


Research, Development and Extension Priorities for Stock Enhancement, Fish Stocking and Stock Recovery

Australian Government
Fisheries Research and Development Corporation

MURRAY-DARLING BASIN COMMISSION

RECFISH AUSTRALIA

Research, Development and Extension Priorities for Stock Enhancement, Fish Stocking and Stock Recovery

National Workshop Brisbane
6-7 February 2006

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Bill Sawynok (Recfish Australia) managed the workshop and the overall project. Ross Winstanley chaired the workshop and provided the summary of the workshop and outcomes.

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1. Key Workshop Findings

A national workshop on research, development and extension (RDE) for stock enhancement, fish stocking and stock recovery was held in Brisbane on 6-7 February 2006. A key outcome of the workshop was the identification a number of priority areas for investment.

Priority Areas for Investment

The broad indications of important future directions for stock enhancement RDE outlined during the workshop point to the following as major priority areas for FRDC and Recfish Australia:

- Experimental application of stock enhancement as a learning tool (ie adaptive management) for fisheries management, and for addressing factors that limit productivity of wild fish stocks.

- The development of aids to management decision-making (ie decision support tools) and information resources suited to community engagement in planning and implementation of stock enhancement programs.

- Improved understanding of the impacts of stocked fish on wild stocks.

- Social and market research to:
  - determine the full range of benefits sought by recreational fishers from enhanced fisheries; and
  - demonstrate the social and economic benefits provided by enhanced fisheries.

- Assessment of the impacts of fish stocking in terms of:
  - success in meeting fishery objectives and angler aspirations;
  - impacts on the environment; and
  - rehabilitating threatened species.

The Workshop also highlighted the importance of engaging recreational fishers and community groups from the planning to the implementation stages of stock enhancement programs – and shifting the focus from inputs (eg numbers of fish released) to outcomes (eg what type of fishery does the community want).

Workshop participants also noted that there is a need for stock enhancement planning and management to be integrated with fisheries and wider natural resource management frameworks. There is also a need to develop national protocols for fish stocking.

2. Background

During 2005, the Fisheries Research and Development Corporation (FRDC) recognised the need for a strategic approach to national R&D investment in the field of fish stock enhancement. Along with coordinated progress towards the restoration of threatened Murray-Darling species of interest to fishers, FRDC faced strong growth in interest in the enhancement of marine and estuarine finfish stocks. Species of interest included mulloway, dusky flathead and barramundi on the East Coast and black bream and snapper in Western Australia.

FRDC recognised that there is no established process - involving researchers, managers and industry - for developing a broad consensus on priority areas for national R&D investment in fish stock enhancement.

To resolve this, in the latter half of 2005, FRDC commissioned Recfish Australia to conduct a workshop to examine national R&D issues and priorities. To meet FRDC's main needs and to keep the workshop manageable, it focused on finfish stock enhancement in marine, estuarine and fresh waters for the benefit of recreational and commercial fishing and for biodiversity conservation. Invitations were extended to fishing bodies, community groups, industry representatives, researchers and managers with current experience in finfish stock enhancement. The list of participants is shown as Appendix 1.

The Workshop program (Appendix 2) featured presentations on the state of stock enhancement at a national level – in terms of freshwater fisheries, threatened species recovery and marine/estuarine fisheries – plus state and local experiences with stock enhancement. Participants then formed separate groups to discuss current practices and R&D priority areas in the fields of threatened species recovery, freshwater fisheries and marine and estuarine fisheries. Finally, these sets of findings were discussed by the whole group to draw out a broad consensus on the key national R&D priorities.

3. Drivers of Stock Enhancement and RDE Needs

The main driver of fish stock enhancement continues to be recreational fishers' ongoing demands for improved quality and variety in recreational fishing opportunities. Though less strident, the community's concerns that threatened species should be rehabilitated also drives recovery programs in many parts of Australia.

Rural communities growing awareness of the value of recreational fishing and the need to diversify their economies is increasingly reflected in community-based fish stock and habitat enhancement programs, backed by the tourism industry and government support.

Access to new impoundments and improvements in mass rearing of popular species are also feeding the demand for stock enhancement.

All of these demands produce responses among governments, management agencies, researchers, fish hatcheries and community-based fish stocking groups. In turn, these responses indicate further needs in the areas of Research, Development and Extension (RDE).

Recent development in state stocking and fish translocation policies and protocols and the advent of mandatory environmental impact and risk assessments have highlighted key information gaps and the need for practical decision support tools. They have also highlighted the need for effective extension programs to overcome the knowledge gaps between regulators and fishing and other community groups keen to undertake fish stock enhancement activities.

4. Performance of Stock Enhancement Programs

Workshop participants observed that fish stock enhancement programs are popular among fishers and the wider community who see them as being beneficial and successful. This popularity and success reflects the community's perceptions of the social, economic and environmental benefits of stock enhancement. These benefits can be viewed from local, regional and state-wide perspectives.

In practice, there is little evidence that recreational fishing stock enhancement projects are planned and conducted with a view to improving the quality and variety of fishing experiences on a broader regional or state-wide basis, matched to anglers' aspirations. The lack of such broad strategic and angler-focused approaches makes meaningful performance assessment difficult and points to the need for a paradigm shift in these programs.

Participants concluded that, in the main, programs linked to threatened species recovery plans have well defined outcomes. Operating in highly modified environments, attaining these outcomes is extremely difficult and success may take decades. Fish translocations, purpose-designed habitat restoration and stocking of hatchery fish are important components in threatened species recovery along with strategies such as the control of pest species, exotic fish predators and competitors.

In contrast, recreational fish stocking programs produce much more immediate results. However, it came as a surprise to many participants to realise that after 150 years most freshwater stocking programs, particularly in south-eastern Australia, continue to be focused on inputs rather than fishing outcomes. The numbers of fish going into the water continue to be the main focus of programs that do much the same thing year after year without really examining the full range of possibilities and the range of fishing experiences sought by anglers. The comment that encapsulated this discussion was

> *"If we were running fish stocking as a business, we wouldn't do it this way!"*

Estuary fish stocking programs have a more recent history. While stocked fish are becoming prominent in catches, whether or not they augment or replace wild fish is yet to be addressed. These developments are being conducted with a stronger focus on the impacts on wild fish stocks and the receiving environment than was the case with native fish stocking in freshwater in the past.

5. Management Approaches

Stock enhancement planning and management should be integrated with fisheries and wider natural resource management frameworks, from the national level down to the local or specific water level. This has occurred to some degree with the adoption of the 1999 *National Policy for the Translocation of Live Aquatic Organisms* and its application in most Australian jurisdictions. Workshop participants noted the related need for national protocols for fish stocking.

Community engagement from the planning stage is essential to ensure that programs address realistic community expectations. Such an approach maximises the degree of shared understanding of the desired outcomes of enhancement projects and shifts the focus away from inputs. In this way, the performance and success of projects can be measured in terms of clear and shared objectives with widespread support and ownership.

Community engagement can also help to unlock the great potential for broad-based stewardship of valuable natural resources (eg fish stocks, threatened aquatic species, and habitat) and adoption of enhancement projects.

6. Management Tools

Decision support tools are needed to assist and support consistency in a number of stock enhancement decision processes:

- Assessment of the need for one or a combination of measures such as stocking, habitat protection or rehabilitation, increased fishery regulation or pest species control.
- Predictive models to inform decisions on stocking numbers, release frequency and timing, fish size, carrying capacity, etc, to optimise conservation, fishery, cost-benefit or other defined outcomes.
- Protocols and models to assist in identifying and minimising risks to aquatic environments, communities and species, and to wild fish stocks.
- Improved success criteria for stock enhancement projects, including measures and alternatives to World Conservation Union (IUCN) criteria for threatened aquatic species recovery.
- Greater use of the experimental opportunities offered by stock enhancement, including adaptive management of fisheries and improved understanding of wild fish stocks.

7. Research Needs

The requirements for ESD-based management of fisheries and conservation of aquatic biodiversity through stock enhancement strategies are constrained by the current state of knowledge in many areas. The Workshop identified a number of key areas where biological, economic and social research is needed to overcome these constraints:

- Knowledge of the basic biology, population dynamics, diseases, habitat requirements (for each life history stage) and other aspects of threatened species, fished species and potential stock-enhanced fishery species.
- Understanding the extent of and factors contributing to the variability of natural recruitment and the need and scope for stock enhancement strategies to augment recruitment.
- Identification of natural recruitment bottlenecks and experimental approaches to either removing or circumventing them (eg by stocking).
- Development of reliable methods for demonstrating the impacts of stocking on wild con-specific fish populations, eg stock enhancement, genetic shifts, fish condition.
- Development of hatchery and release strategies for maximising the survival of stocked fish.
- Investigation of the trophic, habitat and other ecological impacts of stocking on receiving ecosystems.
- Strategies needed to avoid adverse genetic impacts of stocking hatchery-produced fish.
- Practical and inexpensive batch marking techniques allowing stocked fish to be identified by non-destructive methods for several years after release.

- Improved hatchery and release practices to increase fitness of released fish in terms of survival, growth and attainment of fishery or conservation objectives.

- Predicted impacts of climate change on aquatic ecosystems and their implications for current stock enhancement programs and future R&D needs.

- Surveys of community aspirations, attitudes and satisfaction in relation to the benefits (current and potential) provided by stocking-enhanced fisheries and healthy natural aquatic ecosystems.

- Assessment of social and economic benefits provided by enhanced fish stocks and aquatic ecosystems.

- The development and application of predictive models to identify critical information needs and the biological and environmental parameters for successful stock enhancement.

8. Extension

The success of the Workshop was largely due to its uniqueness in assembling recreational fishers, industry, researchers and managers to examine R&D priorities relating to fish stock enhancement for fisheries and biodiversity purposes. Apart from a brief workshopping session where participants separated into three groups, all presentations and discussions were held as a single group activity.

The positive interactions between participants with different backgrounds and primary interests resulted in stimulating discussions built around a strong sense of common purpose. The success of these interactions highlights the need for such communication, dialogue and information exchange at a community-wide level on an ongoing basis. In this regard, a key message from the Workshop is the importance of development and extension as well as research. This message has registered with FRDC who will be working with Recfish Australia and other stakeholders in the delivery of pragmatic solutions that benefit recreational fishers, conservation interests and the wider community.

Appendix 1 – Workshop Program

WORKSHOP DATES

6-7 February 2006

WORKSHOP LOCATION

QDPIF Auditorium 1 DPIF Building 80 Ann Street Brisbane

WORKSHOP SCOPE

- Marine stock enhancement of fish species in estuaries
- Freshwater fish stocking in open systems and impoundments
- Stock recovery for threatened or endangered species

WORKSHOP OBJECTIVE

- Identify the key research, development and extension issues associated with stock enhancement, fish stocking and stock recovery

WORKSHOP PROGRAM

6 February 2006

CHAIR – Ross Winstanley

9.00am OPENING AND WELCOME Dan Currey on behalf of Deputy Director-General, Department of Primary Industries and Fisheries

9.10am WHAT THE WORKSHOP AIMS TO ACHIEVE/THE NEED FOR R&D GUIDANCE Patrick Hone FRDC

9.30am THE STATE OF PLAY NATIONALLY Ross Winstanley Wayne Fulton PIRVic

10.00am THE STATE OF PLAY IN MARINE FISH STOCK ENHANCEMENT Matt Taylor UNSW

10.20am MORNING TEA

10.40am THE STATE OF PLAY IN FRESHWATER FISH STOCKING Wayne Fulton PIRVic

11.00am THE STATE OF PLAY IN STOCK RECOVERY OF ENDANGERED OR THREATENED SPECIES Mark Lintermans ACT

11.20am FRESHWATER STOCKING IN QLD Anita Wohlsen DPIF

11.40am BLACK BREAM IN BLACKWOOD RIVER WA Greg Jenkins Challenger TAFE

12.00am FRESHWATER STOCKING IN NSW Cameron Westaway NSWDPI

12.20am LUNCH

1.00pm MULLOWAY IN NSW Matt Taylor UNSW

1.20pm FRESHWATER STOCKING IN VICTORIA Greg Hayes PIRVic

1.40pm STOCKING IN TASMANIA David Jarvis Tas Inland Fisheries

2.00pm BARRAMUNDI IN NORTH QUEENSLAND ESTUARIES John Russell DPIF

2.20pm GIPPSLAND LAKES BREAM Sandy Morison PIRVic

2.40pm MAROOCHY RIVER STOCKING Adam Butcher DPIF

3.00pm AFTERNOON TEA

3.20pm MURRAY COD/TROUT COD RECOVERY Simon Nicol ARI

3.40pm RESTOCKING SWAN RIVER Frank Prokop Recfishwest

4.00pm HABITAT RESTORATION Jim Tait Econcern

4.20pm OPTIONS FOR MARKING FISH David Crook Arthur Rylar Institute

4.40pm WHAT IS OUR AIM FOR TOMORROW? Ross Winstanley/Matt Barwick FRDC – Setting the scene for the second day

5.00pm Finish

7 February 2006

9.00am Commence

Break up into 3 workshop groups to address the research and development priorities in each of the 3 areas identified.

- Marine stock enhancement of fish species in estuaries
- Freshwater fish stocking in open systems and impoundments
- Stock recovery for threatened or endangered species

Action Items and what will happen after the workshop (Ross Winstanley)

12.00pm Finish and Lunch

Appendix 2 - List of Workshop Participants

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Appendix 3 – Workshop Papers

The Need for Broad National Priorities for Stock Enhancement R&D: an Overview

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The initial impetus for this workshop came from FRDC's recent experience with funding proposals for fish stock enhancement projects. Along with coordinated progress towards the restoration of threatened Murray-Darling species of interest to fishers, FRDC faced strong growth in interest in the enhancement of marine and estuarine fish stocks. Species of interest include mulloway, dusky flathead and barramundi on the East Coast and black bream and snapper in Western Australia. The need for a strategic approach to national R&D investment was clear.

A fundamental part of FRDC's approach to such issue analysis, planning and priority setting processes is the co-involvement of industry with managers and researchers. FRDC recognised that, in the field of fish stock enhancement no such process exists at a national level. The states are responsible for managing recreational fisheries and for related stock enhancement decisions. They do so largely in isolation from each other, hence the lack of national management forums and processes.

In 2000, the Australian Society for Fish Biology (ASFB) conducted a national stock enhancement workshop[1], as part of its series examining key fisheries scientific and management issues. However, the proceedings represented the perspectives of scientists and managers – without recreational fisher or other industry input – and was not intended to produce national R&D directions and priorities. Like the ASFB event, a 2002 workshop on the management of stock enhancement in the Murray-Darling Basin[2], which also lacked effective industry input, noted the need for improved engagement of fishers and the wider community in stock enhancement processes.

Recfish Australia's 2001 R&D plan[3] examined the recreational fishing sector's operating environment and the R&D activities most likely to yield "the best environmental, social and economic outcomes for the recreational sector". When addressing strategic information needs of fisheries enhancement, the FRDC-funded plan made no specific mention of fish stocking.

The Australian Fisheries Management Forum's 2005 R&D plan[4] addressed stock enhancement in some detail, particularly in terms of the important area of preventing adverse environmental impacts. However, the lack of focus on benefits to fishers reflected their absence from the plan development process.

In short, FRDC's 2005 need for a broad consensus on priority areas for national R&D investment in fish stock enhancement could not be met from existing sources. To resolve this, in the latter half of 2005, FRDC commissioned Recfish Australia to conduct a workshop to examine national R&D issues and priorities. Planning for this workshop shifted quickly from a focus on enhancement of marine and estuarine fish stocks for the benefit of recreational fishing to fish stock enhancement in marine, estuarine and fresh

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[1] Moore, A, and Hughes, R (Eds) 2005. *Stock enhancement of marine and freshwater fisheries*. ASFB Workshop, Albury NSW, 7-12 August 2000.
[2] World Wildlife Fund 2002. *Managing fish translocation and stocking in the Murray-Darling Basin*. Canberra.
[3] Recfish Australia 2001. *Investing in a sustainable fishing future: the national research and development plan for the recreational fishing sector of the Australian fishing industry*. FRDC Project 2000/313.
[4] AFMF 2005. *National research strategic plan for Australian fisheries and aquaculture 2005 – 2010.*

waters – for the benefit of both recreational and commercial fishing and for biodiversity conservation. Further expansion to include crustaceans, molluscs and other groups was rejected to keep the workshop to a manageable size and focused on FRDC's main needs.

Over the next two days we will examine what is driving stock enhancement around Australia. Foremost among these drivers are recreational fishers' continuing demands for improved quality and variety in recreational fishing opportunities and the community's concerns that threatened species should be protected and rehabilitated wherever possible. In the case of recreational fisheries, stocking is the most tangible, instant (to outward appearances), highly publicised and politically attractive expression of a user-pays benefit. Rural communities growing awareness of the value of recreational fishing and the need to diversify their economies is backed by the tourism industry and is increasingly recognised by governments. The rising influence of local stocking groups reflects the demand, awareness and recognition referred to. It also illustrates the willingness of local communities to take on fisheries management and development responsibilities and the importance of fisheries agencies building close links with community groups.

Recfish Australia's outline of the need for this workshop[5] noted that state stocking policies and protocols have often been developed in isolation from fishers and community stocking groups. As a result, a key obstacle to be overcome is the knowledge gap on the appropriateness and risks of stocking as a management tool. This knowledge gap has often led to political lobbying and intervention into well informed and objective decision processes.

Access to new impoundments and improvements in mass rearing of popular species (some of which are also threatened) are feeding the demand for translocations and stock enhancement. The wide publicity given to success stories – measured in fishing and economic terms – only adds to these demands. As FRDC has found, the interest – mainly in the recreational fishing sector - has now spread from freshwater to estuarine and marine species.

How are governments responding to these pressures? Are the agencies who manage stock enhancement in each jurisdiction engaging their respective fishing and conservation interest groups effectively? Is the lack of basic information resulting in these groups' aspirations being denied by government regulation and risk management protocols?

We will hear about a range of stock enhancement models involving fishers, their representative bodies, stocking groups, governments and their agencies. The Queensland model, centering on local stocking groups, is both popular and successful in terms of meeting angler demands and has just last month been boosted by several grants under the Australian Government's Recreational Fishing Community Grants Program. States which have recreational fishing licences have a variety of processes by which recreational fishers and industry participate in decision-making and stocking activities. For example, in Victoria the annual stocking program for salmonids and native fish is determined through a series of regional meetings involving angler and industry representatives along with fisheries managers, scientists and – where appropriate - biodiversity and water managers. The resulting plans apply to stocking funded from government, fishing licence and private sector sources. We can expect to gain some insights into the extent to which such arrangements fully satisfy all fishing, industry and biodiversity conservation interests. One thing is clear – where consultation and "engagement" processes fail to satisfy their expectations, appeals through the media and political avenues continue to provide popular and often-successful alternatives.

From Mark Lintermans and Simon Nicol we can expect to hear about how community concerns regarding threatened species are being recognised and responded to by governments. Responses include direct, such as stocking and habitat improvements, and indirect, such as translocation policies and mandatory risk assessments for recreational

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[5] Recfish Australia 2005. *National workshop on research and development priorities of stock enhancement, fish stocking and stock recovery.* FRDC Project No.2005/323

fishery releases. We may also hear how the recreational fishing sector is reacting to these responses.

Together with outlines of the translocation and stocking protocols, environmental risk assessments, ecosystem modeling and other tools, these insights will help us to understand how we can improve the delivery of environmental, fishing, social and economic benefits of stock enhancement. In doing so they should enable us to identify the priority areas for national investment in stock enhancement RDE.

Freshwater Fisheries Stock Enhancement; a national perspective

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Abstract

This paper presents a very broad overview of the main emphasis of freshwater fish stocking around the country before then making some generalisations on information requirements for successful stock enhancement that emerge as common elements.

Freshwater Fish Stocking

Freshwater fish stock enhancement in Australia dates back to the 1860's when salmonids were first introduced into Tasmania. With the development of breeding techniques for native fish in recent years a number of these species are now also widely stocked primarily for recreational purposes. Across Australia the emphasis differs somewhat from one State to another with a broad focus as follows;

Northern Territory	Limited Barramundi stocking in impoundments
Queensland	Native fish in impoundments and rivers
New South Wales	Native fish in impoundments and rivers Salmonids in impoundments and rivers
ACT	Native fish in impoundments
Victoria	Native fish in impoundments and rivers Salmonids in impoundments and some rivers
Tasmania	Salmonids in impoundments
South Australia	Salmonids in some rivers
Western Australia	Salmonids in impoundments

The general picture is that stocking with salmonids predominates in the southern states where conditions suit with natives being used more frequently further north.

Whilst this describes the general picture as it stands, if fishery stakeholders were to take a structured approach to freshwater fish stocking they would probably start by first considering whether there is in fact a need to stock or not. In other words, will stocking provide the outcome they want – whatever that may be. As a general comment quite a lot of fish stocking is done simply because it has always been done or because there is a perception that because fish are being released they must be contributing to the catches.

Research in Tasmania and Victoria with river populations of salmonids for example has shown that stocking trout in rivers usually contributes little to angler catch (Nicholls, 1958; PIRVic unpublished). This situation requires some qualification in situations where conditions may not support natural reproduction. At the other end of the country in

Queensland, studies have shown significant returns from stocked barramundi in rivers (Rimmer & Russell, 1998) and there are many examples of good returns from stocking impoundments in particular. At the same time in NSW and Victoria, the contribution of some stocked native fish to catches in riverine situations is being questioned.

With these comments in mind, there are a couple of processes that have been documented to consider the need to stock. For example, the ASFB Stock Enhancement Workshop Proceedings from Albury in 2000 (Moore and Hughes, 2000) concluded with a process to consider whether stocking is required or not. Molony *et al*. (2003) also published a review of the subject entitled Stock Enhancement as a Fisheries Tool. Both of theses reports proposed a flow chart type process. The use of this type of evaluation, or some other structured method, would certainly bring some objectivity to the stocking process. What it would also do is identify a lot of the information gaps either directly or indirectly.

If it is then decided that stocking is considered as a viable option to achieve the outcome intended, most State's have some form of stocking or translocation protocol in place to assess the risk or the implications of the stocking proposal. This process will also raise a number of information gaps in many cases.

In practice, most State's now have some form of translocation protocol that should guide the stocking process, but the way in which ongoing stocking decisions and levels are made does still vary around the country and for various types of waters within a State.

A number of the presentations to follow will no doubt present specific information from the various states, so from here the objective is to put forward some of the R&D issues that have been raised through direct contact with State Fisheries researchers and managers. There is certainly a lot of overlap around the country and in many areas it is surprising how little progress has been made on what are fairly basic issues.

The information gaps fall reasonably comfortably into groups although it is not suggesting that all issues have been covered.

Impact of Stocking

In broad terms this is generally what the state-based translocation protocols are attempting to assess. In addition there have also been some specific reviews related to fish translocation. For example the MDBC sponsored workshop 'Managing Fish Translocation and Stocking in the Murray Darling Basin' held in Canberra in 2002 (Phillips, 2003). That workshop came up with a number of recommendations that are included as background material to this workshop. It identified a number of knowledge gaps primarily related to minimising impacts of stocking.

There are several major areas where information is required as follows:

- Impact of stocked species on native fauna (or other recreational species) through eg predation, competition, disease, escape etc; and
- Impact of stocked species on genetic composition of wild stock.

Stocking from hatcheries is often assumed to be a threat to wild populations due to reduced genetic diversity and subsequent genetic drift in the wild population. Whilst there is no doubt that genetically sound breeding and stocking programs are required the genetic impacts of stocking programs on native species are yet to be fully evaluated.

- Impact of stocked species on habitat.

Management Information

This group of issues relates primarily to the success (or otherwise of stocking).

- **Is the fishery sustainable without stocking and would some other form of management change this?**

This question is often overlooked for social reasons, and it is in large part the objective of the flow chart process referred to earlier. In some cases at least, stocking may not be the solution, however, once a decision is made to stock, how can the best fishery be obtained?

