiny lobster. In some species, large females also produce several clutches per year, whereas small females cannot. The effects of reduced size are not limited to female attributes.

In unfished populations, male spiny lobsters can be five times the biomass of females, whereas in fished populations male and female size are typically quite similar because few fisheries have sex-biased size limits. The difference in male size in fished and unfished populations may have important implications for reproductive success because large males: (1) acquire more and larger females for mating, (2) produce more sperm per sperm packet (spermatophore) ensuring higher fertilization success, (3) produce more spermatophores per year, (4) and can recharge their sperm stores more rapidly than small males.

Less is known about the consequences of smaller individual size on non-reproductive aspects of lobster population dynamics. As for many species, the probability of natural mortality for lobsters is inversely related to size, so smaller lobsters in fished populations are likely to be subject to higher rates of predation if their predators are not similarly fished down to a smaller individual or population size. Disease is not generally thought to be a significant determinant of abundance in most natural populations of lobster, although evidence is growing that declining environmental quality may be linked with emerging diseases that recently have had significant impacts on some lobster populations. If resistance to disease is tied to physiological changes associated with maturity or size, then fishery-induced alterations in size structure could alter natural disease dynamics. For example, a recently discovered viral disease that infects and kills primarily juvenile and subadult Caribbean spiny lobster could become even more significant as the juvenile to subadult fraction of the population increases with fishery pressure on large individuals. In some marine species, large individuals are more nomadic, whereas in other species large individuals display greater philopatry. For spiny lobsters, movement generally scales with size with respect to benthic life history stage, but among adult lobsters, the limited evidence available suggests that the largest individuals move less than smaller adults. If so, then intense fishing may lead to more nomadic spiny lobster populations. The evolutionary consequences for spiny lobster populations under heavy selective mortality on large individuals is not known, although general theory on life history evolution presumably applies. High mortality on large individuals results in selection for slower growth and earlier maturity among other traits, which at its extreme, could result in a negative feedback with fishery regulations ratcheting down minimum size limits.

Community Effects: It is not inconceivable that the effects of loss of large individuals in fished populations could in turn cascade to impact marine communities. The potential for such impacts is likely to be directly proportional to the strength of the trophic connections between the fished species and other members of the community. Spiny lobsters have been implicated as important benthic predators in many systems, but demonstrable evidence of their importance on benthic communities seems to be limited to temperate, subtidal hard-bottom communities. In places like southern California, South Africa, and New Zealand the effects of foraging spiny lobster on sea urchins and molluscs (e.g. mussels, gastropods, abalone) can dramatically alter the community structure of the sessile benthic community. In particular, large lobsters can consume a greater number and range of prey sizes so their impact is more pervasive than for small individuals. Evidence for similar effects in tropical systems and in muddy or sandy sediments is lacking.

Beyond the direct predatory effects that large spiny lobster may have on communities, there have been few if any studies on other potential impacts that the loss of large individuals may spark in communities. Changes in individual mobility, for example, be it by drifting larvae or wandering adults may influence the “stability” of the ecosystem or its resistance to disturbances due to the loss of population connectivity and thus community impacts. Lobsters are themselves prey to even larger marine predators, so changes in lobster relative size due to fishing is also likely to alter natural predator-prey dynamics.

In conclusion, much of what we know about the effect of dramatic changes in individual size within fished populations centres on effects that are manifested at the population level, and those effects can be significant. Studies on the subsequent impacts on the community have focused on trophic interactions. The conclusions of those studies appear to depend largely on the number of strong interactions in which the species in question is engaged. Other potential effects on the community independent of trophic relationships are poorly known and investigated.

Department of Biological Sciences
Old Dominion University
Virginia, USA
Email: mbutler@odu.edu

3.1.3 Benthic community structure and variation in indirect effects of fishing in Australasian kelp forests

Russ Babcock

Studies from Australasia provide some of the best evidence so far available to demonstrate the widespread direct and indirect effects of fishing on benthic habitats. In north-eastern New Zealand predatory target species in no-take marine reserves have increased in density by between 3.8 (rock lobster *Jasus edwardsii* (Langlois *et al.* 2005a)) and 14 times (snapper *Pagrus auratus* (Willis *et al.* 2003)) the density of fished populations. These changes can be rapid (3 years in the case of snapper (Denny *et al.* 2004)) and lead to a range of other measurable effects on rocky reefs and adjacent soft sediment systems. The most conspicuous effect of the recovery of predator populations is that coralline algal-dominated urchin barrens revert to kelp (*Ecklonia radiata*) forest habitat (Babcock 2003). This change is the result of a trophic cascade driven by predation on sea urchins (*Evechinus chloroticus*). Experimental manipulations have shown that mortality of urchins inside no-take reserves can be up to 7 times higher than outside reserves, and that predation by rock lobsters is responsible for a significant proportion (45%) of this mortality (Shears and Babcock 2003). Measurable effects of predation are also found off the edge of the reefs in adjacent soft sediments, where community structure is measurably different between reserves and fished areas (Langlois *et al.* 2005a). The main taxa responsible for this difference were bivalves (*Dosinia* spp.), and caging experiments have shown that mortality of *Dosinia* is much higher in the reserves than outside (Langlois *et al.* 2005b). Once again rock lobster was the main predator, as indicated by characteristic breakage patterns on dead shells.

Changes in algal habitat structure brought about by trophic cascades are in turn associated with other, less direct, changes to reef communities. For instance, the reduced intensity of grazing by urchins results in increases in the proportion of coralline algal turfs as well as in kelp biomass (Babcock 2003). These turf dominated habitats are not suitable for grazing limpets (*Cellana radians*) that are more common on urchin barrens, outside reserves. The trochid gastropod *Cookia sulcata* however, appears to recruit in larger numbers to turf habitats and its pattern of abundance is the reverse of that shown by *Cellana*. Other common grazing gastropods show no clear patterns. Changes in cryptic fish communities are also associated with changes in algal habitat, and total cryptic fish and species numbers are lower inside reserves than outside, presumably as a result of higher levels of predation inside the reserves (Willis and Anderson 2003). Interestingly, these effects were strongest inside the kelp forest habitats, suggesting the potential for complex interactions between fish behaviour and habitat, in which predators may benefit as much or more than prey from increased habitat complexity.

While urchin barrens such as those described here are present in many parts of New Zealand and Australia, as well as around the world, their distribution is far from uniform. Urchin barrens are not found in sheltered turbid habitats in north-eastern New Zealand, either inside or outside marine reserves, nor are they found on all offshore islands. The primary example of the latter is the Poor Knights Islands where only small discrete patches of urchin-dominated habitat have been described, even before the islands were declared a fully no-take area. The reasons for these patterns are yet to be fully explained, but appear to be related to two factors: the relative abundance of urchin recruits and the productivity of algal communities. Very few urchins, and still fewer recruits, are found on sheltered turbid rocky reefs of northeast New Zealand, as urchin recruitment appears to be inhibited by sedimentation (Andrew and Choat 1985). Conditions are quite different at the Poor Knights which experience high water clarity and are alternately bathed by the subtropical East Auckland Current (an extension of the East Australian Current) and high-nutrient waters upwelled by the East Australian Current (EAC) and episodic wind events (Zeldis 2004). These conditions may favour algal growth while at the same time limiting the up-current sources of urchin recruits.

In Australia similar variability can be seen. For example at Rottnest Island in Western Australia, algal habitats are relatively uniform across fished and unfished areas, despite a 6.5-fold difference in lobster (*Panulirus cygnus*) density (Babcock, unpublished data). Coralline algal-dominated urchin barrens are totally absent on the temperate western Australian coast, yet at the same latitudes on the east coast extensive barrens are created by the urchin *Centrostephanus rogersii* in New South Wales. These barrens are spreading to Tasmania with the recent more frequent southern incursions of the EAC. While no evidence exists yet for New South Wales (Andrew and O'Neill 2000), studies in the Maria Island marine reserve off Tasmania have shown that predation by lobster *(J. edwardsii*), which are approximately ten times more abundant in the reserve, can also reduce urchin density relative to the densities in fished areas (Edgar and Barrett 1999). Considering the apparently similar levels of fishing pressure on both east and west coasts of Australia, as well as similarities in their dominant flora and fauna, we might expect algal habitats to respond similarly, but they do not.

Such inconsistencies in the structure of temperate coastal ecosystems to fishing pressure present real difficulties for predicting their responses, and consequently for the consistent implementation of ecosystem based fisheries management. I suggest that differences between the east and west coast benthic habitats are likely to be the result of contrasting ecosystem dynamics rather than differences in levels of fishing pressure. Waters of Western Australia are relatively clear and nutrient poor compared to those of the east coast. These differences may be important in that they may limit the recruitment of urchins in Western Australia, while promoting recruitment of urchins in New South Wales and Tasmania. The recent expansion of urchin barrens to north-eastern Tasmania (Bryan 2002) is a clear example of the importance to urchin recruitment to the development of barrens. A general theory to explain this variation in temperate reef structure is proposed in which the strength of top-down (fishing) effects are modified by bottom-up factors such as the availability of nutrients and recruits (Menge *et al.* 1997), and by the strength of interactions between key elements of kelp forest ecosystems, such as predators and urchins, or urchins and kelp. Broadly speaking the distribution of urchin barrens in Australia and New Zealand is consistent with this theory. Obtaining the data to test the theory presents significant logistical challenges but is probably attainable through a collaborative approach to obtaining comparable data sets at appropriate scales, and utilizing nascent marine protected area networks.

CSIRO Marine Research
Western Australia, Australia
Email: russ.babcock@csiro.au

References

Andrew, N. L., Choat J. H. 1985. Habitat related differences in the survivorship and growth of juvenile sea urchins. *Marine Ecology Progress Series* 27:155-161

Andrew, N. L., O'Neill, A. L. 2000. Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. *Marine and Freshwater Research* 51:255-263.

Babcock, R. C., 2003. The New Zealand marine reserve experience: the science behind the politics. In 'Conserving marine environments: Out of sight out of mind?'. (Eds P. Hutchings and D. Lunney.) pp. 108-119. (Royal Zoological Society of New South Wales: Mosman NSW, Australia.)

Bryan J. 2002. Sea Urchin Threat to Tasmanian Rocky Reefs. *The Tasmanian Conservationist* 285:11.

Denny C. M., Willis T. J. Babcock R. C. 2004. Rapid recolonisation of snapper (*Pagrus auratus*: Sparidae) within an offshore island marine reserve after implementation of no-take status. *Marine Ecology Progress Series* 272:183-190.

Edgar, G. J., Barrett, N. S. 1999. Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants *Journal of Experimental Marine Biology and Ecology* 242:107-144.

Langlois, T. J., Anderson, M. J., Babcock, R. C. 2005a. The influence of reef associated predators on adjacent soft-sediment communities. *Ecology* 86:1508-1519.

Langlois, T. J., Anderson, M. J., Babcock, R. C., Kato, S. 2005b. Marine reserves demonstrate trophic interactions across habitats. *Oecologia* (in press).

Menge, B. A., Daley B. A., Wheeler P. A., Dahlhoff E., Sanford E., Strub P. T. 1997. Benthic-pelagic links and rocky intertidal communities: bottom-up effects on top-down control? *Proceedings of the National Academy of Science* USA 94:14530-14535.

Shears, N. T., Babcock, R. C. 2003. Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progress Series* 246:1-16.

Willis T. J., Anderson M. J. 2003. Structure of cryptic reef fish assemblages: Relationships with habitat characteristics and predator density. *Marine Ecology Progress Series* 257:209-221.

Willis, T. J., Millar, R. B., Babcock, R. C. 2003. Responses of snapper *Pagrus auratus* (Sparidae) to marine reserve protection in northeastern *New Zealand Journal of Applied Ecology* 40:214-227.

Zeldis, J. R. 2004. New and re-mineralised nutrient supply and ecosystem metabolism on the northeast New Zealand continental shelf. *Continental Shelf Research* 24:563-581.

3.1.4 Drivers for ecosystem-based fisheries management in Australia

Colin Buxton[1], Stewart Frusher[1] and Wes Ford[2]

The concept of *"sustainable development"* emerged during the 1970s and 1980s, following concerns about the impacts that unrestrained economic growth and development were having on the environment. The World Commission on Environment and Development (WCED 1987) recognised that we need to ensure that:

"development...meets the needs of the present without compromising the ability of future generations to meet their own needs"

The term *"*Ecologically Sustainable Development*"* (ESD) was adopted in Australia to emphasise the importance of the environment to long-term survival and to ensure that there was a balanced approach in dealing with environmental, social and economic issues. The National Strategy on ESD (COAG 1992), which was agreed to by all Australian State governments, includes three key objectives:

1. To enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations;
2. To provide for equity within and between generations; and
3. To protect biological diversity and maintain essential ecological processes and life-support systems.

ESD has often been wrongly assumed to address only environmental issues, as the management of natural resources should be about more than just setting minimum biological limits. It requires improving the quality of human life from the utilisation of resources while only having an acceptable level of impact on the environment. Importantly, the National Strategy for ESD (Fletcher 2002) specifies that the guiding principles and core objectives need to be considered as a package: no objective or principle should predominate over the others. Thus, to be consistent with ESD principles:

"resources not only need to be used sustainably, but how they are used, who benefits and when, along with the impacts of their use, all need to be evaluated"

Moreover, society's goals and values often influence what are considered to be the acceptable levels of change, sometimes well above any biologically-based limit and as these attitudes develop and evolve, the acceptable levels may change over time.

The ecosystem-based approach (EBA) is seen as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is thus a method by which the three objectives: conservation, sustainable use and equitable sharing, can be met. EBA is broadly accommodated within the mandate of many international and regional Conventions covering the marine jurisdiction (National Oceans Office 2003). These international, regional and domestic laws and agreements, dealing with the sustainable management of ocean resources, facilitate the implementation of an ecosystem-based approach. However, an inherent challenge in effectively applying these agreements for ecosystem-based oceans management is that most established ocean areas are managed according to politically defined boundaries that do not match ecosystem boundaries. The most desirable condition is where the spatial extent of a managed area fully coincides with the spatial extent of an ocean ecosystem or set of contiguous ecosystems. For example, while the Law of the Sea Convention acknowledges that "the problems of ocean space are closely related and need to be considered as a whole", the legal boundaries set for maritime zones do not coincide with ecosystem boundaries. This inconsistency provides the challenge to ocean users and managers to ensure that ocean activities are managed across jurisdictional boundaries to achieve sustainable ecosystems into the future.

Southern rock lobster provides us with a good example. Three States manage this fishery and there are five management zones. Several of these zones have different size limits and different management strategies. This resource is connected by recruitment from a relatively common larval pool. The southern rock lobster has an extended larval phase with the larvae from any specific zone likely to contribute to various other zones. Without knowledge of the source and sink dynamics of the recruitment process, management in each zone can impact on other zones and the resource as a whole.

Since the Earth Summit and the first conference of parties to the *Convention on Biodiversity,* the term "ecosystem-based approach" (and related concepts such as sustainable forest management, integrated marine and coastal area management, integrated oceans management, ecosystem based management, ecosystem based fisheries management and environmental management systems), has appeared in many international and regional forums. It is important to note that internationally, the most significant progress in implementing an ecosystem-based approach in the marine environment has occurred within the fishing sector.

The ESD Working Group (ESD Working Group Meeting 11, July 2004, Brisbane) attempted to clarify the relationship between ESD, ecosystem-based management (EBM), ecosystem-based fisheries management (EBFM), integrated oceans management (IOM) and environment management systems (EMS), which forms a continuum in the sustainable management of fisheries. It determined that ESD is the overall goal and that the other terms like EBFM describe strategies that are being used to work towards the goal of ESD. In any assessment using an ESD framework, all relevant environmental issues, social and economic outcomes and governance issues can be covered, the main difference is the scope of the issues that are being addressed.

Importantly, as noted by Pikitch *et al.* (2004), EBFM reverses the order of management priority, starting with the ecosystem rather than the target species. Drivers for EBFM include government policy, community expectations and auditing, market access, multiple use management and a risk assessment approach to fisheries management. In addition, the literature contains an increasing number of studies that illustrate mounting concerns around the world that the single species approach to single species fisheries management has problems.

Pikitch *et al.* (2004) consider four issues relating to risk:

1. Minimising the risk of irreversible change to species assemblages and ecosystem processes.
2. Avoiding degradation of ecosystem – indicators
3. Evaluating long-term socio-economic benefits and ecosystem consequences
4. Generating the knowledge base sufficient to understand the consequences of human actions

In moving towards an EBFM framework we need to be convinced that EBFM will succeed where conventional fisheries management has failed. EBFM will not be cheap and involves new multi-disciplinary approaches to addressing management. We need to determine what these resources are and whether we can achieve EBFM with the resources at our disposal. As signatories to the Precautionary Principle in resource management, policy development is framing management in an adaptive environment that requires "burden of proof" that resource extraction industries are not impacting deleteriously on the environment. Such policy development is proceeding at a rate that is currently outstripping science.

In Tasmania we are approaching EBFM through an integrated fisheries approach. As outlined by Frusher and Buxton (2006), this approach focuses on understanding how our key fished species use their habitats, how they interact with other species and the trophic web that they are part of.

As a starting point we advocate a research response that incorporates the following elements:

1. Detailed habitat mapping;
2. Using marine protected areas to establish baselines against which the effects of fishing can be measured;
3. Defining key predator-prey relationships;
4. Understanding habitat utilisation;
5. Characterising changes to essential habitat; and
6. Evaluating the impacts of introduced and invasive species.

1 *Tasmanian Aquaculture and Fisheries Institute*
University of Tasmania
Tasmania, Australia
Email: colin.buxton@utas.edu.au

2 *Department of Primary Industries, Water and Environment*
Tasmania, Australia

References

COAG. 1992. 'The National Strategy for Ecologically Sustainable Development.' (AGPS: Canberra, Australia.) 128 pp.

Fletcher, W. J. 2002. Policy for the implementation of Ecologically Sustainable Development for Fisheries and Aquaculture within Western Australia. Western Australia Department of Fisheries Fisheries Management Paper No. 157, Perth, Australia. 70 pp.

Fletcher, W. J., Chesson, J., Sainsbury, K. J., Hundloe, T., Smith, A. D. M., Whitworth, B. 2002. National ESD reporting Framework for Australian Fisheries: The "How to Guide for Wild Capture Fisheries". Final report to the Fisheries Research and Development Corporation, Project No. 2000/145. Western Australia Department of Fisheries, Perth, Australia. 120 pp.

Frusher, S., Buxton, C. 2006. Multi-layered approaches to evaluating impacts of lobster fishing. In 'Proceedings of the National Symposium on Ecosystem Research and the Management of Fish and Fisheries'. (Eds T. M. Ward, M. C. Geddes and S. Mayfield.) pp 69-71. (Australian Society for Fish Biology: Canberra, Australia.)

National Oceans Office 2003. 'Developing an Ecosystem-Based Approach for Managing Ocean Activities - Outcomes from the Workshop on 'Ecosystem Based Management of Ocean Activities', Cairns, Australia, June 2003.' (National Oceans Office: Hobart, Australia.) 13 pp.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J., Sainsbury, K. J. 2004. Ecosystem based fishery management. *Science* 305:346-7.

WCED. 1987. 'Our Common Future.' (Oxford University Press: Oxford, U.K.) 400 pp.

3.1.5 Multi-layered approaches to evaluating impacts of lobster fishing

Stewart Frusher and Colin Buxton

Introduction

The marine environment can be separated into two major components, physical and biological. The physical component includes the benthic habitat and the water, with variables such as substrata, water currents, nutrients, temperature, salinity, pollution. The biological component includes all of the faunal and floral elements. To understand the impacts of fishing on the marine environment we need to understand how fisheries interact with both components of the marine environment. In the absence of exploitation, fish species interact directly through predator-prey interactions or indirectly through competition for food and space including habitat usage.

The physical impact of lobster fishing on the environment is considered to be negligible because it has a small footprint and passive gear (Frusher 2006). The major impact of lobster fishing may therefore be considered as that associated with removing lobsters from the environment. Estimates of biomass removal for eastern Tasmania for example indicates that over 90% of the legal-sized biomass has been removed.

The Tasmanian Aquaculture and Fisheries Institute (TAFI) initiated a series of projects to address the emerging issues of Ecological Sustainable Development (ESD) and ecosystem-based fisheries management (EBFM).

Approach

TAFI's approach has been to progressively build layers that address the different physical and biological requirements of EBFM. The first layer was to provide a comprehensive understanding of the habitat through the SEAMAP Tasmania project. Using relatively inexpensive technology (colour echo sounders, global positioning systems and a single beam mapper) marine and estuarine environments have been mapped at a 1:25,000 scale to a depth of approximately 40 m revealing the relief and physical composition of the benthos (relative hardness). The second layer associated with the habitat mapping component is a comprehensive "ground truthing" of the habitat using digital video transects, still photography and grab sampling. This also identifies the fixed biological components of the habitat (e.g. seagrasses, kelp, sponge gardens). Once the habitat and its fixed components are identified we can then overlay the more mobile components – the non-fixed fauna. These are normally achieved through underwater surveys, fishing and sampling devices such as traps, trawls, grabs, plankton tows, and towed and static video observations including baited videos. The final layer has two components. The first evaluates how the different biota interact, including predator-prey associations, competitive associations including habitat and food usage and intra- and inter-specific behaviour. The second component builds on these two-way interactions to reveal trophic pathways.

Habitat usage

In addition to identifying different habitat types it is also important to understand how the habitat is used. From a fisheries perspective this includes both the fisher and the fished species and its ecosystem. To understand the impacts of fishing it is necessary to know the spatial and temporal amount of effort expended by the fishing fleet. This is usually recorded in statistical fishing blocks that can include a number of differing habitats. For species associated with specific habitats it is important to know the extent of the fishable habitat within a fishing block.

The quality of the habitat is also important, as differing habitat types will support differing amounts of fish. The carrying capacity of the habitat is dependent on a number of factors including food quantity and availability, shelter, home range and behavioural interactions such as mating. Catch and effort data obtained from the fishing fleet does not necessarily translate to fish density in any specific region. Fishing economics (e.g. fishing closer to home port) and market demands (e.g. premium price paid for inshore red rock lobsters) will often dictate fishing effort and bias catch rates.

Habitat usage also includes the matching of animal behavioural patterns such as migrations and aggregations. Certain species are highly vulnerable as they move between different habitats (e.g. 'whites' run of the western rock lobster as the lobsters move from inshore to offshore reefs). Many species aggregate at certain sites to spawn and are often highly vulnerable during this period. Nursery regions are often crucial for sustainability of resources and have been recognised as no-take regions (e.g. shark nursery grounds and mangroves).

Finally, at the predator-prey level, the predation pressure is a product of the probability of the prey being on a habitat (e.g. reef) and consumption rate.

Understanding habitat usage is logistically difficult in the subtidal marine environment. Observation is often limited to inferring relationships through remote techniques (e.g. tagged lobsters in traps) but may include direct visual observations by diving or remote video. Marine acoustic telemetry is a relatively new research tool being investigated by TAFI to understand habitat usage. To-date we have trialled both the rapid acoustic positioning system (VRAP) and the static acoustic receiving stations (VR2) technologies. The VRAP system consists of three buoys that are anchored up to 500 m apart in an equilateral triangle depending on the substrata type and rugosity. Acoustic tags are attached to the target species and individual movement is obtained through triangulation of the signal. The data are relayed to an observing station where real time movements are observed and recorded. This system is used to record movement of the order of 200 – 500 m.

The VR2 system establishes an array of acoustic receivers that create a "curtain" that is strategically positioned to detect the movement of tagged animals. For example, receivers are placed across the mouths of bays or estuaries or surrounding areas of interest. The range of the receivers overlap so that any animal with an acoustic tag will be recorded by at least one of the receivers as it moves through the curtain. Thus it is possible to record the timing and frequency that an animal visits a particular region and the path taken. The second array that has been trialed is an intensive array of receivers placed in a specific habitat type. The receivers cover the habitat so that their range of reception overlaps and every part of the habitat is at least in the reception of one receiver. It is therefore possible to determine which area of the habitat a tagged animal is using based on the combination of receivers that record the signal. For animals that are confined to the habitat for substantial periods of time there is the possibility of the receivers recording large numbers of signals (hits). To simplify the analysis of these data we have developed a software package called TRITON that identifies the unique position of the multiple hits and produces a file that can be readily overlaid on habitat maps in GIS programs such as ARCView. This method has been used successfully on a number of species including lobster and a number of prey species, octopus and draughtboard sharks.

Species Interactions

Evaluating predator-prey relationships from traditional stomach or gut content analysis is difficult for most lobster species because of the maceration of the prey. However, to understand the importance of removing biomass from the system, and hence evaluate the effects of fishing, these predator-prey interactions are important. We are using remote underwater infrared cameras for this purpose with a combination of baited traps and tethering experiments. The video is telemetered to a receiving station that enables real time viewing as well as recording of the images. Mesocosm experiments are being used to evaluate the usual biases associated with tethering experiments. For example, we have observed crabs predating on tethered juvenile lobsters in the wild, but were able to demonstrate that they were unsuccessful in mesocosm trials where lobsters were untethered.

DNA techniques are also being used to evaluate lobster diets. Faecal material is being screened to detect the presence, and frequency of occurrence, of specific prey items. This method has been successfully used on a number of species by our collaborators at the Australian Antarctic Division. The technology offers the following advantages:

1. The method, which involves extracting faecal material from the anus of the lobster after applying gentle pressure to the abdomen, is non-destructive. Samples can therefore be obtained from MPAs (often required as 'controls' in effects of fishing studies) and the commercial catch as the lobster can be returned to the fisher quickly and without harm.

2. Sampling is logistically simple. Samples can be obtained through existing projects or from commercial operations. There is no need to destroy the animal or take the animal back to a laboratory. The faecal material can normally be obtained from a lobster in 2-4 minutes.

3. Sampling is inexpensive, there is no need for diving and in many cases the samples can be obtained from existing sampling or commercial fishing operations.

4. Costs of analysing the data. A major cost for the DNA dietary analysis is isolating a specific marker for each organism. As new markers are obtained they are normally placed on a DNA Bank that can then be used by others. Established markers can be purchased from commercial companies. An ultimate goal is to have a reference library of all southern Australian marine organisms.

Preliminary results show that DNA can be successfully obtained from faecal material, that the detection signal is present in the faecal material at least up to 36 hours after feeding (aquaria trials) and that similar detection ratios were found between diver caught and trap caught lobsters. The current output from this DNA detection method is a binary signal and new developments are focusing on quantification of the signal to determine the amount of prey item in the sample.

The research described above is being undertaken by an FRDC project entitled "*Towards integrated multi-species management of Australia's SE reef fisheries: A Tasmanian example*".

Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Tasmania, Australia
Email: stewart.frusher@utas.edu.au

Reference

Frusher, S. 2006. The Tasmanian southern rock lobster fishery – ecosystem implications. In 'Proceedings of the National Symposium on Ecosystem Research and the Management of Fish and Fisheries'. (Eds T. M. Ward, M. C. Geddes and S. Mayfield.) pp 81-85. (Australian Society for Fish Biology: Canberra, Australia.)

3.1.6 Ecosystem effects of abalone fishing in Victoria

Greg Jenkins

There is a growing awareness of the impacts of fisheries on the marine ecosystem and the need for ecosystem-based fisheries management. Fisheries, particularly export fisheries, are increasingly being required to show that they are ecologically sustainable. The prime objective of the recently completed management plan for the Victorian abalone fishery is to formalise management of the abalone fishery firmly within the framework of ecologically sustainable development. Here I review the current body of knowledge related to the relationship between abalone and the reef ecosystem, and the effects of abalone fishing on that ecosystem. Recommendations are made as to the optimal design of experiments to determine the effects of abalone fishing on Victorian coastal reef ecosystems.

The ecosystem effects of removing the target species

Any effects of reducing the abundance of abalone by fishing on the ecosystem will depend on the strength and direction of dependencies between abalone and other species.

Feeding – From the juvenile stage the role of abalone in the ecosystem is more that of a scavenger than a grazer because they feed primarily on drift algae. Overall, by feeding primarily on drift macroalgae, abalone appear not to have a structurally important role in the reef ecosystem in terms of feeding and diet. Notwithstanding this, the importance to the system of removing significant amounts of drift algae in areas of high abalone abundance is not understood.

