Natural Resources and Environment

AGRICULTURE
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Fish Movement and Migration – an ASFB Workshop

David C Smith

Project No. 99/336

AUSTRALIAN SOCIETY for FISH BIOLOGY

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Victoria
The Place To Be

MARINE & FRESHWATER RESOURCES INSTITUTE

Fisheries Research and Development Corporation

Fish Movement and Migration - an ASFB Workshop

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NON-TECHNICAL SUMMARY

99/336 Fish Movement and Migration – an ASFB Workshop

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Objectives:

1. To undertake a national workshop on fish movement and migration
2. To produce a 'benchmark' publication on the current knowledge of fish movement and migration

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Non Technical Summary

Through the generous support of FRDC and State, Territory and Commonwealth fishery agencies, the Australian Society for Fish Biology (ASFB) has hosted a national workshop series since the early 1980's with eminent local and overseas scientists presenting keynote addresses on major themes. Increasingly, overseas scientists and managers have begun to attend these workshops as their reputation has spread. The primary purpose of these workshops is to promote the opportunity for the national fisheries research expertise to focus on a technical area or subject of current national or regional significance.

The topic of this workshop was fish movement and migration. The importance of this to fish conservation and management has been increasingly realised. In freshwater, improved fish passage has long been an issue for fish biologists and it is seen as one of the major areas for river rehabilitation over the next decade. Spatial models that take into account fish movements, explicitly or implicitly, are now widely used and/or being developed for stock assessment purposes. Changed fish movement due to varying environmental conditions may have significant impacts on species availability/catchability, and an understanding of these relationships is crucial to the interpretation of abundance indices. In addition, there are major implications for the management of migratory fish species, particularly those that span jurisdictional boundaries.

This Australian Society for Fish Biology workshop was the first time that migration and movement of fish has been considered in a national forum. It provided a forum in which the

latest techniques were presented in case studies from Australian and overseas situations. It brought together over 100 scientists, managers and other stakeholders with general or specific interests in movement and migration. The workshop covered theoretical aspects; techniques for measuring movement and migration, particularly new approaches and technologies (such as radio-telemetry, smart tags and otolith micro-chemistry); environmental determinants; barriers and human interference; analysis and input into spatial models; and management implications

Keynote papers by invited speakers, Dr Geoff Arnold, CEFAS, and Dr John Eiler, NMFS, demonstrated the significant technological developments that have greatly improved our understanding of the patterns of fish movement and migration. Such methods are providing surprising insights. Often the results show that fish movements are more complex and quite different from what were assumed or expected.

The Workshop Proceedings contain the papers given by each speaker as well as a record of the discussion following each paper and session. A final discussion period includes concluding remarks from the Drs Arnold and Eiler.

The citation for the proceedings is:

Hancock, D.A., D.C. Smith and J.D. Koehn (eds) 2000. *Fish Movement and Migration*. Australian Society for Fish Biology, Sydney, 288p

Proceedings are sent to all workshop delegates and ASFB members. Additional copies can be obtained from ASFB's Newsletter Editor: Kylie.Hall@nre.vic.gov.au for $25.00 per copy plus postage.

KEYWORDS: Fish, movement, migration, tags, ASFB

FINAL REPORT

99/336 Fish Movement and Migration – an ASFB Workshop

Background

The Australian Society for Fish Biology (ASFB) has taken the lead in encouraging international scientific links in fisheries research and management in Australia. Through the generous support of FRDC and State and Territory fishery agencies, ASFB has hosted a national workshop series since early 1980's with eminent local and overseas scientists presenting keynote addresses on the major themes. Increasingly, overseas scientists and managers have begun to attend these workshops as their reputation has spread. The purpose of these workshops is to:

- promote the opportunity for the national fisheries research expertise to focus on a technical area or subject of current national or regional significance - such area or subject to be identified by the membership of the society or by the Council, as appropriate;
- support, where appropriate, visiting fisheries scientists of acknowledged expertise in the workshop subject area to offer a national or international perspective;
- assist in the publication of workshop proceedings as a benchmark document of current knowledge in the workshop subject area; and
- identify and define research questions of national fisheries significance.

This ASFB workshop will be the first time that the migration and movement of fish has been considered in a national forum.

In 1988, ASFB and the then Bureau of Rural Resources convened a workshop on tagging, 'Tagging - Solution or Problem'. This workshop focussed on all aspects of tagging. Tags as a means of measuring movement and migrations in fish were considered as part of the current workshop proposal. However, the emphasis here was on new approaches and technologies. There have been major technical advances in the last 10 years.

Need

Most fish and other exploited aquatic species exhibit movement and/or migrations during some part of their life cycle. In recent years the importance of these migrations to fish and fisheries management has been increasingly realised. Changed fish behaviour due to varying environmental conditions has significant impacts on species availability/catchability and hence the interpretation of abundance indices. In freshwater, improved fish passage is seen as one of the major areas for river rehabilitation to be conducted over the next decade. Spatial models which take into account, explicitly or implicitly, fish movements are now widely used. Recent technological developments allow for greatly improved analysis of the patterns of fish

movement and migration. This Australian Society for Fish Biology workshop will be the first time that migration and movement has been considered in a national forum.

The workshop brought together scientists, managers and other stakeholders with general or specific interests in movement and migration. The workshop covered theoretical aspects; techniques for measuring movement and migration, particularly new approaches and technologies (such as radio-telemetry, smart tags and otolith micro-chemistry); environmental determinants, barrier and human interference; analysis and input into spatial models; and management implications.

Objectives

1. To undertake a national workshop on fish movement and migration
2. To produce a 'benchmark' publication on the current knowledge of fish movement and migration

Methods

The 1999 ASFB workshop was held at Bendigo, Victoria. The Workshop and Conference followed the now standard format with the Workshop "Fish Movement and Migration" held on Tuesday, 28 and Wednesday 29 September, a lay day on Thursday, 30 September, and the Annual Conference on Friday, 1 October and Saturday, 2 October. All sessions were held in the recently renovated Bendigo Regional Arts Centre.

The two-day workshop addressed issues concerning movement and migration during four sessions:

Overview - current knowledge and recent developments

Keynote addresses - Dr G Arnold and Dr John Eiler (brief CVs are given below))

Techniques for measuring	Chair John Gunn
Environmental determinants, barriers & human interference	Chair John Koehn
Analysis, interpretation and spatial models	Chair Andre Punt
Management implications	Chair Nick Rayns

The workshop provided a forum in which the latest techniques were presented in case studies from Australian and overseas situations.

As in previous workshops, the Chairs of each session selected a number of panellists covering a wide range of topics within each session theme. Considerable time was allocated during each session for general discussion that was recorded by rapporteurs. As in previous years, workshop discussions were an important component of the workshop publication.

The workshop was co-convened by David Smith and John Koehn.

Keynote speakers

Dr Geoff Arnold
Program Leader
Centre for Environment, Fisheries and Aquaculture Science
Lowestoft, England.