- **What is the optimum stocking density?**

Is there a reliable tool for assessing the number of fish to stock, recognising that productivity may vary from one water to another. Some recent work in Queensland (Simpson *et al*. 2002) and in NSW addresses this question. With the stocking emphasis being on impoundments there will be a large amount of variation from site to site. This issue has the potential to become even more significant as more stocking is often too simply equated with better fishing.

- **Is bigger better?**

The question still arises even in relation to salmonids that have been stocked in this country for in excess of 100 years. Recent work has been undertaken in Victoria and in WA for salmonids; in Queensland for barramundi and bass; and in Victoria for Murray cod. The answer is generally not just a one size fits all as the presence or absence of predators for example has accounted for site to site variability.

- **What size is most cost effective?**

This is not the same as the previous issue and relates more to hatchery production and transport as well as angler returns than it does just to size and survival alone.

- **What stocking frequency works best?**

This may vary depending on the species, the receiving habitat or the outcome required. For example, short-lived species require more frequent stocking than long-lived ones.

- **What species (or combination) works best?**

Some work suggests that some combinations of species may not be suitable under certain circumstances (eg barramundi and bass). In other cases it may be more important to be concentrating on what the desired public outcome is.

- **What is the contribution of stocked fish to the catch and/or the population?**

A reliable marking technique would be particularly useful here. There is some NSW work in progress with batchmarking of golden perch also genetic studies from PIRVic contributing to this for Murray cod.

- **Are anglers getting the benefits?**

It's not enough to simply say that the fish have been released and that's the end of it. There are some instances where fish are being stocked with little angler return. Also do managers actually know what anglers want?

- **What 'harvest' management strategies give the best outcome?**

- **Size/bag limits** - whilst these are management tools they are best determined through creel feedback rather than social policy. In many cases present bag limits have little impact in regulation of harvest of recreational species.
- **Catch and release (release survival)** - Whilst this is a matter of personal choice, catch and release has limited value in regulation of harvest of most recreational species and may in fact be a detrimental strategy in some fisheries.

Creel survey methodologies are now very sophisticated but can be expensive. However they do enable very good interpretation of catch information provided the questionnaire design is appropriate. Good follow-up angler catch information needs to be part of any stocking strategy evaluation. In other words, a well-designed monitoring strategy determined by what the original stocking objectives are.

Angler demographics

Various levels and varying degrees of specificity are often required and/or used by different groups. Following are examples of what might be obtained:

- Harvest information; and
- Angler aspirations/opinions.

Some of these two may fit better in the previous section but the information is usually collected along with other detail such as:

- Angler origins;
- Angler participation rates; and
- Economic information.

This information is usually collected by some form of creel or questionnaire survey. For example, the recent National Recreational and Indigenous Fishing Survey gives a broad coverage of Australia's recreational fisheries. On a different scale some detailed creel surveys have been undertaken on individual fisheries particularly in Victoria. There are some economic surveys of particular areas such as Queensland dams. The long running Tasmanian inland fisheries postal questionnaire which has now been done annually since about 1986 is another example.

The angler demographics can be useful to various stakeholders many of whom may be outside the fisheries management/ recreational angler group. For example, this information can be important to directly promote support for a fishery as well as to direct infrastructure or other developments. The angler aspirations should also feed into management strategy development etc.

In summary, most states collect some information by way of monitoring but not all of this is effectively planned nor is it always used effectively. This National perspective is intended to start the process of consideration of the important issues for stock enhancement. The challenge for this workshop is now to prioritise those areas that would benefit from a National R & D approach.

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Marine Stock Enhancement in Australia – Status and Regulation

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Whilst enhancement of freshwater fish stocks in Australia through release of hatchery-reared fingerlings has a long history, the stock enhancement of marine fishes and invertebrates have mostly been limited to pilot scale projects. This paper briefly identifies the current status of marine stocking in Australian states, and the regulatory requirements governing marine stocking practices in Australia.

National Perspectives

The Australian Society for Fish Biology (ASFB) held a national workshop in 2000 to examine freshwater and marine stock enhancement in Australia. One of the major outcomes of the workshop was the formation of the ASFB working group on stock enhancement, which developed a code of practice for stock enhancement in Australia (see Butcher 2001), to encourage an adaptive management approach to the practice.

The Commonwealth Department of Agriculture Fisheries and Forestry (AFFA) has no specific legislation dealing with stock enhancement. The most relevant piece of Commonwealth legislation is the National Policy for the Translocation of Live Aquatic Organisms (AFFA 1999). This policy focuses on developing appropriate risk assessments and monitoring programs when stocking Australian waterways. In addition, marine stocking practices should be considered in terms of the National Strategy for Ecologically Sustainable Development.

Two major reviews were recently published by Australian researchers, offering novel ideas on marine stock enhancement in Australia from both a biological (Taylor et al. 2005) and management standpoint (Molony et al. 2003). Whilst these reviews have differing perspectives on some areas, they present a fresh direction from which stock enhancement research and development can progress in Australia in a responsible and pragmatic way.

New South Wales

New South Wales began pilot investigations into mulloway (*Argyrosomus japonicus*) stocking in 1995 (Fielder et al. 1999), which was later extended to riverine systems to investigate the predatory and environmental impact of stocked mulloway in estuaries. A new research project into mulloway stocking has just commenced in New South Wales, aiming too refine release techniques (size, site, and season of release), examine the genetic impacts of mulloway stocking, develop strip spawning techniques for wild mulloway, resolve the recruitment dynamics of mulloway, and validate estimates obtained from the Predatory Impact Model (a new approach to estimating stocking density and predatory impact being developed by the University of NSW). In addition, pilot research into the stocking of abalone seed has been undertaken in New South Wales, aimed at developing a means to re-establish self sustaining populations of abalone along the NSW coast.

At present there is no policy in New South Wales specifically governing the release of marine species into open waters in New South Wales, although an Environmental Impact Assessment (EIA) is planned for the conclusion of the current mulloway project. At present, releases for research purposes are regulated under the current NSW Department of Primary Industries and Fisheries framework for issuing permits for freshwater stocking.

A Review of Environmental Factors must be completed for each project, organisms must be marked, and cohorts of released animals must be certified disease free. In the absence of an EIA, there are currently no protocols in place to address the genetic considerations of marine stocking. Genetic considerations are being addressed in the current mulloway stocking project.

Victoria

A trial stocking of marked black bream (*Acanthopagrus butcheri*) was undertaken by DPI Victoria in the Gippsland Lakes in 2004. The aim of this stocking was to assess the technical feasibility and possible benefits of enhancement for recreational fisheries. Whilst this was an isolated stocking event, further black bream stocking trials are planned for the future.

All marine stocking and translocation in Victoria is managed in accordance with the National Policy for the Translocation of Live Aquatic Organisms described above. Stocking proposals are evaluated by a Translocation Evaluation Panel, and each proposal (with the possible exception of recurring stocking) is required to undergo a full impact and risk assessment before permits to stock are granted. Genetic, disease and monitoring considerations of marine stocking are considered in the above process.

South Australia

There have been no deliberate releases of marine organisms in South Australian waters to date. PIRSA are currently working on a stock enhancement policy for South Australia to manage any future releases. A draft policy should be finalized in early 2006.

Western Australia

Hatchery-reared black bream (*Acanthopagrus butcheri*) have been released into the Upper Swan River and Blackwood estuary, to determine the survival, growth and recruitment to the recreational fishery (Lenanton et al. 1999, Dibden et al. 2000). Open system stocking of black bream has shown up to 12% of tagged fish recaptured up to three years later by recreational fishers, with recaptured fish showing a growth rate significantly higher than wild fish of the same age. Other releases for research purposes include snapper (*Pagrus auratus*) stocking in Shark Bay, and release of brown tiger prawns (*Penaeus esculentus*) in the Exmouth Gulf. Invertebrate stocking programs aimed at actual enhancement of stocks (as opposed to primary research) have seen stocking of saucer scallops (*Amusium balloti*), greenlip abalone (*Haliotis laevigata*) and trochus (*Tectus niloticus*) in different regions within the state.

At present, there are no legislative requirements to obtain a license or seek approval for the release of marine fish in Western Australia, however it is intended that powers be introduced under the *Fish Resource Management Act 1994* to allow the Department of Fisheries to regulate releases. Releases of non-endemic species are currently regulated under the states translocation policy. Also, a draft policy document relating to marine stocking in Western Australia has been prepared, incorporating genetic, disease and monitoring considerations of marine stocking (see Borg 2000), but has not been finally approved and implemented. This document will provide a framework for assessing marine stocking proposals in WA.

Northern Territory

The only marine stocking work to date in the Northern Territory has been limited stocking of Darwin Harbor and the Howard River with health-tested barramundi (*Lates calcarifer*) fingerlings from the NT Darwin Aquaculture Centre. No marking or monitoring was carried out on these fish. There are no marine stocking projects planned or currently underway in the Northern Territory.

Whilst there are is no specific policy regulating marine stocking in the Northern Territory, all stocking must be in accordance with an S16 permit under the *NT Fisheries Act 1988*.

Assessment of the permit application involves consideration of disease and monitoring issues for stocked fish.

Queensland

Several marine finfish species have been stocked in open systems in Queensland. Marked barramundi (*Lates calcarifer*), sand whiting (*Sillago ciliata*) and dusky flathead (*Platycephalus fuscus*) fingerlings have been stocked as part of research programs (Rimmer & Russell 1998, Butcher et al. 2000), with the barramundi stocking research program ongoing. Invertebrates currently stocked in Queensland include the pearl oyster (*Pinctada* spp.), saucer scallop (*Amusium japonicum balloti*), edible oyster (*Saccostrea* spp.) and various species of sea cucumbers. Other marine finfish stocked in Queensland waters include the golden javelin fish (*Pomatomus kaaken*).

Queensland is developing a draft policy dealing with all releases of fish into Queensland waters (DPI 2000). The policy exerts that stocking should proceed in a responsible fashion only where there is a demonstrated need to stock, with a risk assessment, and monitoring and evaluation component in each proposal. Stocking of public waters for research purposes is authorised under a Queensland Fisheries Service Permit, however all research projects must conform to the principles set out in the above policy. Also, marine stocking may be governed by Queensland DPIF's translocation policy.

Tasmania

Tasmania has several invertebrate stocking projects underway, including the sea urchin (*Heliocidaris erythrogramma*), southern rock lobster (*Jasus edwardsii*), blacklip abalone (*Haliotus rubra*) and the greenlip abalone (*Haliotus laevigata*). Excluding sea urchins, these projects all include a research component, with scallops and sea urchins currently being farmed commercially.

Permits are issued by DPIWE Tasmania for both research and commercial marine stocking, under the *Marine Farming Planning Act 1995* and *Living Marine Resources Management Act 1995*. License and permit conditions usually include a monitoring component and testing for diseases, however genetic factors are not included in assessment and issuing of permits (with the exception of Genetically Modified Organisms, which are prohibited).

Conclusions

All current marine stocking in Australia can be classified as research or pilot work, with the only enhancement programs aimed at enhancing stocks of invertebrate species. All states (and territory) appear equipped to deal with marine stocking proposals, and state governments' ability to identify and consider the possible risks of marine stocking will only benefit from further stocking trials and research. Where marine stocking does not fall under a policy or permit system, draft policies are currently being developed, or development is intended for the near future. The advent of these new policies is evidence that marine stock enhancement is increasingly being considered as a management option. Whilst these policies or frameworks for assessing marine stocking typically address monitoring, disease and translocation, it appears that the genetic risks of stocking are not given appropriate consideration in some cases. Also, these policies should aim to integrate the responsible approach to marine stock enhancement (Blankenship & Leber 1995) with legislated fishery management requirements. Possibly the largest challenge lying ahead in the development of marine stock enhancement will be reconciling stocking practices with the guiding principles of Ecologically Sustainable Development.

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Estuarine Fish Stock Enhancement in Australia

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Abstract

Stock enhancement is a pragmatic way of addressing declining fish stocks in estuarine systems. Stocking of recruitment limited species should occur in systems where the carrying capacity can support new recruits. Several drivers for estuarine stock enhancement exist in Australia, including political will, high recreational fishing pressure and stock recovery, however there is limited policy governing estuarine stocking events. States typically assess estuarine stocking proposals under permit systems and translocation protocols. Successful estuarine pilot studies in Australia have stocked barramundi *Lates calcarifer*, black bream *Acanthopagrus butcheri*, mulloway *Argyrosomus japonicus*, and flathead *Platycephalus fuscus*. A further 14 vertebrate and invertebrate marine species have been stocked, with varying degrees of monitoring and success. Stocking events should only occur in suitable areas where there is an identified need (i.e. recruitment limitation), and stocking levels should not be dictated by hatchery production capacity or funds available for the purchase of fingerlings. To facilitate further development of estuarine stocking technology in Australia, research should address feasibility of stocking, ecosystem suitability, recruitment dynamics of target species, marking techniques, safe stocking densities, environmental impact, and optimising stocking strategies. Future research projects should give consideration to experimental design, including control estuaries and assessments prior to the stocking events.

Estuarine Stock Enhancement in Australia

The enhancement of estuarine fishes and invertebrates through stocking have mostly been limited to pilot scale projects in Australia, with a total of 17 species stocked nationwide for limited periods of time in last 10 years (Table I). Successful estuarine pilot studies include barramundi *Lates calcarifer*, black bream *Acanthopagrus butcheri*, mulloway *Argyrosomus japonicus* and flathead *Platycephalus fuscus*. As yet, there are no ongoing programs that stock estuarine finfish, and only three invertebrate species are stocked as part of ongoing enhancement programs. The relative inertia in developing estuarine stock enhancement to address declining fish stocks is largely the result of the lack of information regarding the potential effects of stocking estuarine systems, and the probability of failure and consequent waste of resource. Whilst opportunities exist in Australia where stocking may prove useful in the recovery and enhancement of fisheries (Taylor et al. 2005), advancement in estuarine stocking can only be achieved through research into the effects of stocking, strategies that maximise the survival and minimise the impacts of released fish, and application of the responsible approach to marine stock enhancement (Blankenship & Leber 1995).

Rationale Behind Estuarine Stock Enhancement

Recruitment limitation has been identified as one of the most important factors in restoring populations of top-level predators after overfishing, as available resources fail to increase recruitment levels once above a certain threshold (Doherty 1999). Recruitment limitations may arise from physical barriers such as constricted estuarine channels (Taylor et al. 2005), weirs (Cattrijsse et al. 2002), and lack of sufficient freshwater flows to facilitate a freshwater signature for recruits to seek (see Hall 1986). Biological factors limiting recruitment may include a reduction in the spawning stock to levels that can no longer increase the numbers of recruits to historical levels, and high predation during larval settlement (Doherty et al. 2004).

Stock enhancement aims to overcome these recruitment limitations through the release of fingerlings, thus bypassing the high-mortality larval stage (Shepherd & Cushing 1980), and removing the need for settlement cues. Instances where physical barriers in systems are present, such as the intermittently closed opening landlocked lagoons (ICOLLs) of South Africa and temperate Australia, provide good opportunities for successful stock enhancement (Taylor et al. 2005). In these systems, the recruitment of estuarine species is often limited, and stocked biomass is largely retained within the release areas because of the physical barriers to migration (Taylor et al. 2005). Urbanised estuaries also provide opportunities for stock enhancement (Elliott & Hemingway 2002), as there is often both high recreational fishing pressure combined with low levels of natural recruitment.

Key Drivers for Estuarine Stock Enhancement

Stock enhancement is a popular activity with politicians as the stocking of fish is very tangible to the community and is seen as providing something, rather than taking away fishing rights through closing areas or limiting access. Whilst strong political support can lead to enhancement programs, at times the important considerations of designing and evaluating the stocking program are not given thought or funding to proceed along with the enhancement.

Enhancement also receives strong support from recreational fishers, who are an increasingly important part of fishing activities (Henry & Lyle 2003). Although the increasing tendency to catch-and-release helps to balance the impacts of increasing angling pressure (Winstanley 2005), some heavily targeted species are not sufficiently protected by catch regulations or may be recruitment limited (Taylor et al. submitted). Stocking may have a role to play in addressing the conflicts between recreational anglers and professional fishers regarding resource allocation, and fishing methods that produce excessive bycatch and habitat damage.

Finally, fisheries enhancement through stocking can play an important part in recovery programs for estuarine species if undertaken responsibly. The major challenge with this is identifying situations where stocking is likely to make a difference, whilst having minimal environmental impact. This can only be determined through well planned pilot studies aimed at addressing factors including natural recruitment, growth, genetics, survival and environmental impact.

Enhancement technology has progressed from the release of millions of larvae observed overseas around the turn of the century (Chan et al. 2003). A comprehensive 10-step responsible approach has been developed to maximise the success of enhancement efforts (Blankenship & Leber 1995), and the advantages of this have been demonstrated (Leber & Arce 1996, Ziemann 2004). Pilot stocking projects in Australia, however, may be both financially and temporally constrained (Taylor et al. 2005), so pilot work in Australia should address the most pressing issues: identifying a need for stocking, determining a suitable location and suitable stocking densities, maximising survival of stocked fish and assessing the social, economic and environmental impacts.

Policy Development

Stocking policy in Australia is under development in several states (Borg 2000, DPI 2000, Molony et al. 2003, Lenanton & Norriss 2005), however there is no coordinated national approach to estuarine stocking at present. Given the many unknowns associated with the practice, funds and effort should initially be channelled into pilot studies aimed at resolving key research issues. When effects and strategies for stocking have been addressed, research should be extended into policy governing estuarine releases.

In the absence of a estuarine stocking policy, pilot-scale projects should be assessed through a simple decision making process (e.g. Cadwallader 1999) and permit system, following a suitable assessment of the potential environmental effects of the project (e.g. a Review of Environmental Factors). Most states currently have assessments and protocols to govern estuarine stocking, however the genetic risks of stocking are rarely given sufficient consideration. Full-scale programs should not be permitted unless they follow on from comprehensive pilot-scale evaluations addressing the key issues.

Community Engagement

Community awareness of estuarine stocking practices is essential to prevent dissent toward bodies that stock fish, such as state governments or community groups and fishing clubs. Several perceptions of estuarine stocking exist within the community. People who are generally well informed may have heard about many of the stocking failures that have occurred overseas, and fail to understand the reasons behind these failures, and how recent stocking events follow a different approach to fisheries enhancement. Some in the community also see stocking as a negative thing, a perception that has arisen from species introductions which many people automatically associate with stocking events. Also, many fail to see any distinction between freshwater or impoundment stocking and estuarine stocking practices, and believe they are essentially the same thing.

The perception that methods used to create impoundment fisheries can be used to enhance wild estuarine stocks (Cadwallader 1999) may create problems in the future, with communities requesting local waterways be stocked with popular species purely because they believe stocking results in better fishing, and want the financial and aesthetic benefits that flow on from this. Ignorance of a demonstrated need or a firm scientific basis for stocking may result in waste of money, effort, and potentially unnecessary environmental damage. However, strong community involvement in estuarine stocking can help foster stewardship of estuarine resources, as observed with freshwater stocking programs in Queensland and stocking of black bream in the Swan River, Western Australia. These two considerations need to be balanced to obtain the best outcomes for estuarine stocking projects.

The regular flow of information to the community regarding the progress of stocked fish will help maintain community interest and foster community support for estuarine stocking. To maximise aesthetic benefits, community groups and fishing clubs should be involved in the actual stocking event, which will be of great interest to many people. Community involvement can be further expanded by enlisting the assistance of recreational fishers to partake in the monitoring of the stocking events through anglers diaries and catch returns. This has the added benefit of lowering the scale of fishery independent sampling programs, whilst enhancing the results of the project.

Production Capabilities

In Australia, over 23 estuarine species can be reared through aquaculture (Battaglene & Fielder 1997, Taylor et al. 2005) at densities of several hundred-thousand. However, as is the case elsewhere in the world (e.g. Leber 1999), advances in enhancement technology has not kept pace with the production technology.

Releases of estuarine finfish in Australia have often arisen as a result of the successful production of finfish by aquaculture facilities, and serve simply as a means of disposing of hatchery-reared fingerlings at the conclusion of the study. Hatchery production capacity alone should not drive the release of hatchery-reared progeny (Blankenship & Leber 1995). Whilst the availability of aquaculture technology plays a role in species selection, species should always be evaluated for their suitability for stock enhancement using key biological parameters (such as high growth and low natural mortality; Munro & Bell 1997), evidence of recruitment limitation (Doherty 1999), and available carrying capacity in the target ecosystem (Leber et al. 1995, Taylor et al. 2005). With these considerations in mind, ideal candidates for estuarine stocking in Australia include barramundi *Lates calcarifer*, black bream *Acanthopagrus butcheri*, mulloway *Argyrosomus japonicus*, flathead *Platycephalus fuscus* and the brown tiger prawn *Penaeus esculentus*.

Key Issues

Financial and temporal constraints may preclude the full integration of the 10-step responsible approach to marine stock enhancement. This necessitates the identification of key issues that should be addressed to facilitate successful and responsible stock enhancement with minimal environmental effects. Pilot research should initially identify ecosystems in which there may be available carrying capacity, identify which species to stock in this system conduct a thorough review of the biology of this species, develop marking techniques, determine safe stocking densities for the enhancement study and assess environmental impact, and finally develop stocking strategies that maximise growth and survival.

Stocking Density and Environmental Impact

The major concern associated with estuarine stocking is the unknown impacts that stocking may have on target ecosystems. Predator-prey relationships show that stocking low densities of a top-level predator may have significant effects on prey species (West 2005), which in turn may lead to displacement of competitors and wild conspecifics. If estuarine stocking is to fit within the principles of ESD (e.g. conservation of biodiversity) the potential environmental effects associated with stocking must be quantifiable, and stocking targeted at levels that the ecosystem can support. These levels may be limited by either prey availability or presence and area of key habitat, however relationships between predation by stocked fish and environmental impact may not be straightforward. For example, recent evidence suggests that increased predation pressure on lower trophic levels can act to increase production (Christensen & Pauly 1998). Small-scale manipulative ecological experiments will help to resolve these interactions (Miller & Walters 2004).

Once environmental impact has been addressed, these data can be further developed to address other factors fundamental to successful enhancement programs, such as quantifying enhancement targets and production of stocked fish, and economic analyses (Blankenship & Leber 1995).

Core Biology and Ecology

Successful stock enhancement requires a sound knowledge of the biology and ecology of the target species (Loneragan et al. 2003). This includes knowledge of forage requirements, habitat use, predator-prey interactions and recruitment dynamics. Establishing the food and habitat requirements for stocked fish will determine the suitability of stocking sites. Understanding the interactions of the target species with their predators and prey will reveal how trophic resources are utilised by stocked fish, and the potential for predation on these recruits.

Recruitment limitations may not be present all the time, and therefore stocking of a species need not be automatically undertaken every year, but rather only in years where recruitment is poor. Populations of black bream in Western Australia provide a potential example for such a strategy. Recruitment in this species varies greatly between years providing an opportunity to enhance in years of low natural recruitment and not in years when natural recruitment is high. It is ideal to have a fish population sustained naturally by wild recruits, however the productivity of a fishery may be enhanced by "topping up" with hatchery recruits during years of poor recruitment. Resolving the recruitment dynamics of the target species will demonstrate under what conditions recruitment limitation occurs, and thus determine criteria (such as oceanographic or environmental conditions) that indicate the need for stocking on a year-to-year basis. Thus, by monitoring the presence and success of wild recruits, stocking can be scaled back in times of adequate wild recruitment. In addition, stocking should be timed to coincide with size modes in the wild population (Willis et al. 1995), which will reduce the incidence of predation on conspecifics and enhance the survival of stocked cohorts.