Competition – An important taxon with regard to community structure on many temperate reef systems where abalone is found are sea urchins. Abalone tends not to occur in urchin barrens, implying that urchins are competitively dominant when food is limiting. When food is not limiting, however, abalone may be superior competitors for space (crevices). The question in terms of the ecological effects of abalone fishing is whether correlations between abalone and urchin abundances only reflect responses of abalone to urchin density, or whether the reverse can occur and urchins can be affected by abalone density. Experimental work is required to test this hypothesis. If correct, increased urchin abundance could be a potential indicator of ecological effects though abalone fishing.

Predation – A variety of taxa prey on abalone, including molluscs such as whelks and octopus, starfish, crustaceans including crabs and rock lobsters, and fishes such as wrasses and rays. The crucial question in terms of ecosystem impacts of the fishery is the dependency of any predator on abalone prey and more studies are needed on other predator species to determine whether any strong dependence on abalone prey occurs.

Direct effects of fishing practices

Fishing techniques and practices can have significant effects on ecosystems. Practices such as trawling with nets and dredges, fishing with explosives and a suite of others have an obvious potential impact on the ecosystem. Compared to these, dive fisheries would intuitively be relatively benign. Further, problems of bycatch mortality or discard with other fishing methods do not exist in the abalone fishery.

The ecological effects of diving practices used in abalone fishing have not been quantified. Mechanical damage through anchoring, and the dragging of the abalone catch bag and hookah hoses have the potential to have impact on the substratum and algal canopy. Because the concentration of divers is a major factor in potential impact, the effect of commercial abalone diving might be expected to be less severe than for recreational diving in localised areas. Direct effects on the ecosystem may also occur from other activities associated with abalone fishing. For example, introduced pest species may be inadvertently transported on or in boat hulls. This translocation problem could be exacerbated where abalone are held in live tanks on board fishing vessels and water is exchanged in a different area to where it was taken up.

Ecological Indicators

Ecologically sustainable management will require suitable indicators that can be measured against reference points that trigger management actions. Three types of indicators have been proposed to assess the effects of fishing: (1) population based, (2) assemblage based (ignores interactions), and (3) community based (i.e. trophic paths, biomass flows). Given that the effects of fishing are likely to be more subtle in a diver-based fishery compared to other fisheries, assemblage and community-based indicators may not be sufficiently sensitive. The identification of so called "ecologically dependent" species may provide the most suitable indicators. These are species that will show population responses to variation in abalone abundance caused by fishing. Examples would be predators that have a dependence on abalone prey or competitors that are sensitive to variation in abalone abundance. The indicator might be the abundance, growth rate, condition or some other trait of the dependent species, and reference levels would be based on these factors.

An experimental approach to assessing ecosystem effects of abalone diving

Two major problems usually confront the selection of indicator species for the effects of overfishing. One is that fishing has been undertaken for a considerable time period and therefore pre-fishing conditions are unknown, making the determination of reference points problematical. Secondly, correlations between fishing effects and ecosystem changes may be found but causation is very difficult to establish because the systems do not lend themselves to experimentation. In the case of the abalone fishery, however, both of these problems can be addressed. Firstly, it is possible with subtidal reef ecosystems to use marine protected areas (MPA) as a proxy for knowledge of pre-fishing conditions. Secondly, unlike most other systems, communities occupying hard substrata such as subtidal reefs offer the opportunity to use experiments to determine dependence and causality.

Manipulative experiments to assess the ecological impact of the abalone should simulate different levels of fishing, across a range of spatial and temporal scales. The first step in the process of establishing experiments would be to examine existing data for correlations between abalone abundances and other ecosystem components based on existing monitoring data. This analysis would provide an initial screening for species that may be affected by variation in abalone abundances and therefore should be measured explicitly in experiments. Because questions of ecosystem impact are framed around showing no effect of fishing, statistical power is a major consideration. Some assessment of the level of replication required for sufficient statistical power, based on pre-defined effect sizes of biological importance, could be made by analysing the variability in taxa collected in existing monitoring programs.

For manipulations, experimental plots would be set up to encompass more than one reef system along the coast to give greater generality to the results. If possible, these experimental locations would include MPAs, so that an inside/outside MPA treatment could be applied. This would allow comparison of results in fished and unfished environments to assess the affect of interactions with other fisheries and to help establish reference points for any indicators selected. Experimental plots would be set up where abundances of abalone would be manipulated. Results would indicate whether removal of abalone had any significant effect on coexisting species, and if so, allow the selection of indicator species and the determination of reference points.

Marine and Freshwater Systems
Primary Industries Research Victoria
Victoria, Australia
Email: greg.jenkins@dpi.vic.gov.au

3.1.7 *In situ* and *ex situ* trophic consequences of fishing

Rod Connolly

Managing fishery harvests for ecosystem sustainability requires conservation of ecological processes. Energy transfer among trophic levels is one of the central organising themes in ecology (Polis *et al.* 2004), and underpins patterns in populations and assemblages of organisms (biodiversity). Harvesting of marine animals might alter energy pathways either in the immediate vicinity (*in situ* consequences) or in adjacent habitats (*ex situ* consequences).

Stable isotope analysis has proven to be a useful method of tracing energy and nutrient pathways in aquatic systems. One advantage that isotope analysis has over traditional methods such as stomach content analysis is that it provides information about the ultimate autotrophic source of nutrition for animals at any trophic level. The method relies on different autotrophs (e.g. macroalgae and seagrass) having different isotope signatures, that are then propagated through the trophic levels of a food web. Analysis of carbon isotopes is particularly useful since: (1) carbon isotope signatures of autotrophs are predictably different because of known differences in photosynthetic pathways and carbon sources, and (2) signatures remain essentially constant even after multiple trophic interactions. It is a relatively straightforward exercise to collect representative samples of potential autotrophic sources and of the animals being studied, and to analyse their carbon isotope signature (ratio of $^{13}C/^{12}C$). The contribution of different sources to the consumer signature can then be analysed using mixing model algorithms.

Carbon isotope analysis has been used to trace energy pathways for animals associated with temperate rocky reefs (e.g. Jennings *et al.* 1997). In future, it could be used to measure predictable trophic consequences of harvesting invertebrates from temperate reefs in conservation areas. Harvesting of lobsters, for example, might increase sea urchin densities, resulting in decreased kelp and foliose red algae and subsequent increased cover of crustose and filamentous algae (Edgar and Barrett 1999). For animals such as urchins and abalone, *in situ* on reefs and relying at least partly on drifting vegetation, increased consumption of drift seagrass from adjacent meadows can be expected. Since seagrass has a signature more enriched in ^{13}C than algae, this would be detectable as enrichment in the carbon isotope signature of animal tissue (e.g. a shift in the carbon isotope signature from -20‰ to -15‰).

Ecosystem sustainability also requires that ecological processes are conserved in habitats adjacent to where animals are harvested, and this is particularly important for energy pathways. Since the ultimate autotrophic source at the base of marine food webs can come from a different habitat to that where animals occur (Lepoint *et al.* 2000), harvesting of reef animals may affect habitats adjacent to reefs that rely on organic material exported from reefs. Carbon isotope analysis has been used to determine trophic pathways in these soft-sediment habitats, including pathways involving important Australian fisheries species (Loneragan *et al.* 1997, Connolly *et al.* 2005). Using lobster harvesting as an example of the potential effects of harvesting reef animals, a shift in the dominant autotrophic support from algae to seagrass would be expected for fish and invertebrates in sand areas adjacent to reefs. This shift would potentially also be important for animals on distant intertidal mudflats and beaches relying on allochthonous material from deeper waters. Again, the altered energy flow would be detectable as a shift toward enriched carbon isotope signatures of animal tissue.

Any effects of harvesting on trophic pathways would interact with existing trophic influences of landscape features such as reef size and distance from river mouths. Even without any harvesting, for example, animals such as urchins and abalone on small patch reefs surrounded by seagrass would be more reliant on drift seagrass than their counterparts on larger reefs.

Where the carbon isotope signatures of two or more autotroph sources are similar and unable to be distinguished, isotopes of other elements able to separate the sources can be employed. Nitrogen isotope signatures are altered by fractionation between trophic levels. This fractionation means that nitrogen is useful for indicating the trophic level of consumers, but not for tracing sources. Sulphur isotope signatures are particularly conservative, faithfully tracing trophic pathways even over many trophic interactions. Sulphur is therefore the most useful element to employ in conjunction with carbon (Connolly *et al.* 2004). Analysis of lipids can also be useful where isotopes are unable to resolve food webs.

Overall, stable isotope analysis is a useful and efficient tool for detecting trophic shifts resulting from harvesting of aquatic animals. It can be used both *in situ* on reefs and *ex situ* in adjacent soft-sediment habitats, and can be used to analyse shifts in trophic pathways for individual species or suites of species at any level from herbivores to higher carnivores.

Centre for Aquatic Processes and Pollution
Griffith University
Queensland, Australia
Email: r.connolly@griffith.edu.au

References

Connolly R. M., Guest M. A., Melville A. J., Oakes J. M. 2004. Sulfur stable isotopes separate producers in marine food-web analysis. *Oecologia* 138:161-167.

Connolly R. M., Hindell J. S., Gorman D. 2005. Seagrass and epiphytic algae support the nutrition of a fisheries species, *Sillago schomburgkii*, in adjacent intertidal habitats. *Marine Ecology Progress Series* 286:69-79.

Edgar G. J., Barrett N. S. 1999. Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. *Journal of Expiemental Marine Biology and Ecology* 242:107-144.

Jennings S., Renones O., Morales-Nin B., Polunin N. V. C., Moranta J., Coll J. 1997. Spatial variation in the 15N and 13C stable isotope composition of plants, invertebrates and fishes on Mediterranean reefs: Implications for the study of trophic pathways. *Marine Ecology Progress Series* 146:109-116.

Lepoint G., Nyssen F., Gobert S., Dauby P., Bouquegneau J. 2000. Relative impact of a seagrass bed and its adjacent epilithic algal community in consumer diets. *Marine Biology* 136:513-518.

Loneragan N. R., Bunn S. E., Kellaway D. M. 1997. Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study. *Marine Biology* 130:289-300.

Polis G. A., Power M. E., Huxel G. R. 2004. 'Food webs at the landscape level.' (University of Chicago Press: Chicago.)

3.1.8 Top-down and bottom-up effects across temperate Australia

Sean Connell

The idea that changes to fishing pressure can result in system wide changes often assumes strong top-down effects. The existence of such trophic cascades requires 'key-stone' species at each trophic level. Indeed, there are numerous high profile demonstrations of strong control of tropical and temperate habitats via benthic grazing as a function of direct or indirect fishing pressure.

We quantified the spatial configuration of subtidal habitats and inhabitants across temperate Australia (Figure 1: WA, SA, NSW) and discovered the south coast to differ substantially from the east coast. Western and South Australian rocky reefs have relatively few benthic grazers capable of shaping benthic habitats that are primarily dominated by extensive tracts of canopy-forming algae, punctuated by 'gaps' comprising turf-forming or foliose algae. Eastern Australian reefs not only support extensive tracts of canopy-forming algae, but also dense populations of grazers, particularly urchins which form more extensive populations and barrens towards the southern border of New South Wales and sparse populations (and no barrens) in northern NSW and southern Queensland.

South Australian experiments tested the existence and strength of a key trophic link that could have explained this disjunct pattern. We tested the effects of grazing pressure on benthos in a locality of unusually high grazer diversity and abundance over three summer and winter seasons and found that while the effects of grazing could be detected, its effects were negligible. We then retested the effects of grazers (natural densities *v*. removals) across central New South Wales and across South Australia. We detected strong grazing pressure in NSW that could be affected by overfishing in the past and future, but little to no effects of grazing across South Australia (i.e. contemporary fishing is unlikely to have major effects beyond the direct removal of target species). After establishing weak 'top-down' effects in South Australia, we then tested for 'bottom-up' effects of nutrients. We found that enhanced levels of nutrients, comparable to discharges across South Australia's metropolitan coast, would not only re-create the highly unusual habitats associated with human-dominated coast, but also that of Australia's most populated coast (Sydney).

We are less certain that changes to fishing pressure in South Australia will have substantial effects on the 'ecosystem'. Instead, South Australians may need to be more concerned about what they add to their coast (coastal run-off) than what they remove from their coast (abalone, urchins, fish).

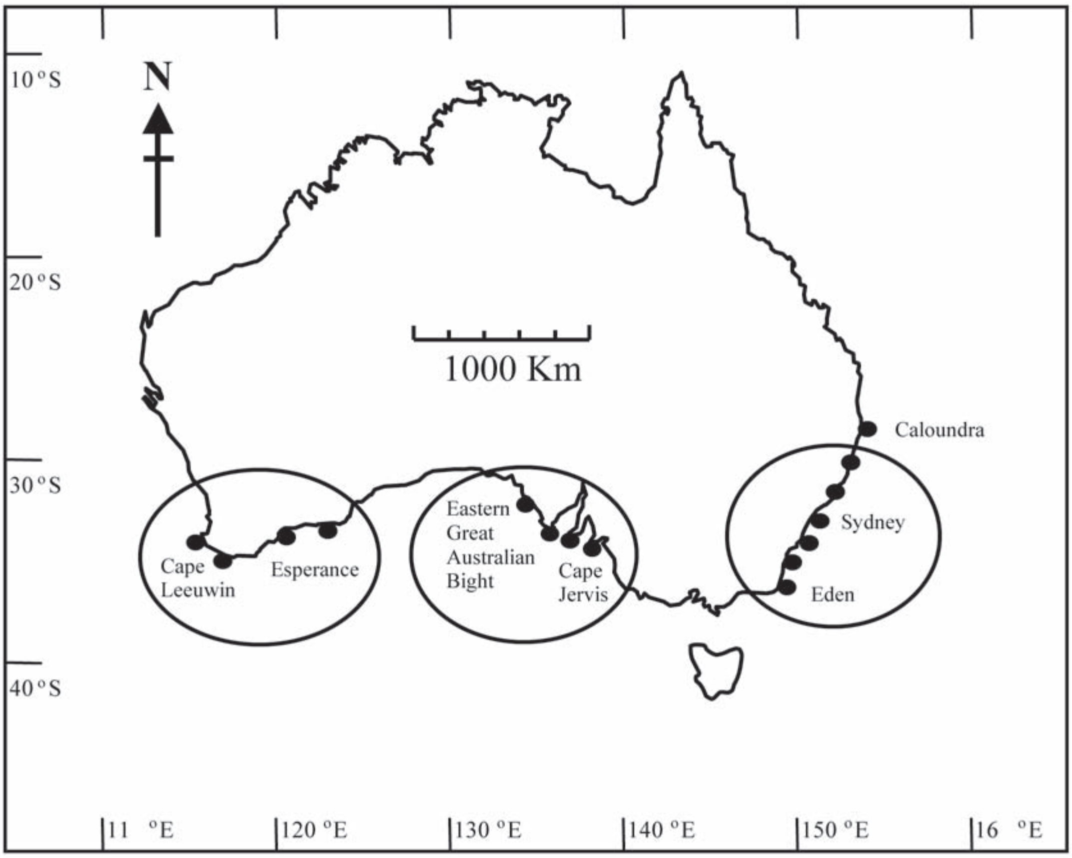


Figure 1. Locations used to quantify subtidal habitat and observe the consequences of herbivore loss. For more detail see: http://www.marinebiology.adelaide.edu.au/research/projects/regional.html

Southern Seas Ecology Laboratories
School of Earth and Environment Sciences
University of Adelaide
South Australia, Australia
Email: sean.connell@adelaide.edu.au

3.2 Focused case study: abalone and rock lobster on temperate reefs

3.2.1 Introduction

Australia's southern temperate reefs were chosen as the benthic ecosystem around which to base discussions, as they support Australia's most valuable commercial fisheries. The rock-lobster and abalone fisheries are the two dominant commercial fisheries operating within this region and are among the most valuable fisheries in southern Australia. As such, these fisheries have received considerable research activity.

The benthic case study was structured into two components. Firstly, building on the diverse presentations in session 1, researchers from Tas, WA and SA provided a brief overview of the abalone and rock-lobster fisheries in their State, including descriptions of the knowledge of the ecosystem effects of fishing and identification of current and forthcoming research programs and approaches for undertaking these assessments. These presentations greatly assisted the workshop and comprised:

1. Craig Mundy (The Tasmanian abalone fishery: ecosystem implications;
2. Stewart Frusher (The Tasmanian southern rock lobster fishery – ecosystem implications);
3. Adrian Linnane, Stephen Mayfield and David Currie (South Australian abalone and rock-lobster fisheries: synopsis and ecosystem effects of fishing);
4. Lynda Bellchambers (Western Rock Lobster Research for Sustainability); and
5. Craig Johnson (Detecting indirect effects of fishing on the dynamics and structure of rocky reef communities)

The second component was a workshop that identified key management needs and research questions; considered options and approaches to benthic ecosystem research; and discussed national strategies and approaches.

3.2.2 The Tasmanian abalone fishery: ecosystem implications

Craig Mundy

In the absence of baseline data on community structure and function, research on the ecosystem effects of a fishery must consider spatial and temporal variation in fishery performance and the history of management actions. A brief overview of the Tasmanian abalone fishery is provided, with a summary of the major ecological features (wave energy, temperature, dominant macroalgae).

Gear effects are generally minimal in abalone fisheries around the world, leaving direct and indirect effects on communities the key ecological impact associated with removal of commercial quantities of abalone. Understanding ecological impacts of removal of abalone will also require more detailed data on the scale at which abalone interact with the habitat they occupy. This in turn requires knowledge on frequency and extent of movement, and for example, whether abalone have home sites. A recent study on small spatial/time scale movements in abalone has shown that approximately 50% of animals at a site at Maria Island over an 11 week period have a home range of less than $0.1m^2$, and have identifiable 'home scars'. The remaining 50% showed a broad range of movement, with distances up to 35 m travelled in a single day. The relatively sedentary nature of a large proportion of the abalone suggests the ecological effects of removal of individual abalone are limited, but collectively, removal of a population is likely to have a measurable effect on benthic communities.

Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Tasmania, Australia
Email: craig.mundy@utas.edu.au

3.2.3 The Tasmanian southern rock lobster fishery – ecosystem implications

Stewart Frusher

Background

Tasmania offers a unique opportunity to study the marine environment. It is oceanographically complex, being the meeting place of three major water masses: the nutrient-poor East Australian Current that extends partway down Tasmania's east coast; the nutrient-poor Leeuwin Current (often called the Zeehan Current) that extends from northern Western Australia to the south west of Tasmania; and the nutrient-rich cooler waters of the sub-Antarctic Convergence which meets these waters at their southern boundary. Being an island, Tasmania is also unique for a State in that it has eastern, western, southern and northern seaboards. The different coasts also exhibit a range of different meteorological situations. The west coast has limited infrastructure and few ports and is subject to strong westerly winds that minimise fishing opportunities. In contrast the more sheltered east coast has seen the greatest expansion in both fishing activity and general infrastructure that has resulted in fishing ports extending along the entire coastline. These physical conditions make Tasmania a fascinating natural laboratory to study a range of marine activities and Tasmania's rock lobster fishery highlights the reason why.

The variation in growth rates of southern rock lobster in Tasmania is the greatest demonstrated for any lobster fishery around the world. The large variability provides the contrast necessary to understand the mechanisms that underpin biological patterns.

This contrast also has implications for management. Although managed as a single unit, spatial patterns in growth combined with spatial and temporal patterns in effort make management complex. The eastern and western fisheries are very different. The western fishery comprises larger boats that remain at sea for up to a week whereas the eastern fishery comprises many smaller vessels that are away from port for far fewer days per trip. An exception is the northwest where fishers, operating in the highly productive waters adjacent to King Island, often leave and return to port in the same day.

The following summary highlights the extent of variation found in several of the biological parameters important for assessing the fishery:

1. At the minimum legal size limit (110 mm and 105 mm carapace length for males and female respectively) annual growth rates are up to eight times faster in northern Tasmania compared to the southern Tasmania. This impacts on the elapsed time between settlement as post larvae and recruitment to the fishery;
2. The size at which 50% of the population begin to mature (carry eggs) in southern Tasmania is almost half the size found in northern waters;
3. Using traps with closed escape gaps, the number of lobsters caught per trap is 20 to 30 times greater in southern regions; and
4. This contrast is, to the author's knowledge, the greatest variation found in a lobster fishery anywhere in the world.

Ecosystem Implications

Traps impact on the ecosystem in two ways. Firstly, the weight and structure of the traps can physically damage the reefs and, secondly lost traps can continue to ghost fish causing continual death to both lobsters and bycatch species.

On any lobster boat it is common to see pieces of seaweed attached to the trap that has been pulled from the habitat. A study by Casement and Svane (1999) found that the damage caused by traps was no more than caused by the surge associated with storm damage and concluded that lobster trap fishing was benign. Underwater video recording of traps has shown that lobsters can easily escape from traps. Studies in Tasmania have seeded traps with lobsters and the largest bycatch species – draughtboard sharks. Results found both species to easily escape from traps. The final evidence, to demonstrate that ghost fishing is not an issue in the Tasmanian lobster fishery, occurs when traps are hauled after being left at sea for several days, often due to bad weather. On virtually all occasions the catch in these traps is substantially reduced.

Bycatch in the Tasmanian rock lobster fishery has been summarised by Frusher and Gibson (1998). Although only very few bycatch species are caught per set of 40 traps, there are just over 16 million traps set and hauled each year in southern Australia (WA, SA, Vic and Tas.). A recent honours study of bycatch from traps without escape gaps found that bycatch varied considerably between years and that there had been no noticeable change in species composition over the last 12 years. Frusher and Gibson (1998) were also able to demonstrate that the use of escape gaps minimised the bycatch with a reduction of approximately 80%. The most common species caught in traps with escape gaps were wrasse, leatherjackets and draughtboard sharks. The sharks are released alive and the wrasse and leatherjackets are retained for bait. Releasing the wrasse and leatherjackets is normally not viable as these fish suffer from barotrauma.

Removal of the target species results in lower densities of the legal sized component of the catch and a truncated size distribution in favour of smaller lobsters. These two issues are considered to have the greatest ecosystem impact and the Tasmanian Aquaculture and Fisheries Institute (TAFI) has focused its ecosystem research in this area. On the East Coast of Tasmania, estimated legal sized biomass was less than 10% of an unfished population. Since introduction of the individual transferable quota system in 1998, legal size biomass has been estimated to have increased in all regions. However, there are concerns about the sustainability of inshore stocks as there has been a redirection of commercial effort towards the more highly prized inshore stocks together with a doubling of recreational licences over the last eight years.

In northern Tasmania, where the average size at onset of maturity is either above or close to the minimum legal size limit, the reduction in mature females by fishing has resulted in estimates of egg production less than 20% of an unfished population. Not only is this of concern for recruitment to the fishery, phyllosomae, the lobster larval phase, spend between 9 and 24 months in oceanic waters and as one of the largest macro-zooplankton species would be expected to contribute to the pelagic oceanic ecosystem.

Research by Pederson (2003) and Ling (in progress, unpubl data) have demonstrated that larger lobsters are able to consume larger urchins and that the density of lobsters in reserve populations can maintain urchin densities below the numbers sufficient to cause overgrazing and barrens.

A comparison of the size distribution of catches obtained in lobster traps that were set during the day and overnight in a reserve population has demonstrated that it is primarily only the very large lobsters that forage on the reef during both night and day. These lobsters would be expected to have access to a different suite of prey items than the smaller lobsters that forage only at night.

Outstanding Issues

The following biological issues were raised by the Department of Environment and Heritage (DEH) during assessment of the Tasmanian rock lobster fishery:

1. Inter-jurisdictional effects of fishing on egg production. As the resource is spread over three States (SA, Vic and Tas.) it was considered important that each State maintained its egg production at appropriate levels.
2. Egg production in northern Tasmania. As outlined earlier, the levels of egg production in northern Tasmania are low and mechanisms to improve egg production in this region are being considered.
3. Impact of skewed sex ratios (male only fishery in southern Tas.). In southern Tasmania the growth rate of females lobsters is extremely slow. The majority of female lobsters in water depths greater than 40 m die before reaching the legal size limit. In these regions the Tasmanian fishery is primarily a male only fishery and sex ratios as high as 6:1 in favour of females have been recorded.
4. Improved by-product reporting and interactions with protected species. Although considered to be negligible, several species of fish are kept as bait and there are occasional reports of seals being caught and drowned in traps and turtles being drowned through entanglement with buoy lines.
5. By-catch assessment. As stated earlier lobster pots catch a range of fish species although the catch rate is extremely low due to the inclusion of escape gaps.
6. Monitoring fished and unfished regions. This was identified as the most appropriate way to determine the impacts of fishing.

Current Project/Programs

1. A Fisheries Research and Development Corporation (FRDC) funded project is currently underway to understand transport mechanisms of lobster phyllosomae larvae and identify possible sources and sinks of the larvae.
2. An objective of the current lobster management plan is to increase legal sized biomass. A direct result of an increase in legal sized biomass in northern Tasmania is an increase in egg production.
3. Laboratory projects to study the number of females that can be inseminated by a single male has demonstrated that males can fertilise eggs of substantially more females than the largest sex ratios found in the fishery. This is further supported by the near 100% presence of mature females carrying eggs during the brooding period.
4. By-product is recorded in the general fish logbooks and interactions with protected species in the lobster log books.
5. By-catch studies with and without escape gaps are undertaken as regular components of fishery-dependent and-independent catch sampling projects.

6. Comparisons of inside and outside non-fished regions are undertaken as part of routine surveys associated with TAFI's fishery-independent and Marine Protected Areas projects.

In addition to the specific DEH requirements TAFI has a number of projects that relate to ecosystem studies:

1. SEAMAP Tasmania is providing detailed habitat maps of shallow water (<40 m) regions around Tasmania. Mapping of deeper water regions is planned using multi-beam swath-mapping.
2. A number of projects have focused on species-specific interactions with lobsters including octopus, draughtboard sharks and urchins.
3. A FRDC project evaluating reseeding of juvenile lobsters documented predators of juvenile lobsters in the wild.
4. Components of a number of FRDC projects have evaluated new developments in technology and analytical methods to understand movement and survival in different life history phases of the southern rock lobster. This includes tagging technology (from micro-wire to acoustic tags), analytical methods for improved estimates of survival and movement from tagging data, and the use of underwater video systems for direct observational studies.

New projects

TAFI has just commenced a project funded by FRDC to investigate integrated multi-species management of Australia's southeast reef fisheries using Tasmanian east coast reefs as an example. This project will focus on Tasmania's two most valuable reef species: abalone and rock lobster. As identified in studies in the Maria Island Marine Protected Area (Buxton *et al.* 2004) there appears to be a relationship between these two species. In addition to a focus on this specific issue, the project will explore non-destructive methods for identifying specific dietary interactions and impacts of reduced lobster and abalone densities.

Future Directions

1. Fishery productivity: Healthy and properly functioning ecosystems are the backbone of sustainable fishing industries. Productive ecosystems support productive fisheries and understanding the impact on productivity and ecosystem integrity of fishing, pollution and invasive marine pests are thus important to the fishing industry.
2. Accreditation: There is a growing trend, particularly in Europe and America, for products to have industry accreditation. The southern rock lobster is a premium product and suitable for high valued niche markets. The often touted "water to waiter" supply chain management issue affects both the product and the fisher. Accreditation will require having a 'clean and green' image in addition to documented and demonstrable sustainable fishing practices at the ecosystem level.
3. Risk management: The environment is dynamic and no two years or even two decades are the same. Understanding how the ecosystem changes and responds to change is required for longer-term risk management. In addition to natural change, we are all aware of the increase in the warming of the planet through global warming. Often referred to as "climate change", this change is expected to impact on storm events, terrestrial run off and oceanic currents. Lobsters, which have extended oceanic larval phases, are likely to be vulnerable to changes in currents. The recent increase in

the number of sub-tropical fish and invertebrate species in north-eastern Tasmania is considered a direct result of increased flow of the East Australia Current. The impact that these species have on our reef ecosystems is unknown, although the southern expansion of the barren-forming urchin *Centrostephanus rodgersii* along Tasmania's east coast is possibly linked to this event.

Understanding the ecosystems that support our fisheries is an investment in the future of both the fished species and the fishers.

Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Tasmania, Australia
Email: stewart.frusher@utas.edu.au

References

Buxton, C. D., Barrett, N., Gardner, C., Edgar, G. 2004. Evaluating the effectiveness of marine protected areas as a fisheries management tool. Final report to the Fisheries Research and Development Corporation, Project No. 1999/162. Tasmanian Aquaculture and Fisheries Institute, Hobart, Australia. 384 pp.