Geoff Arnold is internationally acknowledged for extensive research into the movement and migration of fish. At CEFAS he leads a large group of scientists whose scientific foci are studies into the movement, behaviour and migration of fishes in the North Sea and NE Atlantic Oceans. He also has responsibility for a team of electronics engineers who have been very active in developing new tools with which to collect data on movement and behaviour. Dr Arnold and his team have used multi-beam sonar, acoustic tracking and recently also data storage tags to examine the movement of species such as plaice and cod. He chairs ICES working groups on migration and recently co-authored a paper on the ground-breaking work his lab is conducting using data storage tags.

Dr John Eiler
Project Leader
National Marine Fisheries Service
Juneau, Alaska USA

John Eiler is a senior fisheries biologist with extensive experience in the study of fish movement and migration. He is currently Project Leader, Yukon River Salmon Studies. Much of his recent work has been studying the movement patterns of salmonids using radio telemetry.

Results/Discussion

The workshop was well attended with over 100 participants. Mr Ross Hodge, Executive Director, Seafood Industry Victoria, welcomed delegates and their partners to the workshop at a welcome function held at the Bendigo Art Gallery on Monday 27th September 1999.

The Workshop Program and presentation abstracts are given in Appendices 3 and 4, respectively.

The Workshop Proceedings contain the papers given by each speaker as well as a record of the discussion following each paper and session. A final discussion period includes concluding remarks from the Drs Arnold and Eiler. Full papers were received from all but three panellists.

The citation for the proceedings is:

Hancock, D.A., D.C. Smith and J.D. Koehn (eds) 2000. *Fish Movement and Migration*. Australian Society for Fish Biology, Sydney.

Proceedings are sent to all workshop delegates and ASFB members. Additional copies can be obtained from ASFB's Newsletter Editor: Kylie.Hall@nre.vic.gov.au for $25.00 per copy plus postage.

Issues for the Future

The workshop was generally regarded as very successful, covering a broad range of current studies on fish movement and migration and their implications for management.

To assist organisers of future workshops of this type, two issues are identified that should be considered.

ASFB workshops attract considerable interest and the format has been developed over time to enable the greatest participation possible. It is important to ensure that there is adequate time for discussion during each session or else the workshop is in danger of becoming a series of seminars. Generally, this was achieved during the current workshop. Session Chairs have to be ruthless regarding time taken by panellists to get across key points. They also need to ensure that discussion periods are not dominated by a few participants only.

In the past, presenters were required to provide abstracts prior to the workshop and full manuscripts afterwards. Future organisers should consider requesting full papers prior to the workshop. This will ensure timely publication of the proceedings and that papers are received from all participants.

Benefits

The Australian Society for Fish Biology (ASFB) has taken the lead in encouraging international scientific links in fisheries research and management in Australia. Through the generous support of FRDC and State and Territory fishery agencies, ASFB has hosted a national workshop series since early 1980's.

In recent years, there have been significant technological developments that have greatly improved our understanding of the patterns of fish movement and migration. Such methods are providing surprising insights. Often the results show that fish movements are more complex and quite different from what were assumed or expected. The Overview Papers by invited speakers, Dr Geoff Arnold and Dr John Eiler, provided striking examples of this. They demonstrated the role that new technologies have played in improving our understanding of fish migrations, providing a valuable international perspective.

This workshop, attended by over 100 scientists, managers and other stakeholders, provided a “snapshot” of the current techniques and information on fish movement and migration. The published proceedings provide a “benchmark” on this important are of fish and fisheries biology.

Acknowledgements

FRDC was the principal sponsor for the workshop and has generously supported ASFB workshops since 1988. The Murray-Darling Basin Commission, Fisheries Victoria and Parks Flora and Fauna of the Department of Natural Resources and Environment, Melbourne Water, Hallprint Tags, the Floy Tag Co. and Lotek Marine Technologies, were also significant contributors to this workshop.

John Koehn co-convened the workshop and was a Session Chair, and the other Session Chairs, John Gunn, Andre Punt and Nick Rayns are thanked for their help with the program and for ensuring the workshop ran smoothly.

The other members of the local organising committee for the workshop and conference were: Martin Gomon, Rob Day, Sandy Morison, Kylie Hall, Tarmo Raadik, Brenton Zampati, Victor Gomelyuk, Tim O'Brien, Simon Nicol and Dianne Bray.

The proceedings were edited by Don Hancock, David Smith and John Koehn, and the text editor was Diane Mahon.

Appendix 1: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licences. The intellectual property associated with information produced from the project is shared between FRDC and ASFB. FRDC has been acknowledged in all publications resulting from the project.

The copyright for material presented in the workshop proceedings is held by the Australian Society for Fish Biology.

Appendix 2: Staff

Dr David Smith	MAFRI, Vic	Principal Investigator
Mr John Koehn	ARI, Vic	Co-Investigator/Session Chair
Dr Andre Punt	CSIRO	Session Chair
Dr John Gunn	CSIRO	Session Chair
Dr Nick Rayns	NT DPIF	Session Chair
Mr Sandy Morison	MAFRI, Vic	Workshop Treasurer
Ms Diane Mahon	MAFRI, Vic	Text Editor and administrative support
Dr Don Hancock	WA	Proceedings Editor

Appendix 3 Workshop Programme

Monday 27 September 1999

7.00pm Workshop Welcome Function (Bendigo Art Gallery)

Tuesday 28 September 1999

8.40am **Welcome and Introduction**
David Smith

Opening remarks from FRDC
Alex Wells

9.00 **Overview Address - Unravelling mechanisms of fish migration: a 30-year perspective**

Geoff Arnold

9.45 Morning Tea

10.00 **Session 1 - Techniques for Measuring**

Chair's Introduction
John Gunn

Why use radio tags to study freshwater fish?
John D. Koehn

Fishways as tools for monitoring movement patterns of large fish populations
Ivor Stuart

Is there a role for 'uncontrolled' tagging in 'real' fisheries science?
Julian G. Pepperell

Acoustic tracking
Geoff Arnold

From plastic darts to computer-controlled pop-up satellite tags
John Gunn

Acoustic tracking of small-scale movement in juvenile southern rock lobster (*Jasus edwardsii*)
David Mills, Caleb Gardner, Sam Ibbott and Simon Willcox

Shark tagging: a brief history of methods
John Stevens

Application of otolith chemistry to studies of fish movement and migration
Naomi Clear and John M. Kalish

Discussion of Session 1
Chaired by John Gunn. Recorded by Barry Bruce

12.45 Lunch

1.30 **Overview Address - Fish movements – the missing piece**
John H. Eiler

2.15 **Session 2 - Environmental determinants, barriers and human interference**

Chair's Introduction and Overview
John D. Koehn

Taking the mystery out of migration
Martin Mallen-Cooper

Environmental cues in the reproductive migrations of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) in Lake Eucumbene, New South Wales
Richard Tilzey