Genetics

There has been minimal integration of core genetic principles into the planning and execution of estuarine stock enhancement in Australia, with the only current example being the use of 100 black bream broodstock for the Blackwood River project in Western Australia (Jenkins et al. 2005). Genetic management of the hatchery and enhancement program are of primary importance, as damage to genetic resources can rarely be ameliorated (Utter 1998). The consequences of genetic damage generally include reduced fitness, fecundity and growth (Moore 2005). At present, minimal genetic monitoring is conducted for freshwater stocked fish even though in many cases fish are spawned from a relatively narrow genetic base. For estuarine stocking, it is essential that the population genetic structure of the target species be known before stocking is commenced (Taylor et al. 2005). The presence of localised genetic variation will mean that fish stocked in these locations should be spawned from broodstock taken from the population to be stocked. Strip spawning of wild individuals in the area to be stocked is a pragmatic way of avoiding the holding and exchange of large numbers (>100) of broodstock in the hatchery (Taylor et al. 2005). Stocking pilot studies should examine this, and evaluate the population genetic structure of the target species.

Growth and Survival

Growth and survival of stocked fish is a product of adequate food and key habitat availability, stocking strategies, and genetic fitness. The presence of adequate key habitat is particularly critical for species that use refugia to limit their predation risk (Biro et al. 2003, Walters & Martell 2004). Habitat is often a limiting factor in consideration of carrying capacity for stocked fish, as to great a stocking density may saturate refugia and introduce density-dependent effects on the wild fish, such as increasing mortality and reducing growth (e.g. Lorenzen 2005, 2006). When evaluating carrying capacity in terms of food resources, it is also important to consider that forage resources outside of key habitats may not be efficiently exploited by stocked fish, as extended excursions from refuge increases predation risk. A thorough assessment of the habitat use and diet of stocked fish from the time at stocking to the size when they are caught, will allow stocking to be targeted to the correct area at the correct densities, thus maximising growth and survival of stocked fish.

Determining optimal release strategies will also maximise growth and survival, and these should be assessed using factorial-design release-recapture experiments (Leber et al. 1995). Strategies requiring optimisation include size-at-release, site-of-release, and also timing of release for those species with protracted spawning periods. Growth and survival can generally be monitored through both fishery dependant and independent sampling.

Bio-economic Modelling

Bio-economic modelling of enhancement activities is important to understand the costs of stocking and the benefits and links between production and survival of released fish until capture. Bio-economic models provide a useful framework to link the production, biology, fishery and economics of enhancement and provide a focus to help establish the objectives and performance measure for the success of enhancement (Loneragan et al. 2004, Ye et al. 2005, Loneragan et al. 2006).

Conclusions

Whilst most key issues identified here will have to be evaluated on a species-by-species basis, the design of research projects can be augmented as experience is gained through pilot stocking projects. A common problem experienced in estuarine stocking research is the lack of research prior to the stocking event, as there is usually political pressure to stock. Good experimental design needs some baseline against which to measure results, and should involve a research stage prior to stocking, for example, conducting a localised stock assessment prior to the stocking event, and one at the conclusion of the project (e.g. Jenkins et al. 2005). Also, research projects must consider the use of control sites, to facilitate robust statistical analysis (Moore & Hughes 2005).

Of the 17 marine species stocked in Australia, five have a life-cycle that involve estuaries or semi-enclosed systems. Given the positive results of pilot studies, future work should concentrate on addressing these areas of research to facilitate larger scale enhancement. For example, core research on black bream should focus on resolving factors affecting recruitment limitation and environmental impact, and then define objectives for enhancement and release strategies. The environmental impact of stocked mulloway is now known, and research is now resolving recruitment dynamics, release strategies, and cost-benefit analysis of enhancement. Whilst the current barramundi enhancement research ceases in 2006, with the setting of explicit enhancement objectives, this work may be extended into a full-scale enhancement program. Pilot stocking research has provided a solid basis for the development of enhancement technology for these species in other areas, such as the stocking of black bream in the Gippsland Lakes, and the stocking of mulloway in the Blackwood River. Barramundi stocking may also be extended to address the decline of barramundi in the Northern Territory.

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Table I Marine stocking projects undertaken in Australia to date

Species	**Common name**	**State**	**Purpose**
Platycephalus fuscus	Flathead	Queensland	Pilot research
Sillago ciliata	Sand whiting	Queensland	Pilot research
Pomatomus kaaken	Golden javelin fish	Queensland	Pilot research
Lates calcarifer	Barramundi	Queensland Northern Territory	Pilot research & disposal of surplus aquaculture production (NT)
Pinctada spp.	Pearl oyster	Queensland	Enhancement of commercial fishery
Amusium balloti	Saucer scallop	Queensland	Enhancement of commercial fishery
Saccostrea spp.	Edible oyster	Queensland	Enhancement of commercial fishery

Argyrosomus japonicus	Mulloway	NSW	Pilot research
Acanthopagrus butcheri	Black bream	Western Australia Victoria	Pilot research
Pagrus auratus	Snapper	Western Australia	Pilot research
Penaeus esculentus	Brown tiger prawn	Western Australia	Enhancement of commercial fishery
Amusium balloti	Saucer scallop	Western Australia	Enhancement of commercial fishery
Haliotis laevigata	Greenlip abalone	Western Australia Tasmania	Enhancement of commercial fishery
Tectus niloticus	Trochus	Western Australia	Enhancement of commercial fishery
Heliocidaris erythrogramma	Sea urchin	Tasmania	Enhancement of commercial fishery
Jasus edwardsii	Southern rock lobster	Tasmania	Pilot research & enhancement of commercial fishery
Haliotus rubra	Blacklip abalone	Tasmania	Pilot research & enhancement of commercial fishery

A Review of Stock Enhancement Activities for Threatened Fish Species in Australia

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Abstract

There are currently 83 taxa listed as threatened under State, Territory or National legislation in Australia. These comprise 66 freshwater, 14 marine and 5 estuarine species. Threatened taxa were categorised on average adult body size into small (TL < 200 mm) or large (TL> 200 mm) species, with the majority of taxa being small (71 percent). Stock enhancement activities are documented or known for at least 15 threatened fish taxa, and these are reviewed. In this review stock enhancement includes the release of captive-bred fish, the translocation of wild fish, and activities involving provision of artificial spawning substrates. The release of captive bred fish is only considered where this activity was for conservation purposes, rather than the enhancement of recreational fisheries. The stocking of captive bred individuals occurred for five species, predominantly large freshwater taxa, whilst translocation has been employed for nine taxa, all freshwater species. Enhancement of spawning sites has only been documented for one marine species.

Introduction

A total of 83 taxa are currently listed as threatened under State, Territory or National legislation in Australia (Appendix 1), comprising 66 freshwater, 14 marine and 5 estuarine species. Only those listings with statutory effect were used in the compilation of this listing, so IUCN and the Australian Society for Fish Biology listings (Baillie *et al*. 2004; ASFB 2005) are not included. Threatened taxa were categorised on average adult body size into small (TL < 200 mm) or large (TL> 200 mm) species, with the majority of taxa being small (71 percent) (See list at the end of this paper).

Definitions

In this review stock enhancement includes the:

- Release of captive-bred fish;
- The translocation of wild fish; and
- Activities involving provision of artificial spawning substrates.

This review includes traditional stocking activities using hatchery-bred fish, but excludes stocking for recreational purposes. This means that stocking activities for a species before it was listed as threatened (eg Murray cod stocking, most silver perch stocking etc) or stocking for threatened species where recreational fisheries are still operational (and the stocking is intended to support these fisheries) are not included.

Similarly translocations are included in the scope of this review where the translocation was for conservation (rather than fishery enhancement) purposes. As for stocking, this then excludes historical translocation actions for currently listed species before they were considered threatened (eg Trout cod (Cadwallader and Gooley 1984); Macquarie perch (Cadwallader 1981) Freshwater catfish (Harris and Battaglene 1990) etc.

Stock enhancement is here defined to include one specific habitat enhancement activity (the provision of artificial spawning substrates or transplantation of natural spawning substrates), but otherwise excludes general habitat rehabilitation activities such as riparian restoration, fish passage enhancement etc. This review excludes the provision of artificial spawning habitat where it was for small-scale research purposes, rather than stock enhancement (e.g Lintermans 1998; Saddlier 2001).

What's Been Done So Far?

Stock enhancement activities are documented or known for at least 15 threatened fish taxa (Table 1). The stocking of captive-bred individuals has occurred for five species, predominantly large freshwater taxa, whilst translocation has been employed for nine taxa, all freshwater species. Enhancement of spawning sites has only been documented for 1 marine species (Table 2). Translocation has most often been employed with small freshwater species such as galaxiids (Table 3), although translocation has occurred for the large freshwater species, Macquarie perch, in recent decades (Lintermans 2003) and more are planned (Lintermans unpubl. data). Other translocations of this species occurred historically for fisheries enhancement reasons in Victoria (Cadwallader 1981) and NSW (Stead 1913; Cataract Dam and Mongarlowe River (Harris and Rowland 1996)). Translocation has also occurred for Freshwater catfish in Victoria.

Table 1: Number of threatened fish in each category, (with number of taxa subject to documented stock enhancement activities in brackets)

	Size	Number of Threatened Species	Examples
freshwater	Small	50 (9)	Gudgeons, galaxids, pygmy perch etc
	Large	16 (5)	Cods, perch, catfish
marine	Small	4 (1)	Handfish
	Large	8 (0)	Sharks, tuna
estuarine	Small	0 (0)	
	Large	5 (0)	Sawfishes, Glyphis etc

Table 2: Number of taxa in each category of Australian threatened fish for which Stock enhancement activities are documented.

	Size	Hatchery releases	Translocation	Spawning site enhancement
freshwater	Small	1	7	-
freshwater	Large	3	2	-
marine	Small	1	-	1
TOTAL		5	9	1

The stocking of hatchery-bred individuals is most often employed in the conservation of large-bodied freshwater species such as the cods (*Maccullochella* spp)(Lintermans et al. 2005). All four species of Australian freshwater cod have been the subject of extensive stocking programs (Table 3), although in the case of Murray cod, this has been for recreational fisheries enhancement rather than threatened species enhancement (Lintermans and Phillips 2005). The stocking program for Trout cod (*Maccullochella macquarienis*) has been the most extensive of the three endangered cod species, having been in operation for 20 years and releasing more than 1 million fish across three jurisdictions in the Murray-Darling Basin. The use of captive breeding and stocking of hatchery-derived offspring has rarely been used for small freshwater species, with the exceptions being the Pedder Galaxias (*Galaxias pedderensis*)(Jackson 2004) and a recent initiative involving Southern Purple-spotted gudgeon (*Mogurnda adspersa*). Stocking hatchery-bred fish has also been trialled with the Spotted handfish *Brachionichthys hirsutus.*

The Spotted handfish is the only species (marine or freshwater) that has been the focus of artificial enhancement of spawning habitats, although the use of spawning tubes has been employed to research the reproductive ecology of a number of freshwater species such as *Gadopsis bispinosus*, *G. marmoratus* and *Maccullochella ikei* (Lintermans 1998; Jackson 1979; G. Butler pers. comm.). The Spotted handfish has been subject to spawning habitat enhancement both through the provision of artificial substrates and the translocation of natural algal spawning substrate (DEH 2004; Green and Bruce 2005)(Table 3).

How has the Practice of Stock Enhancement Changed Recently?

There is now a growing appreciation of the many issues associated with fish stocking and translocation for both recreational and threatened species (Harris 2003). A recent workshop on this topic in the Murray-Darling Basin resulted in 27 recommendations on how current practice might be improved, covering a range of areas including implementing the *National policy for the translocation of live aquatic organisms*, use of formal risk analysis frameworks, quality control and accreditation for hatcheries, stocking and translocation programs for recreational and conservation purposes, and community education and participation initiatives (Phillips 2003). The genetic implications of stock enhancement programs for both threatened and non-threatened species has received significant attention in Australia in recent years (Bearlin & Tikel 2003; Gilligan 2005; Moore 2005), and the move to certification of hatchery programs is a positive step to producing genetically better fish (Rowland and Tully 2004).

Some jurisdictions are now employing strict protocols to assess translocations (see DPI 2005) or at least have publicly accessible stocking and translocation policies (e.g. NSW DPI 2005). However, there still remain significant knowledge gaps for stock enhancement activities for threatened species. A recent project comparing the movement patterns of hatchery-reared and wild sub-adult trout cod in the Murrumbidgee River NSW found that hatchery-reared individuals had significantly different movement patterns immediately after release, with hatchery fish initially moving much larger distances. The same project also recorded significantly higher mortality of hatchery than wild fish, with only 1 of 27 hatchery fish surviving the 12 month study, compared to 18 of 31 wild fish (Ebner *et al*. in prep). The high mortality of newly released captive-bred individuals is a major problem with stock enhancement programs worldwide, with highest mortality occurring during or immediately after release (Olla *et al*. 1994, 1998; Brown and Day 2002)

So What Have We Learned So Far?

Conventional Stocking of Hatchery-reared Fingerlings

We know that for the stocking of hatchery-reared fingerlings:

- It is relatively easy and cheap to do once breeding techniques have been developed;
- many times fingerlings survive reasonably well to sub-adult or adult level;
- It takes a long time for results to become apparent (ie detecting recruits from stocked fish); and
- Conventional stocking has not had a great success rate in establishing self-sustaining populations of either threatened or non-threatened species.

Stocking of Hatchery-reared Sub-adults

From the recent project (Ebner et al. in prep) involving stocking of hatchery-reared sub-adults, we know that:

- It is expensive to on-grow fish (take up pond space that is needed for other breeding programs etc);
- Behavioural responses may be changed (accustomed to being fed with pellets, changed dispersal behaviour); and
- Hatchery-reared had high mortality (predator naïve, reduced foraging capacity?).

Translocations

Translocation has been widely used overseas in the conservation of threatened fish species (Maitland 1995; Minckley 1995) with a number of criteria proposed for consideration in planning such activities (IUCN 1987; Williams et al. undated). We know that for the use of translocated individuals to establish new populations it is:

- Easy and effective for small bodied species (Ambassids, Gudgeons, Galaxids etc);
- They are still wild fish, so not predator naïve, and so there are no hatchery-induced behaviour changes;
- Translocations are also applicable and effective for large freshwater species:
    - Trout cod (Sevens Creek, Cataract Dam)
    - Macquarie perch, (Yarra River, Queanbeyan River, Mongarlowe River, Cataract Dam)
    - Freshwater catfish (central Vic)
    - Silver perch (Cataract Dam)
    - Murray cod (Lake George etc)
- Relatively low numbers of fish are required to establish populations;
- Expensive hatchery facilities are not required; and
- Investment in the development of captive-breeding programs is not required.

Translocation appears to offer a relatively quick and inexpensive means of establishing new populations of threatened species.

What are the Knowledge Gaps for Stock Enhancement of Threatened Fish Species?

As there has been relatively little attention devoted to stock enhancement of threatened species compared to recreational species, there are still many knowledge gaps to be filled. Knowledge gaps vary according to whether a hatchery-based or translocation approach is being considered.

Hatchery programs

- Why aren't fingerling stocking programs very successful (in establishing new populations) for threatened fish?

- Whilst ‘fish community’ conservation approaches (lower Murray, lower Darling, Lachlan rivers etc) are desirable from a holistic management viewpoint, are they going to be sufficient to recover individual threatened species?
- What are the behavioural differences induced by hatchery rearing (see Olla et al. 1994, 1998)?
- We need to develop and use modelling (see Bearlin et al. 2002) so we can better play the *numbers game* when trying to establish new populations (more fish, larger fish, fewer stocking sites etc).
- How can we address behavioural deficits of hatchery-derived fish (see Brown and Laland 2001; Berejikan et al. 2001; Brown and Day 2002; Kelley et al. 2005)?
- Are improvements needed to our current release practices?
- We need better methods (non-destructive) for discriminating hatchery and wild fish.

Translocations

- Why don’t we use them more often?
- What are the cost benefit considerations of using different life stages in translocation attempts (juveniles/sub-adults/adults)?
- What are the effects on donor populations?

Many stock enhancement activities for threatened species are poorly documented (often residing in the memory or notebooks or few individuals) and rarely reported in peer-reviewed literature (often consigned to internal agency reports or the ‘grey’ literature. Similarly, many stock enhancement programs have no or inadequate monitoring programs, often poorly resourced or inadequately designed. If we are to learn from the past we must monitor, document and publish the results of previous attempts.

What are the Extension Issues in Stock Enhancement for Threatened Species?

The most successful threatened species programs have active participation from community or interest groups, and this participation needs to be an integral part of all recovery programs. Messages that need to be clearly imparted to beneficiary groups include that:

- Stocking is not the universal panacea for recovery of threatened fish;
- Threatened fish recovery is a long-term commitment (decades, not years);
- A species has not “recovered” just because you can catch lots of them at the stocking sites. Until there is clear evidence of sustained recruitment over a number of years, protective harvest controls should not be prematurely removed.

Conclusions

It is disappointing that so little has been done in terms of active stock enhancement for threatened fish, in contrast to the considerable efforts devoted to stock enhancement of recreational species. Only 15 of 83 threatened fish species have had any stock enhancement actions devoted to them, and this clearly needs to be rectified if threatened species list are not to continue to expand in the future. Stock enhancement activities have a clear and vital role to play in potentially delisting currently threatened species.

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Table 3: Stock enhancement activities documented for individual fish taxa in Australia

Species	**Common Name**	**State**	**Stocked / Translocated / other**	**Year**	**Life stage involved**	**Numbers**	**Successful?**	**Reference**
Brachionichthys hirsutus	Spotted Handfish	Tas	Stocked	1999	juveniles	155	No	DEH 2004
Brachionichthys hirsutus	Spotted Handfish	Tas	Artificial spawning substrate enhancement	1998		>550 (3 sites)	Limited spawning occurred	DEH 2004; Green & Bruce 2005
Brachionichthys hirsutus	Spotted Handfish	Tas	Transplanting natural spawning substrates (algae)	2002		1 site	?	DEH 2004
Galaxias auratus	Golden Galaxias	Tas	Translocated			2 populations in farm dams	Yes	Jackson 2004; Hardie 2003
Galaxias fontanus	Swan Galaxias	Tas	Translocated	1989-95	Adult & juveniles	Total of 567 fish over 10 populations	9 pops established, 1 failed	Jackson 2004
Galaxias parvus	Swamp Galaxias	Tas	Translocation proposed (2004??)					M. Beitzel pers. comm..
Galaxias pedderensis	Pedder Galaxias	Tas	Translocated and 11 juveniles from captive breeding	1991-97	Adult & juveniles	34 into Lake Oberon	Yes (limited success with captive breeding)	Crook & Sanger 1997; Jackson 2004
Galaxiella pusilla	Dwarf Galaxias	Vic	Translocated	2005	Adults and juveniles	851	Yes	Tucceri 2005
Paragalaxias mesotes	Arthurs Paragalaxias	Tas	Translocated	2002		174	Reintroduced to Woods Lake. Success unknown	Jackson 2004
Gadopsis bispinosus	Two-spined Blackfish	ACT	Translocated	2004	59	Adults and sub-adults	unknown	Lintermans unpubl data

Table 3 (continued): Stock enhancement activities documented for individual fish taxa in Australia

Species	Common Name	State	Stocked / Translocated / other	Year	Life stage involved	Numbers	Successful?	Reference
Macquaria australasica	Macquarie Perch	ACT	Translocated	1980, 1984/85	adults	57 in 1980; 41 in 84/85	1980 attempt successful; 1984/85 attempt unsuccessful	Lintermans 2002, 2003
Maccullochella ikei	Eastern Freshwater Cod	NSW	Stocked	1989, 1997 onwards	fingerlings	220,000	Good survival but reproduction?	NSW Fisheries 2004
Maccullochella peelii mariensis	Mary River Cod	Qld	Stocked	1983	fingerlings	416,300 to 2004	reproduction?	Lintermans et al. 2005
Maccullochella macquariensis	Trout Cod	ACT, NSW Vic	Stocked	1986-2005	Mostly fingerlings but some sub-adults	1,166,370 to 2004	Recruitment likely in approx 2 populations, & potentially in another 2 pops	Lintermans et al. 2005 S. Nicol pers. comm
Mogurnda adspersa	Southern Purple-spotted Gudgeon	NSW, SA	Stocking	2004 in NSW, 1996/97 in SA	juveniles	2500 fish (2 sites) in one stream (NSW), SA unknown	NSW unknown, SA yes	D. Gilligan unpubl data; M. Hammer pers comm..
Tandanus tandanus	Freshwater Catfish	Vic	Translocated	1999, 2002, 2004	Mainly adults, some juveniles	331 in 1999 87 in 2002 938 in 2004	1999 transfers, yes. 2002 & 2004 unknown	P. Clunie pers comm
Ambassis agassizii	Olive Perchlet	SA	Translocated	1997	unknown	unknown	unknown	M. Hammer pers comm

List of threatened species from State, Territory and National listings

Species	**Common Name**	**State**	**Marine / Freshwater**	**State Status**	**EPBC Status**	**Body size**
Brachionichthys hirsutus	Spotted Handfish	Tas	Marine	EN	EN	Small
Brachionichthys politus	Red Handfish	Tas	Marine		VU	Small
Sympterichthys sp. (CSIRO #T1996.01)	Waterfall Bay Handfish	Tas	Marine		VU	Small
Sympterichthys sp. [CSIRO #T6.01]	Ziebell's Handfish	Tas	Marine		VU	Small
Galaxias auratus	Golden Galaxias	Tas	Freshwater	rare	EN	Small
Galaxias fontanus	Swan Galaxias	Tas	Freshwater	EN	EN	Small
Galaxias johnstoni	Clarence Galaxias	Tas	Freshwater	EN	EN	Small
Galaxias parvus	Swamp Galaxias	Tas	Freshwater	Rare		Small
Galaxias pedderensis	Pedder Galaxias	Tas	Freshwater	EN	Extinct in wild	Small
Galaxias tanycephalus	Saddled Galaxias	Tas	Freshwater	EN	VU	Small
Galaxias brevipinnis	Climbing Galaxias	SA	Freshwater	[V]		Small
Galaxias olidus	Mountain Galaxias	SA	Freshwater	[R]		Small
Galaxiella pusilla	Dwarf Galaxias	Tas Vic SA	Freshwater	Rare (Tas) L (Vic) [V] (SA)	VU	Small
Galaxias olidus var. fuscus	Barred Galaxias	Vic	Freshwater	L	EN	Small
Galaxias truttaceus	Spotted Galaxias	SA	Freshwater	[R]		Small
Galaxias truttaceus hesperius	Western Trout Minnow	WA	Freshwater	R		Small
Paragalaxias dissimilis	Shannon Paragalaxias	Tas	Freshwater	VU		Small
Paragalaxias eleotroides	Great Lake Paragalaxias	Tas	Freshwater	VU		Small
Paragalaxias julianus	Western Paragalaxias	Tas	Freshwater	rare		Small
Paragalaxias mesotes	Arthurs Paragalaxias	Tas	Freshwater	EN	EN	Small
Prototroctes maraena	Australian Grayling	Tas Vic SA	Freshwater	VU (Tas) L (Vic) [EN] (SA)	VU	Small
Neoceratodus forsteri	Queensland Lungfish	Qld	Freshwater		VU	Large
Gadopsis bispinosus	Two-spined Blackfish	ACT	Freshwater	VU		Small
Gadopsis marmoratus	River Blackfish	SA	Freshwater	PROT [EN]		Large
Macquaria colonorum	Estuary Perch	SA	Freshwater	[EN]		Large
Macquaria australasica	Macquarie Perch	ACTN SWVi c SA	Freshwater	EN (ACT) VU (NSW) L (Vic) [EN] (SA)	EN	Large
Maccullochella ikei	Eastern Freshwaterwate r Cod	NSW	Freshwater	EN	EN	Large
Maccullochella peelii mariensis	Mary River Cod	Qld	Freshwater		EN	Large