Casement, D., Svane, I.1999. Direct effects of rock lobster pots on temperate shallow rocky reefs in South Australia. South Australian Research and Development Institute (Aquatic Sciences) Report No. 52, Adelaide, Australia. 24 pp.

Frusher, S., Gibson, I.1998. Bycatch in the Tasmanian rock lobster fishery. In 'Establishing meaningful targets for bycatch reduction in Australian fisheries'. (Eds C. Buxton and S. Eayrs). pp. 73-81. (Australian Society for Fish Biology: Sydney, Australia.)

Pederson, H. G. 2003. Population dynamics of the sea urchin *Heliocidaris erythrogramma* on the east coast of Tasmania. PhD Thesis, University of Tasmania, Australia.

3.2.4 South Australian abalone and rock-lobster fisheries: synopsis and ecosystem effects of fishing

Adrian Linnane, Stephen Mayfield and David Currie

Rock lobster

The southern rock lobster, *Jasus edwardsii*, has been fished in South Australian waters since the 1890s, but the commercial fishery did not develop until the late 1940s and early 1950s when overseas markets for frozen tails were first established. Since then, there has been a gradual change to live export with over 90% of the current commercial catch exported live, mainly to China. The fishery is South Australia's most valuable resource, with an annual value of A$110M in 2002/03.

The fishery is primarily a day fishery with lobster pots set overnight and hauled at first light. The pots are steel-framed and covered with wire mesh that incorporates a moulded plastic neck. The catch is initially stored live in holding wells on boats and then transferred to live holding tanks at the numerous processing factories.

The fishery is divided into two zones, Northern and Southern. The Southern Zone (SZ) is relatively small, extending from the mouth of the Murray River to the Victorian border and covering an area of 22,000 km^2, whereas the Northern Zone (NZ) is larger, extending from the Murray mouth to the Western Australian border and covering an area of 207,000 km^2. Input controls including limited entry, pot restrictions and seasonal closures were adopted in both fisheries during the 60s, 70s and 80s. However, concerns about the status of the resource lead to the introduction of a quota system in the SZ in 1993/94 and the NZ in 2003/04.

SARDI Aquatic Sciences provide PIRSA Fisheries (the management agency) with annual stock assessments detailing fishery statistics on catch and effort as well as outputs from models. In addition, annual puerulus settlement indices (PSI) are correlated with pre-recruit indices (PRI) in an effort to estimate the relationship between PSI and future recruitment to the fishery.

The effects on the ecosystem from harvesting rock lobster in SA are largely unknown. A recent study on by-catch levels within the fishery indicated that by-catch from pots was dominated by finfish species, which accounted for over 95% of the total by-catch by number in both zones. The species composition was similar across both zones with leatherjackets, wrasses, bearded rock cods and perch being the most common. In comparison with other fisheries, the by-catch from the fishery appears relatively low. However, as the by-catch is dominated by relatively few species, ongoing monitoring and risk assessment of these populations is needed to ensure by-catch levels do not affect the long-term sustainability of these species.

Proposed future research involves estimating the level of interaction of the South Australian rock lobster fishery with pinnipeds. Given that 39 of 64 Australian sea-lion colonies occur in SA, and the attraction of pinnipeds to pots, this research proposal directly responds to concerns raised by the Department for the Environment and Heritage, about the interaction of these species with the South Australian rock lobster fishery.

Abalone

The SA abalone fishery is among the State's most valuable fisheries. The total catch in 2002/03 was ~890 t with a landed value of approximately $36 million. Directly and indirectly, the fishery provides employment for between 300 and 400 people.

The fishery is managed in three separate Zones (Western, Central and Southern) with an array of input (e.g. limited entry) and output (e.g. TACC) controls. Unlike most abalone fisheries outside of Australia, the SA abalone fishery is considered stable and sustainable.

Single divers operate from large, typically multi-hulled, vessels that are launched and retrieved daily to harvest the catch. Legal-sized abalone are prised from the reef using an abalone iron. In the Western and Central Zones the catch is shucked at sea, and the shells and offal discarded. The catch from the Southern Zone is landed in shell.

SARDI Aquatic Sciences provide PIRSA Fisheries with timely and quality information for sustainable management of the resource. This information is typically contained in annual stock assessment reports provided for each Zone that contain syntheses and analyses of both fisher-dependent (i.e. catch and effort) and fisher-independent (i.e. fishery-independent surveys) data. Model development is ongoing for both species. Notable features of the fishery include initial high catches, a general increase in CPUE over time and a reduction in the spatial extent of the fishery.

The effects on the ecosystem from harvesting greenlip and blacklip abalone in SA are poorly understood. Because the vessels operate 'live' and divers remove only legal-sized abalone, direct physical impacts and bycatch are negligible. Further, interactions with endangered/protected species (e.g. great white sharks, *Carcharodon carcharias*) are rare. However, the indirect effects of abalone removal on other species in the ecosystem may be considerable.

Fisheries Research and Development (FRDC) research proposal: "Measuring the ecosystem effects of abalone and rock lobster fishing on the structure and dynamics of temperate reef communities".

There are increasing international and national pressures to manage fisheries according to the principles of Ecologically Sustainable Development (ESD). Implementing ESD for Australia's fisheries means that the research focus for fisheries management must change from the traditional single-species approach to a more integrated multi-species framework. Provisions of the Commonwealth Environment Protection and Biodiversity Act now require ESD assessment before export approval is granted. This means that the need to move to ecosystem-based management regimes is pressing for high value export fisheries, such as those for rock lobster and abalone.

Whilst the ecosystem effects of fishing have generated considerable scientific interest over the last few years, most of this attention has focused on the direct impacts of equipment, especially trawl gear. In contrast, indirect effects that occur through alterations to ecosystem structure have received little attention. Paradoxically, in marine systems, indirect effects can be as important as direct effects. In fact, for fisheries, such as those for rock lobster and abalone, where the direct effects are low, indirect effects are potentially more significant.

The indirect effects of fishing are usually more difficult to assess than direct effects and fall into two major categories. The first is a reduction in predation pressure and/or prey availability through reductions in the abundance of target species. The second is changes in predation pressure or prey availability resulting from reductions in the size structure of the target population.

If funded this FRDC proposal will address the need for information on the potential ecological effects of rock lobster and abalone fishing by providing: (i) insights into the ecological roles of rock lobster and abalone in South Australia's temperate reef ecosystems; (ii) insights into the effects of removing adult abalone and rock lobster on the structure and dynamics of benthic communities; (iii) knowledge to assist the development of a suite of performance indicators for monitoring the ecological effects of South Australian rock lobster and abalone fisheries; and (iv) knowledge to assist the development of a framework for multiple use of South Australian marine protected areas.

SARDI Aquatic Sciences
South Australia, Australia
Email: linnane.adrian@saugov.sa.gov.au

3.2.5 Western rock lobster research for sustainability

Lynda Bellchambers

The Western rock-lobster fishery has averaged a catch of 11,300 t per season over the past ten years which makes the fishery Australia's most valuable single species fishery, with a gross value of between $300 and $350 million per annum. The fishery is managed in three different zones: south of latitude 30° S (C Zone), north of latitude 30° S (B Zone) and a third off-shore zone (A Zone), within the northern area, around the Abrolhos Islands.

The fishery has a well-developed catch prediction system based on puerulus (first post-larval stage 9-11 months old) settlement index from nine coastal sites. Post-larval recruitment to the fishery is continuously monitored and annual puerulus settlement fluctuates in response to environmental conditions, such as strength of the Leeuwin Current and the frequency and intensity of low-pressure systems generating westerly winds. Fluctuations in catches are due primarily to variations in puerulus settlement three and four years prior to the season in which the catch is landed. The ability to predict future catches is very important for the fishery's management because arrangements and options can be assessed against the established objectives in the context of predicted catch trends.

The safe breeding stock level required to provide the necessary recruitment is estimated to be between 20% and 25% of the virgin (or unfished) breeding biomass. In more recent times this biological reference point has been equated to a more tangible reference point – the size of the breeding biomass in 1980. All biological indicators for this fishery show that the overall breeding stock levels remain in good condition, a result that is attributed to the management action taken in 1993/94. Breeding stock levels are measured with an Independent Breeding Stock Survey (IBSS) conducted at six coastal sites, three of which are surveyed annually (Lancelin, Dongara and the Abrolhos Islands). The remaining three sites (Fremantle, Kalbarri and Jurien Bay) are surveyed every five years.

In 1999/2000 the West Coast Rock Lobster Managed Fishery became the world's first fishery to receive Marine Stewardship Council Certification. As part of this process an ecological risk assessment and an environmental management strategy were completed. A number of risks were identified in the risk assessment at either a moderate or low level. The MSC certifiers highlighted two key issues: the interaction of the fishery with protected fauna such as sea lions and leatherback turtles, and the lack of information on the ecological impact of removing rock lobster biomass from the environment.

An Ecosystem Scientific Reference Group (EcoSRG) was established to identify issues associated with the ecological impact of removing rock lobster biomass from the environment. The EcoSRG acknowledged that there were more data available on the shallow (< 30 m) water ecology of lobsters than for deep-water lobsters, although this was still limited in relation to determining the effects of lobster fishing on coastal ecosystems. In contrast the deep- water (>40 m) ecology of lobsters was relatively unstudied. Given the relatively lower percentage of lobsters taken in shallow waters (high abundance of undersize) the EcoSRG acknowledged that the ecosystem effects of fishing in the shallow water were likely to be much less than in deep water where most of the animals are legal size. As complementary studies on the effects of lobster fishing in shallow waters were planned as part of the marine park proposal, it was reasonable that the initial focus of research should be on the deep water effects of fishing.

The EcoSRG subsequently devised an operational plan and conceptual model as a guideline for future research proposals. The four key areas in the operational plan were:

1. Habitat mapping;
2. Size structure and density of lobsters;
3. Trophic dynamics; and
4. Lobster behaviour

The conceptual model is based on a two stage approach, firstly of identifying patterns and secondly investigating the underlying processes.

In August 2004, the Department of Fisheries Western Australia submitted and subsequently received funding for Fisheries Research and Development Corporation (FRDC) project 2004/049 "The effect of western rock lobster fishing on the deepwater ecosystems of the west coast of Western Australia". The project was designed and devised in consultation with the EcoSRG to fit within the EcoSRG conceptual model. The objectives of the project are as follows:

1. To identify gradients in the density/size distribution of western rock lobster to enable selection of representative areas;
2. To assess the catchability of western rock lobster and its relationship with population abundance and size structure; and
3. To identify the relationship between the deep-water habitat and the density/size distribution of western rock lobster to enable a preliminary evaluation of the impact of lobster biomass removal in the deep water.

To meet the project objectives and to fit within the EcoSRG strategic framework a phased approach was adopted with the program focusing on Jurien Bay to complement existing shallow water research being conducted by the Strategic Research Fund for the Marine Environment (SRFME; CSRIO and Universities). Year 1 of the project involves:

1. Preliminary identification and mapping of the deepwater rock lobster habitat using existing data sources (i.e. fishermen and maritime industry, with some detailed underwater video calibration of selected transects at locations from the Independent Breeding Stock Survey);
2. Modelling (desk study) of the changes in the biomass and size composition of the deepwater lobster stocks, based on historical data, with incorporation of some initial catchability information being undertaken as part of the existing breeding stock work (FRDC project 2003/005);
3. A pilot approach to assessing whether historical variations in lobster abundance are associated with detectable differences in the deepwater ecosystem (i.e. flora and fauna on and around the reefs); and
4. Preliminary assessment of rock lobster gut contents to establish appropriate survey methods as well as the dominant prey items in the diet.

The second phase (Years 2 and 3) of the project would involve:

1. Replicate locations for mapping of the deepwater rock lobster habitat and video assessment of additional transects;
2. Further investigation of deepwater catchability to enable catch rates to be more directly related to actual abundance and size composition of deepwater stocks; and
3. A more detailed examination of food web relationships (both predators and prey) for deepwater rock lobsters using, for example, dietary analysis.

Department of Fisheries
Western Australia
Australia
Email: lbellchambe@fish.wa.gov.au

3.2.6 Detecting indirect effects of fishing on the dynamics and structure of rocky reef communities

Craig Johnson

The work presented in this overview focuses on two key questions concerning the dynamics and structure of shallow rocky reefs on the east coast of Tasmania, *viz*. whether fishing can (1) cause shifts in community and habitat structure to forms less able to support commercial fisheries, and (2) exacerbate the spread of introduced marine species. In particular, I consider whether fishing of predators (rock lobsters and reef-associated fishes) can increase the risk of formation of sea urchin barrens, whether fishing of herbivores (abalone) can increase the risk of barrens habitat, and explore the relationships between fishing of rock lobsters, sea urchins and spread of the introduced kelp *Undaria pinnatifida*.

In examining mechanisms underpinning barrens formation, the initial focus was on the common sea urchin *Heliocidaris erythrogramma* (Pederson 2003, Johnson *et al.* 2004). A logical series of experiments and surveys were conducted. In sequence, we addressed whether predators can eat *H. erythrogramma*, whether predators do eat *H. erythrogramma*, the identity of predators, the nature of size-specific relationships in predator-prey interactions, whether large scale patterns in the distribution of *H. erythrogramma* and its predators are consistent with the results of the experiments conducted at smaller scales and, most importantly, whether observed rates of predation on this sea urchin have any impact on its population dynamics. Predation rates on both tethered and tagged-but-untethered *H. erythrogramma* in marine protected areas were high, and much greater than predation rates on similarly tethered and untethered sea urchins at adjacent fished sites that support fewer predators. Caging experiments controlling the access of predators to untethered sea urchins indicated significant predation by rock lobsters (*Jasus edwardsii*) but not by reef-associated fishes. Mortality of *H. erythrogramma* was seven-fold higher in the presence of lobsters. Patterns of abundances at large scales were consistent with this result in that densities of *H. erythrogramma* were negatively correlated with abundances of legal sized rock lobsters, but there was no relationship between the abundances of *H. erythrogramma* and reef fishes. Further caging experiments revealed that lobster predation on *H. erythrogramma* is highly size-specific in that sub-legal lobsters are able to consume only small sea urchins, while only large legal-sized lobsters are able to capture and consume the largest sea urchins. Under natural circumstances we showed that mid-sized *H. erythrogramma* are most vulnerable to predation by lobsters since small animals remain cryptic and are not available to foraging lobsters while the largest urchins attain a size refuge from all but the largest lobsters. Models of the population dynamics of the sea urchin show clearly that, for a variety of plausible scenarios of *H. erythrogramma* recruitment, based on estimated predation rates of untethered sea urchin in the field, depletion of legal-sized lobsters by fishing is all that is necessary to account for increases in the population of sea urchins to the point where barrens formation is highly likely. By the late 1990s the biomass of legal sized lobsters on the east coast of Tasmania has been estimated as 2-8% of the virgin stock.

Research similar to that just described on *H. erythrogramma* is now commenced on another species of sea urchin, *Centrostephanus rodgersii*. This species is a relatively recent arrival in Tasmania, most likely as a result of transport of larvae from NSW, reflecting a greater magnitude of southwards incursions of the East Australian Current associated with climate change. This species has a greater capacity for formation of barrens habitat than does *H. erythrogramma*, and we have shown that both the range of this species and extent of barrens habitat on the east cost of Tasmania continue to expand. This is problematic for a range of reasons, not the least of which is that there is no commercial fishery for blacklip abalone (*Haliotis rubra*) and rock lobsters on *C. rodgersii* barrens. These two fisheries are the most important in Tasmanian state waters, and together are valued at ~$A150m p.a. before processing. In line with results of experiments with *H. erythrogramma*, we have shown that large legal-sized rock lobsters but not reef-associated fishes are important predators of this sea urchin. Our ongoing work is attempting to estimate the minimum biomass of large lobsters necessary to minimise risk of overgrazing of seaweeds by this herbivore.

We also recently commenced work to address whether fishing of blacklip abalone increases the risk of shifts to habitat types not conducive to supporting abalone populations at densities suitable for commercial fishing. We are testing two hypotheses: first, whether fishing abalone, as a potential competitor of *C. rodgersii*, can increase the risk of formation of barrens habitat by this sea urchin. The other idea to examine is whether reduced grazing pressure by fishing abalone realises increases in the cover of sessile benthic invertebrates, which will potentially reduce the carrying capacity of the environment for abalone. Initial work has not indicated effects of abalone on sea urchin behaviour, but initial experiments suggest that addition of *C. rodgersii* results in a greater proportion of the abalone population seeking shelter in cryptic habitat. Also, there is evidence at some sites of a negative relationship between abalone density and the cover of sessile marine invertebrates and the algal/sediment matrix.

Our study of the invasion dynamics of the Asian kelp (*Undaria pinnatifida*) was motivated by suggestions that this species could displace native algal assemblages on shallow reefs. This concern was based on observations in some areas showing a shift from diverse assemblages of native seaweed species to virtual monocultures of *U. pinnatifida.* A detailed series of experiments and surveys showed conclusively that on the east coast of Tasmania, establishment of *U. pinnatifida* at high densities first requires disturbance to reduce the cover of native canopy-forming brown algae (Valentine and Johnson 2003, 2004). By far the most important habitat for proliferation of *U. pinnatifida* in this way is the *H. erythrogramma* barrens. Although this sea urchin consumes *U. pinnatifida*, in most years the growth of the kelp outstrips the capacity of the sea urchin to graze it. Thus, our overall conclusion is that the single greatest factor contributing to establishment of this introduced kelp at high densities is fishing of rock lobsters to the point where *H. erythrogramma* populations can expand to form barrens habitat (Johnson *et al.* 2004).

Finally, this research points to several positive feedbacks in the dynamics of this system which pose clear impediments to goals of management for productive and sustainable reef ecosystems. The most obvious is that if predation by rock lobsters is critical in maintaining populations of sea urchins at levels where they are unlikely to form barrens habitat, then formation of sea urchins barrens unable to support large legal-sized lobsters at high densities reinforces persistence of the sea urchin barrens in the absence of other sources of significant sea urchin mortality. Another important positive feedback arises on some *H. erythrogramma* barrens in that formation of the barrens facilitates establishment of a matrix of filamentous algae and accumulated sediment ~4-15 mm deep over the boulder substratum. This sediment / algal matrix appears to limit recruitment of native canopy-forming algae, even in experimental plots inoculated with spores of native algae and from which both sea urchins and *U. pinnatifida* are removed. These experiments highlight that rehabilitation of sea urchin barrens is likely to be extremely difficult.

Acknowledgements

The work presented here has largely been undertaken by Joe Valentine, Hugh Pederson, Scott Ling, and Elizabeth Strain as part of their PhD studies. Jeff Ross, Simon Talbot and Karen Miller assisted with several aspects of the studies on *Centrostephanus rodgersii*. The work has been supported by research grants from Australian Research Council, Fisheries Research andDevelopment Corporation, Tasmanian Aquaculture & Fisheries Institute and the University of Tasmania.

School of Zoology
University of Tasmania
Tasmania, Australia
Email: craig.johnson@utas.edu.au

References

Johnson, C. R., Valentine, J. P., Pederson, H. G. 2004. A most unusual barrens: Complex interactions between lobsters, sea urchins and algae facilitates spread of an exotic kelp in eastern Tasmania. In 'Proceedings of the 11th International Echinoderm Conference, München'. (Eds T. Heinzeller and J. H. Nebelsick.) pp 213-220. (Balkema: Leiden, Germany.)

Pederson, H. G. 2003. Population dynamics of the sea urchin *Heliocidaris erythrogramma* on the east coast of Tasmania. PhD Thesis, University of Tasmania, Australia.

Valentine, J. P., Johnson, C. R. 2003. Establishment of the introduced kelp *Undaria pinnatifida* in Tasmania depends on disturbance to native algal assemblages. *Journal of Experimental Marine Biology and Ecology* 295:63-90.

Valentine, J. P., Johnson, C. R. 2004. Establishment of the introduced kelp *Undaria pinnatifida* following dieback of the native macroalga Phyllospora comosa in Tasmania, Australia. *Marine and Freshwater Research* 55:223-230.

3.2.7 Workshop discussions and summary

Initial workshop discussions reflected the different level of knowledge among States and the varying views of the participants, thereby clearly identifying the complexity of the issue. To progress, participants resolved to focus on addressing one single question: What should we do differently in response to ecosystem-based fisheries management (EBFM)?

Three key components to addressing these issues in the future were identified. Firstly, fishery/ecosystem managers need to develop clear objectives for EBFM, including identifying acceptable levels of threat from fishing to the ecosystem. However, as it was considered that fishing at any level is going to have some effect on the ecosystem, it was noted that the impacts of fishing are only important if the fishing activity causes a demonstrable threat to the environment.

Secondly, the economic and social implications of ecologically based fishery assessment should be more widely recognised and assessed. It was noted that, in many circumstances, these data are available and should be used in a timely manner to ensure a holistic approach.

Thirdly, there is a requirement to amend the scientific approach. Historically, and in many cases currently, fishery management has had a single-species approach. It was recognised that this has provided the basis for long-term monitoring and it was agreed that this process should not be abandoned. However, participants acknowledged that by combining the single-species approach with consideration of direct and indirect effects on non-target species, progress would be made towards EBFM. This will permit appropriate and relevant scientific responses to the needs of management.

It was agreed amongst the workshop participants that progress towards EBFM requires three components. These are (1) an understanding of the key processes of the operation likely to affect the ecosystem; (2) ongoing and if necessary development of long-term monitoring; and (3) the development of predictive capacity.

By necessity, key processes need to include the direct and indirect effects of fishing. It was widely acknowledged that basic ecological knowledge (e.g. the extent of habitats, predator/prey and competitor interactions) is lacking for some of Australia's largest benthic fisheries (e.g. southern rock lobster and abalone); in some cases, even basic biological knowledge of the target species is lacking. Hence, there was recognition of the need to identify and fill these gaps in the knowledge base, particularly for key target species, and their role in the broader ecosystem. This would facilitate an understanding of the ecological processes. It was broadly agreed that this information needed to be linked to habitat mapping in a similar vein to the terrestrial maps produced through the 'Mapping Australia' project.

It was noted that long-term monitoring was essential, with a need to use spatial closures and/or marine protected areas for comparative and baseline purposes, and for conducting 'mega-scale' experiments. This would require ongoing funding and increased education, collaboration and co-ordination among all stakeholders (including the fishing industry, and non-government and Government organisations) within the States. Monitoring must be adequate, and its appropriateness tested to ensure adequate predictive capacity. Without providing rigorous predictive ability, fishery managers, and resource managers in general, cannot be provided with the necessary decision-making tools to develop a predetermined process of decision making based on acknowledged, agreed and acceptable risk.

In conclusion, spatial differences in the structure and function of benthic communities, and differences in both the knowledge on the biology of key species and ecosystem-based projects among States, precluded a National Strategy. However, it was evident that a high level of communication among States was paramount to successful EBFM in Australia.

Presentation and workshop summaries provided by Stephen Mayfield in association with speakers and workshop participants.

4

Managing fish & fisheries in rivers & estuaries with limited & variable flows




4.1 National and international case studies to provide a conceptual framework

4.1.1 Fish and freshwater in South African estuaries

Alan Whitfield

The functioning of estuaries relies on a natural dynamism imposed on these systems by riverine and marine influences. The increasing abstraction of fresh water from both large and small river catchments in southern Africa has had the effect of forcing some estuaries into artificial cycles, i.e. natural successions now have human-imposed trajectories that are changing estuarine variability and forcing some systems into extreme states and others into becoming 'arms' of the sea. This has had deleterious consequences for certain processes within these systems and retarded a return towards the conditions prevailing in the pre-impoundment estuary (Whitfield and Bruton 1989).

The ichthyofauna has responded to the above changes in a variety of ways. Where river flow has declined considerably, or ceased altogether for extended periods, fish recruitment has shown a considerable decrease (Whitfield *et al.* 1994). This can be related to the collapse in planktonic productivity that negatively affects zooplanktivorous fishes (Whitfield 1995), as well as decreased amounts of olfactory cues entering the sea for the attraction of larval and juvenile marine fishes into these estuaries (Whitfield 1994). Hypersaline conditions can result in both a reduced species diversity and abundance (Whitfield and Wooldridge 1994). However, where estuaries lose their normal estuarine salinity gradient and become arms of the sea, there is often an increase in fish species diversity due to stenohaline marine taxa entering the estuary. Unfortunately the gain in small numbers of marine stragglers is insufficient to compensate for the decline in estuarine-dependent fishes that usually dominate these systems (Whitfield 1998).

Conversely, major river flooding causes significant decreases in both species diversity and abundance due to a rapid decline in salinity, increased suspended sediments, reduced dissolved oxygen levels, and a collapse in the availability of pelagic and benthic food resources (Whitfield and Paterson 1995). However, the 'resetting' of estuaries by episodic events is part of the essential cycle that maintains and enhances estuarine productivity and habitat diversity. Recovery by estuarine-associated fishes from such events is usually rapid and is linked to a variety of factors, especially estuary morphometry that has a direct influence on the flushing or retention of estuarine biota (Whitfield and Harrison 2003).

The biotic and abiotic factors that determine the distribution and abundance of fishes in southern African estuaries are strongly driven by riverine inputs (Figure 1). Freshwater flows interact directly and indirectly with the fishes that inhabit estuaries. For example, river floods directly influence estuarine water temperature, salinity, pH, turbidity, nutrient status, organic inputs, dissolved oxygen concentrations and olfactory cues; and indirectly affect mouth state, tidal prism, habitat diversity, productivity, fish recruitment, food availability and competition (Whitfield 1996). Previous estuary-associated fish studies, particularly those that have been laboratory based, have tended to examine the effects of one or two factors in isolation (e.g. salinity and temperature). However, with the realisation that multiple factors impinge on the lives of fishes in estuaries, research emphasis is now moving away from attempting to determine the influence of isolated environmental variables and adopting a more holistic approach.

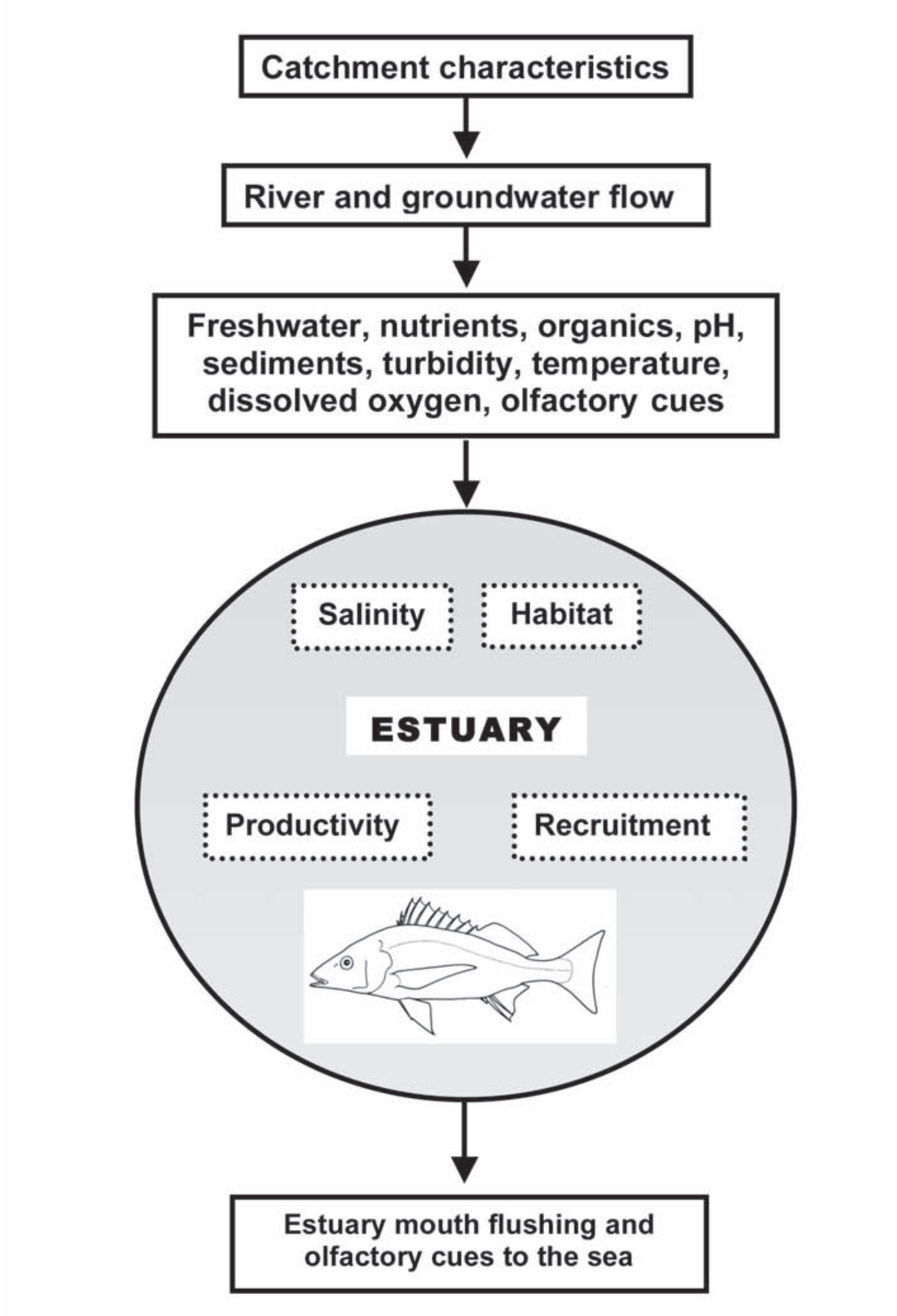


Figure 1. Diagrammatic representation of the primary riverine inputs to an estuary and the possible impacts on this through-flow on processes such as fish recruitment and productivity.