3.00 Afternoon Tea

3.30 Environmental determinants of the movement and migration of juvenile southern bluefin tuna
John Gunn and Jock Young

Overcoming physical barriers to fish migration
Tim O'Brien

Sampling to detect the impact of barriers on fish movement
Tim Marsden

Characteristics of movement of adult King George whiting (*Sillaginodes punctata*) in South Australian waters
A. J. Fowler and W. A. March

Migration and assessment of glass eels (*Anguilla australis*) in the Snowy River system, south-eastern Australia
Lachlan J. McKinnon, Geoff J. Gooley and Richard J. Gasior

Discussion of Session 2
Chaired by John Koehn. Recorded by Pam Clunie

5.15 Close

Wednesday, 29 September 1999

9.00 Session 3 - Analysis, interpretation and spatial models

Chair's Introduction
André E. Punt

Modelling school shark (*Galeorhinus galeus*) movement in the Southern

Shark Fishery
Terence I. Walker, André E. Punt, Bruce L. Taylor and Lauren P. Brown

Do Bayesian concepts assist the ability to interpret migration and movement patterns of freshwater fish?
Simon Nicol

Including spatial structure when conducting yield-per-recruit analysis
André E. Punt and Gurong Cui

Directing experiments in freshwater ecology using spatial population models developed in freshwater fish
Charles R. Todd

10.15 Morning Tea

10.45 Preliminary analysis of migration of adult, red-legged, banana prawns in Joseph Bonaparte Gulf, northern Australia
R. A. Kenyon and D. J. Die and N. R. Loneragan

Computer visualisation of spatial models for communication and management
James Scandol

A spatial representation of the tiger prawn (*Penaeus esculentus*) fishery in Shark Bay, Western Australia
N. G. Hall and R. A. Watson

Discussion of Session 3
Chaired by André Punt. Recorded by Robin Thompson

12.00 Lunch

1.00 **Session 4 - Management Implications**

Chair's Introduction
Nick Rayns

The fishery for Australian salmon: management issues
Stephen McCormack

Management implications for movement and migration in a rock lobster fishery
Will Zacharin

Managing Pacific tuna fish: an Australian perspective
Dorothea Huber

Fisheries management implications of barriers to movement and migration by fish in New South Wales
Andrew C. Sanger

The challenge of spatially managing fish movement and migration throughout Northern Australia: the experience with tropical snappers

Ray Clarke

Tasmanian whitebait – A multi-species fishery targeting migrating fishes
Wayne Fulton

Management implications of fish movement and migration - the role of the consultant
John McGuckin

Discussion of Session 4
Chaired by Nick Rayns. Recorded by Patrick C. Coutin

3.30 Afternoon Tea

4.00 **Session 5 General Discussion**
Chaired by David C. Smith. Recorded by Alexander Morison

5.15 Close

Appendix 4 Abstracts

Overview Address

Unravelling mechanisms of fish migration: a 30-year perspective

Geoff Arnold
CEFAS, Lowestoft Laboratory, Pakefield Road, Lowestoft Suffolk NR33 0HT UK

We have learnt more about fish migration over the last 30 years, since the introduction of the acoustic tag, than in the preceding 75 years, following the invention of the Petersen disc. The rate of progress continues to accelerate. Acoustic tags allowed us to track free ranging individually identified fish over several days and describe their patterns of vertical and horizontal movement in some detail. Archival tags have allowed us to extend these observations over several years and replicate observations with large numbers of fish, without using a research vessel. Pop-up tags, which float to the surface after a pre-set time and communicate with satellites, should allow us to recover large amounts of data independently of the fisheries. The aim of my overview, which will concentrate mostly on marine fish, is to assess the scientific advances made with these new tools and suggest possible avenues for future research. I will start by summarising what we knew about the linkages between production cycles, water circulation and fish life histories in the late 1960s and then describe how our views have changed as a result of recent research. I will attempt to synthesise work done in the open ocean, as well as on the continental shelves, and also to indicate what the new observations reveal about possible mechanisms of orientation and navigation.

Fish Movements – Tactics for Survival

John H. Eiler
National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway Juneau Alaska 99801 USA

Movement patterns are an important component in the life history strategies of fish species, and provide the mechanism for accessing and utilizing resources necessary for survival. Fish populations adapt their movements to accommodate to restrictive local conditions. Although often oversimplified due to the difficulty in collecting data, or considered ancillary to other types of information, an understanding of movement and activity patterns can provide significant insight into the management of fish populations. Advances in technology are providing new tools for collecting detailed information to address these information needs. Information from three studies on fish species in Alaska, USA will be presented and discussed in relation to survival strategies and management considerations.

Session 1 – Techniques for measuring

Introduction

John Gunn
CSIRO Marine Research, PO Box 1538, Hobart VIC 7000

In the last decade, fisheries science has benefited from the development of a wide range of new technology and methods to directly measure or indirectly reconstruct the movement of fishes in both marine and freshwater environments. The panelists in this session will describe a number of these new approaches, review their advantages, disadvantages and potential for use in describing movement, migration and behaviour of teleosts and invertebrates. As most of the panelists are actively involved in research using the new approaches, they will briefly highlight results from studies they have undertaken.

Our objective within the session is to promote discussion and involvement of the audience, and in so doing promote the appropriate application of new technology and methods into Australian.

Session 2 - Why use radiotags to study freshwater fish?

Introduction

John Koehn
Freshwater Ecology, Arthur Rylah Institute, 123 Brown St, Heidelberg VIC 3084

A wide range of techniques and methods are available for marking and tagging fish. Selecting the most appropriate tagging method depends both on the purpose for which tagging is required and the species on which it is to be used. Which method will best help answer the questions being asked? Tagging and marking can be divided into two categories: those which provide a batch mark and those which can identify individual fish. This paper provides a brief review of all tagging techniques considering the benefits and constraints of each. Sonic and radio tags have the added advantage of allowing individual fish to be tracked on a continuous basis and 'observations' and measurements made of 'natural' behaviour. The differences between the use of sonic and radio tags are discussed for the study of freshwater fish. Options for different radio frequencies, tag configurations, tracking devices, data loggers, remote stations, costs and attachment techniques are explored. The benefits of the development and use of radio tags in Australia for the study of Murray cod and other species are given as examples.

Fishways as tools for monitoring movement patterns of large fish populations

Ivor Stuart
Freshwater Ecology, Arthur Rylah Institute, 123 Brown St, Heidelberg VIC 3084

The recent advent of effective fishways has presented researchers with an important opportunity to not only monitor large scale fish movements, but to also quantify other more subtle behavioural habits exhibited by native fish. Traditional count data are useful to determine the effectiveness of a fishway and assess long term changes in the abundance and species composition of migratory fish populations. However, several emerging technologies will potentially further develop this research. For example, the entrance of a fishway is a very useful site for remote scanning of fish previously tagged with active or passive internal tags. Such technology is now commonly used and is advantageous because there is no requirement for continued handling of migrating fish. Hence, long-term data, such as fish home range and timing of spawning movements can be reliably collected. Several case studies will be presented outlining the current technologies and methods used for monitoring of large migratory fish communities in fishways, their advantages and possible limitations. Effective incorporation of such movement data into practical management plans for enhancement of native fish populations and control of non-native fish will also be discussed.