Maccullochella peelii peelii	Murray Cod	Vic SA	Freshwater	L (Vic) [R] (SA)	VU	Large
Maccullochella macquariensis	Trout Cod	ACT NSW Vic SA	Freshwater	EN (ACT, NSW) L (Vic) PROT [EN] (SA)	EN	Large
Neosilurus cooperensis	Cooper Creek Tandan	SA	Freshwater	[R]		Large
Neosilrus gloveri	Glover's Catfish	SA	Freshwater	[R]		Small
Tandanus tandanus	Freshwater Catfish	SA Vic	Freshwater	PROT [V] (SA) L (Vic)		Large
Bidyanus bidyanus	Silver Perch	ACT NSW Vic SA	Freshwater	EN (ACT) VU (NSW) L (Vic) PROT [V] (SA)		Large
Anguilla australis	Short-finned Eel	SA	Freshwater	[R]		Large
Mordacia mordax	Short-headed Lamprey	SA	Freshwater	[EN] (SA)		Large
Geotria australis	Pouched Lamprey	SA	Freshwater	[EN] (SA)		Large
Pseudaphritis urvilli	Congolli	Sa	Freshwater	[R]		Small
Gobiomorphus coxii	Cox's Gudgeon	Vic	Freshwater	L		Small
Philypnodon sp 2	Dwarf Flathead Gudgeon	SA	Freshwater	[R]		Small
Hypseleotris klunzingeri	Western Carp Gudgeon	SA	Freshwater	[R]		Small
Hypseleotris sp	Muray-Darling Carp Gudgeon	SA	Freshwater	[R]		Small
Hypseleotris compressa	Empire Gudgeon	Vic	Freshwater	L		Small
Milyeringa veritas	Blind Gudgeon	WA	Freshwater	R	VU	Small
Mogurnda clivicola	Flinders Ranges Gudgeon	SA	Freshwater	[V] (SA)	VU	Small
Mogurnda adspersa	Southern Purple-spotted Gudgeon	NSW Vic SA	Freshwater	EN POP (NSW) L (Vic) PROT [EN](SA)		Small
Mogurnda thermophila	Dalhouse Purple-spotted Gudgeon	SA	Freshwater	[R] (SA)		Small
Chlamydogobius gloveri	Dalhousie Goby	SA	Freshwater	[R]		Small
Chlamydogobius japalpa	Finke Desert-goby	NT	Freshwater	VU		Small
Chlamydogobius sp. A	Elizabeth Springs goby	Qld	Freshwater	EN	EN	Small
Chlamydogobius sp. B	Edgbaston goby	Qld	Freshwater	EN	VU	Small
Pseudomugil mellis	Honey Blue-eye	Qld	Freshwater	VU	VU	Small
Scaturiginichthys vermeilipinnis	red-finned blue-eye	Qld	Freshwater	EN	EN	Small
Ambassis agassizii	Olive Perchlet	NSW SA Vic	Freshwater	EN POP (NSW) PROT [EN](SA) L(Vic)		Small
Nannoperca oxleyana	Oxleyan Pygmy Perch	NSW Qld	Freshwater	EN (NSW) VU (Qld)		Small
Nannoperca australis	Southern Pygmy Perch	NSW SA	Freshwater	VU (NSW) PROT [EN] (SA)		Small
Nannoperca variegata	Ewens Pygmy Perch	SA Vic	Freshwater	PROT [EN](SA) L (Vic)	VU	Small
Edelia obscura	Yarra Pigmy Perch	Vic	Freshwater	L	VU	Small
Pristis zijsron	Green Sawfish	NSW NT	Marine	EN (NSW) VU (NT)		Large

Glyphis sp. A	Speartooth Shark	NT	Estuarine	EN	CE	Large
Glyphis sp. C	Northern River Shark	NT	Estuarine	EN	EN	Large
Pristis microdon	Freshwaterwater Sawfish	NT	Freshwater/ estuarine	VU	VU	Large
Pristis clavata	Dwarf Sawfish	NT	Marine/ estuarine			Large
Anoxypristis cuspidata	Narrow Sawfish	NT	Marine	VU		Large
Rhincodon typus	Whale Shark		Marine		VU	Large
Carcharias taurus	Grey Nurse Shark (east and west coast populations)	NSW Vic NT WA Qld	Marine	EN (NSW) L (Vic) DD (NT) R (WA) EN (Qld)	CE (east coast) VU (west coast)	Large
Carcharodon carcharias	Great White Shark	NSW SA Vic Tas WA	Marine	VU (NSW) PROT (SA) L (Vic) VU (Tas) R (WA)	VU	Large
Himantura chaophraya	Freshwaterwater Whipray	NT	Freshwater/ estuarine	DD		Large
Raja sp. L. (Last & Stevens, 1994)	Maugean Skate	Tas	Marine	EN	EN	Large
Thunnus maccoyii	Southern Bluefin Tuna	NSW Vic	Marine	EN (NSW) L (Vic)		Large
Craterocephalus fluviatilis	Murray Hardyhead	NSW Vic SA	Freshwater	EN (NSW) L (Vic) [EN] (SA)	VU	Small
Craterocephalus stercusmuscarum fulvus	Fly-specked Hardyhead	Vic SA	Freshwater	L (Vic) [R] (SA)		Small
Craterocephalus dalhousiensis	Dalhousie Hardyhead	SA	Freshwater	[R]		Small
Craterocephalus gloveri	Glover's Hardyhead	SA	Freshwater	[V]		Small
Epinephelus daemelii	Black Cod	NSW	Marine	VU		Small
Neochanna cleaveri	Australian Mudfish	Vic	Freshwater	L		Small
Ophisternon candidum	Blind Cave Eel	WA	Freshwater	R	VU	Small
Potamalosa richmondia	Freshwater Herring	Vic	Freshwater	L		Small
Melanotaenia fluviatilis	Murray-Darling Rainbowfish	Vic SA	Freshwater	L (Vic) [R] (SA)		Small
Melanotaenia eachamensis	Lake Eacham Rainbowfish	Qld	Freshwater		EN	Small
Lovettia sealii	Tasmanian Whitebait	Vic	Freshwater	L		Small
Pingalla lorentzi	Lorentz' Grunter	NT	Freshwater	VU		Small
Scortum neili	Angalarri Grunter	NT	Freshwater	VU		Large

Key: CE = critically endangered EN = endangered
V = vulnerable R = rare
DD = Data Deficient
L = listed (under the Victorian Flora & Fauna Guarantee Act 1988)
PROT = protected under SA Fisheries Act 1982
[xx] = status proposed in SA under the Department of Environment & Heritage 2003 Discussion Paper
Small = species with average adult total length < 200 mm

Large = species with average adult total length > 200 mm
EPBC = Environment Protection and Biodiversity Conservation Act 1999

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NT: http://www.nt.gov.au/nreta/wildlife/threatened/specieslist.html
WA: http://www.naturebase.net/plants_animals/watscu/index.html
Qld: http://www.epa.qld.gov.au/nature_conservation/wildlife/threatened_plants_and_animals/
ACT: http://www.environment.act.gov.au/nativeplantsandanimals/thrtspecinfo.html
NSW: http://www.fisheries.nsw.gov.au/threatened_species/threatened_species
Tas: http://www.dpiwe.tas.gov.au/inter.nsf/WebPages/SJON-58K8WK?open
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Freshwater Stocking in Queensland

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Overview

Queensland's fish stocking program is based on the creation of freshwater recreational fisheries using native species. The program is a partnership between Government and local communities with community-based fish stocking groups forming the core of the operation. Stocking groups purchase fingerlings from commercial hatcheries and now stock almost every suitable impoundment in Queensland resulting in the formation of valuable recreational fisheries throughout the State. To support the stocking program, DPI&F have provided small annual grants to stocking groups to help with maintaining their local fisheries.

Since the introduction of the stocking program in 1986, freshwater impoundment fishing has significantly increased in popularity. This led to the introduction of the user-pays Stocked Impoundment Permit (SIP) Scheme in 2000 which currently applies to 29 of these stocked impoundments. The SIP Scheme has resulted in a further acceleration of stocking activities in those impoundments involved, with funds raised by the Scheme being used primarily to purchase fingerlings for the impoundments.

Many stocking groups are now able to afford to stock their dams to the maximum numbers stated on their stocking permits, a situation which rarely occurred before the SIP Scheme. The impacts of the increase in stocking activity are not yet fully understood.

In the current environment of Ecological Sustainable Development (ESD), concerns have been raised regarding the lack of information on impacts of stocking. Determining the ecological impacts of the stocking program is a priority for freshwater fisheries management as well as determining optimal stocking strategies and socio-economic impacts of the stocked fishery.

Drivers for Stock Enhancement

In 1986 the Queensland Government's Recreational Fishing Enhancement Program was introduced with freshwater stocking forming one component of this. The initial aims of the freshwater stocking program were to stock inland storages with native fish, create a recreational fishing resource, attract tourism and reduce the pressure on saltwater, estuary and wild riverine fisheries. This resulted in widespread development of freshwater fishing opportunities throughout the State.

Before 1986, stocking was primarily research driven with fish such as saratoga, silver perch, sleepy cod and sooty grunter distributed to water bodies to evaluate survival and establishment. Very little consideration was given to the impacts of translocation during these times. Many translocations were one off events and often the species did not establish. However other translocations resulted in the creation of valuable recreational fisheries. For example, stocking of south east Queensland coastal impoundments with golden perch, silver perch and saratoga has helped create recreational fisheries that are economically valuable to local communities. These valued fisheries have been allowed to continue under legislative provisions.

The stocking program has achieved significant economic development in some rural communities with the development of local specialist industries such as charter, bait and tackle, accommodation and boat construction as well as fish hatcheries – these industries provide jobs and economic benefits for local regional communities.

The current objective of the fish stocking program is to create new fisheries or to restore existing fisheries using native fish.

Only native species are stocked in Queensland and those species approved for stocking are:

- Australian bass
- Barramundi
- Eel-tailed catfish
- Golden perch
- Khaki bream
- Mary River cod
- Murray cod
- Redclaw crayfish
- Silver perch
- Sleepy cod
- Sooty grunter
- Southern saratoga

Nearly every suitable freshwater impoundment in Queensland is now stocked. Some stretches of river are also stocked however these are generally upstream of waterway barriers such as weirs or barrages.

The different types of fish stocking programs carried out in Queensland are tabled below:

Stocking Type	**Description**	**Program**
Conservation stocking	Conservation stocking is carried out by government agencies as part of a recovery program for endangered or threatened species.	Mary River Cod recovery program
Enhancement stocking	To improve or restore species abundance and diversity in an otherwise depleted waterbody.	Barramundi stocking into freshwater rivers in north Queensland
Put, grow and take fisheries	Create and maintain recreational fishing opportunities in impoundments.	Fish Stocking Program Stocked Impoundment Permit Scheme
Fodder fish	Small, prey fish are introduced to waterbody to provide food to larger stocked species	Fish Stocking program Stocking groups with a general fisheries permit allowing this activity
Private waters	Fish released in farm dams for numerous reasons	Stocking privately owned waters (eg farm dams) - landowners
Mosquito control	Small native fish released to help control mosquito numbers	Local council programs

Conservation stocking is more specialised than other types of fish stocking, with close attention paid to the genetic diversity of stocked fingerlings. It is usually carried out by government agencies as part of a recovery program for endangered or threatened species. Currently conservation stocking is undertaken in Queensland as part of the Mary River cod recovery program.

Enhancement stocking is carried out in riverine areas. Although the main aim of this stocking has been to enhance recreational fishing opportunities, it may also help to restore the natural diversity of degraded riverine areas.

Put, grow and take fisheries comprise the majority of stocking activities in Queensland's freshwater impoundments where most native sportfish cannot breed. The primary purpose of impoundment stocking is to create or enhance recreational fishing opportunities, and thereby contribute to local recreational opportunities and tourist-related income. Stocking activities for recreational fisheries are currently undertaken by community-based stocking groups.

Fodder fish have been introduced to some waterbodies containing large predatory stocked fish. The most popular fodder fish are gar and bony bream. No hatcheries produce these fish, therefore stocking groups must obtain a general fisheries permit allowing them to catch fodder fish from elsewhere in the catchment and place them into waterbodies listed on their stocking permit.

Stocking of private waters (eg. farm dams) can be undertaken by land owners without a permit provided that they use fish that are indigenous to the catchment. DPI&F has produced a pamphlet for the general public called *Stocking fish in farm dams and other waters on private land.* Stocking fish that are not contained in these guidelines requires a general fisheries permit.

Mosquito control can be undertaken by local councils or land owners who stock small native fish such as gudgeons and rainbowfish, which will eat mosquito larvae. Councils require a permit if they are stocking public waters. Stocking in private dams or ponds does not require a permit provided the species stocked are native to that area. DPI&F have produced a brochure called *Native fish for mosquito control in South-east Queensland* that outlines the best species for effective mosquito control.

Policy Development

The effective management of fish stocking activities in Queensland is underpinned by legislation, policy documents and permits for the authorisation of activities. Within DPI&F, the fish stocking program is administered by the Freshwater Fisheries and Habitat Section.

Under Fisheries legislation a person must not release non-indigenous fisheries resources or aquaculture fisheries resources into Queensland waters without a General Fisheries Permit for stocking Queensland waters. This has been the case since 1996.

A stocking permit will only be issued to a community-based fish stocking group that has submitted an up to date five year stocking management plan signed off by their regional DPI&F liaison officer. Permits specify maximum numbers for each species that can be stocked into each waterbody or stretch of river and are issued for five years.

The *Fisheries (Freshwater) Management Plan 1999* (the Management Plan) provides a list of catchments that each approved species is permitted to be released into. These basins include catchments within the natural distribution of the species and also catchments in which recognised recreational fisheries had been developed as the result of previous stocking in catchments outside of the natural distribution of the species.

The Management Plan also lists river catchments in which translocations are not permitted. Specifically, all river catchments in the Murray-Darling, Lake Eyre, Gulf of Carpentaria and Bulloo-Bancannia drainage divisions, and in 28 river basins in the East Coast drainage division. At the time the legislation was made, these catchments were considered of special conservation value. In most cases they had not received any translocations or translocated species had not established, they contained one of more threatened species and had not suffered extensive habitat degradation. In most cases, they contain native fish of high recreational value and there is no justification for translocating other species. In the remaining river catchments on the East Coast translocations may be considered.

A Stocking and Translocation Committee is consulted as necessary and provides advice to DPI&F on applications from stocking groups to stock species which constitute a translocation or to stock new (previously unstocked) river systems. Membership includes representatives of the aquaculture industry, stocking groups, recreational fishers and conservation interests.

Stocking of farm dams or private waters does not require a permit if stocked with local native species or those listed in the legislation as approved for the catchment. Approval for other fish species must be sought from DPI&F.

DPI&F have several policies that have been established to aid decision makers when considering stocking proposals. A brief description of the DPI&F policies is provided below.

Translocation of Fishes in Queensland

Translocation principles have been developed and are to be considered when assessing an application for the translocation of fish species:

1. Stocking public or private waters with translocated species or non-indigenous genetic stocks of a species will be considered only where a clear potential economic, social or conservation benefit can be demonstrated and where no alternative native species in the drainage basin have similar potential;
2. Translocations will not be permitted in catchments where:
    - Tthe integrity of native fish communities remains substantially intact ; and/or
    - Tthere are one or more threatened species of fish (conservation priority catchments); and/or
    - There are several native fish species of value (translocation unnecessary catchments).
3. Translocation of species accorded threatened status because of habitat loss or other factors is supported. Here, the emphasis should be on the establishment of breeding populations;
4. With the exception of threatened species, preference will be given for translocating species that will not reproduce in their target environment;
5. Where a basin or river system is contiguous with another State, the agreement of that State will be obtained before any translocation can take place. Queensland will seek reciprocal agreements from other States;
6. All potential translocations will be subject to a disease risk assessment to minimise the risk of disease transfer; and
7. All proposals to translocate fish species or non-indigenous genetic stocks of the same species should be considered case by case according to the decision-making protocols and procedures.

A standard decision-making protocol has been developed for translocation proposals. The protocol ensures that the right questions are asked, that decisions are made using consistent principles and an assessment of the risk involved forms part of the decision-making process. Translocation proposals are considered by the Stocking and Translocation Subcommittee who provide advice to DPI&F.

This policy provides for continued stocking of some non-endemic species, for example, golden perch and silver perch into selected coastal catchments, as their impacts on receiving systems are considered minimal, and the likelihood of the species establishing self-sustaining populations is low.

Translocation of barramundi between management units
This policy refers to Evolutionary Significant Units (ESUs) and Management Units (MUs). ESUs may be defined as historically isolated and independently evolving sets of populations. MUs are the ecological components of the ESUs that may be managed, but not necessarily

preserved as separate entities in order to maintain processes and conserve the larger ESU. There are 6 barramundi MUs across Australia, being:

- South east Gulf of Carpentaria stock (Point Parker to Pera Head);
- North west Cape York stock (Pera Head to Escape River);
- East coast Cape York stock (Escape River to Cooktown);
- Mid north east coast stock (Cooktown to Burdekin River);
- Central east coast stock (Repulse Bay to Shoalwater Bay); and
- South east coast stock (Fitzroy River to Mary River)

Given the low level of genetic differences between MUs, limited translocation between adjacent units is to be permissible where a clear social and economic benefit can be demonstrated.

Principles for Stocking New Freshwater Rivers
This policy relates to applications that are received for stocking “new rivers” (ie. rivers not previously stocked under the fish stocking program) and sections of rivers (including downstream of stocked impoundments) that have not been previously stocked. The onus is on the stocking group to demonstrate a need to stock. For example, demonstration of an understanding of the cause of a decline in natural stocks is required to determine the best mechanism to improve species abundance. A stocking program may not be a long term solution for the problem so alternatives such as habitat restoration or improved fish passage must be considered while assessing a stocking application.

Stocking Native Fish for Mosquito Control in Freshwater
DPI&F encourages stocking of native freshwater fish for mosquito control in the following circumstances:

(a) Native fish are not present in the waterbody; and
(b) It is unlikely that native fish will migrate to the waterbody; and
(c) The species of freshwater fish proposed for stocking is found naturally in the local area; and
(d) The surrounding habitat is suitable for both mosquito control and stocking of small native freshwater fish.

The guidelines are targeted at local governments, developers and community groups and outline the procedures to be followed to undertake such an activity.

Full policy documents are available from the Freshwater Fisheries and Habitat Section of DPI&F.

Community Engagement

A special aspect of fish stocking in Queensland is its emphasis on the development of the fishery on a partnership basis with local communities. Their role is central in that no waterbody is considered for stocking unless a community-based stocking association is in place to oversee the development of the fishery. Currently Queensland has 75 fish stocking groups which are responsible for stocking and otherwise enhancing their local freshwater fisheries. Almost all of the stocking in Queensland is carried out by these stocking groups with DPI&F support.

The role of the community based fish stocking groups includes:

- Develop fish stocking management plans;
- Selection of fish species, numbers (up to a permitted maximum) and size for stocking;
- Obtaining necessary approvals from DPI&F;
- Carrying out approved/permitted stocking operations;
- Providing advice on monitoring the fishery and associated habitat;
- Provide a liaison and education function;

- Organising funding arrangements (e.g. raffles, fishing competitions, government grants);
- Participation in consultation processes;
- Participation in monitoring activities (e.g. netting, trapping, creel surveys); and
- Undertake/support risk assessments and development of contingency plans to cope with fish going over dam walls etc. where appropriate and obtain relevant permits.

A number of groups also operate their own hatcheries or grow-out facilities.

Fisheries workshops have been held annually (one Northern and one Southern workshop) since the introduction of the stocking program which provide an opportunity for stocking group members to liaise with fisheries staff and other stocking groups. This facilitates transfer of information and enables groups to keep up to date with Departmental policy positions and stocking strategies. It also provides DPI&F with an opportunity to consult with stocking groups on any emerging issues.

The Freshwater Fishing and Stocking Association Queensland (FFSAQ) is the peak body for stocking groups in Queensland and as a major stakeholder, DPI&F consult with them frequently. FFSAQ has representation on a number of Departmental committees such as the Freshwater Management Advisory Committee, Stocking and Translocation Committee, SIP Committee and the Stocking Strategy Working Group.

Financial Support for Community-based Fish Stocking
As the popularity of stocked freshwater impoundment fisheries increased, stocking groups found it difficult to raise money to put enough fish into the dams to maintain successful recreational fisheries. A user-pays system was agreed to by the community and the Stocked Impoundment Permit (SIP) Scheme was introduced in 2000. The Scheme requires anglers to purchase a permit to fish on 29 of the stocked dams in Queensland. Monies raised by the scheme are used for administration of the Scheme (no more than 25%) and the rest is divided up between the stocking groups involved in the Scheme to use for purchase of fingerlings or other approved activities for the enhancement of their local fisheries.

Stocking groups not on the SIP Scheme receive small annual grants from DPI&F.

Production Capabilities

The Department has played a role in the development of hatchery techniques for production of species for stocking purposes. However, it is not considered core business of the Queensland Government to produce fingerlings for stocking and so the technology is subsequently passed on to the private sector.

In the late 1990's fingerlings of barramundi and limited mangrove jack were available free of charge to northern stocking groups from DPI&F Northern Fisheries Centre. These fingerlings were produced during the development of hatchery production techniques. This technology has since been passed onto private hatcheries and DPI&F production has ceased.

The majority of fingerlings are sourced by stocking groups from privately owned commercial hatcheries which are regulated by fisheries (aquaculture) development approvals. Some stocking groups have also established their own hatcheries to grow-out or produce fingerlings. These non-commercial operations are regulated via general fisheries permit.

Specific attention is paid to genetic diversity in the production of fingerlings for conservation stocking purposes with only limited hatcheries permitted to produce threatened species for stocking purposes. Mary River cod are currently the only species stocked for conservation purposes under a recovery plan in Queensland and only two hatcheries are permitted to produce Mary River cod for stocking purposes.

Key Issues

ESD Assessment of the Stocking Program
In the current environment of ecological sustainable development, conservation groups, GBRMPA and Wet Tropics Management Authority have raised concerns regarding the lack of information on impacts of freshwater stocking. The number one priority for DPI&F freshwater fisheries for the past few years has been the assessment of the Queensland stocking program against Ecologically Sustainable Development (ESD) principles.

The first stage of this process was to develop a position paper on stocking in Queensland which has been prepared in draft. This paper aims to provide an account of all past and current stocking activities in Queensland and to identify information gaps and provide direction for an ESD assessment.

Funding for this project has been sought from a number of sources over the past few years however it has not been considered a priority by the funding agencies.

Monitoring and Evaluation of Impacts of Stocking
Comprehensive and quality data is crucial for management of fish stocking programs within Ecologically Sustainable Development guidelines. While there does not seem to have been any major catastrophes due to stocking in Queensland, the ecological impacts of stocking in impoundments and rivers remain relatively poorly understood. Especially the impacts of translocated species which form the basis of a number of successful recreational fisheries and the effects of stocking on threatened species and ecosystems, other native species, genetic impacts and impacts on habitat.

An evaluative assessment is required on activities that have occurred to ensure management decisions are based on the best possible information to manage the stocking program in a sustainable manner while continuing to meet the recreational fishing needs of the community.

Development of Optimal Stocking Techniques
Stocking permits state a maximum number of fish that can be stocked annually in each waterbody based on a maintenance level of 100-200 fingerlings per hectare of surface area at full supply level. Impoundments are rarely at full supply level and sometimes are drawn down to very low levels. Currently it is up to the individual stocking group to determine how many (up to a permitted maximum) and at what size fish are stocked, time of year they are stocked and release site.

In the past, stocking groups have had to rely on fundraising to purchase fingerlings to stock into the dams. The introduction of the SIP Scheme and associated funding has resulted in a significant increase in stocking activities in a number of impoundments in Queensland. While many groups are responsible when it comes to stocking during times of low water levels and will reduce or stop stocking activities, there is an obvious potential for overstocking, the effects of which remain little understood.

A number of fisheries have started displaying signs that stocking has not resulted in the type of fishery that was sought after or expected. For example, a fishery with numerous very large fish but little evidence of any smaller size classes coming through making it hard for the average angler to catch a fish or the opposite situation where there are a multitude of small fish suggesting growth rates are now very slow and fish are not recruiting into the fishery, possibly as a result of overstocking.