South African Institute for Aquatic Biodiversity
Grahamstown, South Africa
Email: a.whitfield@ru.ac.za

References

Whitfield, A.K. 1994. Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. *Marine Ecology Progress Series* 105:257-267.

Whitfield, A.K. 1995. Threatened fishes of the world: *Syngnathus watermeyeri* Smith, 1963 (Syngnathidae). *Environmental Biology of Fishes* 43:152.

Whitfield, A.K. 1996. A review of factors influencing fish utilization of South African estuaries. *Transactions of the Royal Society of South Africa* 51:15-137.

Whitfield, A.K. 1998. Biology and ecology of fishes in southern African estuaries. *Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology* 2:1-223.

Whitfield, A.K., Bruton, M.N. 1989. Some biological implications of reduced fresh water inflow into eastern Cape estuaries: a preliminary assessment. *South African Journal of Science* 85:691-695.

Whitfield, A.K., Harrison, T.D. 2003. River flow and fish abundance in a South African estuary. *Journal of Fish Biology* 62:1467-1472.

Whitfield, A.K., Paterson, A.W. 1995. Flood-associated mass mortality of fishes in the Sundays estuary. *Water SA.* 21:385-389.

Whitfield, A.K., Paterson, A.W., Bok, A.H., Kok, H.M. 1994. A comparison of the ichthyofaunas in two permanently open eastern Cape estuaries. *South African Journal of Zoology* 29:175-185.

Whitfield, A.K., Wooldridge, T.H. 1994. Changes in freshwater supplies to southern African estuaries: some theoretical and practical considerations. In 'Changes in fluxes in estuaries: implications from science to management'. (Eds K.R. Dyer and R.J. Orth.) pp. 41-50. (Olsen & Olsen: Fredensborg, Denmark.)

4.1.2 Estuarine fisheries that vary with freshwater flow and implications for management: an example from central Queensland

Ian Halliday and Julie Robins

We investigated the importance of freshwater flows to the barramundi fisheries in the Fitzroy River (central Queensland) on time scales ranging from decades to days. In the Fitzroy region, the annual commercial catch of barramundi has fluctuated in a cyclical nature between four and 40 tonnes over the six decades for which catch data are available (i.e. 1945 to present day). High variation in annual freshwater flow and rainfall are characteristic of the region. Mean annual (i.e. September to August) freshwater flow to the Fitzroy River estuary is 3.73 million ML, with minimum and maximum annual flows of 0.8 million ML and 52.4 million ML, respectively. Patterns of freshwater flow in the Fitzroy River are typical of estuaries in sub-tropical and tropical Australia, being dominated by summer floods and winter droughts, but varying seasonally as a consequence of rainfall patterns. In general, seasonal increases in freshwater flow occur between November to May, with the largest average monthly flows occurring in February. Between June and October, freshwater flow can drop to almost zero. Water resources in the Fitzroy River are highly regulated, via 19 dams and weirs, and one tidal barrage. However, this level of infrastructure development is unable to withhold seasonal episodic floods associated with cyclones.

Decadal scale fluctuations in barramundi catch are significantly correlated with stream flow and coastal rainfall within the region (r^2 = 0.542, see Robins *et al.* 2005) with the highest catches being recorded three to four years after successive wet summers. These fluctuations have occurred despite extensive changes within the catchment that include land clearing for agriculture, construction of numerous dams and weirs and a tidal barrage that obstructs upstream fish passage and effectively halved the area of the estuary. In the past 20 years management changes affecting the commercial and recreational fishing sectors have included the introduction of minimum (580 mm) and maximum (1,200 mm) size limits (total length), restriction on set-net mesh sizes and lengths, bag limits, seasonal spawning closures, weekend and area closures. These management changes have been implemented to decrease fishing effort and reallocate resources between fishing sectors. Stocking of fingerlings in the upper catchment has also occurred. Some stocked fish enter the fished estuarine population, but the contribution of stocked fish to the spawning population or their contribution to the commercial catch has not been monitored.

To examine the yearly impacts of freshwater flow on estuarine barramundi population, we examined the age structure of barramundi in the commercial catch to determine if year-classes could be followed through time and if variation in year-class strength was correlated with freshwater flow. The year-class strength of barramundi was positively correlated with freshwater flow (and coastal rainfall) in spring and summer (Staunton-Smith *et al.* 2004). Strong year-classes persisted through time (i.e. over the three years of sampling) suggesting that year-class strength is determined during the first year of life and most likely during the critical period from egg to small juvenile when wetland swamps and supra-littoral areas are used as nursery habitats by the small (>50 mm) fish probably less than three months old. The ability to access these nursery habitats during this time is likely to be critical in the maintenance of healthy barramundi populations. We speculate that freshwater flows created by river floods and/or coastal rainfall play a role in allowing access to and from these nursery habitats.

Seasonal effects of freshwater flow on the growth of barramundi were examined using catch and release tagging data collected over the past 15 years within the Fitzroy region by the Australian National Sportfishing Association (ANSA). As expected, growth rates of barramundi were significantly higher in summer and spring than in winter and autumn (as per Xiao 2000). After accounting for seasonal effects, growth rates also varied significantly with freshwater flow, being greater at higher flow rates. There were lower and upper thresholds beyond which growth rates did not change with freshwater flow. These were 130,000 ML/season and 1.3 million ML/season respectively. However, between these limits, growth rates increased curvi-linearly with increased freshwater flow. We speculate that increased growth rates may result from increase trophic productivity that occurs as a consequence of freshwater flow events.

The estuarine barramundi population available to the fishery is affected by freshwater flow on very short time frames (i.e. on a daily scale) stimulating the within-estuary movement of individuals present in the estuary, thereby increasing their catchability. Freshwater flows (i.e. floods) also enable the downstream movement of mature barramundi from freshwater riverine habitats to the estuary, thereby increasing the number of fish available to the fishery. Prior to a 1.3 millon ML flow at the beginning of the 2003 barramundi season, the commercial catch was predominantly four year olds (based on otolith assessment). These fish contributed 70% of the catch, with seven-year-olds (11%) being the next most common. No two-year-olds were present in the sample. The strong four- and seven-year-old fish came from the 1999 and 1996 spawning seasons, both of which were wet years with summer freshwater flows greater than two million ML. After the flow in February 2003 we re-sampled the commercial catch. The age structure of the catch changed significantly, with 35% of barramundi caught being two-years-old. Four-year-olds dropped to 20% of the catch, compared to 70% before the flow. Seven-year-olds were still present within the catch and were at similar levels as before the flow (~10%).

Freshwater flowing into estuaries is an important driver of the size of barramundi populations with large changes occurring in response to decadal scale changes in river flow because of climate variability. At yearly time-scales, freshwater flow can influence the strength of the year-class and the size of the population that recruits to the fishery three to four years later. Freshwater flow also appears to affect the growth rate of fish within the system, and flow is a major contributor to the distribution and redistribution of fish within the freshwater and estuarine parts of the system. The role of freshwater flow needs to be understood so that we can predict and manage the likely impacts of anthropogenic changes to freshwater flow regimes particularly were large modifications to the hydrology of the system occur. However, our data in the Fitzroy River system suggests that medium to minor modifications of the flow regime could affect certain aspects of estuarine fisheries dynamics, such as dampening growth rates or catchability influences.

Understanding the role of freshwater flow on barramundi populations is likely to have important implications for fisheries management. For example, during droughts (i.e. extended low flow decades such as the 1960s and 1980s), it is likely that barramundi populations are reduced as a consequence of successive years of low recruitment (i.e. year-class strength). During such times, the barramundi population was possibly at greater risk from fishing pressure and other anthropogenic impacts. It may also be that a drought-stressed population is also more in need of freshwater when freshwater flows eventually increase (i.e. floods occur).

Greater knowledge of the role of freshwater in the lifecycles of estuarine fish and the duration between flow events that populations can withstand is needed to assist in assessing risks to the sustainable management of fish in rivers with variable flow. Current water and fisheries management needs to take into account variability in the population and flow-related risk when setting targets and outcomes of the water or fishery management scenarios.

Southern Fisheries Centre
Department of Primary Industries and Fisheries
Queensland, Australia
Email: ian.halliday@dpi.qld.gov.au

References

Robins, J.B., Halliday, I.A., Staunton-Smith, J., Mayer, D.G., Sellin, M.J. 2005. Freshwater flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. *Marine and Freshwater Research* 56:343-360.

Staunton-Smith, J., Robins, J.B., Mayer, D.G., Sellin, M.J., Halliday, I.A. 2004. Does the quantity and timing of freshwater flowing into a dry tropical estuary affect year-class strength of barramundi (*Lates calcarifer*)? *Marine and Freshwater Research* 55:787-797.

Xiao, Y. 2000. Use of the original von Bertalanffy growth model to describe the growth of barramundi, *Lates calcarifer*. *Fishery Bulletin* 98:835-841.

4.1.3 Trophic basis of fish assemblages in an Australian dryland river.

Stephen Balcombe and Stuart Bunn

Introduction

Dryland rivers are rivers that run through arid or semi-arid landscapes. In Australia, many of the river channels across the continent are classified as lowland rivers, most of which are described as dryland systems (Thoms and Sheldon 2000). Dryland rivers are often characterised by numerous channels and vast floodplains. Furthermore, they often exist as isolated and turbid waterholes. As these rivers flow through dryland regions with unpredictable rainfall and runoff, their flows are also highly variable.

Cooper Creek in the Lake Eyre Basin of Australia is hydrologically one of the world's most variable rivers (Puckridge *et al.* 1998). Its catchment covers 296,000 km^2 of which approximately 35% is floodplain characterised by a vast network of anastomosing channels that connect during episodic floods. In Cooper Creek, the most common hydrological condition is that of disconnected, turbid waterholes. During extended dry periods these waterholes serve as refugia for up to 12 species of native fish, a range of aquatic biota and other wildlife such as terrestrial birds and animals.

Results and Discussion

Light extinction (where photosynthesis cannot take place) in Cooper Creek waterholes often occurs less than 30 cm below the water surface. Despite the high turbidity, rates of benthic primary production within waterholes are high compared with other rivers and streams in Australia (Bunn *et al.* 2003). Much of this production is associated with a narrow littoral band of algae, restricted to the photic margins. Stable isotope ratios of producers and consumers have shown that the food web supporting fish assemblages in these waterholes is fuelled largely by this "bath tub ring" of algae (Bunn *et al.* 2003). There is also evidence that pelagic production can be an important contributor to some species, however, terrestrial inputs appear to be minor. This apparent lack of importance of terrestrial inputs is somewhat surprising given that they represent significant drivers of aquatic production in other large floodplain river systems (Vannote *et al.* 1980, Junk *et al.* 1989).

Traditional diet analyses have confirmed the findings of the isotopic data, with fish feeding on consumers of benthic algae and zooplankton in dry season waterholes (Balcombe *et al.* 2005). The volumes of zooplankton in the diet were higher than expected from the isotope findings, suggesting that fish may assimilate a disproportionate contribution to their biomass carbon from opportunistic feeding on large-bodied benthic invertebrates such as yabbies and prawns (*Cherax* and *Macrobrachium*). It is likely that prey resources, especially benthic invertebrates, were depressed on the two sampling occasions as these waterholes had not had any flow for at least 18 months and no significant overland flood for seven years (Balcombe *et al.* 2005). It does appear, however, that the Cooper Creek fish assemblage is comprised of trophic generalists that can opportunistically feed on whatever is available at any given time. This trait enables these fish to last out extended periods of no flow and low food resources.

During episodic flooding, the Cooper Creek floodplain provides a rich and abundant array of food such as ephemeral crustaceans, micro-crustaceans, dipteran larvae, other aquatic invertebrates and stranded terrestrial arthropods. Most species of fish in Cooper Creek use the inundated floodplain during floods (unpublished data). Not only does this allow dispersal among waterholes but also access to a rich food resource, much of which would be returned to waterhole when floods recede (Lewis *et al.* 2001).

Preliminary stable isotope results show that most fish species on the floodplain feed largely upon algal consumers. However, despite the presence of many stranded terrestrial arthropods, this potential food source does not appear to be an important source of carbon (Balcombe *et al.* 2005). Direct diet analysis revealed that most species have very diverse diets, feeding on a large variety of aquatic production, including invertebrates and plants. Similar to fish in disconnected waterholes, those on the floodplain also do not feed on terrestrial matter to any great extent.

Conclusions

Given that Cooper Creek exists predominantly as a series of disconnected waterholes, the fish assemblages rely on the presence of permanent waterholes, whose food webs are fuelled by the algal bathtub ring. While floods provide a vast array of food sources in comparison to waterholes, inundation of the floodplain occurs irregularly. The long-term maintenance of fish assemblages, therefore, may rely more on the persistence of some permanent waterholes in the landscape and ultimately the benthic algae that supports the food web. Any changes to the natural flow pattern, as would occur through water resource development, such as waterhole abstraction, would impact on bathtub rings. These impacts would flow through the food web and ultimately to the fish assemblages they support.

CRC for Freshwater Ecology
Centre for Riverine Landscapes
Faculty of Environmental Sciences
Griffith University
Queensland, Australia
Email: s.balcombe@griffith.edu.au

References

Balcombe, S. R., Bunn, S.E., McKenzie-Smith, F.J., Davies, P.M. 2005. Variability of fish diets between flood and dry periods in an arid zone floodplain river. *Journal of Fish Biology* 67:1552-1567.

Bunn, S. E., Davies, P. M., Winning, M. 2003. Sources of organic carbon supporting the food web of an arid zone floodplain river. *Freshwater Biology* 48:1-17.

Junk, W. J., Bayley, P. B., Sparks, R. E. 1989. The flood pulse concept in river-floodplain systems. In 'Proceedings of the International Large River Symposium.' (Ed. D. P. Dodge.) pp. 110-127. (*Canadian Special Publication of Fisheries and Aquatic Sciences* 106:110-127.)

Lewis, W.M., Jr., Hamilton, S.K., Rodríguez, M., Saunders, J.F., III., Lasi, M.A. 2001. Foodweb analysis of the Orinoco floodplain based on production estimates and stable isotope data. *Journal of the North American Benthological Society* 20:241-254.

Puckridge, J. T., Sheldon, F., Walker, K. F., Boulton, A. J. 1998. Flow variability and the ecology of arid zone rivers. *Marine and Freshwater Research* 49:55- 72.

Thoms, M. C., Sheldon, F. 2000. Lowland rivers: an Australian perspective. *Regulated Rivers Research and Management* 16:375-383.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., Cushing, C. E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130-137.

4.1.4 Catchment processes and estuary fisheries: impacts of environmental change on fishery production in estuaries of the south coast of Western Australia

Kim Smith[1] and Paul Close[2]

On the south coast of Western Australia, the ~600 km stretch of coastline between Point D'Entrecasteaux (116° latitude) and Esperance (122° latitude) there are about 25 estuaries. The physical characteristics of these estuaries are similar (estuary basins of 3-48 km^2, typically 1-2 m in depth, wave-dominated, small tidal range of 0.4-1.3 m, a prominent sand bar/entrance delta to ≤ 3 m height above mean sea level). An unusual feature of this south coast region is a very strong gradient in rainfall, declining from about 1400 mm per year in the west to about 300 mm per year in the east. A comparison of estuaries along this natural gradient provides an opportunity to examine the effects of variable rainfall and river flow on estuarine fish communities. Trends in commercial fishery catches from these estuaries can be used to examine the effects of variable rainfall and flow on estuarine fishery production.

Most estuaries in the western half of this region (i.e. west of Albany) are seasonally open (SO) to the sea. Heavy winter rains cause water levels to rise and sand bars are usually breached in spring. A few western estuaries are permanently open (PO). By contrast, eastern estuaries (i.e. east of Albany) are often closed (OC) for extended periods (i.e. years). Low and non-seasonal rainfall, coupled with high evaporation rates, limited freshwater input to eastern estuaries, which frequently become hypersaline and may dry out completely in summer.

Trends in the composition of estuarine fish communities reflect these strong alongshore physical gradients. Typically, the most diverse and abundant fish communities occur in PO estuaries. Slightly lower diversity occurs in SO estuaries. Lowest diversity and abundance occurs in OC estuaries (Hodgkin and Lenanton 1981, Potter *et al.* 1993, Potter and Hyndes 1994, 1999, Young and Potter 2002). Hence, there is a gradient in estuarine fish diversity and abundance along the south coast, declining from west to east. The fish communities in eastern estuaries are particularly depauperate - at certain times fewer than 5 species can be found in eastern estuary basins (e.g. Young and Potter 2002). A limited number of species complete their entire life cycle within south coast estuaries (Lenanton and Hodgkin 1985, Potter *et al.* 1993). Diversity and abundance in the estuaries is significantly boosted by marine-spawned species that enter as juveniles or adults. Therefore, diversity and abundance are partly determined by the frequency and duration of sand bar openings, which limit opportunities for recruitment. Diversity and abundance are also limited by the type of estuarine environment, especially in OC estuaries. Hyper-saline conditions that develop after a sand bar has been closed for an extended period are unfavourable for many marine- and estuarine-spawned species.

Thirteen estuaries (7 OC, 3 SO and 3 PO) on the south coast are currently open to commercial fishing (Figure. 1). Trends in annual fishery production follow trends in rainfall and river flow. Annual landings are lower, less diverse and more variable in OC estuaries than in PO or SO estuaries. Over the last 10 years, mean (± S.D.) annual landings from OC, SO and PO estuaries have been 186 ± 95, 1175 ± 259 and 1858 ± 376 kg. km^2, respectively. In each estuary category, 2, 8 and 15 species, respectively, comprised about 90% of the annual catch.

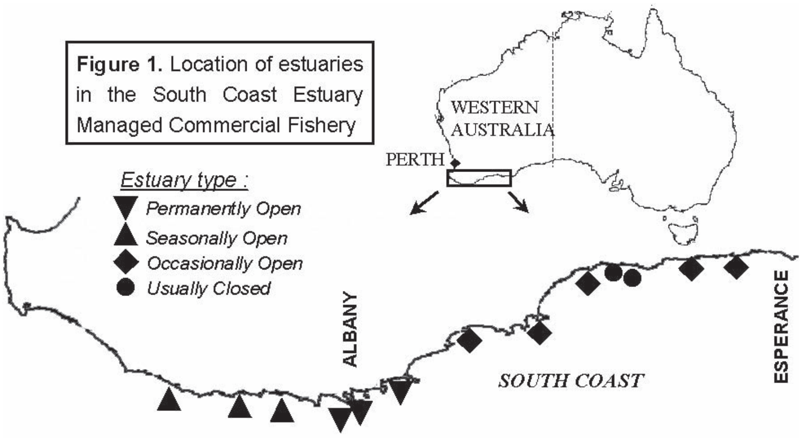


Figure 1. Location of estuaries in the South Coast Estuary Managed Commercial Fishery

The above trends suggest that increases in freshwater flows to these estuaries will result in more abundant and diverse fish communities and higher fishery production. Indeed, this appears to have occurred over the last 50 years. Anecdotal evidence strongly suggests that the clearing of vegetation in many catchments (up to 90% in some cases) has dramatically increased runoff and river flow rates since the 1950s. Catch rates have also increased, especially in the OC estuaries of the eastern region. Unfortunately, the mechanisms responsible for the catch increase are unclear, due to limited physical and biological monitoring data from early years. An increase in the frequency of sand bar openings has probably contributed to an increase in fishery production by enhancing recruitment. Other possible mechanisms include increased productivity under eutrophic conditions and increased reproductive success by estuarine spawners during high flow periods (especially black bream).

Irrespective of the mechanisms, it appears that fishery production in these estuaries is positively related to rates of annual rainfall and river flow. In future, the south coast is likely to experience a decrease in flow (both total annual and maximum flow), due to climate change, ground/surface water extraction and/or revegetation of catchments. Any decrease in abundance and diversity of fish that occurs as a consequence has implications for commercial and recreational fisheries, and for other dependent industries such as tourism. Interestingly, the poor catchment management practices of past decades probably enhanced estuarine fishery production, but better catchment management in future could lead to lower production.

1 *Department of Fisheries*
Western Australia, Australia
Email: ksmith@fish.wa.gov.au

2 *Centre of Excellence in Natural Resource Management*
University of Western Australia
Western Australia, Australia

References

Hodgkin, E. P., Lenanton, R. C. J. 1981. Estuaries and coastal lagoons of south western Australia. In 'Estuaries and Nutrients.' (Eds B.J. Neilson and L.E. Cronin.) pp 307-321. (Humana Press: New Jersey, USA.)

Lenanton, R. C. J., Hodgkin, E. P 1985. Life history strategies of fish in some temperate Australian estuaries. In 'Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration'. (Ed. A. Yanez-Arancibia.) pp 267-284. (UNAM Press: Mexico City, Mexico.)

Potter, I. C., Hyndes, G. A. 1994. Composition of the fish fauna of a permanently open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. *Marine Biology* 121:199-209.

Potter I. C., Hyndes, G. A. 1999. Characteristics of the ichthyo faunas of southwestern Australian estuaries, including comparisons with holarctic estuaries and estuaries elsewhere in temperate Australia. *Australian Journal of Ecology* 24:395-421.

Potter I. C., Hyndes, G.A., Baronie, F. M. 1993. The fish fauna of a seasonally closed Australian estuary. Is the prevalence of estuarine-spawning species high? *Marine Biology* 116:19-30.

Young, G. C., Potter, I. C. 2002. Influence of exceptionally high salinities, marked variations in freshwater discharge and opening of estuary mouth on the characteristics of the ichthyofauna of a normally-closed estuary. *Estuarine, Coastal and Shelf Science* 55:223-246.

4.1.5 The highs and lows of fish recruitment in floodplain rivers

Alison King[1] and Paul Humphries[2]

Recruitment can be defined as the survival of a cohort until a reference point in the life cycle, where the reference point can variously be defined as: a particular age, maturity or entry into a fishery.

Survival of the young stages of fish, and therefore subsequent recruitment strength, is thought to be at its maximum if predation is low, food and habitat availability are high and temperature is optimal for growth. Indeed, strength of subsequent cohorts is most likely related to the match or mismatch of the timing of the abundance of larvae and these conditions. Recent models have sought to explain how larvae may encounter these favourable conditions in Australian floodplain rivers (Harris and Gehrke 1994, Humphries *et al.* 1999). This presentation seeks to review recent evidence and propose a new classification scheme demonstrating a range of recruitment strategies.

Flow-related recruitment models for fish in Australian rivers

The "flood recruitment model" explicitly invokes the significance of the floodplain and the importance of flooding to recruitment strength for a number of species (Harris and Gehrke 1994). The model suggests that flooding can either act as a spawning cue for some species and can also indirectly enhance larval and juvenile survival by providing abundant food and habitats on the inundated floodplain. However, recent studies have suggested that rises in flow or inundation of the floodplain as either spawning cues or to enhance recruitment, may not be as critical as previously thought for some native species (Humphries *et al.* 2002, Gilligan and Schiller 2003, King *et al.* 2003, Mallen-Cooper and Stuart 2003, Meredith *et al.* 2002).

The "low flow recruitment hypothesis", by contrast, emphasised the importance of shallow, still, littoral habitats in the main channel environment for fish recruitment, suggesting that these environments provide a warm, food-rich nursery refuge for growing larvae (Humphries *et al.* 1999). Studies have now confirmed that a range of species are able to spawn and recruit successfully during low flow periods in floodplain rivers (Humphries *et al.* 2002). Additionally, a number of species, such as crimson-spotted rainbowfish, carp, Australian smelt and gambusia, use still littoral and backwaters as nursery areas (King 2004a). King (2004b) has also suggested that there is an abundant larval food source within the main channel of floodplain rivers during low flow periods, without connection to inundated floodplains.

Both the flood recruitment model and the low flow recruitment hypothesis imply highly variable interannual recruitment, that is independent of density and intimately linked to flow conditions. The recruitment strength of some species, such as Murray cod, may be more related to density-dependent factors such as the availability and subsequent use of suitable juvenile habitats that are perhaps less controlled by flows. Additionally, other more generalist species, such as Australian smelt and flathead gudgeons, are probably able to recruit under a wide range of environmental conditions and within a diversity of habitat types.

A new recruitment model for riverine fishes

In light of recent work, we now propose a more generalised conceptual model of recruitment strategies for fish in floodplain rivers that incorporates both high and low flow conditions, and proposes five recruitment strategies (King 2002).

1. Flood specialists (e.g. golden and silver perch – note: still under review)
2. Flood opportunists (e.g. carp)
3. Low flow specialists (e.g. crimson-spotted rainbowfish, carp gudgeons and gambusia)
4. Generalists (e.g. Australian smelt and flathead gudgeon)
5. Main channel specialists (e.g. Murray cod, river blackfish and mountain galaxias)

This presentation has outlined the available evidence of how flow regimes affect recruitment of Murray-Darling Basin fish species, and that recruitment can be influenced by flows through a variety of mechanisms at all stages of a fish's life cycle. However, we believe we're only just starting to understand how these factors operate for Murray-Darling Basin fish, and we suggest that we need more information on relative importance of these factors, how they might vary in importance between species, environmental conditions (e.g. droughts and wet years) and also spatially and temporally. We urgently need to understand these mechanisms to inform the current management efforts to restore flow altered river systems and their native fish fauna.

1 *Freshwater Ecology*
Arthur Rylah Institute for Environmental Research
Victoria, Australia
Email: alison.king@dse.vic.gov.au

2 *CRC for freshwater Ecology*
Department of Biological Sciences
Monash University
Victoria, Australia

References

Gilligan, D., Schiller, C. B. 2003. Downstream transport of larval and juvenile fish in the Murray River. Final report for the Natural Resources Management Strategy, Project No. NRMS R7019. NSW Fisheries, Narrandera, Australia. 66 pp.

Harris, J. H., Gehrke, P. C. 1994. Modelling the relationship between streamflow and population recruitment to manage freshwater fisheries. *Agricultural Systems and Information Technology* 6:28-30.

Humphries, P., King, A. J., Koehn J. D. 1999. Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* 56:129-51.

Humphries, P., Serafini, L. King A. J. 2002. River regulation and fish larvae: variations through space and time. *Freshwater Biology* 47:1307-31.

King, A. J. 2002. Recruitment ecology of fish in floodplain rivers of the southern Murray-Darling Basin, Australia. PhD Thesis, Monash University, Australia.

King, A. J. 2004a. Ontogenetic patterns of habitat use by fishes within the main channel of an Australian floodplain river. *Journal of Fish Biology* 65:1582-1603.

King, A. J. 2004b. Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna. *River Research and Application*s 20:883-897.

King, A. J., Humphries P., Lake P. S. 2003. Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* 60:773-786.

Mallen-Cooper, M., Stuart I. G. 2003. Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* 19:697-719.

Meredith, S., Gawne, B., Sharpe, C., Whiterod, N, Conallin, A., Zukowski S. 2002. 'Dryland floodplain ecosystems: influence of flow pattern on fish production'. (Murray-Darling Freshwater Research Centre: Mildura, Australia.)