Is there a role for 'uncontrolled' tagging in 'real' fisheries science?

Julian G Pepperell
Pepperell Research & Consulting Pty Ltd, PO Box 818, Caringbah NSW 2229

Tagging of fish by fishery participants is popular for many reasons. The best known examples of this activity are so-called cooperative tagging programs through which recreational anglers tag and release fish as part of a broad scale tagging undertaking. There are many such programs in operation around the world, some of which have been in operation for many years. Periodic reviews of long term programs allow assessment of their progress, utility and application to research goals.

The main differences between user-based and scientific tagging operations tend to lie in the areas of planning and quality control. Scientifically tagged fish may be caught by more 'fish friendly' methods, be more carefully handled and be more accurately measured. It is also likely that scientifically based tagging operations result in better quality data overall since data on all fish released are retained. These differences appear to be intuitively obvious, but may not necessarily real. Are scientifically based tagging programs really so well structured, and do they always (or even usually) achieve their goals? And in practice, how poorly structured are user-based programs?

A review of user-based tagging programs will be presented, demonstrating their strengths and weaknesses. Examples of results which would not otherwise have been forthcoming will be discussed.

Acoustic tracking

G. P. Arnold
CEFAS Lowestoft Laboratory, Pakefield Road, LOWESTOFT Suffolk NR330HT UK

Acoustic tags (30-300 kHz) are used to track marine fish because sound propagates well in the sea; they can also be used in freshwater, if there is no aeration. Simple 'pingers' transmit regularly; transponders transmit on receipt of an external signal. Both can be used to telemeter environmental, or physiological data. Tags can be individually coded by modulating frequency or pulse repetition rate, or using pseudo random (PN) numbers, which allow large numbers of fish to be tracked simultaneously. A simple tracking system (directional hydrophone, receiver and headphones) provides only an approximate indication of fish location. Accurate location requires a fixed hydrophone array, a towed hydrophone array, or a mobile sonar. A 30 kHz tag may have a range of more than 1 km; a 300 kHz tag usually has a range of less than 400 m. Frequencies of 30-50 kHz are commonly used for tracking large pelagic fish; frequencies of 150-300 kHz are used with small fish or in conjunction with imaging sonars. Weather permitting, a large research vessel can track an individual fish until the tag batteries are exhausted, usually after 10-15 days at the most. With a small boat, track duration is limited more by human endurance.

From plastic darts to computer-controlled pop-up tags

John Gunn
CSIRO Marine Research, GPO Box 1538, Hobart TAS 7001

The development of electronic tagging technology over the last decade has provided today's fisheries researchers with many new options for studying the movement and migration of marine fishes. Conventional tags (dart, disc, internal etc) have provided us with only points of release and recapture, and often these reflect the distribution of fishing effort rather than the true movements of fish.

Acoustic tags provide a means of examining movement patterns in very fine detail. When they include environmental (water temperature) or physiological (EMG) sensors they also allow us to study the interaction of the animal with its environment. However, the duration of most tracks is limited by the technology (in particular battery power), cost (tracking vessel charter etc) and human endurance (tracking is a very labour intensive activity). There is also a question of whether a tagged animal behaves "normally" in the first 24-48 hrs tagging when it is being followed by a vessel.

Since their development in the early 1990's, archival tags have been used extensively in tunas (Australia and the US) and ground fish (UK/Europe). These tags are miniature data loggers incorporating environmental sensors (light, temperature, depth). They can record data every few minutes for years, allowing researchers to study the daily/weekly/seasonal/inter-annual variation in movement, migration, behaviour and physiology of their study animals. They are relatively expensive ($2000) and can only be

used where the expected recapture rate warrants the cost of tags. The data from these tags have provided researchers with a quantum leap in the understanding of their animals, and in many cases has shown that models of movement and migration developed from conventional tagging have been seriously flawed. Although the studies conducted to date have focussed on large animals (tags currently available are 50-70 mm in length and weigh 25g in air) archival tag manufacturers are currently designing and testing tags that will be suitable for use in fish as small as 500g.

Pop-Up satellite transmitting archival tags currently being developed and tested in the US, Europe and Australia promise to provide all the data logging functionality of archival tags without the need to recapture the fish. These tags are a hybrid of an archival tag and a satellite transmitter, allowing researchers to program data collection over a specified period and a predetermined release date. On that date, a corrosive link within the tag is activated, allowing the tag to release from the fish, float to the surface and start transmitting a summary of the data collected to a NOAA satellite carrying an ARGOS receiver. Only a small fraction of the data collected can be transmitted to the satellite due to low transfer rates. This presents significant problems in transmission of position estimates as these often involve considerable data manipulation. At present manufacturers are testing on-board geolocation estimation software.

Acoustic tracking of small-scale movement in juvenile southern rock lobster (*Jasus edwardsii*).

David Mills
Tasmanian Aquaculture & Fisheries Institute, GPO Box 252/49, Hobart TAS 7001

A rock lobster aquaculture industry based on on-growing wild-caught puerulus (late larval stage) is likely to commence in Tasmania in the near future. To ensure that puerulus extraction has no effect on the wild fishery, it is proposed that, after a year of on-growing, a number of lobsters be released equivalent to the proportion that would have survived in the wild. Current best estimates put first year survival at around 25%. Information on survival of released animals is required before this method of compensation can be employed.

Acoustic tracking has been used successfully to monitor short term survival and behaviour of lobsters released after on-growing for 1 year. On-grown and wild-caught lobsters were tagged with acoustic transmitters, and released on an area of patch reef. Each transmitter emitted a unique frequency to allow individual identification of lobsters in close proximity. The combination of a sensitive, narrow-band boat-mounted receiver, and a diver-held receiver enabled tagged lobsters to be located regularly by divers. Movement was accurately measured, habitat preference and behaviour assessed, and comparisons made between wild and on-grown animals. Lobsters were re-captured at the completion of the field trial to asses feeding success, and change in condition during liberty. While this approach to tracking was labour-intensive, data quality was high, and the ability to recapture animals invaluable.