Optimal techniques for stocking need to be developed taking into consideration such factors as:

- Type of fishery desired (eg. a trophy fishery, family friendly, mixed species or species specific);
- Carrying capacity and how this is effected by fluctuating water levels in impoundments;

- Numbers stocked;
- Size at release;
- Species composition;
- Cost effectiveness; and
- Harvest strategies (eg, catch and release promoted).

One of the keys to achieving optimal stocked fisheries is education of the public to change the perception that stocking more and more fish will result in a better fishery. It must be acknowledged that issues such as habitat rehabilitation, removal of pest fish and improved fish passage also play a role in the creation of successful fisheries.

Socio-economic Value of the Stocked Fishery
An economic study has been done on the value of three stocked dams in Queensland, which showed the economic value of stocked fisheries to the local community in the order of millions of dollars. An extension of this project to gain an overall understanding of the social and economic importance of stocking activities to Queensland communities would be beneficial. Being able to put a dollar value on the recreational fishery will help raise the profile of the freshwater impoundment fishery and influence funding opportunities for further research and monitoring.

As custodians of the freshwater fisheries resource, DPI&F continue to face the challenge of managing the stocking program without a sound knowledge of the impacts it is having on the ecosystem. DPI&F have adopted a precautionary approach in that no new species will be approved for stocking until the whole stocking program as it currently operates is assessed against ESD guidelines.

A comprehensive understanding of the ecological, social and economic effects of the stocking program will allow for informed management decisions to ensure the program is undertaken in a sustainable manner and for the benefit of all users of the resource.

Freshwater Fish Stocking in NSW

Cameron Westaway, Senior Fisheries Manager Inland, Recreational Fisheries, Department of Primary Industries, NSW, Email: cameron.westaway@dpi.nsw.gov.au

Summary of Workshop Presentation

The NSW Department of Primary Industries stocks 7-8 million native and salmonid fish in approximately 900 sites annually throughout freshwater streams and impoundments in NSW as shown in Figure 1.

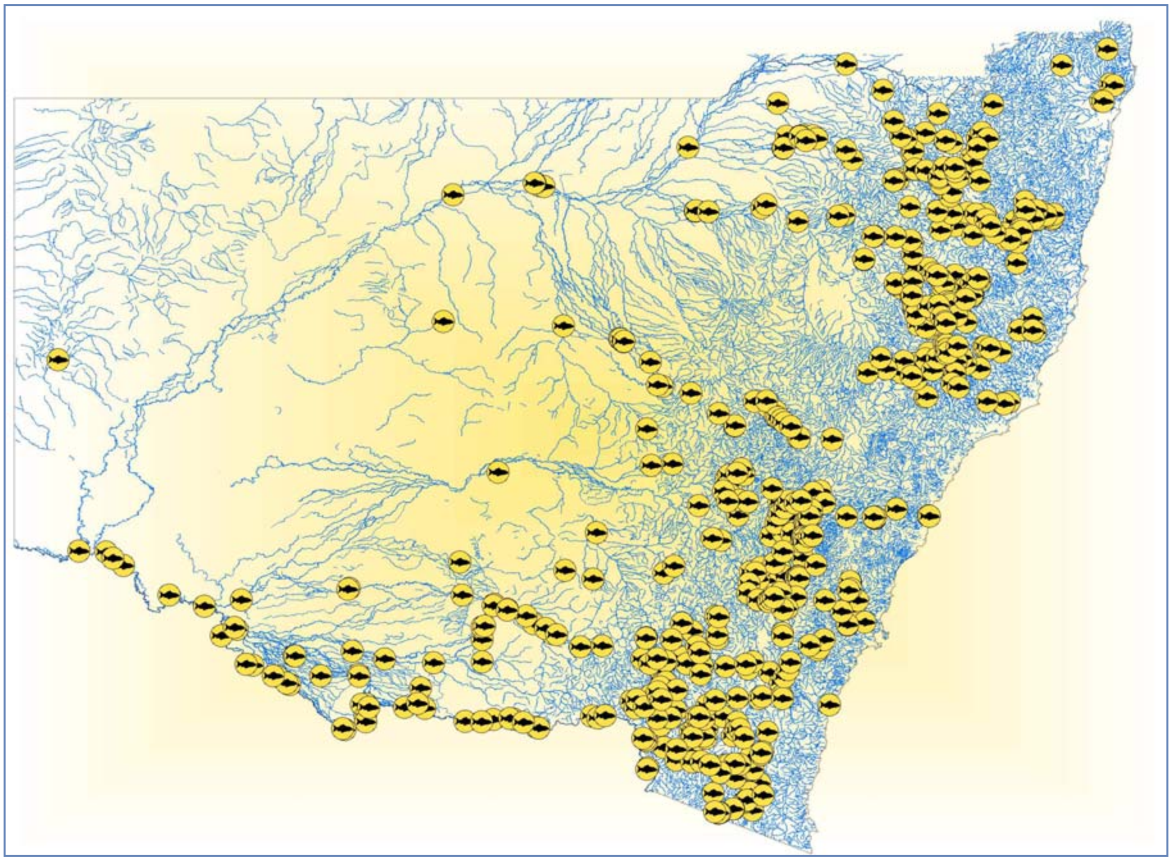

Figure 1: Locations where native and salmonid fish are released in NSW

Stocking Programs

Fish are stocked through four programs funded from consolidated revenue, recreational fishing trust funds and direct angler purchase

Salmonid stocking program (approx 4 million brown, rainbow & brook trout & Atlantic salmon) produced at DPI hatcheries at Jindabyne and Ebor for stocking in impoundments and (in conjunction with acclimatisation societies) in rivers and streams. This program is to maintain and enhance the trout fishery.

Native fish impoundment stocking program (approx 3 million Murray cod, golden perch, silver perch and Australian bass) produced at DPI hatcheries at Narrandera, Grafton and Port Stephens. To maintain and enhance native impoundment fisheries where recruitment is generally poor.

Dollar for dollar program (approximately 800,000 Murray cod, golden perch and Australian bass) produced at approved private hatcheries for stocking in rivers and streams with matching funds from angling groups & the recreational fishing trust fund. This provides for a real and/or perceived need, is an incentive to enter the approval process and provides cash flow for the aquaculture industry.

Conservation stocking program (between 50,000 to 100,000 trout cod, 1,000 purple spotted gudgeon) produced at DPI hatcheries and managed by the Threatened Species Unit. Conservation stocking is for the rehabilitation of threatened species. The Eastern cod program which previously utilised private hatchery is now in abeyance due to the need to assess stocks.

Fish stocked in NSW in 2004/05	
Species	**Number**
Trout cod	100,000
Murray cod	843,302
Australian bass	169,300
Silver perch	391,000
Golden perch	2,394,123
Rainbow trout	2,893,114
Brown trout	830,000
Brook trout	92,080
Atlantic salmon	430,460
Total	8,148,379

Assessment of Stocking

All stocking requires a permit under the Fisheries Management Act and assessment and approval under the Fisheries Management Strategy (FMS). The FMS is a statutory document under the Environmental Planning and Assessment Act 1979 (EPA act).

The FMS process is based on a land and environment court decision whereby most NSW fisheries and fisheries activities would be assessed under EPA act. The FMS assessed the current activity for environmental risks (as well as socio economic impacts) and an environmental impact statement and proposed management arrangements were put forward in a draft FMS. Stocking under the proposed arrangements was re-assessed with an extensive consultation phase, then modified and a final FMS was approved by both Environment and Fisheries Ministers.

The FMS sets out generally where and what species we can stock, a range of stocking restrictions, disease and genetic protocols, assessment process for individual stocking applications, administration, monitoring, research, education as well as reporting and trigger points.

Fisheries Management System Restrictions on Stocking

The following restrictions apply to stocking under the FMS:

- No stocking in systems that haven't been stocked since 1990;
- No stocking within 5kms of certain threatened fish, frog and crustacean species;
- No stocking in wilderness areas, world heritage areas or above 1500m in the Snowy Mountains;
- No stocking of brown trout in Macquarie perch areas;
- No stocking of trout cod in trout cod area and no stocking of Murray cod in Lake Mulwala;

- Individual stockings are assessed under stocking review guidelines using GIS system with sign off required from both recreational management and conservation staff; and
- Hatcheries require a hatchery quality assurance & accreditation process to ensure disease, translocation and genetic protocols are developed (implementation over three years).

The FMS stipulates number of pairs of broodstock and batch management required to meet N_e of 50 for recreational stocking and N_e of 100 for conservation stocking.

Under the FMS, 900 sites were assessed, 10 were rejected and 16 amended.

Conclusions

The main aim of stocking is to provide quality recreational fisheries.

The FMS provides a defendable environmental assessment and management regime which addresses risks and sets a high bar for hatchery production.

There is a need for a suite of tools to predict optimum stocking numbers in different systems.

The best tools are standard fisheries management science (recruitment, fishing mortality, stock status, biology etc) combined with quality marking techniques and angling quality i.e. lots of big fish.

While the program prevents illegal stocking, it creates a cash flow for hatcheries and an angler expectation which will be difficult to wind back if necessary.

Freshwater Fish Stocking in Victoria

Greg Hayes, Manager Inland Fisheries, Fisheries Division, Department of Primary Industries, Vic, Email: greg.hayes@dpi.vic.gov.au

Summary

The stocking of freshwater fish in Victoria is primarily the responsibility of the Fisheries Division (Fisheries Victoria) of the Victorian Department of Primary Industries (DPI). In recognition of the substantial social and economic befits attributable to well managed recreational fisheries, Fisheries Victoria currently stocks 1.3million fish annually into Victorian public waters to enhance inland recreational fishing opportunities.

There is a well-established annual process for reviewing recreational fish stockings programs that involves input from relevant Departmental, industry and community stakeholders.

Recently Victoria has introduced *Guidelines for Assessing Translocations of Live Aquatic Organisms in Victoria* to establish a structured basis for assessing translocation proposals (including fish stockings) within a risk-based framework.

Production capacity for trout and salmon for fish stocking programs has recently been brought back under direct control by Fisheries Victoria. Under the new arrangement brown trout, rainbow trout, Chinook salmon, Murray cod and trout cod are produced at the Department's Snobs Creek facility near Eildon.

Victoria's Inland Recreational Fishery

Victorian anglers enjoy a close proximity to a diverse range of recreational fishing opportunities.

Inland Victoria sustains a range of freshwater recreational fisheries. The most popular are for introduced species such as redfin and trout, although anglers are increasingly targeting native species such as golden perch, Murray cod and Australian bass.

In recent years Fisheries Victoria has stocked 1.3 million fish annually to improve recreational fishing opportunities for freshwater anglers. Brown and rainbow trout, as well as Murray cod and golden perch are stocked in numerous locations. Chinook and Atlantic salmon, silver perch and Australian bass are also stocked.

Yabbies, eels and spiny freshwater crayfish are also popular species targeted by recreational fishers, but are not stocked by Fisheries Victoria.

Table1: The Victorian recreational catch for the more popular inland species, by numbers, as estimated during the 2000/01 the National Recreational and Indigenous Fishing Survey

Species	Number Caught	Stocked
freshwater crayfish and yabbies	1,887,942	No
redfin perch	949,351	No
trout/salmon	345,894	Yes
carp	328,189	No
golden perch	142,276	Yes
Australian bass/perch	74,931	Yes
Murray cod	11,943	Yes

Drivers for Stock Enhancement

The Victorian Recreational Fishing Licence (RFL) covers all forms of recreational fishing in all of Victoria's public marine, estuarine and freshwaters. All RFL sales revenue is paid into the RFL Trust Account, with funds being made available to the Recreational Fishing Grants Program (RFGP). A survey of anglers at the time the RFL was introduced identified their strong support for these funds to be used for habitat works and fish stocking.

A 1997 Fisheries Economic Impact Study that assessed the *Economic Impact of Recreational Fishing in Victoria* identified that recreational fishing is one of the most popular recreational pursuits in Victoria. As a consequence it acknowledged that the recreational fishing sector (including supporting industries) is a major user of natural resources and a significant contributor to state and regional economies in Victoria.

The recently completed National Recreational and Indigenous Fishing Survey (NRIFS) supported this view and estimated that nearly 550,000 Victorians aged 5 years or older go fishing each year. It further identified that Victorians spends $721 per person on recreational fishing (the national expenditure is $552) resulting in recreational fishing contributing $400million annually to Victoria's economy.

Almost half of all angling effort in Victoria occurs on freshwater lakes, rivers and streams. In recognition of the important social and economic contribution inland recreational fishing makes to regional communities stock enhancement is considered a viable management option where:

- Natural recruitment is unlikely to be sufficient to sustain an adequate fishery; and
- Suitable habitat exists for the survival of the targeted species year round.

Legislation and Policy Settings

Several Victorian acts and strategies provide the broad framework for the protection and management of Victoria's aquatic flora and fauna and their associated habitats and these are necessary considerations when developing and maintaining fish stock enhancement programs.

Fisheries Act 1995

The *Fisheries Act 1995* (the Act) is administered by DPI. Fishing activities in all Victorian public waters are managed under the provisions of the Act and the *Fisheries Regulations 1998*.

The Act provides a legislative framework for the regulation and management of Victorian fisheries and for the conservation of fisheries resources, including their supporting aquatic habitats. The objectives of the Act include:

- To provide for the management, development and use of Victoria's fisheries, aquaculture industries and associated aquatic biological resources in an efficient, effective and ecologically sustainable manner;
- To protect and conserve fisheries resources, habitats and ecosystems including the maintenance of aquatic ecological processes and genetic diversity;
- To promote sustainable commercial fishing and viable aquaculture industries and quality recreational fishing opportunities for the benefit of present and future generations;
- To facilitate access to fisheries resources for commercial, recreational, traditional and non-consumptive uses; and
- To encourage the participation of resource users and the community in fisheries management.

Flora and Fauna Guarantee Act 1988

The *Flora and Fauna Guarantee Act 1988* (FFG Act) is administered by the Victorian Department of Sustainability and Environment (DSE). The FFG Act provides an administrative structure to enable and promote the conservation of Victoria's native flora and fauna and to provide for a choice of procedures which can be used for the conservation, management or control of flora and fauna and the management of potentially threatening processes.

Issues associated with the management of some listed species (eg Murray cod, spotted tree frog) and potentially threatening processes (eg Introduction of live fish into waters outside their natural range within a Victorian river catchment after 1770) must be considered when planning and deploying fish stocking programs. Such an approach is consistent with the application of Ecologically Sustainable Development (ESD) principles as required by the Fisheries Act.

Victorian River Health Strategy

The *Victorian River Health Strategy* (VRHS) provides the framework to enable the Victorian Government, in partnership with the community, to make decisions on the management and restoration of Victoria's rivers. The VRHS focuses on the management and ecological condition of rivers and streams. While the major focus will be on activities that occur in the river, the VRHS will also cover impacts of activities in the catchment as they affect condition of the river.

Guidelines for Assessing Translocations of Live Aquatic Organisms in Victoria

In 2003 the Victorian Government released the *Guidelines for Assessing Translocations of Live Aquatic Organisms in Victoria (*Translocation Guidelines*)* to meet its obligations under the *National Policy for the Translocation of Live Aquatic Organisms 1999*. This commonwealth policy requires all states in Australia to develop assessment measures for the translocation of aquatic organisms, including fish. This policy recognised that translocation of live aquatic organisms poses an ecological risk through the potential transmission of diseases, potential impacts on Biodiversity from changes in genetic integrity, and the establishment of feral and or exotic populations.

Stocking proposals in Victoria are conducted in accordance with the Translocation Guidelines and any associated protocols approved by the Secretary, DPI.

To ensure that existing fish stocking programs, and new proposals which have manageable risks, can proceed without the need for individual risk assessments, *Protocols for the Translocation of Fish in Victorian Inland Public Waters* have now been developed and approved. Importantly, fish stocking proposals that meet the criteria outlined in the new protocols will not require an individual risk assessment.

More information on the Translocation Guidelines and associated Protocols can be obtained from the DPI web-site: www.dpi.vic.gov.au/fishing.

Current Stocking Arrangements for Freshwater Fish

Recreational Fish Stockings

The most extensive and routine stockings of fish in inland waters are for the purposes of maintaining and enhancing recreational fisheries.

Native Fish Stocking for Recreational Fishing

Stocking of native, freshwater fish for recreational purposes is mainly focused on golden perch and Murray Cod. This is primarily undertaken in lakes and impoundments although there is some stocking of these species in rivers. Limited stocking with Australian bass and silver perch is also undertaken. Currently about 50 waters are stocked on a regular basis.

Close to 1 million native fish fingerlings are currently released each year. In addition limited quantities of on-grown Murray cod have been trialed as part of a research program being undertaken by Primary Industries Research Victoria (PIRVic) on behalf of Fisheries Victoria.

A number of factors are considered in determining whether a water will be stocked with native fish;

- Is the habitat suitable for survival and growth of fish year round;
- Is natural recruitment insufficient to support a fishery;
- Are the fish accessible to anglers;
- Will enough anglers fish the water to justify the expense involved;
- Is the stocking within the known former natural range of the species; and
- Is there is reasonable evidence the released fish may constitute an unacceptable risk to a threatened species or community?

Stocking of Salmonid Fish Species for Recreational Fishing

Brown trout and rainbow trout are the main species of salmonids stocked. There are also limited releases of Chinook salmon and Atlantic salmon. These are mainly released for recreational anglers in lakes and impoundments.

Salmonids are not normally stocked in rivers and streams on the basis that most streams with suitable habitat to support trout year round already support self-sustaining populations. Current research being undertaken in Victoria is confirming the long held belief that the return on stocked trout is generally minimal when they are released into a river or stream containing such a population. In fact strong evidence from overseas indicates that stocking trout into waters already supporting wild trout may negatively impact these existing populations.

The stocking of trout and salmon species is largely undertaken with yearling fish as this enhances their survival prospects and reduces lead-time between release and potential recapture. Currently about 80 waters are stocked on a regular basis. Approximately 400,000 salmonids are released each year.

As with the native fish stockings a number of factors are considered in determining whether trout are released into a water. Firstly, stocking with trout is excluded from waters:

- Where there is reasonable evidence the released fish may constitute an unacceptable risk to a threatened species or community;
- Where natural reproduction adequately supports a fishery;
- East of the Snowy River catchment;
- Identified as having unacceptable habitat; and

- In National Parks, State Parks and Wilderness Parks as defined under the National Parks Act 1975; Natural Catchment Areas as defined in the Heritage Rivers Act 1992, and Reference Areas under the provisions of the Reference Areas Act 1978.

In the case of salmonid fish, waters will be considered for stocking when:

- Sufficient habitat for the maintenance and growth of the fish exists year round;
- Natural reproduction of salmonids is insufficient to support a fishery; and
- The fish are accessible to anglers and there is a reasonable expectation that enough anglers will fish the water.

Conservation Stockings

These stockings are identified in Action Statements developed under the FFG Act and are managed by DSE. Conservation stockings in Victoria are currently focused on trout cod, freshwater catfish and river blackfish with some consideration of Macquarie perch and dwarf galaxias. These can include stockings via translocation of adults as well as the release of juvenile fish.

Commercial Aquaculture Stocking

These types of stocking are associated with extensive aquaculture projects and are currently focused on eels in Victorian Inland Waters. Translocation issues in these cases are currently addressed through Fishery Management Plans. For example, in the case of eels there are specific circumstances where commercial eel fishers can release juvenile eels into inland waters to allow them to grow naturally prior to recapture and marketing. Recreational fishers also access these fish

Community Consultation

Victoria has a well-established process in place whereby stocking programs for both native and salmonid species are reviewed annually. This process focuses on a series of Regional Fisheries Consultation Meetings held every February and early March in five centres across Victoria.

These meetings provide an opportunity for Fisheries Victoria to engage representatives from the Victorian Recreational Fishing peak body (VRFish) and other stakeholders, including water authorities and catchment management authorities, to establish future directions for fisheries management on a regional basis. The meetings not only determine planned stocking levels for the next season, but also identify fish population surveys requirements and address other fisheries management issues.

A published report of the proceedings of all five meetings is widely distributed.

Production Capacity

In a boost to Victoria's successful fish stocking program the production of trout and salmon has recently been brought back under direct control by Fisheries Victoria after 10 years of production by a private company.

By moving the fish breeding program back to DPI, the Department will be able to have more control over the quality and quantity of fish to meet the objectives of the Government and the recreational fishing sector. The out-sourcing of fish production meant that Victoria had previously been locked into supply contracts that had resulted in inconsistencies with the size, quality and number of fish supplied. DPI Fisheries Victoria will now be better able to control the production of fish to ensure that fish stocked into Victorian waters are produced efficiently and are of good quality.

Under the new arrangement brown trout, rainbow trout, Chinook salmon, Murray cod and trout cod will be produced at the Department's Snobs Creek facility near Eildon. Supplies of golden perch, silver perch, Atlantic salmon and Australian bass are also stocked, but are not produced by the Department at this point in time.

Fish Stocking Challenges

Demonstrating ESD

Inevitably changes in community expectation will result in increased pressure on fisheries managers to demonstrate our current stock enhancement programs are in fact ecologically sustainable, despite the obvious social and economic benefits flowing from these practices.

Some of this pressure will come from anglers who are concerned that a change to an existing stocking regime may impact on existing fishing values (eg what impact will stocking Murray cod have on existing redfin or trout fisheries in an impoundment). Similarly we must exercise caution with stocking levels so we can be confident that the cumulative impact of a number of years stocking combined with a marked change in water levels or variations in the recruitment of invertebrates or forage fish that sustain resident populations of angling species (both stocked and naturally occurring) does not lead to a crash in the fishery.

Other stakeholders are likely to increasingly question the impacts of stocking regimes on Biodiversity values attributable to predation, increased competition for food and modification to natural gene pools in native fish. While documents like the Victorian translocation guidelines and associated protocols put in place measure to manage these risks, the effectiveness of these measures will need to continue to be monitored over time.

Climate Change and Climate Variability

Observations by researchers and fisheries managers indicate that there is strong anecdotal evidence that climate variability is likely to have an increasing effect on inland fisheries over time. Extended or more severe droughts will result in significant reductions in water levels in impoundments that are the mainstay of Victoria's stocked recreational fisheries. Riverine populations of trout and native fish are also likely to be impacted as a result of changed stream flows and increased water temperatures.

Similar impacts are likely to be experienced in the aquaculture sector, which may in turn impact both the availability and cost of hatchery reared fish required for stock enhancement programs.

Stocking is not always the answer

We need to ensure that anglers understand that stocking is not always the answer. Taking trout as a case study, it should be noted that in most fish abundance is related to the carrying capacity of a given stream, which in turn is determined by the quality of in-stream habitat and water flow.

Natural variation in trout abundance often occurs between seasons as a consequence of fluctuations in stream flow and temperature. Trout in Victorian rivers are often subjected to less than ideal conditions during summer. High water temperatures impact trout populations by restricting their distribution, inhibiting growth and even causing mortality in extreme cases.

Stocking fish into areas regularly subjected to such conditions is generally not an efficient use of fish stocking resources. Experience has shown that in these situations best results are generally achieved by improving riparian vegetation coupled with restoring in-stream habitat.

Status of Stock Enhancement in Tasmania

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Overview

After several years of dropping recreational licence sales, the Inland Fisheries Service has managed to reverse this trend after initiating an enhanced stocking regime back in late 2002. This initiative focused on the large scale stocking of adult brown trout into priority waters close to major population centres, as well as increased stocking into previously under-performing waters.

The enhanced stocking regime has also been made possible by the increased assistance of the State's commercial hatcheries. These commercial fish hatcheries contribute rainbow trout, brook trout as well as mature Atlantic salmon - some of which are in excess of 10 kg. In addition Saltas (commercial hatchery) contributed with the growing of brown trout to fry and fingerling stages before their distribution to public waters. These stocks were of larger average size than could be produced at the Salmon Ponds (at that time) and have an increased ability to survive in the wild. Hence such stockings benefit anglers through improved catch rates and assist the Service in enhancing the trout fisheries at various waters around the State.

The Service also undertook a Licence Review Project in January 2004 with the aim to review recent changes and to develop and implement strategies for selling and distributing angling licences.