4.1.6 Effects of seasonal climate variability on barramundi (*Lates calcarifer*) fisheries productivity in the Great Barrier Reef World Heritage Area

Jacqueline Balston

Australia, the land of drought and flooding rain, not only exhibits the largest temporal variability in rainfall of any continent, but is also the driest inhabited continent on earth (Smith 1998). An often harsh and varied climate, our native fisheries and freshwater/estuarine ecosystems have nonetheless evolved in tandem with these conditions and so are affected by changes in both the climate and to freshwater flow regimes, including those imposed by water impoundments. An understanding of the climate systems affecting Australia, and the variability inherent in them, can give insight to how we might best manage for the long-term health and productivity of many of our wild fisheries and the freshwater ecosystems, that sustain them.

Australia's variable climate is the result of a number of atmospheric and oceanographic mechanisms. On an intra-seasonal time frame the Madden Julian Oscillation (MJO) is a large-scale oscillation (atmospheric pressure wave) in the Indian Ocean which varies in frequency (30 – 53 days) and strength from one season to the next due to changes in ocean temperature in the Pacific region (Madden and Julian 1971, Lau and Chan 1986, Gray 1988, Maloney and Kiehl 2001). Pulses of the MJO are associated with increased convection and modulation of monsoonal westerlies, often resulting in increased rainfall and 'active bursts' in the monsoon followed by a strong stabilising and drying influence after passing (Hendon and Liebmann 1990). It reaches maximum intensity over the Indonesian-New Guinea region in the austral summer (December, January and February) weakens by the International Date Line (Madden and Julian 1972, Allan 1988, McGregor and Nieuwolt 1998) and can affect the likelihood and timing of rainfall across much of Australia (Holland 1986; McBride 1987, Hendon and Liebmann 1990, Wheeler and Hendon 2004).

On an inter-annual scale the El Niño / Southern Oscillation (ENSO) is a complex equatorial Pacific coupled ocean-atmosphere system which generates large-scale climate variability both globally and in the Australian region (Allan 2000). It is responsible for up to 40% of the rainfall variability in eastern Australia (Cordery 1998). Normally warm sea surface temperatures (SSTs) in the western Indo-Pacific equatorial region generate convection and bring rainfall to northern Australia in conjunction with the monsoonal system in summer (Figure 1). In La Niña events the western equatorial warm pool is anomalously warm, increasing convection in the region and subsequent strength of the southeast trade winds, the strength and duration of the monsoon and improving the probability of above average rainfall for northern and eastern Australia. The reverse is true during an El Niño event when the western equatorial Pacific warm pool migrates towards the east, depressing surface cold water in the eastern equatorial Pacific and taking with it the key regions of convection and rainfall. During an El Niño event, the southeast trade winds slacken and may revert to westerlies, the incidence of cyclones off the east coast of Australia is reduced and the monsoon is weakened, resulting in reduced rainfall probabilities. El Niño events typically occur every 2-7 years and tend to last for about nine months when established, forming in the southern hemisphere winter and remaining until the following autumn (Allan 2000).

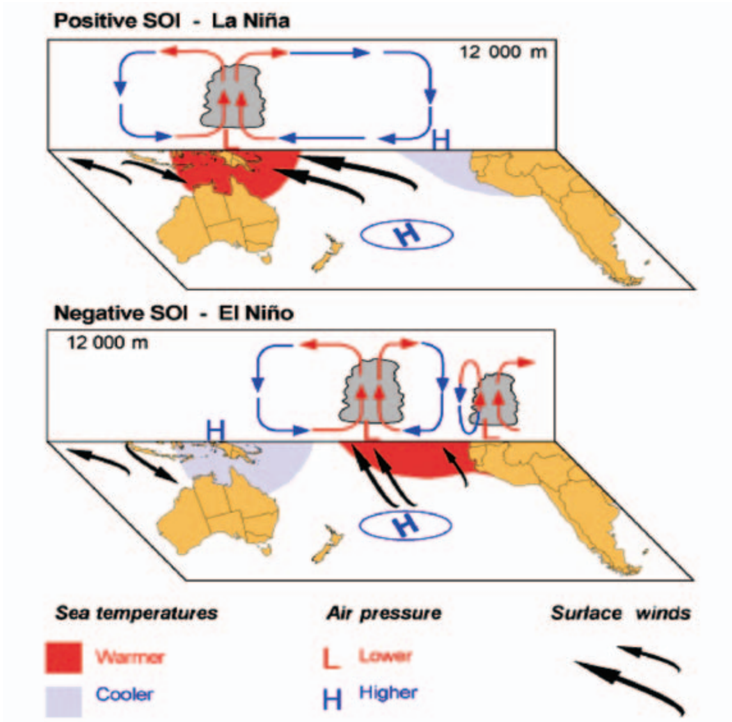


Figure 1: The El Nino Southern Oscillation (ENSO). Diagram shows the relationship between SSTs, atmospheric circulations and the SOI for an El Niño event and La Niña.

Longer-term ENSO like signals include quasi-decadal (11-13 years) and inter-decadal (15-20 years) signals, which account for protracted warm and cold SST events. The interactions between these and ENSO can be synchronous or asynchronous and guarantee that no two ENSO events will be exactly the same, with variations in duration, intensity, impacts and distribution (Folland *et al*. 1998, Allan 2000). The impact of ENSO on freshwater flows is also significant for many parts of Australia (Abawi and Dutta 1998, Chiew and Piechota 1998) (Figure 2) and the use of indices which measure ENSO such as the Southern Oscillation Index (SOI), provide some opportunity for forecasting rainfall and other related climate parameters (Stone and Auliciems 1992).

The latitude of the sub-tropical ridge, or high pressure belt, also affects the climate of Australia, as its average annual and monthly positions vary. In some years the ridge is further north than usual, creating drier conditions across Australia by weakening southerly winds in the winter and strengthening southerlies in the summer months offsetting the rain bearing Southern Ocean and monsoonal moisture sources (e.g. 1910s-1950s) (Allan 1991). In years when the sub-tropical ridge is further south than usual, southerlies are strengthened through the winter months and northerlies in the summer months, channelling moisture over the continent as occurred in the 1860s-1910s and 1950s-1970s and resulting in wetter years (Allan 1991).

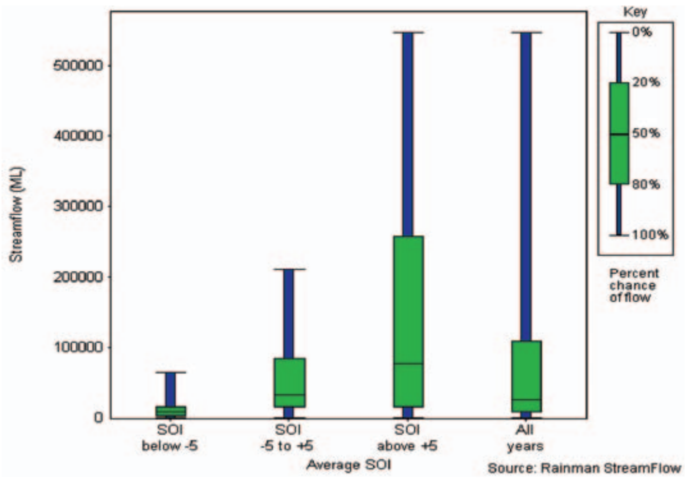


Figure 2: Freshwater flows on the Burdekin River (Sellheim gauge) north Queensland relative to the Southern Oscillation Index (SOI). Data is for flow period September – October from 1947 to 2000 relative to the average June-August SOI.

South of 20°S in Victoria, New South Wales and Western Australia and Tasmania, other mechanisms of atmospheric variability include the Antarctic Circumpolar Wave (ACW) (White 2000) and the Antarctic Oscillation (Gong and Wang 1999) or Southern Hemisphere Annular Mode (SAM) (Thompson and Lorenz 2004). These mechanisms account for sub-tropical variability in climate and rainfall although teleconnections may extend further north. White (2000) suggests that the ACW is responsible for up to 50% of rainfall variance in this region of southern Australia although more recent research is suggesting other mechanisms are having a more dominant effect (Visbeck and Hall 2004).

A study in North Queensland is currently considering a whole range of climate variables and the possible impacts on the wild barramundi fishery of Princess Charlotte Bay north west of Cooktown. Barramundi are reliant on stream-flow to complete their breeding cycle with mature fish flushed out of the rivers in wet years, enabling spawning in estuarine regions, with fingerlings returning to the river systems at the end of the wet season to mature over 2-4 years. This pattern of migration is interrupted in dry years (such as during El Niño events) when minimal flow down the rivers restricts the number of breeding pairs. Preliminary results have confirmed that there is a positive correlation between wet season flows and annual catch. Further analysis will explore possible influences from rainfall, maximum and minimum temperatures, evaporation, radiation, vapour pressure, sea surface temperature, wind, and indices for ENSO and the MJO on the fishery environment at critical stages of the species biological development, and resulting impacts on recruitment success. Outcomes will be used to pull together the essential links between climate variability and fisheries research, modelling and management.

Department of Primary Industries and Fisheries
Queensland, Australia
Email: jacqueline.balston@dpi.qld.gov.au

References

Abawi, G. Y., Dutta, S. C. 1998. Forecasting of streamflow in NE-Australia based on the Southern Oscillation Index. In 'Proceedings of the International Conference on Engineering in Agriculture'. (Ed M. Amjad.) (Society for Engineering in Agriculture: Canberra, Australia.)

Allan, R. J. 1988. El Niño Southern Oscillation influences in the Australasian region. *Progress in Physical Geography* 12:313-349.

Allan, R. J. 1991. Australasia. In 'Teleconnections linking worldwide climate anomalies: scientific basis and societal impact'. (Eds M. H. Glantz, R. W. Katz and N. Nicholls.) pp. 73-120. (Cambridge University Press: Cambridge, U.K.)

Allan, R. J. 2000. ENSO and climatic variability in the last 150 years. In 'El Niño and the Southern Oscillation: Multiscale Variability, Global and Regional Impacts'. (Eds H. F. Diaz and V. Markgraf.) pp. 3-55. (Cambridge University Press: Cambridge, U.K.)

Chiew, F. H. S., Piechota, T. C. 1998. El Niño/Southern Oscillation and Australian rainfall, streamflow and drought: Links and potential for forecasting. *Journal of Hydrology* 204:138-149.

Cordery, I. 1998. Forecasting precipitation from atmospheric circulation and SOI. In 'Proceedings of the British Hydrological Society International Conference, Exeter'. (Eds H. Wheater and C. Kirby.) pp. 61-64. British Hydrological Society: Exeter.

Folland, C., Parker, D.E., Colman, A.W., Washington, R. 1998. 'Large scale modes of ocean surface temperature since the late nineteenth century.' (Hadley Centre: London, U. K.)

Gong, D., and Wang, S. 1999. Definition of Antarctic Oscillation Index. *Geophysical Research Letters* 26:459-462.

Gray, W. M. 1988. Seasonal frequency variations in the 40-50 Day Oscillation*. Journal of Climatology* 8:511-519.

Hendon, H., Liebmann, B. 1990. The Intraseasonal (30-50 day) Oscillation of the Australian summer monsoon. *Journal of the Atmospheric Sciences* 47:2909-2923.

Holland, G. J. 1986. Interannual variability of the Australian summer monsoon at Darwin: 1952-82. *Monthly Weather Review* 114:594-604.

Lau, K. M., Chan, P. H. 1986. The 40-50 Day Oscillation and the El Niño / Southern Oscillation: A new perspective. *Bulletin of the American Meteorological Society* 67:533-534.

Madden, R. A., Julian, P. R. 1971. Detection of a 40-50 Day Oscillation in the zonal wind in the tropical Pacific. *Journal of the Atmospheric Sciences* 28:702-708.

Madden, R. A., Julian, P. R. 1972. Description of global-scale circulation cells in the tropics with a 40-50 day period. *Journal of the Atmospheric Sciences* 29:1109-1132.

Maloney, E. D., Kiehl, J. T. 2001. MJO-Related SST variations over the tropical Eastern Pacific during northern hemisphere summer. *Journal of Climate* 15:675-698.

McBride, J. L. 1987. The Australian summer monsoon. In 'Monsoon Meteorology'. (Eds C. P. Chang and T. Krishnamurti.) pp. 203-231. (Oxford University Press: Oxford, U.K)

McGregor, G. R., Nieuwolt, S. 1998. 'Tropical climatology.' (John Wiley and Sons. Ltd: Chichester, UK.)

Smith, D. 1998. 'Water in Australia: resources and management.' (Oxford University Press: Melbourne, Australia.)

Stone, R. C., Auliciems, A. 1992. SOI phase relationships with rainfall in eastern Australia. *International Journal of Climatology* 12:625-636.

Thompson, D. W. J., Lorenz, D. J. 2004. The signature of the annular modes in the tropical troposphere. *Journal of Climate* 17:4330-4342.

Visbeck, M., Hall, A. 2004. Interannual southern hemispheric atmospheric variability in the NCEP reanalysis between 1980 and 2002. *Journal of Climate* 17:2255-2258.

Wheeler, M. C., Hendon, H. H. 2004. An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *American Meteorological Society* 132:1917-1932.

White, W. B. 2000. Influence of the Antarctic Circumpolar Wave on Australian precipitation from 1958-1997. *Journal of Climate* 13:2125-2141.

4.1.7 Fish passage- from go to whoa needs flow to go

Martin Mallen-Cooper

Movement and migration are important life history traits for fish to optimise survival, growth and recruitment in rivers with variable flow. River regulation in Australia has directly affected fish movements by changing flows and water temperature - the major cues that stimulate fish to move - and by physical barriers.

Over the last twenty years in Australia there have been, and continue to be, major advances in designing fishways to provide fish passage at physical barriers. These advances have aimed to adapt fishway designs to the life history, behaviour and swimming ability of Australian native fish and to low flows and variable hydrology. At present fish passage in Australia has focused on upstream longitudinal movements of fish, but there is an increasing acknowledgement of the importance of downstream and lateral fish movements.

Providing well-designed fishways is still no guarantee of ensuring successful migration. Providing streamflow with some restoration of daily and weekly variability is needed in many cases to stimulate fish to move. At a more basic level, fishways do not work without water and this is a major issue in coastal streams. Tidal weirs and barrages are common in Australia and abstraction of water at these sites often leads to long periods with no water passing to the estuaries. This can be devastating ecologically as the life history strategies of fish populations in coastal streams, particularly catadromy and amphidromy, lead to small juvenile fish aggregating below tidal barriers and being highly susceptible to predation. Streamflow management is an essential component of restoring fish passage and allocation of flows at tidal sites is a particular priority.

Fishway Consulting Services
St Ives Chase
New South Wales, Australia
Email: mallencooper@optusnet.com.au
(Abstract only)

4.1.8 Otolith chemistry to determine movements of diadromous and freshwater fish

Bronwyn Gillanders

Ecology aims to determine the causes of the distribution and abundance of organisms. Two processes that potentially contribute to differences in distribution and abundance are movement and dispersal. Fundamental to the study of animal ecology is an understanding of movement patterns of animals, in both space and time (Pittman and McAlpine 2003). Such information is also important in designing effective conservation and management strategies. When we think of movement in freshwater systems we typically think of diadromous species that move between freshwater and marine waters as a routine phase of their life cycle. Anadromous species (e.g. salmon) migrate to freshwater to breed, whereas catadromous fish (e.g. barramundi) migrate to the sea to breed. By contrast, amphidromy is the migration between freshwater and marine waters or vice versa that is not for the purpose of reproduction, but occurs regularly at some other stage of the life cycle.

Although life histories of fish may involve movement among spawning, growth and refuge habitats, recent studies suggest that the life cycles of many species of fish have been over simplified and that considerable variability may exist within and among populations. For some species diadromy is likely to be facultative rather than obligate. Paradigms of predictability and restricted movement of fish are likely to reflect the use of conventional tagging techniques for determining movement since most of these studies focus on the non-mobile part of the life cycle and larger individuals. Conventional tagging techniques also provide no data on the timing or frequency of movement and the relative importance of different habitats. Therefore, alternative methods for determining the movements and origin of fish are required. One of the most rapidly growing fields of fisheries science is the use of elements in calcified structures such as ear bones to answer ecological questions related to movement. This presentation reviewed the use of otolith chemistry for determining movements (and possible links to environmental flows) of diadromous and freshwater fish.

Otoliths can be used as a natural tag because trace elements within the water in which the fish is found are taken up through branchial uptake by the fish and are eventually incorporated into the otolith (Campana 1999). Therefore, the physical and chemical environment in which the fish is found influences the rate of incorporation of trace elements into the otolith. As new otolith material is added to the outside surface the existing material is not removed so the otolith is considered metabolically inert and the material is deposited in layers, so differences in otolith chemistry have the potential to be correlated with days and years.

Analysis of Sr concentrations has been widely used for tracing salinity history. The expectation is that otolith Sr and salinity are correlated, although there has been limited testing of such an association. Since extensive gradients occur both vertically and horizontally within estuaries, differences in water Sr:Ca can be substantial. Concentrations of ambient Sr are typically an order of magnitude higher in marine waters than freshwater. Thus, parts of the otolith formed when the fish was in marine waters typically exhibit higher Sr:Ca ratios than layers deposited when the fish was resident in freshwater. Many studies do not measure Sr concentration of ambient water and therefore it is not clear whether such a relationship would exist after factoring out the effects of ambient water. Partition coefficients may be a useful way to investigate the effect of multiple factors on otolith chemistry because they factor out the effects of water chemistry.

Although it is widely acknowledged that ambient Sr is higher in seawater than freshwaters, there can be considerable variability within freshwaters (e.g. Figure 2 in Kraus and Secor 2004). Although most values were less than the marine end member, some freshwater Sr:Ca values substantially exceeded Sr/Ca expected for seawater. If the ambient Sr:Ca has a major effect on otolith Sr:Ca, then for fish reared in freshwater with ambient Sr:Ca values greater than marine values (i.e. greater than 9 mmol Sr. mol^{-1} Ca) the otolith Sr:Ca may exceed that of fish reared in seawater. I am not aware of similar data for Australia.

Sr:Ca ratios have been the most widely used of the elemental ratios, but other elements (e.g. Ba) may also be useful indicators of salinity but have been largely unexplored. For example, coral Ba:Ca over time was correlated with salinity near the reef in which the coral was sampled (Alibert *et al.* 2003). The amplitude of the peaks was proportional to the freshening of the waters during most flood events (Alibert *et al.* 2003). In otoliths, ambient Ba:Ca concentrations positively influenced Ba:Ca concentrations of fish otoliths and partition coefficients indicated that ambient Ba:Ca levels had a greater effect on otolith chemistry than either salinity or temperature (Elsdon and Gillanders 2003, Elsdon and Gillanders 2004). A relationship exists between Ba in the water and salinity since barium exhibits estuarine release with peak Ba concentrations depending on salinity, hydrodynamics and transport of riverine suspended particulate matter. The freshwater occupancy of fish, for example, could be determined including timing of movements between freshwater and marine waters and amount of time spent in each habitat (Elsdon and Gillanders 2005). Variation in Ba: Ca ratios may also reflect changes in freshwater input and therefore for non-mobile species, we may be able to use Ba: Ca ratios as an indicator of freshwater input to a system.

Finally, Sr isotopes also offer exciting possibilities for determining movements of fish in freshwater systems since Sr isotopes in stream water and otoliths/vertebrae are positively correlated (Kennedy *et al.* 2000). Therefore, if differences in Sr isotopes exist among different geographical areas then we can differentiate fish from different areas. To date, the majority of Sr isotope studies have focused on salmonids, and they have also focused on bulk analyses rather than looking at life-time signatures. An excellent example of the use of age-specific Sr isotope data was provided by Kennedy *et al.* (2002) where information on whether fish were stocked or not, the natal stream and movements in the freshwater part of the life cycle, as well as timing of movement to marine waters were determined.

Sr isotopes maybe useful for determining movements not only of diadromous fish but also of other freshwater fish, but Sr isotopes will only detect movements below a certain salinity (e.g. 25 in one study and approximately 5 in another). Since Sr isotopic signatures depend on the bedrock geology, it should be possible to predict from geological maps whether sites are likely to show sufficient geochemical variation. The greatest application will be for species that move across strong salinity gradients (such as diadromous species) or between rivers with vastly different geologies.

The application of otolith chemistry to marine fisheries ecology and management has grown significantly over the past decade, but with the exception of diadromous fish, it has only recently been applied to freshwater systems. I have demonstrated the potential use of both elements and isotopes as an aid to understanding movements and origins of freshwater fish and links between systems.

Southern Seas Ecology Laboratories
School of Earth and Environment Sciences
University of Adelaide, South Australia
Australia
Email: bronwyn.gillanders@adelaide.edu.au

References

Alibert, C., Kinsley, L., Fallon, S. J., McCulloch, M. T., Berkelmans, R., McAllister, F. 2003. Source of trace element variability in Great Barrier Reef corals affected by the Burdekin flood plumes. *Geochimica et Cosmochimica Acta* 67:231-246.

Campana, S. E. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Marine. Ecology Progress Series* 188:263-297.

Elsdon T. E., Gillanders B. M. 2003. Relationship between water and otolith elemental concentrations in juvenile black bream Acanthopagrus butcheri. *Marine Ecology Progress Series* 260:263-272.

Elsdon, T. E., Gillanders, B. M. 2004. Fish otolith chemistry influenced by exposure to multiple environmental variables. *Journal of Experimental Marine Biology and Ecology* 313:269-284.

Elsdon, T. E., Gillanders, B. M. 2005. Alternative life-history patterns of estuarine fish: barium in otoliths elucidates freshwater residency. *Canadian Journal of Fisheries Aquatic Sciences* 62:1143-1152.

Kennedy, B. P., Blum, J. D., Folt, C. L., Nislow, K. H. 2000. Using natural strontium isotopic signatures as fish markers: methodology and application. *Canadian Journal of Fisheries Aquatic Sciences* 57:2280-2292.

Kennedy B. P., Klaue A., Blum J. D., Folt C. L., Nislow K.H. 2002. Reconstructing the lives of fish using Sr isotopes in otoliths. *Canadian Journal of Fisheries Aquatic Sciences* 59:925-929.

Kraus R.T., Secor D.H. 2004. Incorporation of strontium into otoliths of an estuarine fish. *Journal of Experimental Marine Biology and Ecology* 302:85-106.

Pittman S. J., McAlpine C. A. 2003. Movements of marine fish and decapod crustaceans: process, theory and application. *Advances in Marine Biology* 44:205-294.

4.1.9 Progress towards an ecosystem-based approach to adaptive fishery management for black bream, *Acanthopagrus butcheri*, in the Gippsland Lakes, Victoria

Patrick Coutin

The Gippsland Lakes in south-eastern Australia support a significant multi-gear commercial fishery and recreational fishery which target black bream and 10 other major species (Coutin 1997). The history of the Gippsland Lakes commercial fishery since 1914 is marked by periods when annual catches of black bream have been high at 203–548 tonnes (1914–19 and 1966–1976) and low at 12–64 tonnes (1937–60). With the lowest catch for 44 years reported as 28 tonnes in 2002/03 (Figure 1), there is renewed concern for the stock. The need to identify and manage the main factors affecting stock abundance has become more urgent. The increasing size and age structure of black bream that are currently supporting the fisheries and a reduction in pre-recruit abundance in fishery independent surveys are indicators of poor recent recruitment (Cashmore *et al.* 2000). Warning signs of lower stock abundance from the declining trends in retained catch rates (Figures 2 and 3) recently prompted a change in management. In December 2003, the legal minimum length was increased from 26 cm to 28 cm for stock conservation and subsequent catches remained low at 30 tonnes in 2003/04. This is an adaptive fishery management action that will be reviewed during 2005.

In the past, fishery regulations have been adjusted in response to indicators of low stock levels, but the population dynamics of black bream are impacted by environmental factors as well as fishing. Drought conditions and low seasonal river flows may be primarily responsible for poor recruitment in some years and lead to lower stock abundance (Walker *et al.* 1998). Although there was some recruitment during the 1980s (Morison *et al.* 1998), no abundant year-classes have entered the fishery since 1989.

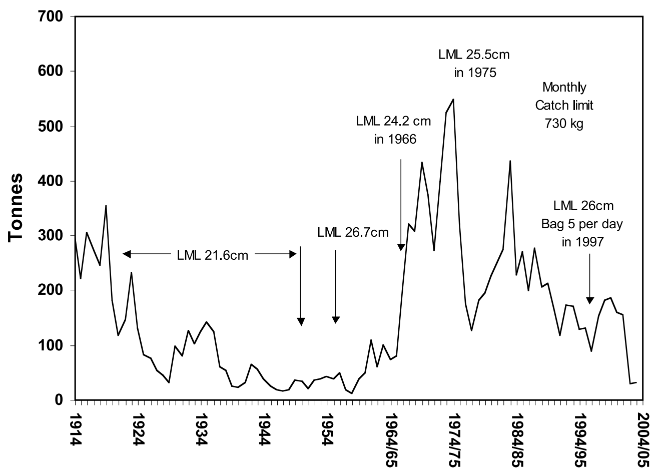


Figure 1. Trend in black bream catches from the commercial haul seine and mesh net fishery in the Gippsland Lakes with changes in the legal minimum length (LML).

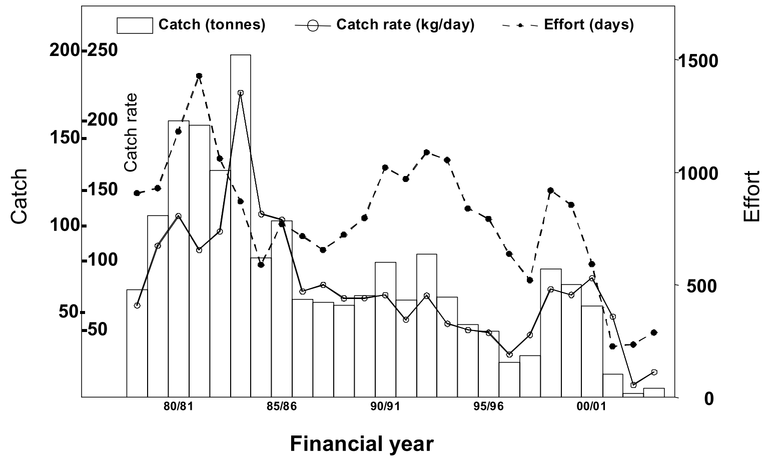


Figure 2. Trend in the haul seine catch, effort and catch rates of black bream.

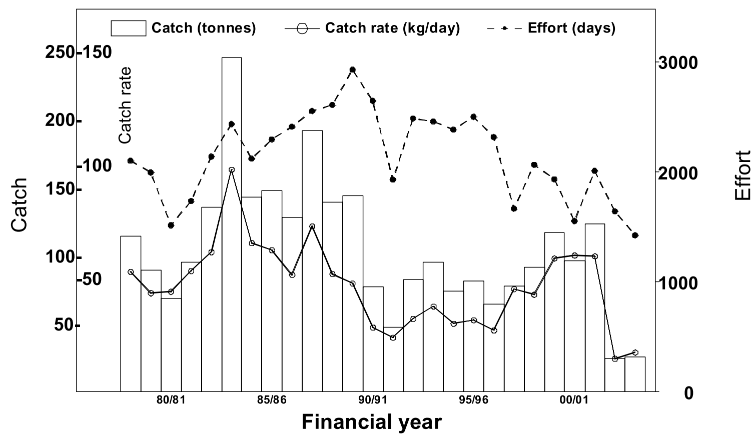


Figure 3. Trend in the mesh net catch, effort and catch rates of black bream.

Predation on pre-recruit black bream by the great cormorant (*Phalacrocorax carbo*), has been estimated to be high (Reside and Coutin 2001), particularly if there is a drought in south-eastern Australia, when large numbers of cormorants and pelicans migrate to the Gippsland Lakes. Consequently, the effect of predation by aquatic birds on the black bream stocks is potentially far greater than the fisheries in some years. Predation may act as a "bottleneck" restricting or modifying recruitment and stock recovery when favourable environmental conditions occur. These complex ecological relationships and constraints on the black bream population have been recognised in the stock assessments (Cashmore *et al.* 2000), and ecosystem-based fishery management presents a long-term challenge for fisheries co-management in Victoria.

Whereas single species management of the Gippsland Lakes fishery recognises that commercial and recreational fishing pressure from retained catches and discards must not further deplete bream stocks, there is increasing emphasis on adaptive, ecosystem-based approaches to research (Longmore *et al.* 1988, Longmore 1990a) and fishery management in Victoria. Ecosystem processes and habitat threats to fish stocks in the Gippsland Lakes have been recognised (Longmore 1990b, Gunthorpe 1997), and policies have been developed to improve water quality (EPA 1995). The Gippsland Coastal Board commissioned CSIRO to develop ecosystem models to assist with decision making. Strategic plans for improving the health of rivers have been prepared by the East Gippsland Catchment Management Authority.