Tagging sharks

John Stevens
CSIRO Marine Research, GPO Box 1538, Hobart TAS 7001

The first large-scale shark tagging programs were initiated during the 1940s using Petersen disc tags (or similar variants) wired through the relatively rigid first dorsal fin. During the same period in Australia, school sharks were tagged with internal Nesbit tags inserted into the body cavity. These tags, developed because of concerns over high shedding rates of early fin tags, still hold the record for the greatest time at liberty of any tagged fish, with some recaptures made 40 years after tagging. The 1960s saw the trialing and use of plastic cattle ear tags (rototags), applied to the first dorsal fin, that had much better retention qualities than the earlier fin tags. The same era saw the initiation of large-scale co-operative game fish tagging programs, particularly in the USA, and the development of dart tags that could be applied without removing the shark from the water. More recently, shark tagging has taken advantage of electronic technology to overcome some of the limitations of standard tagging methods. A number of species have been tracked with acoustic tags. Satellite tags have been used on blue and whale sharks and archival tags have produced exciting results on school sharks.

Application of otolith chemistry to studies of fish movement and migration

John M. Kalish
Bureau of Rural Sciences, PO Box E11, Kingston ACT 2604

In the past decade, research has confirmed that otoliths contain a chemical record that can be interpreted in relation to the past life of individual fish. The extent to which this chemical record can be considered an undistorted log of past environments and, concomitantly, movements experienced by a fish is still open to debate. Furthermore, the complexity of this debate has increased dramatically in recent years. Otolith chemistry has progressed from measurement of major trace elements in whole otoliths by solution-based atomic absorption spectrophotometry, to the quantification of individual isotopes at ultra-trace levels with quadrapole mass spectrometers linked to laser ablation systems. This advance represents the jump from identifying changes in the gross chemical composition of individual otoliths, to the determination of the age at which an individual fish moved into a particular estuary. The instrumental escalation associated with otolith chemistry studies is the result of three key factors: 1) development and increased availability of new analytical instrumentation; 2) a greater appreciation, by fish biologists, of aquatic chemistry and its possible influence on the composition of fish; and 3) increased collaboration with those involved in geochemistry and related disciplines. Although analysis of an individual otolith may have reached new heights in terms of cost and complexity, the detailed information that can now be extracted is unlikely to be attainable by any other method. Furthermore, these data are realised without manipulation of the fish prior to its death, ensuring a virtually unlimited supply of samples.

Environmental determinants, barriers and human interference to the movements of fish.

John Koehn
Freshwater Ecology, Arthur Rylah Institute, 123 Brown St, Heidelberg VIC 3084

The purpose of this paper is to provide an overview and to stimulate discussion for this workshop session. Types of fish movement include: large scale, local, migratory, seasonal, daily, active, passive, diurnal, upstream, downstream and vertical. Some of these movements have well understood, definite purposes, whilst others are not understood at all. Some of these movements have a definite purpose whilst others are not understood at all. Such movements can be stimulated by a range of environmental variables, which can act either alone or in combination with other variables. Many of these variables have been altered by human interference. Barriers to such movements are often common, particularly in river systems. Barriers can be either a physical structure or a non-physical impedance such as an interruption to suitable water quality, quantity or velocity. Many captures of freshwater fish are aided by or rely on the movements of fish. Whilst this forms a major example of human interference, such interference also takes many other forms. The effects of environmental such interference to these movements are illustrated through examples using individual species.

Taking the mystery out of migration

Martin Mallen-Cooper
Fishway Consulting Services, 8 Tudor Place, St Ives NSW 2075

In south-eastern Australia the migration of freshwater fish is a widespread phenomenon and many of the general patterns of migration are well known. Diadromous migrations (between the freshwater and the sea) are common in coastal rivers and potamodromous migrations (wholly within freshwater) are common within the Murray-Darling river system. What stimulates these migrations, how important are they, and how do we best manage them?

Season, streamflow, and water temperature are major cues for migration, sometimes overlaid by diel period. Large rises in river level often stimulate large fish to migrate, but small rises and low flows are very significant cues for the movement of smaller immature fish, and these can be severely affected by river regulation.

The geography of south-eastern Australia, with generally low relief on the coastal plains and for much of the Murray-Darling Basin, has meant that the most common barriers to migration are low-level weirs which are submerged during floods. These barriers are changing the structure of freshwater fish communities in the streams of this region, with the migratory species that appear to be adapting most effectively to these changes being characterised by:

- having facultative migrations, or
- making small-scale migrations that can be completed between barriers, or

- migrating at high flows when the low-level weirs are submerged, or
- migrating on a wide range of flows, including high flows.

Those species or life stages which have obligate or large scale migrations at low or moderate flows (when weirs are barriers) are declining most rapidly. This highlights some priorities for management which include designing fishways for these flows, and providing environmental flows for the fishways to function and to stimulate migration.

Environmental cues in the reproductive migrations of brown trout (Salmo trutta) and rainbow trout (Oncorhynchus mykiss) in Lake Eucumbene, NSW

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During studies into the dynamics of Lake Eucumbene trout populations, the winter spawning 'runs' in a major inlet stream were monitored via a fish-trap. Details of fish entering the trap's upstream chamber, stream depth and air/water temperatures (max/min) were recorded daily during May-October, the spawning season. Also, several mark/recapture experiments were conducted and the reproductive homing behaviour of brown trout resulted in tagged spawners being recaptured in successive years. For both species, the major upstream migration cue appeared to be stream flow, with most fish moving during or immediately after rises in stream level. However, comparison between flow regimes in successive years and the recapture dates of marked brown trout suggested an innate mechanism such as individual maturation cycle, possibly associated with day-length, might over-ride or exert a strong influence on localised environmental migration cues for this species.

Environmental correlates of movement and migration in juvenile Southern Bluefin Tuna

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Southern Bluefin tuna are among the most highly migratory of teleosts. Adults are thought to make spawning migrations each year from feeding grounds in the southern Atlantic, Indian and Southern Oceans to spawning grounds south of Java in the tropical Indian Ocean. From the spawning grounds juvenile SBT are thought to migrate south along the Leeuwin current reaching the south west coast of Western Australia within a year. At this point majority head into the Great Australian Bight, where they spend their summers for the next 3-4 years.

Through a large-scale archival tagging experiment we have been studying the movement, behaviour and physiology of 2-5 year old SBT, in the GAB, and during their winter migrations to oceanic waters in the Indian Ocean and the Tasman Sea. The data collected by the 75+ tags returned to date have provided new insights into cues for migration, short

term and seasonal changes in behaviour, and the links between behaviour, movement and key environmental factors.

Overcoming physical barriers to fish migration

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A recent inventory identified more than 2000 dams and weirs as potential barriers to fish movement in Victoria. Not generally recorded were the large numbers of relatively minor instream structures such as culverts and fords.

Most native fish are unable to leap, many migrate as juveniles with relatively poor swimming capabilities and some species are reluctant to enter darks areas such as pipes. Almost any vertical spill of water such as occurs at stream gauging weirs or eroded culvert outlets, areas of high water velocity, shallow depth or lacking in light such as within a culvert can all prevent or delay fish movement. This may lead to increased predation, loss of breeding opportunities and in some cases the local extinction of fish species.