Drivers and Initiatives

The Inland Fisheries Service is in part, largely dependent on the proceeds of angling licence sales to maintain angler services and maintain some core functions. As such a drop in licence revenue has a direct impact on the ability of the Service to provide for its stakeholders.

Licence sales had been declining for a number of years believed due to a number of factors including in part:

- Increased popularity of marine fishing;
- A steady increase in the cost of the inland recreational licence fee, compared to no requirement for marine licence for handline fishing;
- The collapse of a premier trout water;
- The closure of a popular water due to the discovery of carp; and
- Several key waters under-performing.

Measures had to be undertaken to turn around the Service's declining revenue base and improve the popularity of inland recreational fishing.

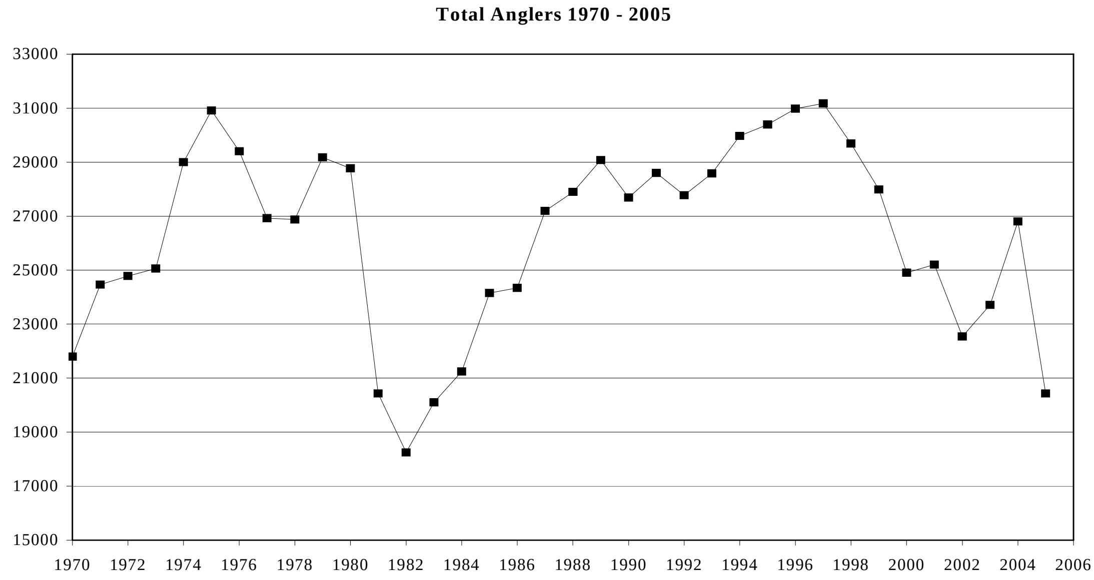

Figure 1: Total number of anglers over time (2005 season is incomplete)

Fisheries Action Plan (FAP) and Popular Waters Project

In December 2002 the Service produced a Fisheries Action Plan. This plan aimed to revitalise under-performing fisheries as well as provide additional fishing opportunities for anglers.

By recommending specific strategies to revitalise these fisheries, it was believed that anglers would return to the sport in the knowledge that the Service had improved the potential to catch fish, thereby helping anglers to justify their investment. Strategies such as:

- Stocking identified waters with adult brown trout;
- Utilising commercial hatcheries to supplement the Services own hatchery production;
- Continuation of releasing trophy sized Atlantic salmon;
- Introducing brook trout into new waters;
- Improved angler licensing procedures; and
- Increased public notification of stocked waters.

These strategies have all been adopted, along with the continuation of some inducements initiated prior to this period.

Following on from the FAP a ‘Popular Waters Strategy’ was adopted whereby selected waters easily accessible and close to large population centres became the focus of intense stocking with various salmonid species with the specific aims of:

- Inducing new anglers into the sport; and
- Maximising opportunities for children and less experienced anglers to catch a fish.

This strategy has proved successful owing in part to the support of the commercial fish hatcheries in the State in providing large numbers of legal or near legal size fish to be stocked into these waters.

Adult Brown Trout Transfers

The Service's main field base is located in the central highlands near Great Lake at Liawenee. The base is sited alongside the main spawning channel for the lake, the man-made Liawenee canal used by Hydro Tasmania to divert water into Great Lake. The canal has fish trapping facilities and access for large transport trucks to load fish.

A small proportion of the spawning run, around 10,000 adult brown trout each year, are trapped and transported to waters identified in the FAP. Initially brown trout were individually tagged to help assess the return angler catch rate and growth of these fish. With tag returns of nearly 20% in the first season, adult fish transfers have continued.

Commercial Fish Hatcheries

Up until 2002-03 the Service had been primarily reliant on its hatchery at the Salmon Ponds to produce the required fish for stocking of public waters. Production at the Salmon Ponds though is largely dependent on the vagaries of the flow and temperature in the Plenty River.

As part of the 'Popular Waters Project', negotiations were initiated with the State's commercial fish hatcheries to secure any surplus rainbow trout that these hatcheries were producing. In addition, the Service had already been receiving limited numbers of ex-Atlantic salmon broodstock from these commercial hatcheries that were transported and released into specific waters identified in the FAP.

The Atlantic salmon received varied in size from 2 kg up to 15 kg, providing the angler an opportunity to target trophy sized fish that otherwise were not readily available.

There has been a steady increase in the availability of surplus rainbow trout from these commercial hatcheries over the past couple of years, with the Service also buying surplus fish at reduced rates.

In 2004-05 Saltas trialed the raising of wild stock rainbow and brown trout, which enabled the Service to stock larger sized wild fish than in previous years.

A recent decision has been made to improve infrastructure and modernise the Service's hatchery at the Salmon Ponds. This will help remove the reliance on commercial hatcheries to provide surplus fish.

Brook Trout

Brook trout in Tasmania had previously been restricted to only a handful of small waters. With the commercial marketing of this species in 2002-03, the Service was able to secure relatively large numbers of brook trout fingerlings and yearlings to stock into waters that had been identified as being suitable in the FAP, this initiative then provided an additional species for anglers to target.

Licensing of Recreational Fishing

Recently the Service has taken steps to become pro-active towards licensing, issuing renewals by mail to the previous years licence holders. Additional payment methods have been introduced, and there has been a steady rise in the take-up rate of renewals.

Licence fee increases over the past several years have only been in accordance with the Government Fee Unit that reflects the Consumer Price Index, whereas in the past increases have at times, been above this.

Additional Incentives

Year Round Waters

Back in 2001 the Service enacted legislation to open seven waters to remain open for fishing all year round. This was initiated to attempt to provide anglers better value for money for their licence fee.

Improved Angler Access

Another recent initiative has been to look into improving angler access into a couple of under utilised waters. This initiative is based on raising the condition of the access into these waters to a suitable standard for either 2-WD or a 4-WD vehicle.

Salmonid stockings

Proposed stocking lists are generated every year, based on historical stocking levels, fisheries performance assessments and management goals to identify stocking requirements in regard to the species, number and size of fish to be stocked in each water.

The ability of the Service to fulfill this proposed stocking list is dependent upon the number of fish successfully raised at the Service's hatchery at the Salmon Ponds as well as on domestic fish stocks donated by various commercial hatcheries within the state.

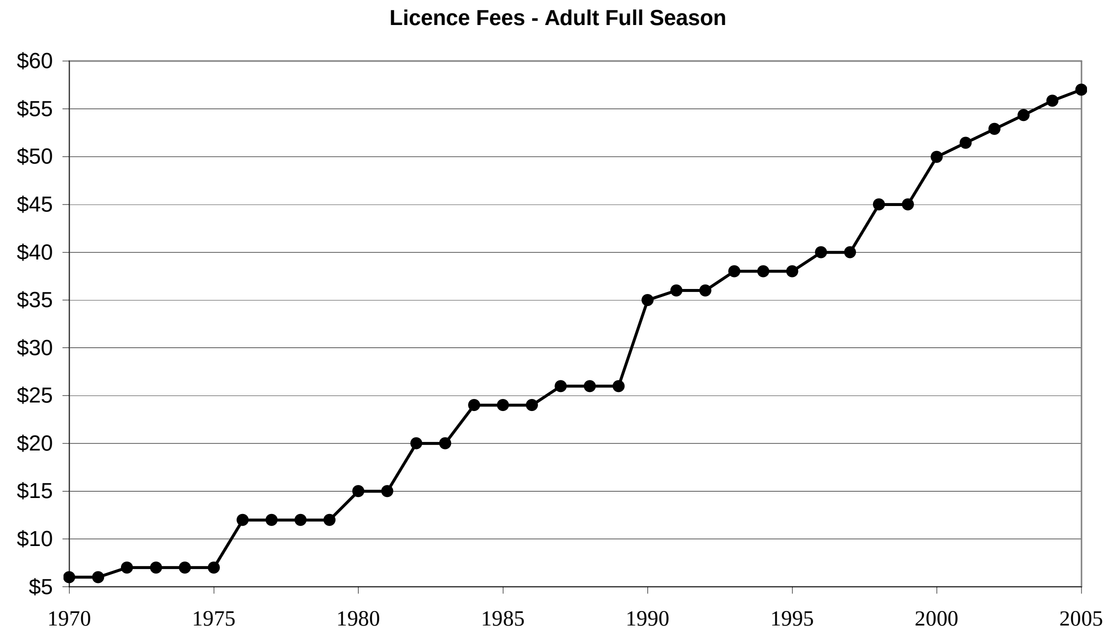

Figure 2: Licence cost over time

The table below provides an indication of total number of fish produced and stocked in recent years from both the Inland Fisheries Salmon Ponds and commercial hatcheries from around the State.

Table 1: Salmonid stockings from fish reared at the Inland Fisheries hatchery compared to commercial hatcheries

Year	Brown Trout		Rainbow Trout		Brook Trout		Atlantic Salmon	
	IFS	Hatcheries	IFS	Hatcheries	IFS	Hatcheries	IFS	Hatcheries
1999/00	154,000		108,800		7,000			250
2000/01	146,700		86,600					200
2001/02	164,200		295,800					384
2002/03	117,300		335,300	700	80,000	17,000		300
2003/04	239,900		554,400	82,700	13,000	10,400		2,330
2004/05	226,900	67,200	4,800	218,000	55,000	48,200		5,490
July05-Dec05	241,600		790	482,300		60,100		1,813

The following four tables provide a better indication of potential fish survival for the 2005 calendar year as average fish weights are provided along with total fish numbers.

Brown trout stockings 2005

Number	Stock	Type	Weight (g)	Origin
1000	Wild	Diploid	2	Salmon Ponds
2600	Wild	Diploid	1	Salmon Ponds
28500	Wild	Diploid	**8.4**	**Commercial Hatchery - Saltas**
2000	Wild	Diploid	4	Salmon Ponds
6350	Wild	Diploid	1000	Inland Fisheries
2150	Wild	Diploid	900	Inland Fisheries
235	Wild	Diploid	3500	Inland Fisheries
227500	Wild	Diploid	0.13	Salmon Ponds
5000	Wild	Diploid	0.16	Salmon Ponds
860	Wild	Diploid	350	Inland Fisheries
5000	Wild	Diploid	1	Salmon Ponds
250	Wild	Diploid	600	Inland Fisheries
2500	Wild	Diploid	55	Inland Fisheries

Total No of Fish = 282,945, Total Weight = 9,932 kg

Rainbow trout stockings 2005

Number	Stock	Type	Weight (g)	Origin
21500	Domestic	Triploid	25	Commercial Hatchery
3000	Domestic	Triploid	40	Commercial Hatchery
1500	Wild	Diploid	5	Salmon Ponds
46500	Wild	Diploid	20	Commercial Hatchery
3000	Domestic	Diploid	40	Commercial Hatchery
104500	Domestic	Diploid	200	Commercial Hatchery
80	Domestic	Diploid	3000	Commercial Hatchery
155	Domestic	Diploid	2000	Commercial Hatchery
10000	Domestic	Diploid	90	Commercial Hatchery
120	Domestic	Diploid	500	School Project

53	Domestic	Diploid	1000	School Project
24884	Domestic	Triploid	200	Commercial Hatchery
460	Domestic	Diploid	200	Salmon Ponds
300	Domestic	Diploid	300	Salmon Ponds
260	Domestic	Diploid	2500	Salmon Ponds
230000	Domestic	Triploid	6	Commercial Hatchery
7000	Domestic	Diploid	200	Commercial Hatchery
15000	Domestic	Diploid	30	Commercial Hatchery
90000	Domestic	Diploid	20	Commercial Hatchery

Total No of Fish = 558,312, Total Weight = 35,003 kg

Brook trout stockings 2005

Number	Stock	Type	Weight (g)	Origin
2500	Domestic	Diploid	23	Commercial Hatchery
16000	Domestic	Diploid	29	Commercial Hatchery
23000	Domestic	Diploid	350	Commercial Hatchery
13200	Domestic	Triploid	220	Commercial Hatchery
40000	Domestic	Diploid	2	Commercial Hatchery
1000	Domestic	Diploid	250	Salmon Ponds
850	Domestic	Diploid	600	Commercial Hatchery
5000	Wild	Diploid	7	Salmon Ponds

Total No of Fish = 101,550, Total Weight = 12,351 kg

Atlantic salmon stockings 2005

Number	Stock	Type	Weight (g)	Origin
2100	Domestic	Diploid	2500	Commercial Hatchery
2040	Domestic	Diploid	3000	Commercial Hatchery
470	Domestic	Diploid	7000	Commercial Hatchery
573	Domestic	Diploid	2500	Commercial Hatchery
1140	Domestic	Diploid	2700	Commercial Hatchery

Total No of Fish = 6,323, Total Weight = 19,171 kg

Fisheries Management

Stocking Issues

In conjunction with the FAP and Popular Waters Strategy, the Service also developed stocking profiles for a number of priority waters. These waters required additional management consideration based on important issues specific to that water. Examples included:

- Presence of threatened aquatic fauna;
- Large populations of non-threatened native fish;
- Other water authorities objectives and uses of that water (eg: Hydro Tasmania);
- Sensitive waters (eg town water supplies);
- Location of water – (eg inside National Park or a recognised wetland); and

- Presence of pest species – (eg redfin perch).

Stocking of waters relevant to any of these issues has to be managed accordingly, with stocking rates kept at or below historical limits.

As an example, fisheries management objectives for fisheries located in sensitive waters are determined in partnership with the relevant authority. Stocking rates may be scaled down and notification of such stockings not widely publicly advertised to help minimise pressure on infrastructure and other issues associated with large numbers of anglers such as waste management.

Type of Fishery

As part of the FAP the Service has attempted to create a range of different fisheries strategically located around the State.

These fisheries range from the 'Popular Waters Program' that provides high catch rate fisheries targeted at the less experienced or family angler located within easy access and commuting distance from large population centres through to the wilderness fisheries of the western lakes that are isolated, contain minimal facilities and contain only wild naturally recruited fish.

In between these extremes are other waters stocked to various levels as well as waters to cater for trophy sized fish and waters that provide an opportunity for anglers to target the whole range of salmonid species available in Tasmania, along with waters managed as rainbow trout fisheries.

There are also waters available for year round angling as well as specific waters to cater for disabled anglers and juveniles.

In addition, all of the States waters have restrictions in relation to angling method ranging from fly-fishing only to artificial lures only to waters available to all legal methods.

Summary

Based on projected licence sales to the end of 2005, this angling season is expected to see another increase in total licence sales with upward trends noted across all licence categories.

The increased angler participation in stocked waters identified under the FAP, shown by creel data coupled with increased licence sales, is encouraging especially when compared against a national trend away from angling in inland waters towards marine fishing. Based on this, stocking of these waters has proved beneficial and will continue.

An overview of Barramundi (*Lates calcarifer*) stocking in Queensland estuaries and coastal rivers

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Abstract

Barramundi is a large piscivorous fish found throughout much of the Indo-west Pacific including northern Australia. Many river systems in north-eastern Australia are being stocked with hatchery-produced barramundi because of concerns over declining catches. Community-based stocking groups have taken a lead role in stocking both inland waters and coastal rivers and estuaries. Since 1993 the Department of Primary Industries and Fisheries has undertaken

a series of experiments in the Johnstone River using barramundi marked with coded-wire tags to develop release strategies, estimate relative survival, determine the contribution of stocked fish to the fishery, obtain life history information and assess cost-benefits. About 16% of the recreational catch and 8% of the commercial catches in the area are stocked fish. There were no significant differences in recapture rates between 50-mm, 70-mm or 130-mm size class stocked fish but the recapture rate of 300-mm size class barramundi was significantly higher than that of the other smaller size classes. The benefit:cost of stocking 300mm size class fish was substantially higher than for the other size cohorts. The choice of release location within the river is important. The relative catch rate from fish released into an upper tidal site was 5.4 fish per 1000 fish stocked compared to 2.0 and 0.5 fish per 1000 fish stocked for the estuarine and freshwater habitats. Fish stocked early in the season (up until December) appeared to have higher survival rates than those stocked later. Break-even analyses showed that, depending on the sizes of fish released, between 2 and 9.8% of stocked fish need to be caught in the fishery to recover the direct costs of stocking. This research into stocking strategies is being progressively adopted by community stocking groups as best practice. Areas where future research is needed including on the ecological impacts of fish stocking, are identified.

Introduction

General

Barramundi, *Lates calcarifer*, (Bloch) is a large, euryhaline centropomid found throughout much of the Indo-west Pacific including tropical Australia where it is a highly prized recreational and commercial species (Greenwood, 1976; Grant, 1997). It also supports a growing aquaculture industry and it was the successful development of technology for the large-scale production of this species in Queensland that prompted interest in stock enhancement.

In the 1980s and 1990s there was considerable concern from industry that the barramundi fisheries in Queensland were in decline, a notion that was supported by available fisheries statistics (Williams, 1997). The reasons for this decline are equivocal but probably include habitat degradation and loss (Russell, 1987) and over-exploitation of the fishery. Fisheries managers responded to this situation by introducing a range of management initiatives and stock enhancement was perceived as one of a number of management tools that could be used to address this decline (Rimmer and Russell, 1998).

History of Barramundi Stocking in Queensland

A barramundi breeding program commenced in Queensland in 1984 with the establishment of a small hatchery at the Northern Fisheries Centre in Cairns (Pearson, 1987). As the demand for fingerlings from the fledgling aquaculture industry grew, other hatcheries were progressively established throughout the state. Initially fertilised eggs were obtained by stripping eggs and sperm from wild-caught fish (Garrett *et al.*, 1987) but this technique was quickly replaced by hormonally-inducing spawning in broodstock held in flow-through seawater tanks (MacKinnon, 1990). The first fish from this hatchery were stocked into the inland waters of Lake Tinaroo in December 1985 at a mean length of 50mm and formed the basis of a very successful *put and take* impoundment fishery.

Subsequently, other impoundments throughout Queensland have been stocked with barramundi and most have resulted in the successful creation of inland fisheries (Hollaway and Hamlyn, 2001). Estuarine and open river system barramundi stockings began at around the same time as the first impoundment releases.

Estuarine and Coastal River Stockings

In Queensland, the first record of an estuarine stocking was in Trinity Inlet adjacent to Cairns city in 1985 using fish that were produced from the fledgling Northern Fisheries Centre hatchery. As hatchery technology developed and more fish became available the number of rivers that were stocked with barramundi grew substantially to a point where now most of the streams on the north Queensland wet tropical east coast and several in Gulf of Carpentaria drainage have been stocked. The accompanying map shows the location of the more than 20 Queensland coastal rivers and estuaries, excluding barrages and weirs, where hatchery-produced barramundi have been released. The apparent poor quality of some batches of hatchery-produced fish and the small sizes that were initially stocked casts some doubt on just how successful these early estuarine stockings were and highlighted a need to develop programs to monitor their success.

The first attempt at monitoring an open river stocking commenced in 1992 when the Queensland Department of Primary Industries and Fisheries (QDPI&F) implemented a voluntary catch card scheme amongst recreational fishers in an effort to determine if river stockings were increasing catches of barramundi (Russell *et al.*, 1996). Unfortunately, low participation rates and highly variable catch rates made this difficult to determine from the data that were collected (Russell *et al.*, 1996).

Another very comprehensive research program monitoring the efficacy of stocking barramundi into the lower Johnstone River commenced in 1993 and used hatchery produced fingerlings marked with coded wire tags (Russell *et al.*, 1991; Russell and Hales, 1992; Rimmer and Russell, 1994; Rimmer and Russell, 1995; Russell, 1995; Russell and Rimmer, 1997; Rimmer and Russell, 1998; Russell and Rimmer, 1999; Rimmer and Russell, 2001; Russell *et al.*, 2002; Russell, 2005a, b). The results of this program are presented in the Research section of this document.

Organisation of Stocking Activities in Queensland

While the initial fish stockings were undertaken by QDPI&F, this role was quickly taken over by numerous community stocking groups that were formed throughout the State. These stocking associations have become a pivotal part of the State's recreational fishing program and no impoundment or river is now even considered for stocking without the involvement of a local stocking association to oversee the development of the fishery (Hollaway and Hamlyn, 2001).

Additional restrictions, including some related to conservation status, make some rivers ineligible for stocking activities of any kind. Where stocking activities are appropriate, QDPI&F, in consultation with the local stocking association, develops a management plan that defines the number of fish that can be stocked per annum in the nominated waterway and clearly identifies the roles and responsibilities of both groups (Hollaway and Hamlyn, 2001).

The groups that stock rivers are primarily self-funded although, depending on factors such as the number of fish that they are permitted to stock, small annual grants are made available to them from the Queensland Government to facilitate augmentation activities. In contrast, many of the groups that stock impoundments have access to monies raised through the Stocked Impoundments Permit Scheme (Hollaway and Hamlyn, 2001). Community engagement and ownership are now a key principle in the management of the State's stocking activities.

Regulations

Fish stocking in Queensland waters must be undertaken in accordance with the requirements of the *Fisheries Act 1994*, the *Fisheries Regulation 1995* and the *Fisheries (Freshwater) Management Plan 1999* and *Nature Conservation Regulation 1994*. Current regulations for stocking activities have evolved since 1986 with the creation of permits, conditions, policies and guidelines. The Fisheries (Freshwater) Management Plan 1999 provides a set of key principles for stocking activities in Queensland including comprehensive guidelines for translocations of fish and crustaceans. Of particular relevance to estuarine barramundi stockings, this plan recognises the importance of maintaining the integrity of the six barramundi genetic management units (Keenan, 1998) that have been identified throughout the state. The general policy on translocation stresses the need to ensure that barramundi originating from broodstock of one genetic strain are not stocked into river systems containing a different strain. However, given the low level of genetic differences between management units, in some cases limited translocation between adjacent units is permissible where a clear social and economic benefit can be demonstrated. Major river systems in the six genetic management units are given at the end of this paper.

Research

Despite the upsurge in community interest in stock enhancement of barramundi in the late 1980s and early 1990s, almost nothing was known about how to most effectively and efficiently stock fish into rivers and impoundments, the benefit-costs of fish stocking and the contributions that stocked fish were making to the recreational and commercial fisheries. Recognising the lack of knowledge on stock enhancement and need to develop a well-balanced, rational and sustainable approach to releases of hatchery-reared barramundi in coastal waters, QDPI&F developed an experimental stocking program to comprehensively investigate a range of stocking related issues.

Marking Techniques

In order to quantitatively assess barramundi stocking programs in estuaries and coastal rivers, it was first necessary to develop a technique to discriminate between hatchery-produced and wild fish. After experimenting with a number of techniques (Russell and Hales, 1992), coded-wire tags were found to be the best marking technique. This type of tag could be successfully implanted into barramundi as small as 30 mm TL and, when applied by an experienced operator, gave high survival and retention rates and did not significantly effect growth (Russell and Hales, 1992).

All stocked barramundi used in the QDPI&F experiments were implanted with coded wire tags, usually in the cheek muscle. Between January 1993 and March 2005 287,135 hatchery-reared barramundi marked using coded wire tags have been stocked into the Johnstone River. Of these, there are records of 3,272 that have subsequently been recaptured.