With the release of the Victorian Government's White paper for water reform, the Government has committed to a process for improving the health of the Gippsland Lakes by providing 25,000 ML of additional environmental flows from the Thomson and Macalister Rivers over the next ten years. The Mitchell River has been recognised under the Heritage Rivers Act as one of the highest value waterways in Victoria and has been officially classed as a 'heritage river', essential for nature conservation areas, and with immense recreational, social and cultural value for Gippsland. Under the Government's Our Water Our Future action plan, risks from willow and weed pollution, riverbank erosion, and loss of natural habitat will be addressed as part of the Victorian River Health Strategy (White and Candy 2002). However, there are major environmental challenges requiring coordinated management actions to achieve long-term solutions. A priority is the reduction of algal blooms in the Gippsland Lakes, which are related to nutrient inputs from several sources. (Longmore 1994a, Longmore 1994b, Longmore 1994c) Several management strategies are aimed at reducing phosphorus inputs from the dairy industry (Gourley 2004) as well as from other sources including sewage treatment discharges, urban drains, and agricultural land.

Conclusion

The Gippsland Lakes, like other large brackish systems, are ecologically complex and vulnerable to impacts from upstream catchment activities as well as those from within the estuaries, swamps, lagoons and Bass Strait. Whether the remedial action that is taking place will be sufficient to restore the Gippsland Lakes and allow higher levels of black bream recruitment in the future needs to be carefully monitored. The adoption of ecosystem based fishery management initiatives is an important step that will assist with coordination of research and management by different Government agencies. Without a better understanding of the ecological processes limiting black bream recruitment, more drastic management approaches, such as seasonal closures or a long-term, large-scale restocking program, may be necessary to support the fisheries.

Marine and Freshwater Systems
Primary Industries Research Victoria
Victoria, Australia
Email: patrick.coutin@dpi.vic.gov.au

References

Cashmore, S., Conron, S., Knuckey, I. 2000. Black Bream 1998. Marine and Freshwater Resources Institute Fisheries Assessment Report No. 24, Queenscliff, Australia. 72 pp.

Coutin, P. C. 1997. Black Bream. Marine and Freshwater Resources Institute, Fisheries Assessment Report No. 18, Queenscliff, Australia. 72 pp.

EPA 1995. Draft State environment protection policy (Waters of Victoria) Schedule F5 - Waters of the Latrobe and Thompson River Basins and Merriman Creek Catchment and Draft Policy Impact Assessment. Environment Protection Authority Publication No. 444, Melbourne, Australia. 125 pp.

Gourley, C. 2004. Improved nutrient management on commercial dairy farms in Australia. *The Australian Journal of Dairy Technology* 59:152–156.

Gunthorpe, L. 1997. Gippsland Lakes fish habitats - 1997. Marine and Freshwater Resources Institute Fisheries Assessment Report No. 16, Queenscliff, Australia. 62 pp.

Longmore, A. R. 1990a. Oxygen concentrations, temperatures and salinities in the Gippsland Lakes, Victoria, 1987-88 and survival of black bream *Acanthopagrus butcherii*. Environment Protection Authority Scientific Series No. SRS89/005, Melbourne, Australia. 21 pp.

Longmore, A. R. 1990b. Saltwater intrusion into Lake Wellington, Gippsland Lakes south-eastern Australia: its causes, effects and control. Environment Protection Authority Scientific Series No. SRS89-006, Melbourne, Australia. 10 pp.

Longmore, A. R. 1994a. Nutrient and chlorophyll concentrations in the Gippsland Lakes 1988–89. Environment Protection Authority Publication No. 419, Melbourne, Australia. 29 pp.

Longmore, A. R. 1994b. Nutrient budget for northern Lake King, Gippsland Lakes 1987–88. Environment Protection Authority Scientific Series No. SRS89-003, Melbourne, Australia. 59 pp.

Longmore, A. R. 1994c. Nutrient release rates for sediment cores from the Gippsland Lakes 1988. Environment Protection Authority Publication No. 420, Melbourne, Australia. 37pp.

Longmore, A. R., Gibbs, C. F., Marchant, K. W. 1988. Water quality in the Gippsland Lakes, July 1984-June 1985: spatial and temporal trends. Marine Science Laboratories Technical Report No. 60, Melbourne, Australia. 71 pp.

Morison, A. K., Coutin, P. C., Robertson, S. G. 1998. Age determination of black bream, *Acanthopagrus butcheri* (Sparidae), from the Gippsland Lakes of south-eastern Australia indicates slow growth and episodic recruitment. *Marine and Freshwater Research* 49:491–498.

Reside, J., Coutin, P. C. 2001. Preliminary estimates of the population, diet and fish consumption of the Great Cormorant (*Phalacrocorax carbo carboides*, Gould 1838) in the Gippsland Lakes, Victoria during 1998. Marine and Freshwater Resources Institute Technical Report No. 27, Queenscliff, Australia 53 pp.

Walker, S., Sporcic, M., Coutin, P. C. 1998. Development of an environment-recruitment model for black bream: a case study for estuarine fisheries management. Final Report to the Fisheries Research and Development Corporation, Project No. 96/102. Marine and Freshwater Resources Institute, Queenscliff, Australia. 74 pp.

White, L. J., Candy, R. B. 2002. 'The East Gippsland River Health Strategy 2002–2007 (draft).' (East Gippsland Catchment Management Authority: Bairnsdale, Australia.) 46 pp.

4.1.10 A national approach for assessing the ecological implications of changing freshwater inflows to Australian estuaries: a process based on processes.

Keith Bishop and W. L. Peirson

Many Australian estuaries have been subject to significant shifts in the size, quality and frequency of freshwater inflow events because of catchment 'development' and water extraction. Given increasing community concern regarding the condition of the estuaries, and as a part of the Federal Government's environmental-flows initiative, a multidisciplinary framework for determining the freshwater requirements of Australian estuaries was developed in 2002 (Peirson *et al.* 2002).

Central to the framework are checklists of major ecological processes by which changes to freshwater inflows can impact the ecology of estuaries and adjacent coastal waters. The checklists (Tables 1, 2 and 3), which are partitioned in relation to the magnitude of inflows impacted, provide a comprehensive means of identifying potentially important inflow-alteration issues. Significant knowledge gaps may be revealed when the pertinence of checklist items is considered.

The developed framework has two components: *a four-step preliminary evaluation phase* (a 'screening' module) that quantifies risk, value and vulnerability of a given estuary and, *detailed five-step investigative phase* that allows proposed developments to be evaluated within an adaptive management framework. The approach has many similarities with a method that is currently being developed in South Africa. Both are holistic, stepwise methods that utilise multi-disciplinary teams of scientists. A focus on the differences between the methods is likely to yield valuable insights for workers in both countries as they struggle to come to terms with a number of very complex issues. Key differences between the methods chiefly concerns the level of prescription, emphasis on identifying key issues, time taken for assessments and the confidence in findings.

Table 1. Checklist of major ecological processes by which altered estuary inflows may cause impacts on estuarine ecosystems and the adjacent marine environment: ***Low-magnitude inflows (Low-).***

Class	Description
Low-1:	*increased hostile water-quality conditions at depth*: reduced inflows → reduced vertical mixing → hostile water-quality conditions in deeper sections.
Low-2:	*extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna:* reduced inflows → extended durations of elevated salinity in the upper-middle estuary → adverse effects on fauna with low salinity tolerance or competition and predation from colonising large salt-tolerant fauna.
Low-3:	*extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora:* reduced inflows → extended durations of elevated salinity in the upper-middle estuary → vegetation loss → reduced bank stability.
Low-4:	*extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota*: reduced inflows → elevated salinity in the lower estuary → invasion by marine biota.
Low-5:	*extended durations when flow-induced currents cannot suspend eggs or larvae*: reduced inflows → extended durations when flow-induced currents cannot suspend eggs or larvae → mortality
Low-6:	*extended durations when flow-induced currents cannot transport eggs or larvae*: Some species rely on flow-induced transport to favourable habitats for later life-history stages.
Low-7:	*aggravation of pollution problems:* reduced inflows → reduced transport and dilution of chemical and biological pollution from the upper-middle estuary.
Low-8:	*reduced longitudinal connectivity with upstream river systems:* Decreased inflows can sever connectivity between the estuary and upstream river systems for mobile fauna (e.g. over tidal-barrier riffles).
Low-9:	*increased retention times in estuary reaches:* reduced inflows → increased retention times in estuary reaches → encouragement of algal blooms if nutrient concentrations were not limiting → associated environmental degradation
Low-10:	*nutrient influxes from density-dependent saline surface water-shallow groundwater interactions:* decreased inflows → upstream penetration of saline waters → substantial nutrient influxes if shallow nutrient-rich groundwater occurs about the estuary → major algal blooms and associated environmental degradation.
Low-11:	*reduced longitudinal connectivity with the downstream marine environment:* decreased inflows → severing surface-water connectivity between the estuarine and marine environments (when inflows approach the sub-surface water seepage rates) → a range of impacts on migrating fauna may result

Table 2. Checklist of major ecological processes by which altered estuary inflows may cause impacts on estuarine ecosystems and the adjacent marine environment: *Middle- and high-magnitude inflows (M/H-).*

Class	Description
M/H-1:	*diminished frequency that the estuary bed is flushed of fine sediments and organic material*: reduced inflows → reduced flushing of fine sediments and organic material → fauna laying eggs on or within hard substrates are vulnerable.
M/H-2:	*diminished frequency that deep sections of the estuary are flushed of organic material*: reduced flushing + decomposition of organic load → hostile water-quality conditions.
M/H-3:	*reduced channel-maintenance processes*: reduced inflows → channel reduction → habitat reduction and potential reduction of tidal exchange flushing.
M/H-4:	*reduced inputs of nutrients and organic material:* decreased inflows → reduced input of natural river-borne nutrients and organic material → reduced biological production.
M/H-5:	*reduced lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to the estuary*: decreased inflows → loss of connectivity and inputs to adjacent water bodies from estuary.

Table 3. Checklist of major ecological processes by which altered estuary inflows may cause impacts on estuarine ecosystems and the adjacent marine environment: *All inflows (All-).*

Class	Description
All-1:	*altered variability in salinity structure: altered inflows* → changed patterns of salinity structure → disruption of life cycles and development synchronization.
All-2:	*dissipated salinity/chemical gradients used for animal navigation and transport:* reduced inflows → dissipate salinity and chemical gradients along and out of the estuary → potential changes to the navigation of mobile fauna.
All-3:	*decreases in the availability of critical physical-habitat features, particularly the component associated with higher water-velocities:* reduced inflows → lower water velocities in upper estuary → biota favouring higher velocity areas are disadvantaged; generally native biota are disadvantaged more than alien biota.

1 *Sugar Creek Rd*
Bungwahl
New South Wales, Australia
Email: bishop@nobbys.net.au

2 *Water Research Laboratory*
School of Civil and Environmental Engineering
University of New South Wales
New South Wales, Australia

Reference

Peirson, W. L., Bishop, K. A., Van Senden, D., Horton, P. R., Adamantidis, C.A. 2002. Environmental water requirements to maintain estuarine processes. Report to Environment Australia. Water Research Laboratory, University of New South Wales, Australia.

4.2 Focused case study: the River Murray and the Murray estuary

4.2.1 Introduction

The Native Fish Strategy for the Murray-Darling Basin 2003-2013 (NFS, MDBC 2003) was developed to rehabilitate fish populations in response to the decline in native freshwater fish across the Murray-Darling Basin in recent decades. Native freshwater fish numbers across the Basin are estimated to be approximately 10 per cent of pre-European levels. In addition:

1. 16 of approximately 35 species are threatened at National or State level,
2. Localised extinctions have been recorded for several species,
3. 'Flagship' species such as Murray cod, Macquarie, Silver and Golden perch and Catfish have declined in range and abundance,
4. 11 alien species now make up to 90% of fish biomass in many areas,
5. Commercial fisheries have declined and been closed in recent years,
6. Recreational fishing success has also declined in recent decades.

The NFS identified the main threats to native freshwater fish as: habitat degradation, flow regulation, reduced water quality, barriers to fish passage, introduction of alien fish species, fisheries exploitation, spread of disease, translocations and fish stocking. The NFS also identifies actions that are anticipated to increase native fish populations to 60% of their pre-European state, over a 50-year period.

An important, but often forgotten component of the Murray River is the Murray estuary. While threats to the River Murray, including the estuary, have been identified (Jensen *et al.* 2000), the status of fish populations in the Murray estuary is not well known. Approximately 80 species have been recorded in the Murray Mouth and Coorong. Of these, 20 species depend on the Murray Mouth and Coorong at some stage of their life cycle. These include anadromous and catadromous fish, estuarine, freshwater and marine migrants and estuarine residents (classifications from Whitfield 1999). Up to another 60 species use the Murray Mouth and Coorong occasionally and opportunistically and are classified as freshwater and marine stragglers (Higham *et al*. 2003). Decreased River Murray flows will affect salinities, nutrients, turbidity and particulates in the Murray Mouth, and low flows limit the area of the Murray Mouth and Coorong that has estuarine salinities. Flow may affect reproduction, recruitment and abundance of the estuarine-dependent fish. Migratory fish need access between the ocean and the Murray Mouth/Coorong and between the Murray Mouth/Coorong and Lake Alexandrina. The Murray Barrages and the restricted Murray Mouth will have had adverse effects on estuarine-dependent and migratory fish. Flows across that barrages are necessary for movement between Lake Alexandrina and the Murray Mouth/Coorong, and freshwater outflow through the Murray Mouth promotes movement between the ocean and the estuary.

As part of NFS activities, the MDBC has supported a series of workshops that have examined issues related to the management of native fish and rehabilitation of their populations. For example, workshops have been held on how to address the issue of cold-water releases from large dams (Phillips 2001), the design and construction of fishways, the downstream movement of fish (Lintermans and Phillips 2004) and the management and rehabilitation of in-channel habitat (Lintermans *et al.* 2005). Examining the interaction of channel and wetland/floodplain habitat was noted at this latter workshop to be an issue deserving of further consideration, particularly in light of the Living Murray Initiative and the future provision of environmental water. In the Murray Mouth and Coorong, studies are being undertaken on fish passage across the barrages between the Murray Mouth and Lake Alexandrina (Ye *et al.* 2002) and the response of fish to outflows from the barrages (Geddes 2005).

The Australian Society for Fish Biology (ASFB) 2004 Fisheries Ecosystem Symposium provided an opportunity to examine perspectives of river flows and channel-floodplain-estuary interactions and their role in the life cycles of native fish. The Symposium was attended by almost 200 scientists and managers, approximately 80 of whom attended the Rivers and Estuaries theme: *Managing fish and fisheries in rivers and estuaries with limited and variable flow*.

On the first day of the Rivers and Estuaries theme, ten presentations were made on the effects of limited and variable flow on the biology and fisheries of freshwater and estuarine fish. The second day of the Rivers and Estuaries Theme of the Symposium took the form of a workshop "The River Murray and Murray estuary Case Study". This report captures the key messages and recommendations for future research and management on native fish associated with the Murray River and the Murray estuary.

The workshop sessions were greatly assisted by presentations from:

1. Mark Lintermans and Jim Barrett (Native Fish Strategy and the Sustainable Rivers Audit),
2. Mark Siebentritt (The Living Murray Initiative: First Step),
3. Shaun Meredith (Wetlands, fish and flow),
4. Brenton Zampatti, Lee Baumgartner, Ivor Stuart and Martin Mallen-Cooper (Lake Hume to the sea: improving fish passage in the Murray),
5. Mike Geddes and Qifeng Ye (Flows, ecosystems and fish: the Murray Mouth and Coorong),
6. John Koehn (Freshwater fish: biology, management and threats in the Murray River).

4.2.2 The Native Fish Strategy and the Sustainable Rivers Audit

Mark Lintermans and Jim Barrett

Native fish populations in the Murray-Darling Basin (MDB) are currently estimated to be about 10 per cent of their pre-European settlement levels. Sixteen of the approximately 35 species in the Murray-Darling basin are listed as Threatened at National or State level. There are localised "extinctions" of several species. Alien species made up almost 90% of the fish biomass in a recent basin-wide survey. In response to the parlous state of the MDB fish community, the *Native Fish Strategy for the Murray-Darling Basin 2003-2013* (NFS) was released in April 2004 and outlines an initial 10-year program of activities as part of a 50 year strategy. The NFS has six driving actions; the actions of protecting fish habitat and managing riverine structures have direct relevance to flow-related biology of fish. Current MDBC NFS flow-related projects include:

1. Effect of environmental flow allocations on lateral movements of native fish in the Barmah-Millewa forest;
2. Assessing the effectiveness of environmental flows on spawning and recruitment on fish populations in the Barmah-Millewa region;
3. Meso-scale movement patterns of native fish (*looking at flow as a stimulus*); and
4. Impacts of managed flows on fish spawning and recruitment.

The Sustainable Rivers Audit (SRA) arose from the need for consistent Basin-wide information on the health of rivers. A pilot study in four river valleys was conducted to trial and refine indicators and methods, with five approaches to evaluating river ecology trialled: fish, macroinvertebrates, habitat, water processes and hydrology. The SRA is related to the NFS and the Living Murray Initiative.

The Living Murray Initiative contributes towards long-term surveillance and monitoring requirements and provides information on iconic species such as Murray cod. The Native Fish Strategy provides a context/framework for investigative monitoring and a 'big picture' of fish status. It also triggers further local or regional investigations into fish status and contributes to general knowledge of the basin's fish species. Fish data/indicators could be used to set targets such as maintaining species richness and nativeness of communities. Together these programs will lead to a better understanding of fish biology in the Murray-Darling basin and provide for conservation and rehabilitation of fish stocks.

Murray-Darling Basin Commission
Australian Capital Territory, Australia
Email: lintermans@netspeed.com.au

4.2.3 Environmental flows

Mark Siebentritt

In November 2003, the Murray-Darling Basin Ministerial Council took a First Step under its Living Murray Initiative to address the declining health of the River Murray system. At the Ministerial Council Meeting, 4 - 14 November 2003, major initiatives were announced:

1. $650+ million investment
2. Objectives for six significant ecological assets
3. 500 GL additional water used on average ($500m)
4. Works program to manage water ($150m)
5. Maximising opportunities with existing water.

The First Step decision focuses on specific ecological objectives and outcomes for six significant ecological assets (Figure 1), and is to be achieved through a variety of measures including water recovery and investment in a capital works program.

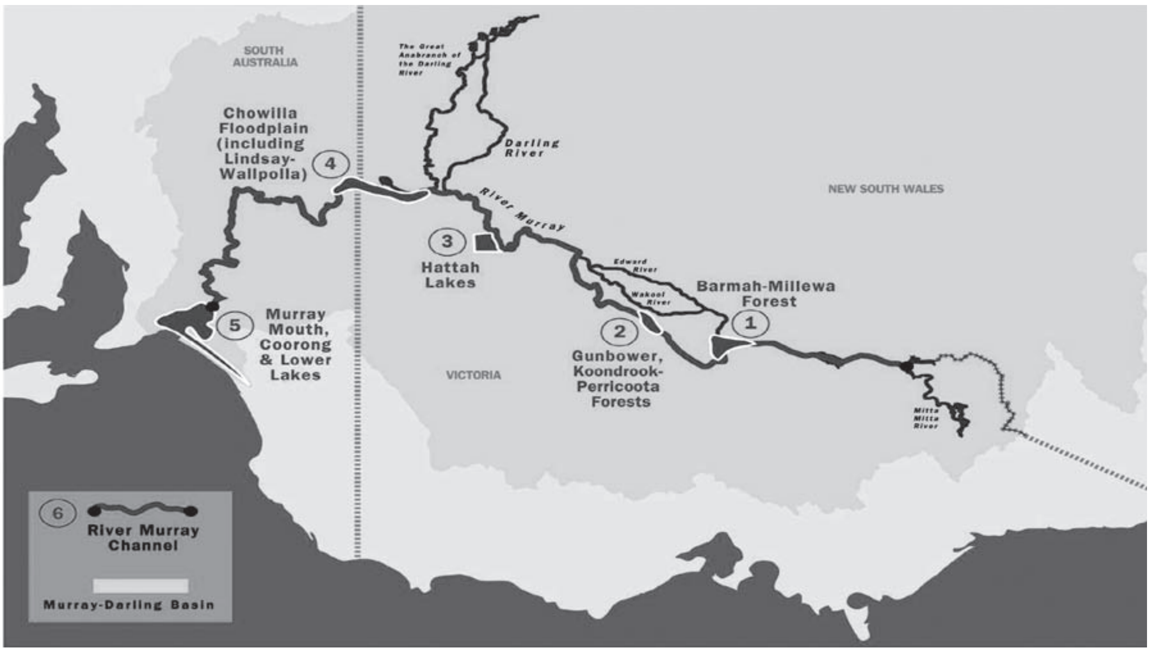


Figure 1: The River Murray showing the six significant ecological assets (SEAs)

The Living Murray is now moving from a policy development into an implementation phase: this poses a new set of challenges. Among them are better understanding the nature of environmental watering opportunities, and developing the tools and information necessary to make informed decisions. Along with other challenges, these have consequences for the way we manage the river, our use of environmental water and our ability to meet the objectives of this initiative. These opportunities for environmental management through flows are demonstrated in two case studies: the Lock 5 enhanced flood in 2000 and the Barrages release of 2003.

The Lock 5 flow enhancement trial involved raising the stop-logs in Lock 5 by 500 mm above normal operating conditions and providing an enhanced flow from Lake Victoria in spring 2000 (DWLBC 2002). This produced a rise in water level upstream of Lock 5. The flow manipulation from the managed release from Lake Victoria is shown in Figure 2, with flows into South Australia (QSA) enhanced beyond flow at Wentworth. This trial is a demonstration of an environmental watering opportunity that can be provided by river flow manipulation. During the study, fish movement was monitored, but no substantial benefits to native fish were recorded.

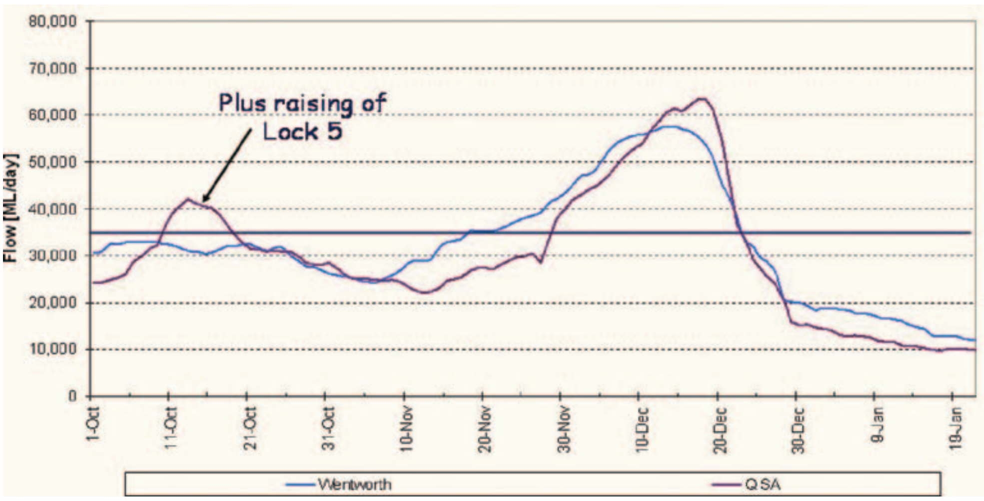


Figure 2: Flows at Wentworth and into South Australia, showing the enhanced flow in spring (October) 2000.

A second example of flow management was the managed barrage outflow of September/October 2003. Flow modelling showed that the barrages at Goolwa and Tauwitcherie could be opened in September to allow an extended period of outflow and the subsequent top-up of Lake Alexandrina from down-river flows (Figure 3). This provided environmental benefits for the Murray Mouth and Coorong and promoted movement and reproductive activity in estuarine fish (Geddes 2005).

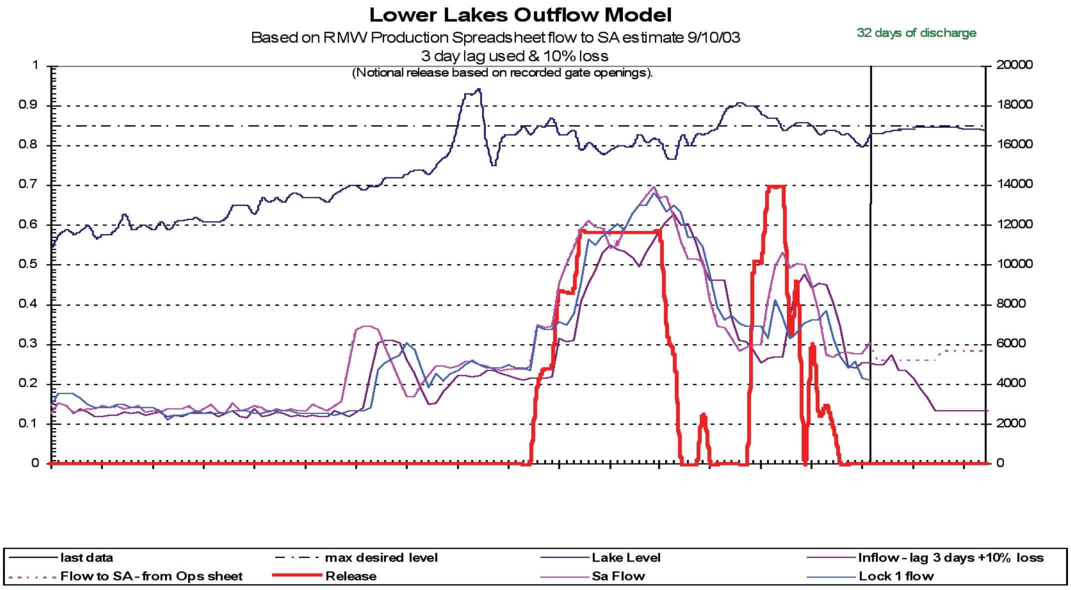


Figure 3: Water levels in Lake Alexandrina, Lock 1 flow and predicted inflows into Lake Alexandrina and release flow from the barrages in September/October 2003.

Murray-Darling Basin Commission
Australian Capital Territory, Australia
Email: mark.siebentritt@mdbc.gov.au

4.2.4 Flows, wetlands and fish

Shaun Meredith

Lindsay Island is part of an anabranch system of the River Murray near the Victorian, NSW and South Australian border. The arrangement of the system provides areas with fast, slow and no flows (Figure 1). This allowed the investigation of relationships between flow and spawning and the occurrence of larval fish.

Figure 1: Lindsay Island region, showing areas of fast, slow and no flow.

Investigations at Lindsay Island found a consistent pattern of spawning for native fish. Murray cod larvae were found in fast flowing waters, while larvae of most other species were found mainly in slow flowing waters and weir pools, although substantial numbers of Australian smelt and carp gudgeons (*Hypseleotris*) were found in the fast flow areas.

Table 1: The numbers of fish larvae collected in various environments in the Lindsay Island region.

Fish	Shallow Pond (no flow)	Weir Pool (slow flow)	Fast Creek (fast flow)	Total
Murray Cod	0	9	37	*46*
Carp	25	12	0	*37*
Bony Herring	4	23	47	*74*
Carp Gudgeon	1,740	1,152	439	*3,331*
Flathead Gudgeon	408	75	30	*513*
Australian Smelt	1,381	6,752	4,293	*12,426*
Rainbowfish	25	19	9	*53*
Hardyhead	150	191	95	*436*
Total	**3,733**	**8,233**	**4,950**	

Results of the study suggested that:

1. Flooding different habitats may produce different recruitment responses and different fish assemblages,
2. Flooding at different times of the year may produce different recruitment responses and different fish assemblages (Table 1),
3. By increasing the spatial (and not just the temporal) diversity of flow habitats, we may be able to increase the biodiversity of fish assemblages,
4. While it is possible to improve spatial and temporal variability under current conditions, overbank flows are still required for food generation and to provide additional larval habitat.

Table 2: Timing of records of larvae for various species in the Lindsay Island area.

Early Season (Aug-Oct)	Mid Season (Nov-Jan)	Late Season (Feb-Mar)	Flood Dependent
Australian Smelt Carp Carp Gudgeon	Hardyhead Rainbowfish Carp Gudgeon Murray Cod Flatheaded Gudgeon	Hardyhead Bony Herring Carp Gudgeon	Golden Perch Silver Perch?