For dams and weirs a number of fishway designs, including rock-ramp, vertical-slot, denil, bypass channel, and fishlifts have been installed to varying degrees of success. However, guidelines designed for use by engineers to provide for fish passage at small structures such as stream gauging stations and culverts are required.

It is critical to the success of any fishway works program that in addition to the hydraulic, engineering and financial constraints of any works, all designs take account of the biological requirements of the species present. At present much of this information is lacking, and further research is required into the biology and behaviour of many fish species to determine burst and sustained swimming capabilities, direction and periods of movement on both a seasonal and diurnal basis, the use of existing fishways, behaviour at other barriers or within weir pools and the influence of factors such as flow regime and the operation of irrigation/regulation schemes on movement and passage past instream structures. It is essential that engineers and biologists work together to formulate appropriate designs.

Sampling to detect the impact of barriers on fish movement

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With the recognition of the detrimental impacts of dams and weirs on native fish populations and the increased interest in fishways in Australia, there has been growing impetus to ensure river regulation agencies are responsible for mitigating the effects of their structures. Before committing considerable sums of money towards the construction of a fishway these agencies often require scientific evidence that the structure is having a measurable impact on

migratory fish communities. To date there have been few studies in Australia which have scientifically demonstrated the impacts of construction of instream barriers on migratory fish communities. Most impacts have been identified from anecdotal evidence provided by ad hoc surveys or angler reports. However, recent studies have refined these earlier efforts using better sampling technology and methodology to show the impacts that weirs and dams are having on the fish communities of the target river systems. Utilising backpack and boat mounted electrofishers to effectively sample the whole fish community above and below impacting structures has enabled us to show convincingly to the operator that there is a requirement for some form of mitigating fish passage device. An outline of the sampling design, techniques and results from studies on the Shoalhaven (NSW), Pioneer and Burdekin Rivers (QLD) indicates the success of this type of study to identify the impacts of dams and weirs.

Characteristics of movement of adult King George whiting (*Sillaginodes punctata*) in South Australia

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The King George whiting is a significant fishery resource of coastal areas of southern Australia. In South Australia, the state which supports the largest fishery, there have been numerous tag/recapture studies which provide information on movement patterns. Between the 1960s-80s approximately 26,000 fish were tagged, from which 1,561 recaptures provided useful data on movement. The patterns of movement varied in a consistent way from place to place. Fish from northern Gulf St. Vincent and Spencer Gulf moved southwards up to several hundred kilometres, but those from the south moved shorter distances, with no systematic directional displacement. As a consequence, population size and age structures varied systematically throughout the fishery area. Such patterns of movement resulted in habitat shifts that were associated with ontogenetic development. Fish ultimately moved from shallow areas dominated by seagrass meadows to relatively deep, off-shore reefs and shoals in exposed locations. The latter, which represented only a small part of the distribution of the species, were the spawning grounds where reproductive activity took place.

The results indicate that adult movement is an obligate step in the life-history of this species, resulting in significant habitat shifts and ultimately the replenishment of relatively small spawning areas. The human activity that most impacts on this process is fishing. This is a "gauntlet" fishery where as the fish move southwards, they must run the gauntlet of the commercial nets, lines and recreational lines targeted at their capture by fishers. The estimates of fishing mortality on the small, young, immature fish is very high. Consequently, management practises must ensure sufficient escapement through the gauntlet to replenish populations at the spawning grounds.

Migration and Assessment of Glass Eels (*Anguilla australis*) in the Snowy River System, South-Eastern Australia

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Juvenile anguillid eels, known as glass eels, form the basis of important commercial fisheries in many parts of the world. The majority of glass eels are used as seedstock for aquaculture as the artificial propagation of anguillid eels is not yet technologically possible. Several environmental cues are thought to influence both the invasion of anguillid glass eels into estuaries from the sea as well as their migration patterns within estuaries. With an understanding of these environmental correlates it is considered possible to determine optimal fishing times to target peak glass eel invasion and migration phases.

The invasion of Australian shortfinned glass eels into south-eastern Australian estuaries was investigated for the purpose of characterising the primary environmental cues associated with such invasions and subsequent migrations. Glass eel assessment surveys were conducted in the Snowy River, south-eastern Australia, as part of a national glass eel assessment program during winter and spring of 1997 and 1998. Catch per unit effort (CPUE) was used to estimate relative abundance of glass eels. Several variables were examined for possible correlations with glass eel abundance including water temperature, salinity, stream discharge, tidal and lunar phase.

CPUE of glass eels was highly variable between years and in most cases significant effects of several environmental variables were observed. The results suggest that the migration of *A. australis* glass eels occurs during discrete seasonal periods in the Snowy River, and that optimum fishing times can be identified using a range of environmental criteria including tidal and lunar phase, water temperature, stream discharge and salinity.

Session 3: Analysis, interpretation and spatial models

Introduction

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Movement and migration can have important implications for management and understanding of the nature of species concerned. However, most of the techniques required to measure movement and migration lead to vast quantities of data, which require model-based methods for interpretation. For example, the results from tagging studies can only be interpreted meaningfully once they have been analysed in conjunction with information on the probability of a tagged animal being recaptured (which may depend on whether it has grown and where it has moved to).

The methods of fisheries science have always included approaches to estimating movement and migration (e.g. Ricker, 1954). However, even the application of simple methods can be computationally prohibitive and this has limited detailed analysis and modelling of data on movement. Recently, however, the availability of computing resources of sufficient power has meant that some more realistic spatial models can now be considered. These, combined with the more rigorous statistical treatment of the data (using, for example, maximum likelihood and Bayesian approaches) means that management advice based on models that explicitly recognise and handle movement and migration may be close at hand (or here already).

References

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of Fisheries Research Board of Canada* 191.

Modelling school shark (*Galeorhinus galeus*) movement in the southern shark fishery

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Tag release–recapture studies during 1947–99 show widespread movement of school sharks throughout southern Australia. Some of these long-lived sharks (>50 years) undertake migrations of more than 2000 km across the range of the fishery and the Tasman Sea. There is evidence of annual movement by a portion of the large animals between the eastern and western regions of the fishery, with some of the population moving north and south on the east coast of Australia. Not so well understood are movement patterns on and off shore. Parameters for quantifying movement rates of sharks between broad-scale and fine-scale regions of the fishery for alternative hypotheses are determined for input into fully sex-, age-, and spatially-structured fishery stock assessment models. The various models deployed take account of the highly length-selective characteristics of the gill-nets of various mesh-sizes used throughout the fishery. The sensitivity of the stock assessment models to alternative stock structuring hypotheses can be tested.

Do Bayesian concepts assist our ability to interpret migration and movement patterns of freshwater fish?

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Obtaining the necessary statistical power to identify fish movement in relation to environmental triggers and comprehend their meaning is often problematic. Classical statistics often requires complex experimental designs to separate confounding effects and

large replication to provide the required statistical power. Bayesian statistics however provides an alternative method for analysing and interpreting movement of fish species. A case study is presented using Murray cod in the Ovens River as an example. In the case study, the trigger for movement is tested against the hypothesis of spring flooding to stimulate the upstream migration of Murray cod over a four year period. The case study explores the outcomes provided by both the Bayesian and classical approaches.