Study site

The QDPI&F research program was undertaken exclusively in the Johnstone River near the township of Innisfail (17°32'S,146°02'E) in northern Queensland (**Error! Reference source not found.**). The river bifurcates about 5kms from its mouth into the North and South Johnstone Rivers and these both have their sources inland on the Atherton Tableland. It is a small (~1630 km^2), predominantly agricultural catchment with a narrow coastal plain (less than 30 km wide) and an escarpment that prevents the upstream movement of fish. There have been considerable anthropomorphic impacts on fish habitat in the catchment with agricultural activities reducing the overall area of wetland habitat within the catchment by about 60% over the past 50 years (Russell and Hales, 1993). The river supports a multi-species (including barramundi) recreational line fishery and a seasonal commercial gill net fishery that is restricted to the lower estuary. There are about five part time commercial fishers operating intermittently in the catchment. The river had not been previously stocked with barramundi before the experimental stocking program began in 1992/93.

Stocking Strategies

To obtain maximum benefits from their stocking activities, community stocking groups need to employ effective and efficient stocking strategies. Pivotal components of the QDPI&F experimental research program included the optimal size of fingerlings at release and the importance of stocking habitat and the timing of fish releases.

Stocking Habitat

The recapture rates of fish stocked in upper tidal, estuarine and freshwater sites from 1992/93 to 1994/95 were 5.3, 2 and 0.5 fish per 1000 fish stocked respectively (Russell *et al.*, 2004). These results indicate that a fish stocked in the upper tidal habitat type is much more likely to be recaptured than a fish stocked in either the estuarine or freshwater location. As the minimum legal size for barramundi in Queensland is 580 mm TL (3-4 years old), it would be most likely that the observed disparities in recapture rates were due to different natural mortalities in the groups rather than fishing mortality (Russell *et al.*, 2004).

One hypothesis that may explain the enhanced survival of fish stocked into upper tidal site in the North Johnstone River was the presence of suitable, structurally-complex nursery habitat at this site. This release site contained abundant beds of aquatic macrophytes, particularly *Vallisneria* sp. which would have provided newly released juvenile fish with both cover and abundant prey. In the south-eastern United States, Rozas and Odum (1988) concluded that submerged plant beds in tidal freshwater marsh creeks not only afford protection from predators but also provided a rich foraging habitat. In some species however, it appears that provision of suitable habitat may not be sufficient to improve survival of stocked fish. Stunz & Minello (2001) found that the vulnerability of wild red drum that settled in structurally complex habitats such as sea grass was lower than those that settled in other habitat types but that this was not true for hatchery reared stocked fish. They suggest that hatchery-reared fish may be more vulnerable to predation than natural fishes and that survival of stocked fish may be enhanced through habitat-related behaviour modification.

While release into a structurally complex habitat in the upper tidal reaches of the North Johnstone River appears to have acted to enhance survival of barramundi, pre-release conditioning to encourage cryptic behaviour responses to predator threats may further assist in reducing mortality. Fushimi (2001) noted that survival of stocked *Pagrus major* was limited by the carrying capacity of the *Zostera* bed which fluctuated from year to year and was difficult to estimate just before release. Similarly, carrying capacity of the macrophyte beds in the Johnstone River is an area that requires assessment.

Seasonal deterioration in water quality in some habitats may severely impact on the survival of stocked barramundi fingerlings (Russell and Rimmer, 2002). For example, in February 1996, barramundi were stocked into a freshwater swamp similar to nursery habitats described in the literature (Moore, 1982; Russell and Garrett, 1983, 1985) but, almost immediately after release, low dissolved oxygen (6.6%) caused the fish to behave in a distressed manner and subsequently resulted in a very high post-release mortality (Russell and Rimmer, 1997; Rimmer and Russell, 1998).

Timing of Release

The timing of the release of stocked barramundi appears to be another important factor in affecting their survival. Over three seasons between 2001/02 and 2003/04, experimental releases of microtagged barramundi into the Johnstone River were made *early* in the season (November-December) and again *late* in the season (January-March) (Russell, 2005b). The annual stockings varied between 22,000 and 40,000 fish with an average size range of about 40-60 mm total length (TL). The recapture rates of those fish stocked *early* in the season were between 3.5 and 23.2 times greater than those stocked *late* in the season (Table 1).

In a separate experiment, 1,525 fish with an average size range between 173-280 mm TL were stocked into the Johnstone River in December 2001 and March 2002 (Russell, 2005b). The recapture rate of the larger fish stocked in December was 21.7 times the rate of barramundi released in March. Russell (2005b) suggested that there are a number of possible reasons for the poor survival of fish stocked late in the spawning season including cannibalism by those barramundi stocked earlier and increased predation. He also suggested that harsher environmental conditions including habitat loss, strong currents and diminished prey availability caused by seasonal river flooding that is common in northern Australia between January and March may also contribute to lower survival of newly stocked fish.

Table 1 Recaptures of *early* and *late* stocked barramundi released into the Johnstone River. Different subscripts refer to comparisons between *early* and *late* recapture rates, P<0.05

Season	*'Early'* Stocked fish	*'Late'* Stocked fish	Total Recaptures
2003-04	253 (1.11%)^{a}	8 (0.11%)^{b}	245 (0.82%)
2002-03	208 (0.67%)^{a}	15 (0.18%)^{b}	223 (0.56%)
2001-02	57 (0.77%)^{a}	16 (0.1%)^{b}	104 (0.43%)

Size at Release

Two separate experiments were undertaken to determine the effects of size-at-release on survival (Rimmer and Russell, 1998; Russell *et al.*, 2004). In the first experiment, equal numbers of two size classes of fish, one *small* (30-40 mm TL) and one *large* (50-60 mm TL) were stocked annually into the Johnstone River beginning in 1992/93 (Rimmer and Russell, 1998). For these size classes, the probability of recapture did not differ significantly (P>0.05) (Rimmer and Russell, 1998). In a second experiment, a wider range of size classes was used to further quantify the effect of size-at-release on survival. In 1997/98 and 1998/99, four different size classes (c.50-mm TL; c. 70-mm TL, c. 130-mm TL and c. 300-mm TL) were released into the estuarine and upper tidal sites in the Johnstone River (Table 2) (Russell *et al.*, 2004). An analysis to compare the proportions of the different size classes of the released fingerlings that were recaptured over a three-year period was performed using a logistic regression (estimated in a GLM routine with binomial errors, logit link and overdispersion parameter estimated). After the model was fitted, pairwise comparisons of the model's coefficients for the size classes were made. The recapture probability for each size class was predicted by averaging the back transformed predicted values (ie. forming marginal predictions on the back-transformed scale) (Russell *et al.*, 2004). There was a significant size-class effect on the recapture rates (P<0.001) of the stocked fish. Pair-wise comparisons indicated that relative recapture rates of the three smaller size classes of stocked fish were significantly less than the recapture rate for the 300 mm TL size class fish. The predicted probability of recapturing a 300 mm size class fish was over 15 times the probability of recapturing a 130 mm size class fish and nearly 29 times more likely than catching a 50 mm size class fish.

Higher survivals in larger stocked fish have been documented in other studies. For example, Munro and Bell (1997) noted a strong correlation between size-at-release and survival and suggested that this reflected the ability of juveniles to escape predation. They suggested that the optimum size-at-release is a trade-off between increased survival at a larger size and the lower cost of releasing younger individuals. Leber *et al.*(1995) also contended that size-at-release was likely to be the principal mechanism for controlling the survival of cultured marine fish in the wild and noted that its importance had been demonstrated with a range of marine species including red sea bream (*Pagrus major*) in Japan, Atlantic cod (*Gadus morhua*) in Norway and red drum (*Sciaenops ocellatus)* in Florida. Fushimi (2001) contended that red sea bream (*P. major*) seed could be released at a smaller size but with less chance of survival.

The effective minimum size of stocking for barramundi is not known but a trial stocking of ~15 mm TL fish in the Burrum River in Central Queensland in the early 1990s resulted in negligible survival (J. Burke, QDPI, pers comm.). In the Johnstone River there have been multiple captures of fish marked with coded wire tags that had a batch average size of 35 mm TL at time of release (QDPI&F, unpublished data), suggesting that the effective minimum stocking size for barramundi is less than this length.

Table 2. Numbers and size classes of barramundi released into the upper tidal and estuarine sites in 1997-98 and 1998-99. Numbers of fish recaptured over a three year period from the stocking dates are given in parenthesis.

Year	50-mm	70-mm	130-mm	300- mm
1997-98	6788 (10)	5532 (13)	6245 (11)	3516 (97)
1998-99	4090 (0)	6112 (3)	6253 (10)	1015 (24)

Benefit-cost Analysis

The benefit-costs ratios in stocking the four size classes of barramundi given in Table 3 were determined using their predicted recapture probabilities as a measure of benefit and the cost measure was the respective unit fingerling production costs derived from a validated hatchery model (Johnston, 1998; Russell *et al.*, 2004). Using the costs of purchasing fingerlings generated by the nursery production model, the largest fish (c. 300-mm TL) are about five times more expensive to produce than the smallest fish (c. 50-mm TL) (Russell *et al.*, 2004) (Table 3). Benefit-cost ratios of stocking 50-, 70- and 130-mm TL size class barramundi were 1.43, 1.78 and 1.22 respectively (Table 3). However, the benefit-cost of stocking larger (300-mm TL) fish was substantially higher (8.36) than for the other smaller sizes (Table 3). This effectively means that 300-mm barramundi are up to nearly seven times more cost-effective to stock, despite the fact that they are up to five times as expensive to produce.

Break-even Analysis

Using the costings derived from a barramundi production model, (Russell *et al.*, 2004 & Table 3), to stock 1000 fish from each of the 50-, 70-, 130- and 300-mm TL size classes would be A$620, A$800, A$1370 and A$3060 respectively. To recoup the costs of the stockings, the numbers of 50-, 70-, 130- and 300-mm size class fish that would need to be subsequently recaptured in the commercial and recreational fisheries would be 20(2%), 25(2.5%), 44(4.4%) and 98(9.8%) respectively. This assumes that the worth of the average fish caught by commercial and recreational fishers were A$50 (Rutledge *et al.*, 1990) and A$25 (2.5 kg at A$25 kg^{-1}) respectively and that the number of fish caught in the recreational fishery is about a quarter of the number caught in the commercial fishery (Grey, 1986; Russell, 1988).

The break-even analysis suggests that the stocking program in the Johnstone River is potentially beneficial to the local community and the fishing industry. Depending on size of stocked fish, only between 2% and 10% need to be caught to recoup the costs of purchasing fingerlings. While larger numbers of 300-mm size class fish needed to be caught to offset higher stocking costs, their relatively high recapture rate compared to the smaller size classes suggests that this is achievable. This analysis is quite conservative and does not include provision for indirect economic benefits (Rutledge *et al.*, 1990; Rutledge *et al.*, 1991) or indirect costs.

Table 3. Model parameters (number of nursery runs per annum) and fingerling production cost outputs from the discounted cash flow model, predicted recapture probability and relative benefit:cost ratio for each size class of barramundi (Russell *et al.*, 2004). (Different superscript letters refer to pairwise comparisons amongst the parameters of the model, P<0.05).

Size class	Runs	Cost/fingerling (AUD)	Predicted recapture probability	Benefit:cost ($x10^3$)
50-mm	18	$ 0.62	0.000888 [a]	1.43
70-mm	6	$ 0.80	0.001423 [a]	1.78
130-mm	2	$ 1.37	0.001673[a]	1.22
300-mm	1	$ 3.06	0.025586 [b]	8.36

Contribution of Stocked Fish to Fishery

To assess the contribution that stocked fish were making to the recreational and commercial barramundi fisheries in the Johnstone Rivers, a fisheries dependent monitoring program was established in early 1996. Anglers were asked to retain the heads of all captured, legal-sized barramundi and return them to a central repository where they were subsequently checked for the presence of tags. A number of incentives including small prizes and automatic entry into a lottery were offered to all anglers who returned fish. Regular inspections, which included scanning for the presence of coded wire tags, were also made of the commercial catches from the Johnstone River through visits to fish processors. All fish were weighed and measured before tags were recovered from stocked fish.

Analyses of the numbers of fish with coded wire tags present showed that stocked fish comprised a maximum of about 16% of barramundi from relevant size classes (>580mm TL) of the catch of recreational fishers but only 8% of the commercial catch (Russell and Rimmer, 2000). Stocked fish usually remained resident around the release sites for a number of years and the inclusion of recreational catch data from these areas in the analyses may have inflated the contribution of hatchery-reared fish to this fishery.

Contribution to Spawning Stock

Most of the stocked barramundi recaptured in the Johnstone River were either immature or mature males although there were an increasing number of fish from the early stockings that had changed sex to females. A spent 903 mm TL female that was originally stocked in the 1993/94 season was caught in the mouth of the Johnstone River on 13 February 2000. This suggests that hatchery produced fish are now contributing to the spawning stock as both males and females (Russell and Rimmer, 2000).

Adoption of Research Results as Best Practice

The results of the research into barramundi stocking in the Johnstone River, particularly with respect to more efficient and cost-effective stocking strategies, are now being adopted by and paying dividends for community based stocking groups. For example, up until recently it was common practice for community groups to use small (~50-70 mm TL) and relatively cheap barramundi for their stocking activities. However as a result of QDPI&F research into best stocking practices, the Cairns Area Fish Stocking Group (CAFSG) is now releasing larger fish. Between December 2002 and October 2005 CAFSG released 6962 barramundi between about 200 and 400-mm TL into Trinity Inlet and the lower reaches of the Barron River (Sawynok, 2005). They also released another 689 barramundi of about the same size into the Mulgrave River in 2004 (Malcolm Pearce, QDPI&F pers. comm.). The release of larger fish also enables community stocking groups to be more proactive in monitoring their fish releases. In conjunction with the QDPI&F and Suntag program operated by the Australian National Sportsfishing Association (Queensland), CAFSG voluntarily tagged all fish with plastic anchor tags before they were released. The flag of the tag contained a message requesting anglers to measure the fish and report the capture to a freecall phone number. These data are then entered into a statewide recreational fishing tag and release database operated by SUNTAG. As a result, data are now being made available to managers and researchers on the efficacy of those stocking operations as well as producing information on the movements and growth of the stocked fish (Sawynok, 2005).

Future Research

In the nearly 20 years that barramundi stocking has been undertaken in Queensland estuaries and coastal rivers there have been considerable advances in areas such as identifying and quantifying survival and the relative efficiencies of various release strategies but there remain a number of key ecological issues that need to be addressed. These include how to recognize and incorporate carrying capacity considerations, species interactions and environmental influences into stocking decisions. The issue of whether stocked fish merely displace existing wild populations rather than enhancing them is a critical (but elusive) question that needs to be resolved for quite a few species.

The theoretical effects that stock enhancement are having on the fitness of wild stocks (eg. domestication, outbreeding depression, inbreeding and adaptability) are potentially damaging to the population but are notoriously difficult to measure (Leber *et al.*, 2005). While there is no evidence that there has been a decline in the fitness of Queensland barramundi stocks as a result of stocking activities, the Johnstone River, because of its very well documented history of stocking activities, would be an ideal field location for future genetics studies.

There is a need for a socio-economic survey to clearly elucidate community attitudes to, and perceptions of, fish stocking and to quantify its economic consequences, particularly for regional and rural communities.

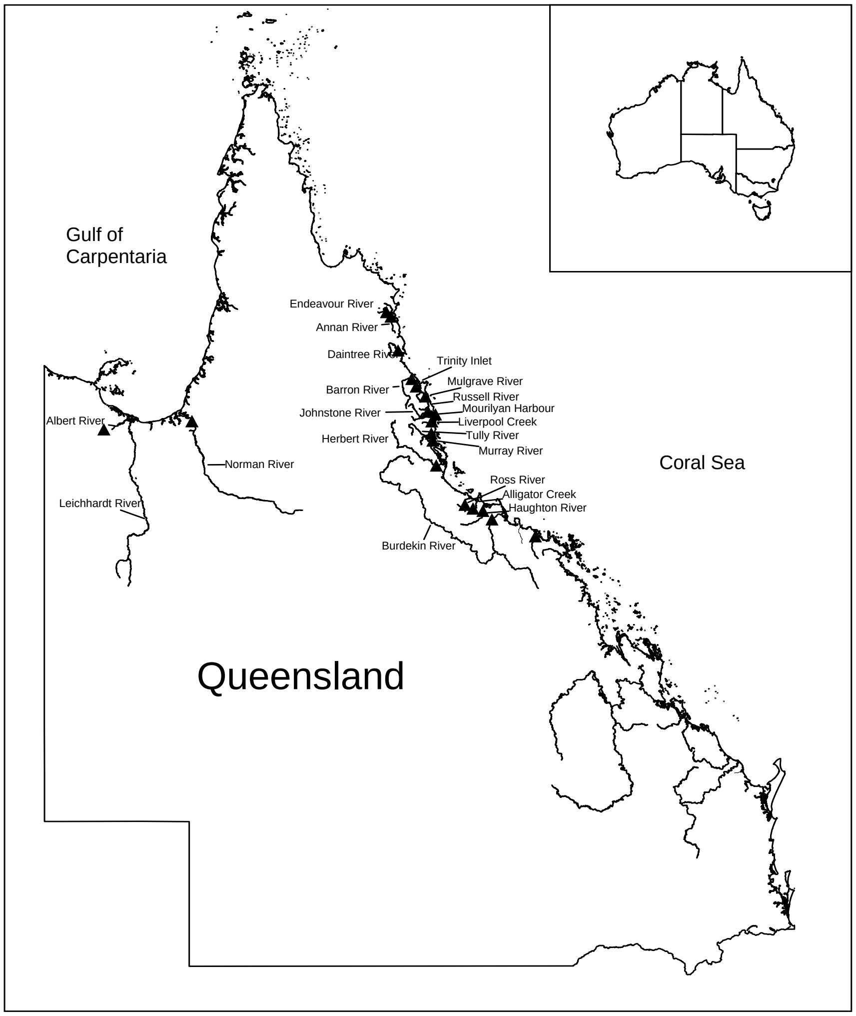
Fisheries managers need ways to integrate complex ecological and environmental information to predict the impacts of fish stocking. One such tool is an ecosystem model which could potentially provide managers with a means of testing management strategies for entire estuaries (and not simply single-species management) in order to protect and enhance the fragile ecosystems that support commercial and recreational fisheries production.

If fish stocking in open waters is to continue, then knowledge gaps on ecological, environmental and genetic impacts will need to be resolved in order to develop best-practice guidelines to ensure the future sustainability.

Location of rivers included in the six Queensland genetic management units.

1. **South east Gulf of Carpentaria stock (Point Parker to Pera Head):** Archer, Cloncurry, Coen, Coleman, Einasleigh, Flinders, Gilbert, Holroyd, L Creek, Leichardt, Mitchell, Morning, Nicholson, Norman, Saxby, Staaten, Watson.
2. **North west Cape York stock (Pera Head to Escape River):** Dulhunty, Embley, Escape, Jackson, Jardine, Mission, Skardon, Wenlock.
3. **East cost Cape York stock (Cooktown to Burdekin River):** Hann, Lockhardt, Normanby, Olive, Jacky Jacky, Pascoe, Stewart.
4. **Mid north east Coast stock (Cooktown to Burdekin River):** Barron, Black, Burdekin, Daintree, Endeavour, Haughton, Herbert, Hinchinbrook Island, Mossman, Mulgrave, Murray, North Johnstone, Ross, Russell, South Johnstone, Tully.
5. **Central east coast stock (Repulse Bay to Shoalwater Bay):** O'Connell, Pioneer, Plane, Shoalwater, Styx

6. **South east coast stock (Fitzroy River to Mary River):** Auburn, Baffle, Barambah, Boyne, Curtis Island, Dawson, Elliot, Fitzroy, Gregory, Isaac, Burnett, Burrum, Calliope, Comet, Kolan, Mackenzie, Mary, Nogo, Nogoa.



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Maroochy Fish Stocking Program

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The Maroochy fish stocking program had its genesis in a 1992 change in Government. The new Deputy Premier was an avid recreational fisher and held an inquiry into ways of boosting the recreational fishing industry in Queensland. The final report made over 50 recommendations, one of which was that the Fisheries Research group investigate stock enhancement in the Pumicestone Passage. I mention this because it demonstrates that political will is one method of rapidly harnessing public investment into stock enhancement. However, the flip side of this is that when governments change, so can funding priorities, as was the case later in 1997 with the Maroochy stocking program.

Although Queensland had a history with successful “put-and-take” impoundment fisheries, we had limited experience with estuarine stock enhancement. These events led to a stock enhancement workshop in September 1994 to review the contemporary knowledge and practices in estuarine fish stocking. The outcomes of the workshop included:

- The selection of dusky flathead (*Platycephalus fuscus*) and sand whiting (*Sillago ciliata*) as the target species;
- The recognition that we did not have the capacity to produce adequate numbers of fingerlings to stock such a large open system as Pumicestone Passage;
- An understanding that any stock enhancement would have to be accompanied by a detailed monitoring program;

- An undertaking that any stock enhancement program would have to have an extended life comparable to the life of the target species, in this case between five to seven years;
- The need for a mass-marking technique; and
- The defining of four broad objectives -
  1. Develop technology to under take large-scale breeding of finfish.
  2. Undertake extensive stocking.
  3. Develop protocols to monitor the effectiveness.
  4. Undertake monitoring program.

By current standards (2006) these objectives are broad in nature, but they represent the reticence of contemporary Fisheries Mangers (1994) to constrain, what was in essence a pilot-scale marine stock enhancement program, and they were designed to promote our understanding of marine stock enhancement issues. Multiple fish kills in the Maroochy River in 1993 and 1994 led to a perception of diminished populations of prime recreational fish species in this small river. In 1995, the Maroochy River was chosen as the site for the stock enhancement trial.

Objective One

Develop Technology to Undertake Large-scale Breeding of Finfish

At the start of this program, we had not examined the aquaculture potential of either target species, but did have some experience in culturing another estuarine species, barramundi (*Lates calcarifer*). Brood stock of each target species were sourced from adjacent waters in Pumicestone Passage and kept in large tanks at the Bribie Island Aquaculture Centre. Fish were induced to spawn and successful mass production of fingerlings of both species was achieved using green water rearing techniques. All fingerlings were fed a diet of live food and exposed to bird predation during the nursery grow out phase to minimise “hatchery domestication” effects. Fingerlings were grown to a size of 45-55 mm prior to stocking and their health was verified using a health assessment index technique similar to that used in stocking programs in the USA.

Objective Two

Undertake Extensive Stocking

Pre-stocking surveys were carried out for 12 months prior to stocking and the data were used to estimate the density of the natural population of each target species. These estimates were used to calculate stocking target figures that would give a reasonable chance of subsequently detecting a signal in the population. Fingerlings were stocked using proportional broadcast stocking methods during four major releases between December 1996 and May 1998. This was probably the most media intensive part of the whole program during which ~100 000 dusky flathead and ~335 000 sand whiting fingerlings were distributed. Two state government ministers, the local Mayor and several Councilors attended the stocking events; along with media representatives from television, radio and newsprint. This helped generate intense public interest in the program.

Objective Three

Develop Protocols to Monitor the Effectiveness of the Stocking

Monitoring required a mass-marking method to differentiate hatchery-reared fish from naturally occurring fish. This was considered to be an integral part of proving the success or otherwise of the stocking trial. We considered four different methods, based on overseas experience, but settled on trialing two: oxytetracycline (OTC) marking and scale pattern analysis (SPA).

OTC trials were unsuccessful with poor uptake of the solution by otoliths. In addition, we were left with large volumes (>5000 l) of polluted water that had to be disposed of by solar evaporation. This method was considered to be unacceptable.

SPA was chosen as the superior option. SPA is based on premise that all hatchery reared fingerlings developed a hatchery fingerprint circulus pattern on the inner portion of the scale. This pattern was different from that found on wild fish scales and could be differentiated by discriminant function analysis. Although this technique was not 100% effective, we were satisfied that the level of error could be quantified.