Murray Darling Freshwater Research Centre
Mildura Laboratory
Victoria, Australia
Email: shaun.meredith@csiro.au

4.2.5 The Lake Hume to the Sea program: an adaptive approach to improving fish passage in the Murray River

Brenton Zampatti[1], Lee Baumgartner[2], Ivor Stuart[3] and Martin Mallen-Cooper[4]

Dams and weirs have contributed to declines in the distribution and abundance of native fish populations within the Murray-Darling Basin. The first fishways considered for the Murray River in the 1980s were designed for potamodromous species, such as silver perch and golden perch. We now know that many species move up and downstream and that we have to cater for movements by a diversity of species and life stages. Fish passage requires good water quality, sufficient flow, and ways of overcoming barriers.

In order to rehabilitate fish communities, the Murray-Darling Basin Commission (MDBC) has committed $25 million over ten years to construct 11 new fishways and restore passage to over 2000 km of the Murray River. A tri-state collaborative approach involving State agencies from New South Wales, Victoria and South Australia was engaged to test the effectiveness of the new fishways. The key research objectives include identifying changes to whole fish communities and assessing the function of each fishway.

A fishway assessment program has been established, with 2 main objectives:

1. Identify changes to whole fish community
2. Assess the function of each fishway by:
    a. top and bottom trapping
    b. automated Passive Integrated Transponder (PIT) systems.

So far, new fishways have been constructed at Lock 7 Lock 8, Lock 15 (Euston) and at Tauwitchere Barrage.

In September 2001, boat electro-fishing commenced to enable a comparison of fish communities before and after fishway construction, and to provide data that will determine the optimum entrance location for the new fishways. New vertical-slot fishways at Locks 7 and 8 were completed in 2003/04 and have low gradients (1:30), a low maximum water velocity (1.4 $m.s^{-1}$) between pools and low turbulence (43 $W.m^{-3}$). The fishways are designed to pass a wide size range of fish (40 – 900 mm long) and represent an attempt at passage restoration for entire fish communities. Initial sampling of the Lock 8 fishway yielded over 18,000 fish from 11 species during a low flow period between November 2003 and March 2004. Monitoring at Lock 8 and Euston Weir fishways has provided some interesting insights:

1. A total of 18,380 fish were recorded from the Lock 8 fishway within the first 5 weeks of operation (size range of 45-850 mm), with most species ascending successfully.
2. Fish can have a learning behaviour, as fish that visited the fishways repeatedly were found to have faster movements. Carp were found to be the fastest in ascending a fishway.
3. Golden perch migration at Euston Weir responded to increased daily fluctuation in flow due to rain rejections. Tributary inflows are unlikely to provide the level of daily fluctuation required on a regular basis.
4. Weir design is an important factor. Overshot gates or stoplogs favour the survival of larvae and juvenile fish, whereas undershot gates can cause mortalities.
5. Irrigation off-takes lead to loss of juvenile and larval fish. However, screening to reduce this impact is very expensive.

6. Interestingly, large numbers of carp gudgeon were found attempting to migrate, which was unexpected. However, very few individuals reached the fishway exit, emphasising the need for research to inform an adaptive fishway design process.

Results indicate the fishway passes most target species; however, some juveniles of small species (20-40 mm long) did not successfully ascend. Automated PIT tag reading systems, installed at both fishways are providing new information on ascent times, learning behaviour, large-scale movements and downstream passage in some fish species. Assessment data from the Lock 8 fishway is being used to maximise the efficiency of future fishways.

1 *SARDI Aquatic Sciences*
South Australia, Australia
Email: zampatti.brenton@saugov.sa.gov.au

2 *Department of Primary Industries*
New South Wales, Australia

3 *Arthur-Rylah Institute for Environmental Research*
Victoria, Australia

4 *Fishway Consulting Services*
St Ives Chase
New South Wales, Australia

4.2.6 Flows, ecosystems and fish: the Murray Mouth and Coorong

Michael Geddes[1] and Qifeng Ye[2]

The former estuary of the River Murray would have included the Murray Mouth, the Lower Lakes and the Coorong. The barrages have isolated the Lower Lakes, Alexandrina and Albert, from the estuary (Figure 1), and low River Murray flows and diversions in the southeast of South Australia have denied water to the Coorong. Outflows from Lake Alexandrina are essential as a source of freshwater, nutrients and particulates, including phytoplankton and zooplankton that might serve as food resources for fish. The lagoon system is now in poor condition, with very high salinities, limited distribution and low abundance of macroinvertebrates, large-scale reduction in the distribution of macroalgae and salt-tolerant macrophytes such as *Ruppia* spp., and limited connection between the ocean and the estuary/lagoon system (Jensen *et al.* 2000). The biodiversity and productivity of the Coorong is now considered to be at an historic low point (Geddes 2003).

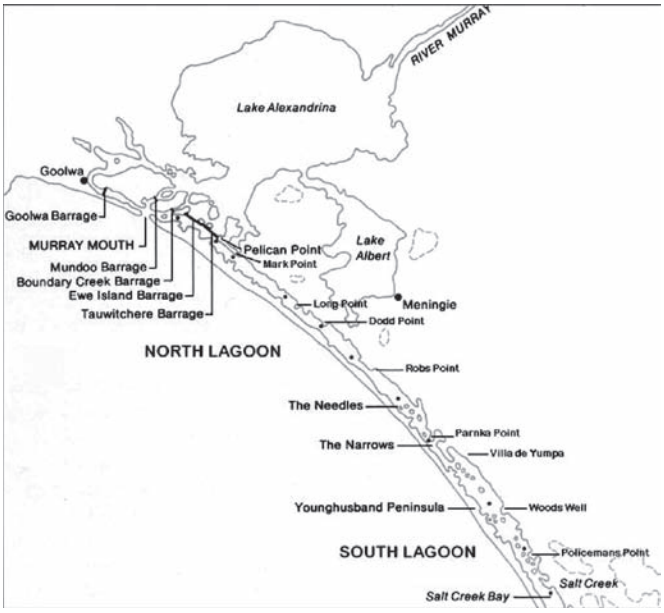


Figure 1: Map of the Murray Mouth and Coorong

Fish use estuaries in many different ways which are summarized in Figure 2. These various patterns of use require access between freshwater, estuarine and oceanic systems. In recent years, flows have been low leading to near-closure of the Mouth and instigation of a dredging program. Although there has been little study of the ecology of the Murray estuary and of the ecosystem that supports important fisheries and small native fish populations, we do know something of the biology of the key species (Figure 3).

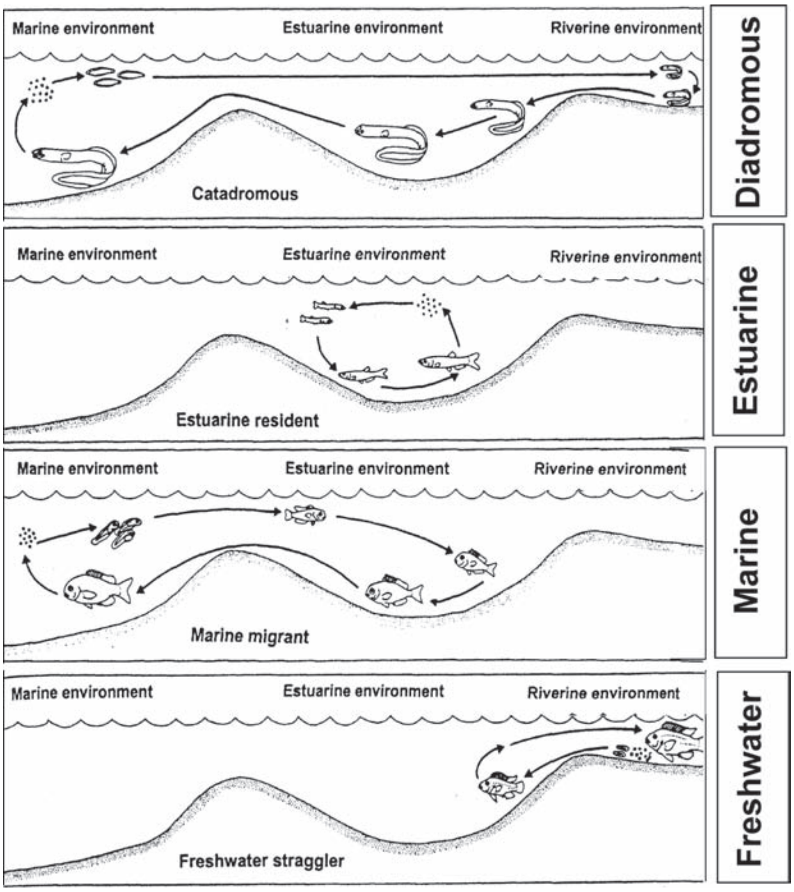


Figure 2: Ways in which fish use estuaries during their life cycles.

Diadromous	Estuarine	Marine
Common galaxias	Black bream	Mulloway
Climbing galaxia	Yellow eye mullet	Sea mullet
Pouched lamprey	Greenback flounder	
Short-headed lamprey	Jumping mullet	
Shortfin eel	River garfish	
Estuary perch	Smallmouthed hardyhead	
Congolli	Bridled goby	
	Tamar River goby	
	Lagoon goby	
	Bluespot goby	

Figure 3: Life cycles of fish using the Murray Mouth and Coorong.

In September-October 2003 a managed release of approximately 300GL over 50 days flowed through the Goolwa and Tauwitcherie Barrages. This presented an opportunity to test some hypotheses relating to the ecological consequences of such an outflow and consider them in the context of adaptive management of flows to the Murray Mouth and Coorong (Geddes 2005). Overall the ecological benefits of the outflow were short-lived and soon after the closure of the barrages the Murray Mouth and Coorong reverted from an estuarine system to a marine-hypermarine coastal lagoon system.

This led to a number of observations:

1. A diverse assemblage of fish species (many non-commercial) at different life stages was attracted to the barrage outflow (Table 1). Fish from 18 mm congolli to 372 mm callop were collected. This highlighted the need for fish passage to allow access to new habitat, promote recruitment and maintain biodiversity.
2. The distribution of key commercial fish extended southwards into the North Lagoon, probably in response to lower salinity and an increase of available habitat.
3. Black bream spawned during the flow event. However, it was difficult to attribute the spawning success to the freshwater release or some other environmental/biological factors.
4. A release rate of 5-10 $GL.day^{-1}$ was sufficient to reinstate a substantial estuary during the outflow.
5. The timing of release in September was suitable for fish and other fauna.
6. There are many ecological processes for which we have little information (e.g. *Ruppia* germination, macroinvertebrate life cycles, fish spawning and recruitment). Extended closure of the barrages has the potential to disrupt or confuse ecological processes and a longer period of discharge (e.g. 90 days) may be required for ecological processes to be sustained and for fish and other biota to complete aspects of their life cycles.
7. Management of the Coorong with limited flow availability should focus on:
    a. Adopting a pattern of release from the barrages that matches as far as possible the natural season pattern, release rate, and period of release, thus reinstating aspects of inter-seasonal and inter-annual variability;
    b. Dredging to maintain the Murray mouth and associated tidal signature, seasonal water level fluctuations and salinity; and
    c.. Use drainage water to complement season of release, release rate, volume of release.

Ultimately, the condition of the Murray estuary and Coorong will depend on some good flood years.

Scientific name	Common name	Scientific name	Common name
Aldrichetta forsteri	Yellow eye mullet	*Galaxias maculatus*	Common galaxias
Rhombosolea taparina	Greenback flounder	*Mordacia mordax*	Short-headed lamprey
Atherinosoma microstoma	Smallmouthed hardyhead	*Pseudaphritis urvillii*	Congolli
Arenigobius bifrenatus	Bridled goby	*Macquaria ambigua*	Callop
Favonigobius tamarensisi	Tamar River goby	*Cyprinus carpio*	Carp
Tasmanogobius lasti	Lagoon goby	*Philypnodon grandiceps*	Flathead gudgeon
Hyperlophus vittatus	Sandy sprat	*Philypnodon sp.*	Dwarf flathead gudgeon
		Retropinna semoni	Australian smelt

Table 1: Fish captured passing through the Goolwa Barrage during the outflow of Sep-Oct 2003.

1 SARDI Aquatic Sciences
South Australia, Australia

&

Environmental Biology
University of Adelaide
South Australia, Australia
Email: mike.geddes@adelaide.edu.au

2 SARDI Aquatic Sciences
South Australia, Australia

4.2.7 Freshwater fish: biology, management and threats in the Murray River

John Koehn

While the purpose of this workshop is to examine flow options, non-flow threats also need to be considered as these may also affect the rehabilitation of fish populations, and indeed in some cases, may negate gains achieved by changes in flows if they are not adequately addressed. Regulated flows are one threat to freshwater fish in the Murray River, but the rehabilitation of native fish populations needs to be undertaken in a 'whole of river' context. This paper aims to provide background for the workshop discussions relating to flows by examining non-flow threats that may also affect (negatively or positively) gains made by improving flows. It will provide a brief, holistic overview of the fish and threats to them, and place environmental flow management in the context of river rehabilitation.

The Murray River is 2,500 km long, is highly regulated, and provides a major supply of water for both irrigation and domestic supply. In addition to irrigated agriculture, the river also supports a major tourism industry. While the Murray River is in New South Wales, it forms a State boundary between New South Wales and Victoria and management is directed by the Murray-Darling Basin Commission (comprising four States and the Commonwealth). The river cannot be separated from its tributaries, which fall under the jurisdictions of other States.

The Murray River has a relatively low number of native fish species (only about 30), compared to many other rivers around the world such as the Amazon (about 1,300 species). Fish management has mainly been focused on those larger species (such as Murray cod, trout cod, golden perch and silver perch) that are highly valued by anglers. While these icon species are important and can be used to engage public support, attention must also be given to other species. Fourteen Murray River native fish species now have some form of conservation listing. For species such as trout cod, the Murray River contains the last remaining natural population. Recently, Murray cod has been listed as a vulnerable species under the Environment Protection and Biodiversity Conservation Act 1998. The agenda for fish management in the Murray-Darling Basin, including the Murray River, is now one of population rehabilitation.

Our knowledge of the ecology of Murray River native fish species, their requirements and interactions, is variable. In the past, this knowledge was largely derived from hatchery-based studies of angling species. While this has progressed to studies of some species and some life aspects in the wild, the fact that several taxonomic studies currently underway are likely to describe several new species, provides an indicator of our overall lack of knowledge.

We have a general understanding of the threats to native fish but limited data on cause and effects. There is a lack of understanding of the interactions between species and between species and their habitats, and factors that may limit populations. Ecosystem processes such as production and reproduction are not explored, nor are concepts such as ecosystem resilience and rehabilitation pathways. While this lack of knowledge may sometimes limit the detail of actions, it will not alter the general direction of the rehabilitation process. It does, however, highlight the need for ongoing investment in knowledge of the riverine ecosystem.

Habitat loss/degradation

Habitat removal and degradation of instream, riparian and floodplain habitats has been widespread long the Murray River. Structural woody habitat is the main habitat component in lowland rivers and de-snagging has been a widespread disturbance. Rehabilitation of woody habitat has been undertaken in pilot studies (Nicol *et al.* 2003) and there is a need for rehabilitation to be undertaken at landscape scales.

Overfishing

Angler take needs to be managed as ecologically sustainable utilisation. Recent information suggests that angler take is impacting on Murray cod population structure, with high mortality at the 50 cm + size range (Nicol *et al.* 2005).

Water quality

Water quality problems have recently been highlighted by a series of large fish kills (Koehn 2005) in major tributaries of the Murray River. Other water quality problems include nutrients, sediment and salinity. Cold water releases from Lake Hume, Lake Dartmouth, Snowy water, affect the upper reaches of the Murray River and impact on the breeding and recruitment of warm water fishes. Such impacts include prevention of spawning, species loss and reduced growth rates (Phillips 2001). This problem, which can be remedied by engineering methods, may prevent population recovery in these reaches.

Barriers to movement

Barriers to movement (both large and small) prevent linear and lateral movements for fish, including links to tributaries and opportunities for recolonisation. Such movements are crucial for the completion of life cycle stages of many species.

Loss in irrigation systems

The loss of larvae, juvenile and adult fish into irrigation channels has recently been highlighted and needs further investigation.

Alien species

Interactions with alien species may have detrimental effects on native fish species. While carp have received the most attention, predation by trout (in the upper reaches) and redfin as well as potential impacts by weather loach which are spreading rapidly in the mid Murray river have been raised for concern. The impacts of other translocated native species such as the broad finned galaxias (introduced via the Snowy Mountains scheme) and spotted galaxias are unknown.

Conclusion

The Murray River needs to be managed as a riverine ecosystem with its linear nature, upstream and downstream influences and long 'edge effects'. It is dependent on catchments which lie across different management zones and jurisdictions. There is a need to rehabilitate many aspects of this degraded river system and while flows and irrigation structures cause the most impacts, they cannot be managed in isolation.

Arthur Rylah Institute for Environmental Research
Victoria, Australia
Email: john.koehn@dse.vic.gov.au

4.2.8 Workshop discussions and summary

The Workshop session consisted of three groups asked to discuss the Ecological Aspects and Management frameworks for particular groups of fish in the River Murray and Murray estuary:

1. Channel specialists and generalists
2. Wetland specialists
3. Estuarine and diadromous species.

Each group considered what were the important flow components that promote habitat quality, recruitment, production and linkages and so advantage fish populations. They were asked to consider what scientific evidence there was for the flow requirements they recommended, and what were the major gaps in our understanding of ecology-flows relationships.

It was highlighted at the workshop that there are many gaps in our understanding of how the flow regime interacts with components of the river and estuary to support or sustain the diversity and abundance of native fish. These knowledge gaps are summarised in the following sections.

Channel specialists and generalists

This group nominally includes Murray cod, trout cod, river blackfish, two-spined blackfish, crimson-spotted rainbowfish, carp gudgeons, australian smelt, bony herring, flathead gudgeons, macquarie perch and freshwater catfish. Knowledge gaps include:

1. Critical water requirements for specialist species and different life stages, life history models, life stage mortalities with different flow regimes,
2. Juvenile recruitment and survival ecology as a function of flow velocity/habitat,
3. Flow-recruitment relationships – do channel specialists spawn or recruit better with floods?
4. The importance of linkages to the floodplain as a source of food and habitat,
5. Relationships between flow and macrocrustaceans /microcrustaceans /food production,
6. Fish abundance in specific habitats and river reaches, and the dependence of these habitats on flow:
    a. diversity of habitats required
    b. differences between species and various life stages
    c. the timing and extent of longitudinal connection,
7. Vulnerability to fishing pressure and predation under different flow regimes (especially in a dry season),
8. Impact of flow on alien species and predation, and how to manage flow so as not to promote exotic species?
9. Interrelationships between flow and other factors such as water quality. Where is water quality likely to be a barrier to fish movement and recruitment?
10. Establishment of basin-wide management units,
11. Impact of restocking on genetic stocks of key native species.

Wetland specialists

This group nominally includes australian smelt, bony herring, carp gudgeons, southern pygmy perch, hardyheads, and possibly golden perch and silver perch. Knowledge gaps include:

1. Species-specific research, including how spawning cues are linked to seasonal variability in flow,
2. The importance of a wetland/floodplain drying phase for wetland specialists,
3. The extent to which some species are wetland specialists or generalists. Some species may live to varying degrees in wetland and other habitats,
4. Integration of knowledge about wetland dynamics with other components of the river or estuary ecosystems,
5. Resolving the conflicting evidence for floodplain spawning and recruitment for golden and silver perch (different populations may have different strategies),
6. How to manage flow to meet the needs of wetland specialists but not promote alien species.

Estuarine and diadromous species

This group nominally includes black bream, greenback flounder, mulloway, yellow-eye mullet, Jumping mullet, river garfish, smallmouth hardyhead, bridled goby, tamar goby, bluespot goby, lagoon goby, common galaxias, climbing galaxias, pouched lamprey, short-headed lamprey, shortfin eel, estuary perch and congolli. Knowledge gaps include:

1. Life history characteristics of fish species (including commercial and forage species),
2. Environmental conditions (including habitat requirements) required for successful recruitment,
3. Dietary information including understanding of trophic levels,
4. The timing and duration of connections between estuary and the ocean,
5. What might be a key species in the Murray Mouth/Coorong that may reflect flow requirements of estuarine fish species (e.g. *Ruppia*),
6. How many marine species come into the estuary to spawn,
7. Fish passage requirements for diadromous fish.

Key Messages

It was agreed that a major benefit of the workshop was the opportunity to consider the Murray River and the needs of native fish from a 'whole of river' perspective. The opportunity for researchers and managers, who might normally work on discrete components of the river systems (e.g. river reaches or sections, in-channel, floodplain or estuary components), to share information and experience to gain a systems-view is relatively rare.

The following key messages emerged from discussion of the many management actions required to protect or enhance native fish:

1. Successful management of native fish in the Murray River requires an holistic approach. It is important that management objectives are clear. Those at the workshop agreed that native fish management should focus on the protection or enhancement of fish communities, rather than individual or a few key species that are the focus of commercial or recreational fishing. Once such management objectives are clear, the information needed to support future management can be made explicit.

2. The flow regime of the Murray River plays a vital role in the successful breeding and recruitment of native fish, both along the river and in the estuary. The natural flow paradigm (Poff *et al.* 1997) provides a useful guide for the range of flow events required by fish communities at various stages of their life cycles. However, it is important to recognise that native fish species may have adapted to a range of cues other than flow (e.g. temperature). Manipulation of the flow regime and other environmental factors (e.g. passage past barriers to fish movement) should aim to enhance recruitment to levels that will rehabilitate native populations in the future, and make conditions less favourable for alien species.
3. Native fish species present in the Murray River have survived a significant loss of floodplain habitat and changes to the flow regime. Future management should consider the flow-related needs of species that have suffered through past management practices and now are no longer present or have a much reduced or fragmented range.
4. The Murray River and most of its tributaries have been regulated to secure water for domestic supply and agriculture. The protection of the remaining, relatively unregulated river systems such as the Ovens River should be given high priority. Such rivers are refuge for many native fish species and so play an important role in the resilience of the Murray River and nearby tributaries. The study of such systems can also provide valuable insights that may be applied to the management of fish communities elsewhere.
5. The long-term survival of native fish communities in the Coorong to meet international obligations under the Ramsar convention requires a functioning Murray estuary, which will require outflows from the barrages more frequently than have occurred in recent years. This is likely to require a combination of an increase in flows, intelligent flow manipulation and works such as dredging. While additional knowledge is needed to optimise the volume and timing of water required to clear the Murray mouth, the serious threat to the state of the Coorong posed by current conditions (Jensen *et al.* 2000; Higham *et al*. 2002; Geddes 2005) means that time available for the collection of new information is limited – action is required now. It was considered that the likely minimal flow requirements from barrage outflow to meet the requirements of estuarine fish in the Murray Mouth area was about 2 to 3 $GL.day^{-1}$ for 60 to 100 days in Spring/Summer. The newly installed fishways are a high priority and it is likely that up to 100 ML/day are required for each of the two fishways at Tauwitcherie barrage, and that this should be augmented with attractant flow from an adjacent barrage. Thus 300 to 500 $ML.day^{-1}$ are required for fishway operation and this should extend over 100 to 150 days.
6. Management to meet multiple objectives may result in conflicting water demands between different sections of the river system. For example, the functioning of the estuary needs more water than is currently delivered from riverine sections. Management of the barrages and the Coorong should focus on establishing the volume of water required to operate new fishways and to maintain a functional estuary, and to determine how much variability in flow-related habitat can be created through flow manipulation.

Opportunities for action

The following actions were identified to complement those identified in the NFS:

1. Manipulation of the various dams, weirs and off-stream storages that are part of the Murray River water supply system provides opportunities for management to achieve ecological outcomes. For example, rainfall in the upper Murray and tributaries in 2003 resulted in flows that were predicted to be in excess of storage capacity in Lake Victoria. The Murray-Darling Basin Commission (MDBC) decided to use this situation to try adaptive management experiments by extending the flooding at Lock 5 and releasing water from the Barrages to manipulate salinity in the estuary, contribute to the opening of the Murray mouth and promote spawning by estuarine fish (M. Siebentritt, MDBC, pers. comm.). While the ecological outcomes of these measures are not yet clear, this exercise highlighted that there are opportunities for flow manipulations to achieve environmental outcomes, and these can be incorporated into the management of the Murray River.

2. River operators are often confronted with tradeoffs, for example between providing water to meet the needs of native fish or other ecosystem components such as floodplain/wetland vegetation. It should be remembered that many aspects of river and estuarine ecology and management for rehabilitation are new to river managers and operators. A challenge in terms of real-time environmental management is to be "event ready" in the face of the often unpredictable timing and magnitude of flow events and the ecological responses that may ensue.

3. Systems level management (i.e. at a broad spatial scale) of the Murray provides opportunities to achieve outcomes for native fish both in the riverine and estuarine environments. For example, the hydrographic data available for the Murray River system is of high quality and can be used to examine ecologically significant components of the flow regime (e.g. extreme events such as drought and flood that drive ecological processes) and assess how these have changed with increasing regulation and diversion of water. This hydrological data can also be used to model how river flow affects salinity profiles downstream of barrages as the basis for management decisions for the estuary. Such tools should be used to reintroduce variability into the system, including on an inter-annual basis, with an emphasis on flow scenarios that may have multiple benefits for different parts of the river and the estuary.

4. The volume of water required to open the Murray mouth and maintain function in the estuary is large compared with the average flow delivered by the river. The potential exists to manipulate levels in Lake Alexandrina and use this water to enhance conditions in the estuary for native fish. Such an approach can reduce the potential for adverse effects on the river (e.g. increased rates of erosion) by delivering large volumes of water over a short period of time.

5. Large-scale manipulations of the Murray River can also be used to demonstrate the potential for enhancing native fish communities while also meeting water demand. Emphasis should be given to explaining the role of flow variability in providing habitat and other conditions necessary for native fish to complete their life cycles. Such manipulations allow for hypotheses relating to the impact on native fish populations to be treated in a scientific manner.

Presentation and workshop summaries provided by Mike Geddes, John Koehn, Jim Barrett and Peter Cottingham, in association with speakers and workshop participants.

References

DWLBC 2002. Lock 5 flow enhancement trial. Department of Water, Land and Biodiversity Conservation, Adelaide, Australia. 40 pp.

Geddes, M.C. 2003. Survey to investigate the ecological health of the North and South Lagoons of the Coorong, June/July 2003. Report to the Department of Heritage and the Department of Water, Land and Biodiversity Conservation. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD03/0103, Adelaide, Australia. 21 pp.

Geddes, M.C. 2005. Ecological outcomes for the Murray Mouth and coorong from the managed barrage release of September-October 2003. Report to the Department of Heritage and the Department of Water, Land and Biodiversity Conservation. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD03/0199-2, Adelaide, Australia. 77 pp.

Higham, J.,Hammer, M., Geddes, M.C. 2002. Fish and invertebrates. In 'The Murray Mouth: exploring the implications of closure or restricted flow'. (Ed. T. Ingliss.) pp. 53-64. (Department of Water, Land and Biodiversity Conservation: Adelaide, Australia.)

Jensen, A. Good, M., Harvey, P., Tucker, P., Long, M. (Eds). 2000. 'River Murray barrage environmental flows: an evaluation of environmental flow needs in the lower lakes and Coorong.' (Murray-Darling Basin Commission: Canberra, Australia.) 152 pp.

Koehn, J., 2005. The loss of valuable Murray cod in fish kills: a science and management perspective. In 'Management of Murray Cod in the Murray-Darling Basin. Statements, recommendations and supporting papers from a workshop held in Canberra, 3-4 June 2004'. (Eds M. Lintermans and B. Phillips.) pp. 73-82. Murray-Darling Basin Commission: Canberra, Australia.

Lintermans, M., Cottingham, P., O'Connor, R. (Eds). 2005. Native Fish Habitat Rehabilitation and Management in the Murray-Darling Basin: Statements, recommendations and supporting papers from a Workshop held in Albury, 10-11 February 2004. Murray-Darling Basin Commission and the CRC for Freshwater Ecology, Canberra, Australia. 101 pp.

Lintermans, M., Phillips, B. (Eds) 2004. Downstream Movement of Fish in the Murray-Darling Basin. Statements, recommendations and supporting papers from a workshop held in Canberra, 3-4 June 2003. Murray-Darling Basin Commission, Canberra, Australia. 104 pp.