Including spatial structure when conducting yield-per-recruit analysis

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Yield-per-recruit analysis is one of the most commonly applied techniques in fisheries stock assessment. However, most applications of this technique assume that length is related deterministically to age and ignore any spatial structure in the population. A variant of yield-per-recruit analysis that allows for variability in growth rate and asymptotic length among individuals, and models the spatial structure of the population by means of a Markov transition process is outlined. This variant is applied to data for tiger flathead, *Neoplatycephalus richardsoni*, off south eastern Australia. The parameters related to growth and depth distribution are obtained through a generalised 'catch curve' analysis.

Integrating stochastic population and spatial models for freshwater fish

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Single population models specifically developed to describe fish dynamics in a riverine system have limitations to the questions that may be asked. These models may be used to consider management options in particular situations such as looking at reintroductions at specific sites. However, if you wish to ask questions of a more complex nature then spatial movement needs to be taken into account and the development of a metapopulation model is required. Single population models have temporal structure and metapopulation models have both temporal and spatial structure. Metapopulation models will help with our understanding of complex movement patterns that can not be covered by an overall single population model, for instance local extinction and recolonisation of patches, spawning migration and recruitment, and the effects of barriers and habitat loss to movement.

Migration of adult, red-legged, banana prawns in Joseph Bonaparte Gulf, northern Australia.

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Red-legged banana prawns (*Penaeus indicus*) are fished commercially in waters between 50 and 100 m in the north-west region of Joseph Bonaparte Gulf, as part of the Northern Prawn Fishery. Spawning occurs within the area of the fishing grounds. Their juvenile phase is found in estuarine habitats in Cambridge Gulf and eastern Joseph Bonaparte Gulf. From these areas, subadult red-legged banana prawns move offshore into deeper waters as they grow. To reach inshore juvenile habitats from offshore spawning grounds, the pelagic larvae and postlarvae must move to the south and east on prevailing tidal currents. In 1997 and 1998, we tagged and released 18013 red-legged banana prawns. The location of recaptures was documented for 916 tagged prawns in 1997 and 512 tagged prawns in 1998. Tag recapture information and commercial fishery logbook information was used to test whether red-legged banana prawns moved continuously to deeper waters or whether they moved first to deep water but then returned to shallower waters. The analysis is based on Porch (1995) trajectory-based models of tag velocity and advection and on compartment models of recaptures per unit of fishing effort. The presence of a return migration to shallower waters in the second part of the year is important to assess the effectiveness of the current spatial seasonal closure which prevents fishers to access the shallow water stock during the first part of the year.

Computer visualisation of spatial models for communication and management

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It has been said that purpose of numerical analysis is insight not numbers. Many fisheries modellers have suggested that the insights generated by their models could be communicated more effectively with appropriately designed visualisation software. Development and wide availability of graphical user interfaces for personal computers over the last ten years has encouraged this view. No rigorous analyses have yet been completed to determine the impact of computer visualisation within fisheries science and management. This presentation examines the motivation and outcomes of two computer visualisation projects for spatial marine models. The models were: (1) CotSim (a model of crown-of-thorns starfish outbreaks on the Great Barrier Reef); and (2) NerkaSim (a spatially explicit migration and production model of sockeye salmon in the north-east Pacific). The success of these visual models for communicating concepts to end-users, particularly managers, is discussed. Spatial model development involves trade-offs that modellers appreciate. These include: numerical efficiency versus run-time visualisation; robustness for users versus feature implementation; numerical efficiency versus platform independence; user-control versus

batch-processing; code flexibility versus model distribution strategies. A list of scientific and management scenarios where visual computer models in fisheries science might be most beneficial is presented.

A spatial representation of the tiger prawn (*Penaeus esculentus*) fishery in Shark Bay, Western Australia

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The fishery for brown tiger prawns, *Penaeus esculentus*, in Shark Bay, Western Australia, experienced reduced recruitment in the early 1980s. It is considered that this decline in recruitment resulted from recruitment overfishing. The measures subsequently implemented to reduce fishing effort on the tiger prawns were constrained by the objective of maintaining the harvest of western king prawns, *P. latisulcatus*, which was the dominant species in the catch. A series of spatial closures was applied to different regions within the fishery in an attempt to reduce effort on brown tigers, yet maintain catches of western king prawns. The closures were intended to take advantage of the spatial structure of the fishery and the migration that occurs between fishing grounds. Until now, a subjective approach has been used, in consultation with the fishing industry, in determining the appropriate closures. A delay-difference model is being developed to represent the spatial structure of the fishery and describe the distribution of the brown tiger prawns through consecutive months of the fishing season. In the absence of explicit information on the rates of migration between fishing grounds, the model represents the migration rates as parameters and estimates these, together with catchability and recruitment parameters, from the observed monthly catch rates within the fishing grounds. It is intended that this model will allow a more quantitative assessment of the impact of seasonal closures of the various fishing grounds. This paper describes the current status of this model and its application to the brown tiger prawn fishery of Shark Bay.

Session 4 – Management Implications

Introduction

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Australia is a large Island surrounded by large and complex marine circulation systems. Within Australia, equally complex but better understood freshwater systems exist. The human impact on these riparian systems has been substantial as we have dammed and diverted major water courses for our benefit. Our impact on marine systems is harder to quantify, but is certainly greatest in nearshore environments.

And what of the fish within these systems, well, they're a nightmare to manage, you can't see them and worse they keep moving around. That's why managers prefer to say they're really managing the fishers – it's easier!

Humans have spent thousands of years dividing up the Earth to claim their own piece of dirt and sea. Fish have failed to respect these boundaries – spawning, feeding and growing up in the same places they have always done for tens of thousands to millions of years. Economists blame the mobility of fish for causing an international "the tragedy of the commons", ie nobody will look after something that belongs to everybody.

Fishers are creatures of economics who have utilised engineering and technology to become as mobile as the fish they catch, and are often as difficult to find. Restricting the number of fishers, limiting the catch and what they could fish with, when they could fish and where they could fish have been used by managers in an attempt to protect these mobile and cryptic animals. Managers have necessarily adopted a "toolkit" approach to deal with the issues that confront them.

The TAC combined with an international agreement is currently the pinnacle of fisheries management. That trans-national icon, the SBT, is arguably the most studied species in Australia – we claim it has been fished down to very low levels and has only a limited chance of recovery, however not all countries share our view! Why not? Science is a pure and objective discipline - so why can't we agree? Australians are honest, reasonable and culturally aware – isn't that enough?!

Still, Australia should not be surprised that international agreement can't be reached, after all the tiger flathead ranges over three or more states and we have three different minimum sizes.