MDBC 2003. 'The Native Fish Strategy for the Murray-Darling Basin 2003-2013.' (Murray-Darling Basin Commission: Canberra, Australia.) 50 pp.

Nicol, S., Todd, C., Koehn, J. Lieschke J. 2005. How can recreational angling regulations help meet the multiple objectives of Murray cod populations? In 'Management of Murray Cod in the Murray-Darling Basin. Statements, recommendations and supporting papers from a workshop held in Canberra, 3-4 June 2004'. (Eds M. Lintermans and B. Phillips.) pp. 98-106. Murray-Darling Basin Commission: Canberra, Australia.

Phillips, B. (Ed.) 2001. Thermal Pollution of the Murray-Darling Basin Waterways: Statements, recommendations and supporting papers from a Workshop held in Lake Hume, 18-19 June 2001. Inland Rivers Network and World Wide Fund for Nature Australia, Canberra, Australia. 89 pp.

Poff, L., Allan, D., Bain, M., Karr, J., Prestegaard, K., Richter, B., Sparks, R., Stromberg, J. 1997. The natural flow regime: a paradigm for river conservation and restoration. *Bioscience* 47:769-784.

Schreiber E.S., Bearlin A. R., Nicol S. J., Todd C. R. 2004. Adaptive management: a synthesis of current understanding and effective application. *Ecological Management and Restoration* 5:177-182.

Whitfield, A.K. 1999. Ichthyofaunal assemblages in estuaries: A South African case study. *Reviews in Fish Biology and Fisheries* 9:151-186

Ye, Q., Higham, J., Johnson, J. 2002. Murray barrage fishway assessment program. Report to the Murray-Darling Basin Commission. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 57 pp.

5. Concluding remarks

The Symposium was an outstanding success, being attended by more than 170 delegates from throughout Australia. There were also six internationally renowned scientists, representing Canada, South Africa and the USA. This broad spectrum of participants ensured wide-ranging discussions across a variety of issues relevant to progressing the move towards ecosystem-based fisheries management (EBFM). The diversity of these discussions and the differences among the three sub-themes were one of the highlights of the event.

There were, however, numerous similarities in the discussions and summaries of each theme. For example, there was general acknowledgement that this is a challenging undertaking, and one that would be greatly assisted by fishery and ecosystem managers developing clear, measurable and agreed objectives for EBFM. There was also consensus in the need for identification of the threats that will be addressed via EBFM, as opposed to more 'traditional' single-species approaches. However, depending on the expected role of a species in the ecosystem and the extent to which it is exploited, the need to retain traditional fishery management (TFM) principles (e.g. the use of single-species stock assessments) as a basis for an EBFM approach was highlighted. There was also agreement that 'gap analyses' should precede focused research, that economic and social implications must be considered, and that funding realities cannot be ignored (i.e. requirement to balance idealism with realism).

Participants across the three themes also agreed on the crucial role of long-term monitoring, coupled with increased community education and stakeholder collaborations, particularly in developing predictive capabilities. There was also agreement on the need to engender a 'whole of system' perspective and for enhanced communication across the broad range of scientific disciplines comprising the scientific community.

The diversity of views about EBFM and the generally broad, rather than specific, outcomes from the workshop indicate that the ecosystem symposium was timely for the Australian fisheries community. EBFM is beyond its infancy, but is still far from being a mainstream feature of fisheries management in Australia: this will take time, much work, and must be preceeded by a clear understanding of what is being attempted and why. An underlying reason for holding a symposium on this topic was to provide a forum for discussion of the EBFM concept within an Australian context. The educational benefits of the workshop, such as clarification of what EBFM means to different groups within the fisheries community (researchers, managers, sectoral representatives), gained through both the wide-ranging discussions and the focused interactions are a significant achievement beyond what can be provided in these proceedings. The crucial exchanges of information facilitated by the workshop may not produce direct "government level" outcomes, but will result in tangible improvements in the way EBFM evolves in the various jurisdictions around Australia responsible for managing (or co-managing) aquatic resources.

6. Delegate list

Name	Organisation	Email
Mr Gordon Anderson	WildFish Consulting	gordon.anderson@bigpond.com
Mr Dean Ansell	Murray-Darling Basin Commission	dean.ansell@mdbc.gov.au
Dr Phillip T Arumugam		arumugam@picknowl.com.au
Crispian Ashby	Fisheries Research and Development Corporation	crispian.ashby@frdc.com.au
Ms Cynthia Awruch	Tasmanian Aquaculture and Fisheries Institute / CSIRO	cynthia.awruch@utas.edu.au
Dr Russ Babcock	CSIRO Marine Research	russ.babcock@csiro.au
Mr Ronald Baker	James Cook University	ronald.baker@jcu.edu.au
Dr Stephen Balcombe	Griffith University	s.balcombe@griffith.edu.au
Ms Jacqueline Balston	QLD Department of Primary Industries and Fisheries	jacqueline.balston@dpi.qld.gov.au
Mr Jim Barrett	Murray-Darling Basin Commission	jim.barrett@mdbc.gov.au
Ms Anna Battese	SA Department for Environment and Heritage	anna.battese@deh.gov.au
Dr Lynnath Beckley	Murdoch University	L.Beckley@murdoch.edu.au
Dr Lynda Bellchambers	WA Department of Fisheries	lbellchambe@fish.wa.gov.au
Mr Christopher Bice	University of Adelaide	christopher.bice@student.adelaide.edu.au
Dr Keith Bishop	Freshwater Biology Consultant	bishop@nobbys.net.au
Dr Stephen Blaber	CSIRO Marine Research	steve.blaber@csiro.au
Miss Ali Bloomfield	SA Department for Environment and Heritage	bloomfield.ali2@saugov.sa.gov.au
Mr Craig Boys	CRC for Freshwater Ecology / University of Canberra	c.boys@student.canberra.edu.au
Prof. George Branch	University of Cape Town	gmbranch@botzoo.uct.ac.za
Mr Barry Bruce	CSIRO Marine Research	Barry.Bruce@csiro.au
Dr Catherine Bulman	CSIRO Marine Research	Cathy.Bulman@csiro.au
Mr Ashley Bunce	Deakin University	ashley.bunce@deakin.edu.au
Dr Mark Butler	Old Dominion University	mbutler@odu.edu
Prof. Colin Buxton	Tasmanian Aquaculture and Fisheries Institute	colin.buxton@utas.edu.au
Mr Darren Cameron	Great Barrier Reef Marine Park Authority	camerond@gbrmpa.gov.au
Prof Anthony Cheshire	SARDI Aquatic Sciences / Science to manage uncertainty	anthony.cheshire@aapt.net.au
Dr Gerry Closs	University of Otago	gerry.closs@stonebow.otago.ac.nz
Mr Anthony Conallin	Murray-Darling Freshwater Research Centre	anthony.conallin@csiro.au
Dr Rod Connolly	Griffith University	r.connolly@griffith.edu.au
Mr Peter Cottingham	CRC Freshwater Ecology / University of Canberra	peter.c@enterprise.canberra.edu.au
Dr Patrick Coutin	PIRVic Marine and Freshwater Systems	patrick.coutin@dpi.vic.gov.au
Ms Karen Crawley	Edith Cowan University	k.crawley@ecu.edu.au
Dr Bob Creese	NSW Department of Primary Industries	bob.creese@dpi.nsw.gov.au
Mr Cameron Dixon	SARDI Aquatic Sciences	dixon.cameron@saugov.sa.gov.au
Mr Brendan Ebner	Environment ACT	brendan.ebner@act.gov.au
Mr Travis Elsdon	University of Adelaide	travis.elsdon@adelaide.edu.au
Mr David Fairclough	Centre for Fish and Fisheries Research / Murdoch University	d.fairclough@murdoch.edu.au
Mr Greg Ferguson	SARDI Aquatic Sciences	greg.ferguson@adelaide.edu.au
Leanne Fernandes	Great Barrier Reef Marine Park Authority	l.fernandes@gbrmpa.gov.au
Dr Rick Fletcher	WA Department of Fisheries	rfletcher@fish.wa.gov.au
Ms Nicole Flint	James Cook University	nicole.flint@jcu.edu.au
Dr Anthony Fowler	SARDI Aquatic Sciences	fowler.anthony@saugov.sa.gov.au
Miss Debbie Freeman	University of Auckland	dfreeman@doc.govt.nz
Dr Stewart Frusher	Tasmanian Aquaculture and Fisheries Institute	stewart.frusher@utas.edu.au

Name	Organisation	Email
Ms Dianne Furlani	CSIRO Marine Research	dianne.furlani@csiro.au
Ms Maria Garcia	Deakin University	rmig@deakin.edu.au
Mr Rod Garrett	QLD Department of Primary Industries and Fisheries	rod.garrett@dpi.qld.gov.au
Dr Daniel Gaughan	WA Department of Fisheries	dgaughan@fish.wa.gov.au
Dr Mike Geddes	SARDI Aquatic Sciences / University of Adelaide	mike.geddes@adelaide.edu.au
Ms Sue Gibbs	Macquarie University	sgibbs@gse.mq.edu.au
Mr Peter Gill	Deakin University	petegill@bigpond.com
Dr Bronwyn Gillanders	University of Adelaide	bronwyn.gillanders@adelaide.edu.au
Dr Simon Goldsworthy	SARDI Aquatic Sciences	goldsworthy.simon@saugov.sa.gov.au
Dr Neil Gribble	QLD Department of Primary Industries and Fisheries	gribbln@dpi.qld.gov.au
Dr Shane Griffiths	CSIRO Marine Research	shane.griffiths@csiro.au
Mr Ivor Growns	NSW Department of Natural Resources	ivor.growns@dipnr.nsw.gov.au
Dr Malcom Haddon	University of Tasmania	malcolm.haddon@utas.edu.au
Mr David Hall	Hallprint Fish Tags	davidhall@hallprint.com.au
Ms Kylie Hall	PIRVic Marine and Freshwater Systems	kylie.hall@dpi.vic.gov.au
Mr Ian Halliday	QLD Department of Primary Industries and Fisheries	ian.halliday@dpi.qld.gov.au
Mr Derek Hamer	SARDI Aquatic Sciences	hamer.derek@saugov.sa.gov.au
Mr Michael Hammer	University of Adelaide	michael.hammer@adelaide.edu.au
Dr Euan Harvey	The University of Western Australia	euanh@cyllene.uwa.edu.au
Mr. Gary Hera-Singh	Lakes & Coorong Fishery	gicahera@lm.net.au
Mr Patrick Hone	Fisheries Research and Development Corporation	patrick.hone@frdc.com.au
Mr Charlie Huveneers	Macquarie University	charlie.huveneers@gse.mq.edu.au
Mr Don Jackson	Mississippi State University	djackson@cfr.msstate.edu
Dr Jean Jackson	Inland Fisheries Service	Jean.Jackson@ifs.tas.gov.au
Mr Gavin James	NIWA National Institute of Water and Atmospheric Research	g.james@niwa.co.nz
Mr Greg Jenkins	Challenger TAFE	greg.jenkins@challengertafe.wa.edu.au
Dr Gregory Jenkins	PIRVic Marine and Freshwater Systems	greg.jenkins@dpi.vic.gov.au
Prof. Craig Johnson	University of Tasmania	craig.johnson@utas.edu.au
Mr Henry Jones	South Australian Fisheries Industry Council	yabby@hotkey.net.au
Mr Matthew Jones	Arthur Rylah Institute for Environmental Research	matthew.jones@dse.vic.gov.au
Mr Cheyne Jowett	Deakin University	cajow@deakin.edu.au
Dr Peter Kind	QLD Department of Primary Industries and Fisheries	peter.kind@dpi.qld.gov.au
Dr Alison King	Arthur Rylah Institute for Environmental Research	alison.king@dse.vic.gov.au
Mr John Koehn	Arthur Rylah Institute for Environmental Research	john.koehn@dse.vic.gov.au
Ms Sandra Leigh	SARDI Aquatic Sciences	leigh.sandra@saugov.sa.gov.au
Dr Adrian Linnane	SARDI Aquatic Sciences	linnane.adrian@saugov.sa.gov.au
Dr Mark Lintermans	Murray-Darling Basin Commission	mark.lintermans@act.gov.au
Ms Julie Lloyd	NT Department of Business, Industry and Resource Development	julie.lloyd@nt.gov.au
Ted Loveday	Seafood Services Australia	tedloveday@seafoodservices.com.au
Dr Jeremy Lyle	Tasmanian Aquaculture and Fisheries Institute	Jeremy.Lyle@utas.edu.au
Mr Jarod Lyon	Arthur Rylah Institute for Environmental Research	jarod.lyon@dse.vic.gov.au
Mr Lachlan MacArthur	Edith Cowan University	l.macarthur@ecu.edu.au
Dr Murray MacDonald	PIRVic Marine and Freshwater Systems	Murray.MacDonald@dpi.vic.gov.au
Dr Michael Mackie	WA Department of Fisheries	mmackie@fish.wa.gov.au

Name	Organisation	Email
Dr Martin Mallen-Cooper	Fishway Consulting Services	mallencooper@optusnet.com.au
Ms Melissa Maly	Department of the Environment and Heritage	melissa.maly@deh.gov.au
Mr Timothy Marsden	QLD Department of Primary Industries and Fisheries	timothy.marsden@dpi.qld.gov.au
Dr Andria Marshall	NT Department of Business, Industry and Resource Development	andria.marshall@nt.gov.au
Dr Vlad Matveev	CSIRO Land And Water	Vlad.Matveev@csiro.au
Dr Stephen Mayfield	SARDI Aquatic Sciences	mayfield.stephen@saugov.sa.gov.au
Dr Sam McClatchie	SARDI Aquatic Sciences	mcclatchie.sam@saugov.sa.gov.au
Ms Alice McDonald	SA Department for Environment and Heritage	alice.mcdonald@deh.gov.au
Mr Bryan McDonald	SA Department for Environment and Heritage	mcdonald.bryan@saugov.sa.gov.au
Mr Lachlan Mcleay	SARDI Aquatic Sciences	mcleay.lachie@saugov.sa.gov.au
Mr Kevin McLoughlin	Bureau of Rural Sciences	kevin.mcloughlin@brs.gov.au
Mr Shaun Meredith	Murray-Darling Freshwater Research Centre	shaun.meredith@csiro.au
Mr Peter Millington	WA Department of Fisheries	pmillington@fish.wa.gov.au
Mr Tony Miskiewicz	Wollongong City Council	tmiskiewicz@wollongong.nsw.gov.au
Dr Bill Montevecchi	Memorial University of Newfoundland	mont@mun.ca
Dr Craig Mundy	Tasmanian Aquaculture and Fisheries Institute	Craig.Mundy@utas.edu.au
Dr Andrew Munro	University of Adelaide	andrew.munro@adelaide.edu.au
Dr Sue Murray-Jones	SA Department for Environment and Heritage	murray-jones.sue@saugov.sa.gov.au
Dr Stephen Newman	WA Department of Fisheries	snewman@fish.wa.gov.au
Dr Damian Ogburn	NSW Department of Primary Industries	nick.ryans@fisheries.nsw.gov.au
Prof Ralph Ogden	CRC for Freshwater Ecology / University of Canberra	rogden@enterprise.canberra.edu.au
Dr Thomas Okey	CSIRO Marine Research	tom.okey@csiro.au
Dr Brad Page	SARDI Aquatic Sciences	page.bradley@saugov.sa.gov.au
Dr Bruce Pease	NSW Department of Primary Industries	Bruce.Pease@fisheries.nsw.gov.au
Mr Matthew Pellizzari	SARDI Aquatic Sciences	pellizzare.matt@saugov.sa.gov.au
Mr Robert Pennington	Australian Seafood Industry Council	bob@penningtons.com.au
Dr Tri Pham	Queensland University of Technology	tt.pham@qut.edu.au
Mr Michael Phelan	NT Department of Business, Industry and Resource Development	michael.phelan@nt.gov.au
Dr Margaret Platell	Centre For Fish And Fisheries Research / Murdoch University	platell@murdoch.edu.au
Dr Jian Qin	Flinders University	jian.qin@flinders.edu.au
Mr Thomas Rayner	James Cook University	thomas.rayner@jcu.edu.au
Mr Matt Reardon	University of Melbourne	m.reardon1@pgrad.unimelb.edu.au
Mr Mark Renfree	University of Queensland	bazz_1313@hotmail.com
Mr Sean Riley	TAS Department of Primary Industries, Water and Environment	sriley@ffic.com.au
Dr Kate Rodda	SARDI Aquatic Sciences	rodda.kate@saugov.sa.gov.au
Mr Paul Rogers	SARDI Aquatic Sciences	rogers.paul2@saugov.sa.gov.au
Mr Thor Saunders	SARDI Aquatic Sciences	saunders.thor@saugov.sa.gov.au
Dr James Scandol	NSW Department of Primary Industries	James.Scandol@dpi.nsw.gov.au
Mr David Schmarr	SARDI Aquatic Sciences / University of Adelaide	david.schmarr@adelaide.edu.au
Ms Shokoofeh Shamsi	University of Melbourne	s.shamsi@pgrad.unimelb.edu.au
Mr Andrew Sharman	TAS Department of Primary Industries, Water and Environment	andrew.sharman@dpiwe.tas.gov.au
Dr Ben Sharp	NZ Ministry of Fisheries	ben.sharp@fish.govt.nz
Dr Nick Shears	Leigh Marine Laboratory	n.shears@auckland.ac.nz
Dr Marcus Sheaves	James Cook University	marcus.sheaves@jcu.edu.au

Name	Organisation	Email
Mr Ahere Sherman	Deakin University	aheresherman@hotmail.com
Ms Celeste Shootingstar	National Oceans Office	celeste.shootingstar@oceans.gov.au
Mr David Short	SARDI Aquatic Sciences	Short.david@saugov.sa.gov.au
Dr Mark Seibentritt	Murray-Darling Basin Commission	mark.siebentritt@mdbc.gov.au
Ms Victoria Slowik	WA Department of Fisheries	vslowik@fish.wa.gov.au
Dr Ben Smith	SARDI Aquatic Sciences	smith.ben2@saugov.sa.gov.au
Dr Kim Smith	WA Department of Fisheries	ksmith@fish.wa.gov.au
Mr Sanjeev Srivastava	The Australian National University	Sanjeev.Srivastava@anu.edu.au
Mr Peter Stephenson	WA Department of Fisheries	pstephenson@fish.wa.gov.au
Miss Megan Storrie	Deakin University	sharkymegs@hotmail.com
Mr Rick Stuart-Smith	University of Tasmania	rstuarts@utas.edu.au
Mr Neil Stump	University of Tasmania	nestump@postoffice.utas.edu.au
Dr Ib Svane	SARDI Aquatic Sciences	svane.ib@saugov.sa.gov.au
Dr Bill Talbot	NSW Department of Primary Industries	bill.talbot@dpi.nsw.gov.au
Dr Jason Tanner	SARDI Aquatic Sciences	tanner.jason@saugov.sa.gov.au
Mr Michael Tokley	Abalone Industry Association of SA Inc.	abaloneSA@esc.net.au
Ms Sally Troy	Department of the Environment and Heritage	sally.troy@deh.gov.au
Ms Kerry Truelove	Things Wet and Salty	helenkerry@ozemail.com.au
Ms Claire van der Geest	SEANET	seanet@corvel.com.au
Mr Paul Van Ruth	SARDI Aquatic Sciences / University of Adelaide	vanruth.paul@saugov.sa.gov.au
Dr Mat Vanderklift	CSIRO Marine Research	mat.vanderklift@csiro.au
Mr Terry Walker	PIRVic Marine and Freshwater Systems	Terry.Walker@dpi.vic.gov.au
Bruce Wallner	Australian Fisheries Management Authority	bruce.wallner@afma.gov.au
Dr Tim Ward	SARDI Aquatic Sciences	ward.tim@saugov.sa.gov.au
Miss Dianne Watson	The University of Western Australia	dwatson@cyllene.uwa.edu.au
Dr Reg Watson	Fisheries Centre, University of British Columbia	r.watson@fisheries.ubc.ca
Dr Dirk Welsford	Tasmanian Aquaculture and Fisheries Institute	Dirk.Welsford@utas.edu.au
Dr Ron West	University of Wollongong	ron_west@uow.edu.au
Dr Alan Whitfield	South African Institute for Aquatic Biodiversity	A.Whitfield@ru.ac.za
Ms Annelise Wiebkin	SARDI Aquatic Sciences	wiebkin.annelise@saugov.sa.gov.au
Ms Tori Wilkinson	Department of the Environment and Heritage	tori.wright@deh.gov.au
Ms Jane Wilson	James Cook University	jane.wilson@jcu.edu.au
Mr John Winwood	SA Pilchard WG - Inland FMC	
Dr Qifeng Ye	SARDI Aquatic Sciences	ye.qifeng@saugov.sa.gov.au
Mr Brad Zeller	QLD Department of Primary Industries and Fisheries	brad.zeller@dpi.qld.gov.au
Dr Yuri Zharikov	University of Queensland	yzharikov@zen.uq.edu.au
Dr Shijie Zhou	CSIRO Marine Research	shijie.zhou@csiro.au

7. Symposium Progam

MONDAY 20 September

Morning: Plenary Sessions (for all three themes)

Session 1: Official Opening

Time	Presentation
8:00am	Registration
8:45am	Welcome: Tim Ward, Symposium Convener
8.50am	Hon Dr Sharman Stone MP, Parliamentary Secretary to the Federal Minister for Environment and Heritage

Session 2: Setting the scene

Time	Speaker	Presentation
9:05am	Tori Wilkinson	Ecological Assessment of Fisheries – Creation, Evolution, Revolution
9:20am	Rick Fletcher	Frameworks for assessing the management of marine resources – how do they all fit together?
9:35am	Leanne Fernandes	Biodiversity protection in the Great Barrier Reef Marine Park
9.50am	Ted Loveday	The Commercial Fishing Industry and Ecological Sustainable Development
10:05am	David Hall	ESD implications for the recreational fishing sector
10:20am	*Morning Tea*	
10:50am	Dan Gaughan	Goals of the Symposium from ASFB perspective

Session 3: International perspective - Keynote addresses from international speakers

Time	Speaker	Presentation
10.55am	William Montevecchi	Influences of Forage Species on Pelagic Food Webs: Signs from Seabirds
11:25am	Mark Butler	Benthic Fisheries Ecology in a Changing Environment: Unraveling Process to Achieve Prediction
11:55am	Don Jackson	Ecosystem Connections to River and Estuarine Fisheries
12:30pm	*Lunch*	

Session 4: Concurrent Sessions

Pelagic		Benthic		Rivers & Estuaries	
Time	Speaker & Presentation	Time	Speaker & Presentation	Time	Speaker & Presentation
1:30pm	Co-ordinators - Introduction	1:30pm	Co-ordinators - Introduction	1:30pm	Co-ordinators - Introduction
1:35pm	Reg Watson - Mapping global fisheries indicators and potential conflicts	1:40pm	George Branch - Biological interactions among rock lobsters, urchins, abalone and kelp: implications for ecosystem management	1:40pm	Alan Whitfield - Fish & freshwater in estuaries in South Africa
2:05pm	Bill Montevecchi - Sea bird indicators of changing pelagic food webs	2:25pm	Mark Butler - The ecological consequences of catching the Big Ones	2:10pm	Ian Halliday - Estuarine fisheries and flow management in central Queensland.
2:35pm	Simon Goldsworthy - Ecosystem approaches to examining seal-fishery trophodynamics: a comparison of a single and multi-species fishery in Australia	2:55pm	Russ Babcock - Benthic community structure and variation in indirect effects of fishing in Australasian kelp forests	2:30pm	Stephen Balcombe - Trophic basis of fish assemblages in an Australian dryland river
3:05pm	Tom Okey - Fishery-predator competition and the effects of predator depletions indicated by trophic models that incorporate benthic-pelagic coupling			2.50pm	Kim Smith - Catchment processes and fishery production in south-west WA
				3:10pm	Alison King - Highs and lows of fish recruitment in floodplain rivers
3:35pm	*Afternoon Tea*	*3:30pm*	*Afternoon Tea*	*3.35pm*	*Afternoon Tea*
3:50pm	Ashley Bunce - Improving fisheries sustainability: using seabirds to manage marine resources	3:50pm	Colin Buxton - Drivers for ecosystem based fisheries management in Australia	3:55pm	Jacqui Balston - Seasonal climate variability of (*Lates calcarifers*) fisheries in the GBR
4:10pm	Peter Gill - Blue whales in the Bonney Upwelling	4:15pm	Stewart Frusher - Multi-layered approaches to evaluating impacts of lobster fishing	4:15pm	Martin Mallen-Cooper - Fish passage – from go to whoa needs flow to go
4:30pm	Cathy Bulman - Trophodynamic Models in the South East Fishery	4:35pm	Greg Jenkins - Ecosystem effects of abalone fishing in Victoria	4:35pm	Bronwyn Gillanders - Otoliths, flows & fish movement
4:50pm	Barry Bruce - Determining ecological effects of longline fishing off eastern Australia	4:55pm	Rod Connolly - In situ and ex situ trophic consequences of fishing	4:55pm	Patrick Coutin -Ecosystem-based management of black bream in the Gippsland Lakes
5:10pm	Norm Hall -Implications from a model of the marine ecosystem off south-western australian	5:15pm	Sean Connell - Australia's southern reefs: theory meets reality	5:15pm	Keith Bishop - Changing freshwater inflows to Australian estuaries
5:35pm	*Close*	*5:35pm*	*Close*	*5:35pm*	*Close*

TUESDAY 21 September

Session 5: Case studies

Pelagic		Benthic		Rivers & Estuaries*	
Time	Speaker & Presentation	Time	Speaker & Presentation	Time	Speaker & Presentation
8:45am	**Chairs** - Overview of previous day	8:45am	**Theme coordinator** - Overview of previous day	8:45am	**Theme coordinator** - Overview of previous day
9:15am	**Chairs** - Introduce case studies	9:15am	**Theme coordinator** - Introduce case studies	8:55am	**Mark Lintermans** - Native Fish Strategy & Sustainable Rivers Audit
9:20am	**James Scandol** - Management issues	9:20am	**Craig Mundy** - Tasmanian abalone fishery	9:10am	**Mark Siebentritt** - Living Murray & MFAT
9:30am	**Sally Troy** - Pelagic bioregionalisation	9:30am	**Stewart Frusher** - Tasmanian rock-lobster fishery	9:25am	**Shaun Meredith** - Flow, wetlands & fish
9:40am	**Jeremy Lyle** - Commonwealth Small Pelagic Fishery	9:40am	**Stephen Mayfield** - South Australian abalone fishery	9:40am	**Martin Mallen-Cooper** - Murray fishways & flow
9.50am	**Dan Gaughan** - WA Pelagic fisheries	9:50am	**Adrian Linnane** - South Australian rock-lobster fishery	9:55am	**Mike Geddes/Qifeng Ye** - Flows, ecosystem & fish: the Murray Mouth/Coorong
10:00am	**Tim Ward** - SA Pilchard fishery	10:00am	**Lynda Bellchambers** - Western Australia rock-lobster fishery	10:10am	**John Koehn** - Fish biology, management & threats
10:10am	**Sam McClatchie** - SA Upwelling system	10:10am	**Craig Johnson** - Detecting indirect effects of fishing on the structure and dynamics of rocky reef communities		
10:20am	**Simon Goldsworthy** - GAB Ecosystem project				
10:30am	*Morning Tea*	*10:30am*	*Morning Tea*	*10:30am*	*Morning Tea*
11:00am	Identify key management needs and research questions. Consider options and approaches to pelagic ecosystem research.	11:00am	Identify key management needs and research questions. Consider options and approaches to benthic ecosystem research.	11:00am	Identify the role of flows in improving habitat quality, recruitment, productivity and linkages for fish in the River Murray. Consider the role of wetlands and non-flow factors in rehabilitation targeted at native fish. Summarise this knowledge by developing a conceptual ecological model for the relationships between fish and flow in the River Murray and Murray estuary.
12:30pm	*Lunch*	*12:30pm*	*Lunch*	*12:30pm*	*Lunch*
1:30pm	Discuss national strategies and approaches	1:30pm	Discuss national strategies and approaches	1:30pm	Develop conceptual model for fish ecology and develop research & management priorities
3:30pm	*Afternoon Tea*	*3:30pm*	*Afternoon Tea*	*3.30pm*	*Afternoon Tea*

Session 6: Closing (for all three themes)

Time	Presentation
4:00pm	Presentations from each theme & general discussion
5:00pm	Close

* Supported by CRC for Freshwater Ecology