The big mistake many fishes make is they spend their juvenile years in estuaries and on the coast. It just so happens that that's where most people live and seasonally migrate to. Problem is these days, there just isn't enough room for us and the fish, and anyway we have better ideas than nature about what the coastal fringe should look like – all those mangroves, seagrass and muddy shallows = mosquitoes, clogged propellers and gooey mess.

Furthermore, gravity sends water and more recently all our runoff and sewerage into estuaries and onto the coast. The sea has been euphemistically referred to as a "sink", trouble is there's no drain!

Because gravity won't stop what its doing, one answer to the pollution problem is not to allow it to reach the coast. Through large-scale irrigation this has almost been achieved in a number of areas. For the fish in these river systems however migration and movement has turned into a health risk come hurdling marathon.

Is it all really as bad as I am making out? Perhaps not, but there's room for improvement and I guess that's where fisheries management comes in! I would now like to introduce 7 people who will speak on specific examples of the management implications of fish movement and migration so you can judge the current situation for yourself.

The Australian salmon fishery management issues

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Australian Salmon are an important commercial and recreational species that are taken in Western Australia, South Australia, Victoria, Tasmania, and New South Wales. There are two separate species (Eastern and Western) both of which udertake extensive migrations. However, for the purposes of this discussion they are being treated as on. Commercial catches have remained relatively stable except in Victoria where the catch has steadily increased and in Tasmania where catches have decreased over the same period. We have reliable assessments that indicate that the western species is being managed on a sustainable basis but assessments of the eastern species are not so reliable.

In Victoria the bulk of the commercial catch is taken from ocean waters between Wilson's Promontory and Mallacoota. Average price is in the order of one dollar a kilo with the catch being sold mainly for rock lobster bait and pet food. Smaller quantities are taken from bays and inlets and because the catch is mainly comprised of juvenile fish they are more acceptable at fresh fish markets. Australian salmon are the dominant species taken by Victorian surf anglers and could make up more than 80% of the total catch. On any weekend when the salmon are "running" anglers in their thousands pursue this species with many travelling to popular locations such as the 90 mile beach, Lakes Entrance and Marlo. The commercial netting of Australian salmon using beach seine and purse seine nets is often carried out in sight of anglers. Most fishing is done from one large boat which attracts sustained and ongoing criticism from anglers and tourism interests. Anglers claim that targeted commercial fishing effectively removes entire salmon schools or, at least, displaces salmon from where anglers can reach them.

The Australian salmon that make up the eastern Victorian commercial and recreational fisheries are part of a stock that is shared with Tasmania and New South Wales. Any action Victoria may wish to contemplate that has an impact on the commercial fishery must have regard for the fact that New South Wales and Tasmania have a long history of exploiting the same stock.

Management implications for movement and migration in a rock lobster fishery

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Rock lobster may migrate significant distances and this phenomena can create implications for the management of these fisheries. Abundance may be influenced by depth, season, temperature, shelter, food and other environmental factors. Scientific advice on migration, including settlement of juvenile rock lobster, can be critical for development of sustainable management strategies. Changes in catch rates across fisheries due to annual changes in

abundance alter the impact of fishing effort and may lead to localised depletion. Movement and migration of rock lobster can also have regional economic impacts due to loss of catch or increased fishing costs. Stock assessment advice needs to consider issues related with movement and migration to ensure appropriate management action can be considered.

Fisheries management implications of barriers to movement and migration by fish in NSW

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There are an estimated 4700 barriers to fish passage in NSW, ranging from partial barriers such as low weirs, to complete barriers such as large dams. The biological impacts of these barriers can range from reduced recruitment and increased mortality, through to local extinctions of affected species.

Management of these impacts in NSW focuses on a number of issues, including:

Assessment of existing barriers and prioritisation of remedial action

Construction of fishways

Stocking programs for important recreational species

Use of barriers as fish traps for pest species

Regulatory and compliance actions to protect vulnerable aggregations of desirable species

Novel approaches to overcoming problems created by barriers

Stocking programs are relatively inexpensive and are widely appreciated by the public as a positive initiative to overcome problems created by barriers. However, there are a number of limitations with stocking programs, including the fact that there is only a small group of species available for stocking.

Construction of fishways is expensive and, to gain maximum benefit, must be coordinated with other fisheries management actions. However, well constructed and maintained fishways can be an important factor in rehabilitation of migratory fish stocks within affected catchments.

The challenge of spatially managing fish movement and migration throughout Northern Australia: our experience with tropical snappers

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Management strategies for wildstock fisheries throughout northern Australia (the *Top End*) provide particular recognition of State/Territory boundaries, often in preference to the ecological boundaries of stocks. Much has been achieved in refining jurisdictional arrangements over the last decade or so with the aim of ensuring compatible and complementary strategies, by adjacent and regional resource agencies, in managing their often shared aquatic resources. It is widely acknowledged that with even a low level of movement, the wellbeing of a fish population in one jurisdiction can be detrimentally affected by actions undertaken within another.

An overview of the management strategies of the topical snapper fisheries throughout the Top End and beyond provides as a valuable stage for discussions on spatial management of stocks, given the strong likelihood of movement across jurisdictional boundaries.

Tropical snappers and emperors are harvested by high-tech line, trap and fish trawl fleets operating in the Kimberly and Pilbara regions of Western Australia, a line fishery operating from Darwin, a fish trawling vessel in NT and Qld waters of the Gulf of Carpentaria. A developmental trawl fishery for red snappers and emperors within Queensland managed waters of the Gulf of Carpentaria has been held over awaiting improved economic conditions. In Indonesia, tropical snappers and emperors are harvested by lines (longlines and handlines) and trawling by subsistence and commercial operators.

Established research strategies seek to gain an understanding of the degree to which stocks are shared, the gathering of comprehensive catch and effort information together with a detailed understanding of the biology, lifecycles and movement patterns. This approach generally relies on fishery dependent estimates, with a view of incorporating the outcomes as the principal basis for fisheries management strategies to ensure long term sustainability. A challenge confronting managers is implementing arrangements for the long-term sustainability of commercial, recreational and subsistence fisheries in the absence of a good understanding of the degree of mixing and migration.

Tasmanian Whitebait – A multispecies fishery targeting migrating fishes

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The Tasmanian whitebait fishery reached a peak commercial harvest of just over 500 tonnes in 1947. It declined to compulsory closure in 1974. The populations recovered somewhat to the extent that an open season was being requested in the mid 1980's

A research program was undertaken to establish whether any harvest was sustainable and if so, how should it be regulated as the multi-species nature of the fishery posed some interesting challenges. For example, the fishery contained at least six main species of fish, some of which were adults and some were juveniles at time of migration. The fishery had been based primarily on the Tasmanian endemic species *Lovettia sealii* that was no longer as common in the migrations.

The research concentrated on the timing and composition of the migrations with a view to determining implications for the management of the species if an open season was declared.

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