Objective Four

Undertake Monitoring Program

Our monitoring program, which began 12 months prior to the first stocking event examined fish from three sources:

- Fishery-independent samples;
- Recreational club trip catches; and
- Commercial net landings.

Our fishery-independent sampling sampled fish from over 30 sites using a variety of nets. Our results failed to highlight to any significant increase in the populations of either target species, primarily due to too much natural variation in population size, a large fish kill during sampling in 1997, and the curtailing of the monitoring program prior to detecting any effect of the second stocking. However, we did detect evidence of a stocked fish led recovery in the fish populations in the months after the fish kill.

We also found strong evidence that stocked fish survived, grew and recruited into the recreational and commercial sector catches. We collaborated with a recreational fishing club to examine the catches of target species during two trips some 18 and 30 months after the first stocking event. SPA of the catch indicated that 47% of flathead (n=13) and 44% of whiting (n=192) were from hatchery origin. Further, we examined the club catch rates from outings between 1994 and 2000 and found that mean club catch rates of whiting increased after 1997.

We examined the target species landed by two commercial fishers between 1997 and 1998. SPA highlighted that 28% of flathead (n=73) and 52% of whiting (n=44) catches were from stocked fish. We also examined the catch records for several commercial fishers between 1988 and 1999. General linear modeling indicated that post 1977, catch rates of both target species either stabilized or increased slightly (after historically declining).

Conclusions

Our stock enhancement trial was able to prove that both target species could be cultured and stocked in adequate numbers to survive, grow and recruit into the recreational and commercial fisheries, but we were unable to prove conclusively that we could enhance the population size of either species in the Maroochy River. Our research has led us to the following conclusions for stock enhancement in sub-tropical Australian waters:

- Estuarine stock enhancement is much more difficult (and expensive) than just buying and stocking fingerlings;
- Monitoring is essential to demonstrate success;
- Stock enhancement will only be successful in the presence of a recruitment bottleneck; and
- Any future proposal for estuarine stocking must follow a responsible approach which includes examining alternative methods of stock rehabilitation.

During the course of this trial, we encountered several questions that would be suitable for further investigation. These included:

- What are the environmental impacts of stocking (including effects on the trophic chain and subsequent effects on flora, habitat and water quality)?
- Does stocking enhancement displace native species (this was perceived as tying into the question of carrying capacity)?
- Does stock enhancement have any long-term genetic impact (can sound hatchery protocols overcome genetic drift)?
- What is the survival rate of stocked fingerlings and does this differ from natural survival rates? This question arose from overseas experience that indicated that stocked fish had a different catchability rate to wild fish.
- Is there a trade-off in survival between stocking larger fingerlings and minimising domestication of fingerlings (keeping fingerlings in the hatchery for as short a time as possible)?

Mulloway (*Argrosomus japonicus*) stocking in New South Wales estuaries

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Abstract

Mulloway stocking research in New South Wales commenced in 1996, and has included 11 stocking events across 4 estuaries. Stocking success has been variable, with greater success obtained in riverine estuaries over coastal lagoons. This observation is explained by the habitat requirements of juvenile mulloway, which are reliant on deep water habitat which provide both food and refuge from predation. Habitat of this nature is uncommon in the estuarine lagoons stocked. Habitat and diet information for juvenile mulloway were drawn together to model stocking density and predatory impact of stocked fish. Model estimates indicate that previous stocking densities may have been up to an order of magnitude too high in the Georges River. Future research will involve validating this model with field estimates, and extending its application to freshwater species. Research will also further define the stocking strategies that result in the greatest survival of stocked mulloway in New South Wales estuaries.

Introduction

Mulloway (*Argyrosomus japonicus*) are a highly prized but elusive sportfish in estuarine and coastal areas of southern Australia (Taylor *et al.* 2005b). The Australian recreational mulloway catch was estimated at over 975 tonnes in 2000/01 (Henry and Lyle 2003), far exceeding commercial catches over the same period. Commercial catches of mulloway in New South Wales have halved in recent times (Taylor *et al.* 2005a), and this decline may be attributed to low environmental freshwater flows (Hall 1986), and the susceptibility of mulloway to estuarine prawn trawling, of which juveniles form a significant non-retained bycatch (Broadhurst and Kennelly 1994). Also, the current minimum legal length of 45cm is half the size-of-maturity for mulloway. The decline of mulloway observed in NSW estuaries has led to an investigation into the feasibility, and environmental and predatory impacts of mulloway stocking (Fielder *et al.* 1999; Taylor *et al.* 2005b).

Mulloway (*Argyrosomus japonicus*) stocking commenced in New South Wales in 1996, with six releases of fingerlings across three intermittently closed opening landlocked lagoons (ICOLLs;

Fielder *et al.* 1999). Current research effort is now directed at developing strategies that maximise the survival of stocked fish, and to resolve the predatory impact of stocked mulloway. The current research project was designed as a tiered approach to assess the predatory impact, with initial research aiming to fill in several gaps in knowledge regarding the biology of mulloway. Initially, the project developed techniques to batch mark mulloway, and marked cohorts were released into an estuarine lagoon (Smiths Lake) and the saline areas of the Georges River, New South Wales. These fish were monitored for up to 2.5 y to compare the growth and forage requirements of stocked and wild mulloway. In addition, key habitats of juvenile mulloway were resolved using acoustic telemetry (Taylor *et al.* submitted-b). These data were drawn together into a model to estimate appropriate stocking density and predatory impact of stocked fish.

Batch Marking Techniques for Mulloway

Juvenile mulloway (54.6 ± 4.6 mm total length, mean ± S.E.) were immersed in oxytetracycline (OTC) solutions ranging between 0-600 mg L^{-1} in salinities of 35 (undiluted seawater) and 5 (diluted seawater), and alizarin complexone (ALC) solutions ranging between 0-60 mg L^{-1} in undiluted seawater. Immersion times were 6, 12 and 24 h, after which the chemical was allowed to dilute out of the treatment tanks.

Otoliths, anal fin spines and vertebrae were analysed for marks after fish were allowed to ongrow for seven days, with mark quality (MQ) assessed using a score of 1-3 in these structures. An MQ score > 2 was the threshold for an acceptable, easily detectable mark. Optimal marking conditions using OTC were 600 mg L^{-1} for 24 h in diluted seawater, and 30 mg L^{-1} ALC for 12 h (Taylor *et al.* 2005b). Acceptable marks were not produced using any OTC concentrations in undiluted seawater, and any marks produced using 200 mg L^{-1} in diluted sea water and ALC concentrations < 30 mg L^{-1} were of poor quality. Growth and survival of fish immersed in OTC or ALC, or reduced salinity was unaffected relative to controls. Transverse sections of vertebrae from the ALC and OTC treatments with the highest otolith mark quality showed no obvious marks (Taylor *et al.* 2005b).

A numerical model of the chemical behaviour of OTC in seawater was developed to describe the decline of available OTC in increasing salinity, and reveal the reasons behind the low mark quality obtained using OTC. Concentrations of available OTC decreased exponentially with increasing salinity. Available OTC concentration in 35 ppt was negligible regardless of how much OTC was added, and only 50% of added OTC was available for uptake at 5 ppt (Taylor *et al.* 2005b). This model allows marking with OTC to be optimised given a species' salinity tolerance.

By marking fish multiple times it is possible to differentiate between cohorts of fish released as different treatments (Tsukamoto *et al.* 1989). Optimal marking techniques were applied to mulloway twice in different combinations (OTC and OTC, OTC and ALC and ALC and ALC). Double marks were produced for all combinations in otoliths and fin spines, with a three- and six-day interval between marking with no loss in mark quality (Taylor *et al.* 2005b). Optimal marking techniques were also applied in batch mode at densities up too 30 kg m^{-3}. Using this technique, 30,000 mulloway were marked per 10,000 L tank, allowing the marking of 130,000 mulloway over 2 days. Batch marking at these densities produced MQ scores > 2 in all fish analysed, with negligible (<1%) mortality.

The detection of marks in anal fin spines facilitated a novel monitoring process for the Georges River. Many anglers that target mulloway release their catch, meaning that many mulloway being caught could not be evaluated for presence of a mark. Kits containing clippers, a clipboard and datasheet, and 25 numbered vials are now distributed to catch-and-release fishers. Upon landing a mulloway, the fisher snips off the anal fin spine, measures the total length and returns the fish to the water. After the kit is full, anal fin spines are returned for mark detection.

Growth and Success of Hatchery-reared Mulloway Stocked in South East Australian Estuaries

Over 212,000 mulloway have been stocked into four New South Wales estuaries between 1996 and 2004 (Table 1; Fielder *et al.* 1999; Taylor *et al.* 2005a; Taylor *et al.* 2005c). Swan Lake, Khappinghat Creek and Smiths Lake were sampled for stocked fish using multi-panel gill nets for 6 – 8 months after stocking. Georges River was sampled for mulloway using an otter trawl and multi-panel gill nets for up to 2.5 y post release. Trawls were towed in deep holes surrounding the release site, and gill nets were set at dawn or dusk in deep holes surrounding the release site for up to five hours. Fish were sampled from the commercial fishery in Smiths Lake, and the recreational fishery in the Georges River for 2.5 y post release, as Georges River is a recreational fishing haven. The growth and success of stocked fish was evaluated.

There were no mulloway recaptured from the stockings in Khappinghat Creek and Swan Lake in 1996/1997, and Smiths Lake in 2003, whilst fish stocked into Smiths Lake in 1997 and 2004 recruited to the commercial fishery after 18 mo (Table 1; Fielder *et al.* 1999; Taylor *et al.* 2005c). The 1997 stocking led to an ~3000% increase in mulloway catch in Smiths Lake, however the stocking had a high cost-to-benefit ratio of 2:1 (considering the cost to rear the fish and the market value of mulloway). Shallow coastal lagoons may provide useful experimental units for resolving release strategies (Taylor *et al.* 2005a), but do not appear optimal for mulloway. Mulloway from the 1997 and 2004 Smiths Lake stocking grew at ~0.9 mm d^{-1} and ~0.6 mm d^{-1} respectively (Taylor *et al.* 2005c), however the 2004 stocking only provided 6 recaptures over two years.

Mulloway from the 2003 and 2004 Georges River stocking grew at 0.6 mm d^{-1} and 0.8 mm d^{-1} respectively. The slightly slower growth in the Georges River was probably due to lower temperatures, with an average summer temperature 2°C lower than Smiths Lake (Taylor *et al.* 2005c). The Georges River was stocked in 2003 with 54,000 mulloway of 80 mm TL, and two other cohorts of size 77 mm (n = 5 200) and 48 mm (n = 19,000) in 2004. Fishery independent recaptures for 18 mo. post stocking represented only 0.1% of the large 2003 release, while 0.2% of the smaller release of 77 mm fish in March 2004 were recaptured (Taylor *et al.* 2005c). Thus, it is possible that the river was overstocked in 2003. Stocking of 48 mm fish in May 2004 gave a much smaller recapture rate of 0.03%. Mulloway stocked in the Georges River in 2003 reached minimum legal length in 18 mo., and appeared in the fishery after 2.2 y (Taylor *et al.* 2005c), comprising ~20% of age-2+ fish sampled from the recreational fishery.

Evaluating the Forage Requirements of Juvenile Mulloway

Ontogenetic transitions in diet often control the distribution or behaviour of estuarine fish species (Werner and Gilliam 1984). Prey and habitat based size structuring of populations has important implications for stocking mulloway, as stocking can be targeted at areas where forage resources are in good supply. Whilst the diet of African *A. japonicus* has been resolved (Griffiths 1997; Marais 1984; Whitefield and Blaber 1978), the ontogenetic changes in Australian *A. japonicus* diet remain unknown.

Stomach contents analysis of stocked and wild mulloway captured from Smiths Lake and the Georges River, revealed size- and estuary-specific diets. The estuarine mysid *Rhopalophthalmus* sp. was most abundant in diets of mulloway <250 mm TL, juvenile school prawns *Metapenaeus macleayi* were common in diets of fish measuring 301-450 mm, and forage fish were most abundant in diets of mulloway >500 mm (Taylor *et al.* submitted-a). The index of Relative Importance (IRI; Pinkas 1971) of mysids decreased with size and IRI of forage fish increased with size. Prawn IRI was greatest for fish 150-600mm (Taylor *et al.* submitted-a). Comparisons between benthic resources and dietary composition revealed that Georges River mulloway consumed prey categories in proportions similar to those in their environment, which indicate that mulloway have a flexible diet and do not actively select prey (Taylor *et al.* submitted-a).

Identifying Key Habitats of Juvenile Mulloway

Ultrasonic telemetry was used to reveal the preferred habitats and activity patterns of sub-adult mulloway in the Georges River. Acoustic transmitters were surgically implanted in 9 hatchery-reared and 12 wild caught mulloway (330-730 mm TL), and were tracked daily for 20 d, and for two periods of continuous tracking over 72 h in a 15 km section of the river.

Key riverine habitats were identified as discrete holes or basins up to 20 m deep (Taylor *et al.* submitted-b). Small mulloway spent over 90% of their time in holes across the day and night, whilst larger mulloway embarked on foraging excursions outside the key habitats at night, spending only 18% of night time in holes (Taylor *et al.* submitted-b). The activity patterns of mulloway varied between small and large fish, due to a diet induced shift in behaviour, as major forage species change from relatively sedentary organisms (mysids and prawns) to a more active prey (baitfish). The diel feeding patterns were evident in significantly longer movements during the night and morning than daytime (Taylor *et al.* submitted-b).

Hatchery-reared mulloway were released in shallow water and deep water habitats. Acoustic tracking revealed initially significantly greater movements in fish released in shallow water compared to those released directly over deep holes, with movement up to 10 km away from the release site in 3 d (Taylor *et al.* submitted-b). Mulloway should be stocked directly into their key habitat to minimise the stress associated with these long post-stocking migrations to find key habitats. Also, the use of key, deep water habitats indicate that survival of stocked mulloway will be sensitive to stocking density.

Developing a Novel Approach for Responsible Stocking of Estuarine Finfish

Habitat and diet data were used to create a general consumption-mortality based model to estimate the appropriate stocking density of an ecosystem and the predatory impact of stocked fish. The Predatory Impact Model contains parameters whose values are generally available in the literature or easy to obtain, including life-history parameters, temperature, habitat area, diet information and production estimates. Simulations for the stocking of mulloway in a 15 km stretch of the Georges River, Sydney, showed the system could support a density of 3,618 and 3,486 50 and 100 mm stocked mulloway respectively. These estimates of stocking density are an order of magnitude lower than the density of mulloway stocked in this section of the Georges River in 2003. This may indicate why a better recapture rate was obtained from the 2004 stocking, where numbers were closer to model estimates (Table 1).

Over the 7 y during which mulloway are resident in the estuary, all stocked fish have an estimated maximum yearly predatory impact of 0.3 t y^{-1} mysid shrimp, 5.9 t y^{-1} baitfish, 1.8 t y^{-1} school prawns, 0.9 t y^{-1} miscellaneous invertebrates and 1.7 t y^{-1} cephalopods. These maximum values represent 34%, 37%, and 23% of former commercial production in the Georges River for bait fish, prawns and cephalopods respectively. Model simulations demonstrate the magnitude of the environmental impact fish stocking may have on an ecosystem, and allow the evaluation of potential predatory impact in terms of the resources available in the system.

Future Research

Research into mulloway stocking will continue over the next five years, and aims to address the following objectives:

1. Validation of the Predatory Impact Model estimates and targeted stocking approach;
2. Assessment of the impact of stocking on prey, competitor and predator species assemblages;
3. Assessment of the genetic contribution of stocked fish in target estuaries, and development of wild spawning techniques to guarantee genetic integrity of fingerlings in future stocking projects;

4. The identification of the season of release, size of release and site of release that provides greatest survival of stocked fish;
5. The resolution of mulloway recruitment dynamics, to allow the identification of instances where recruitment limitations are present and stocking may be required;
6. Evaluation of the contribution of stocked fish to commercial and recreational fisheries;
7. An appropriate cost-benefit analysis for stocking of mulloway; and
8. Further evaluation the Predatory Impact Model for freshwater species, including a review of current freshwater stocking practices in terms of modelled stocking densities.

The research project will be carried out across four estuaries – the Georges River, the Tweed River, the Richmond River, and the Manning River. In order to obtain suitable temporal replication in the study, stocking will be undertaken for three years (2006 – 2008), and monitoring will continue for five years (2006 – 2010) to assess the reproduction of stocked fish and also follow the fish through the relevant fisheries. It is intended to include control estuaries in the design of most experiments.

Conclusions

Research into mulloway stocking has resulted in the development of a pragmatic way of assessing stocking density and predatory impact, which can be extended to other species and freshwater environments. Until recently, stocking densities of fish have been determined by guesswork, hatchery production or by available funds. The results presented here imply that by targeting stocking only toward key habitats, less fish will need to be stocked, but fish will have greater survival. This will result in less environmental impact associated with stocking events, and less financial investment required to grow and stock fish. For example, the 2004 release of mulloway cost $30,000 less than the 2003 release, and gave a better recapture rate (Taylor *et al.* 2005c). Future research will stock low densities of fish to further refine stocking techniques for mulloway, produce data to validate the predatory impact model, and will assess the suitability of the Predatory Impact Model for freshwater species. At the conclusion of the 5 year project, the key areas of research required for the implementation of a larger-scale mulloway enhancement project will have been addressed.

Table I *Argyrosomus japonicus* stocking in New South Wales (Taylor *et al.* 2005c)

Estuary	**Release Date**	**Mark**	**Release Size (mm Total Length)**	**Number Released**	**Number Recaptured**
Khappinghat Creek	11 January 1996*	OTC	40	25 000	0
Swan Lake	24 February 1997*	OTC	50	11 000	0
	3 March 1997*	OTC	52	17 000	0
Smiths Lake	27 February 1997	OTC	58	7 600	
	7 March 1997	OTC	65	10 000	64
	23 March 1997	OTC	106	4 000	
	5 May 2003*	OTC	80	42 000	0
	7 February 2004	OTC	47	18 000	5
Georges River	9-12 May 2003	OTC	80	54 000	71
	3 March 2004	ALC	77	5 200	11
	10 May 2004	OTC	48	19 000	6

* Unsuccessful stocking events for which there were no recaptures of stocked fish

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Restocking of Black Bream (*Acanthopagrus butcheri*) in the Blackwood River estuary: One isolated success or a Portent for the future?

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Abstract

During the last five years, Challenger TAFE and Murdoch University have been conducting a FRDC project aimed at elucidating whether it might be viable to consider restocking, with the black bream *Acanthopagrus butcheri*, an estuary in which the stocks of that species had become severely depleted. For this purpose, adult black bream from the Blackwood River Estuary were used to hatchery rear 220,000 juveniles of this species. After the otoliths of these juveniles had been marked with a chemical tag (Alizarin complexone), these young fish were released into the Blackwood River Estuary. The mark on the otoliths produced by this chemical is still visible *i.e.* over four years after the otoliths had been tagged. In collected samples, the tagged (restocked) fish were found to contribute approximately 73 and 91% of the total number of individuals representing the 2001 and 2002 year classes, respectively. Furthermore, the growth rate of the tagged fish are similar to those of the members of the natural population. These results thus demonstrate that hatchery-reared individuals of a species, such as black bream, can be introduced into an estuary and survive to increase significantly the size of the population of that species in the estuary.

The results of this project raise several important questions. For example, what are the implications of increasing artificially the abundance of one species in an estuary on the other species in that estuary? What are the levels of restocking required to sustain commercial and recreational fishing at an acceptable level and what are the implications for management? What are the reasons for the apparent continued limited success of the natural population of black bream in the Blackwood River Estuary?

Key words: black bream, restocking, aquaculture, Western Australia

Black Bream in the Gippsland Lakes

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The Gippsland Lakes Fisheries for Black Bream

The commercial fishery for black bream in the Gippsland Lakes has averaged around 150 tonnes over a history spanning almost a century. The commercial fishery operates in the lakes, using haul seines and mesh nets. In 1974/75 it produced peak catches in excess of 500 tonnes, but was only 159 tonnes in 2000/01. In recent years, mesh nets have become the main commercial fishing method as increased cover of seagrass and heavy growth of epiphytic algae have made haul seines increasingly inefficient or unworkable. These habitat changes have had little effect on hook fishing by the recreational fishery, which occurs in both the lakes and the lower reaches of the inflowing rivers. The estimated recreational catch of black bream in 2000/01 was about 100 tonnes (calculated from data from the National Recreational and Indigenous Fishing Survey), with large numbers of undersized fish released.

In 2002/03 the commercial catch fell to less than 30 tonnes for the first time in 45 years, with catch rates showing a similar decline. Similar declines were not evident in the data reported by commercial fishers for other target species, indicating that the decline reflected a change in the abundance or availability of black bream and was not simply due to reduced efficiency of the fishing gear. Nevertheless, the relative importance of fishing pressure and environmental change in producing this decline in abundance or availability remain uncertain. Recreational fishers were also reporting low catch rates. Data from creel surveys also showed that catch rates of black bream were low, but did not indicate a similarly substantial decline from previous years.

Following a series of stock assessment workshops between 1996 and 2003 concerns about declining stocks of black bream prompted the introduction of more conservative management measures in December 2003 including an increase in the legal minimum total length from 26 to 28 cm for all bream fishing in the Gippsland Lakes and inflowing rivers. That size limit remains in place.

Population Studies

The biology of black bream is relatively well understood, and the status of the bream population in the Gippsland Lakes has been monitored by an increasingly comprehensive range of fishery-dependent and fishery-independent measures over the past 10 years.

Annual monitoring of the abundance of pre-recruits has been undertaken in the Lakes since 1996. These surveys have recorded more regular recruitment, but at much lower levels than previously seen in the 1980s. Correlations between recruitment strength and environmental variables have suggested strong affects from rainfall and water temperature, but the important parameters in such models have varied over time. Causal mechanisms remain speculative, but an environmentally mediated level of recruitment is consistent with all known facts of black bream biology and data on year-class strength, both from the Gippsland Lakes and elsewhere. Recent assessment workshops have concluded that the absence of any very strong year-classes since 1989 is likely to keep catches and catch rates, in both commercial and recreational fisheries, at or below current levels in the foreseeable future.

Data on age and growth from the mid to late 1990s had indicated that recruitment in the Gippsland Lakes was episodic and that growth rates were slow. Black bream were taking 8 to 9 years to reach a fork length of 20 cm. Growth rates of black bream in the Gippsland Lakes have since been found to be steadily increasing over a 10 year period. They now reach 20 cm in 2 to 3 years. This change is taken to indicate a greatly enhanced food supply per fish, and may reflect increased productivity of the lakes, declining numbers of bream, or some combination of both factors. The faster growth rates may have been helping maintain catch rates in commercial and recreational fisheries while abundance was declining. If maintained, the faster growth may have some positive effects in any recovery of the bream populations. Firstly, fish will recruit to the fishery at a younger age than seen historically. And secondly, fish will move through any size-related bottlenecks (such as that from predation by cormorants) more rapidly and hence with lower mortality.

Stock Enhancement

Stock enhancement is one possible response to the decline in the strength of recruitment of black bream. It could be trialed as a means to overcome the inability of the current level of spawning success to sustain acceptable catch rates in the commercial and recreational fisheries. One of the responses by Fisheries Victoria to the concern over black bream in the

Gippsland Lakes was a trial stocking of 20,000 juveniles in 2004. This trial was considered to be the first step in a long term program to ensure sustainable supplies of bream for both recreational and commercial fishers well into the future. The fish were marked with alizarin complexone and otoliths from the small number of bream of the correct age that had been captured during the pre-recruit surveys are being examined for evidence of marks. None were detected among a small number of fish sampled in December 2004 and those that have been collected in January 2006 have yet to be processed.

Fisheries Victoria is considering further stocking of black bream into the Gippsland Lakes. A well-designed stock enhancement program has the potential to provide important information on the factors that have been limiting recruitment. But although such a measure addresses the symptoms of the problem being faced, it will not by itself help reverse the as yet unknown causes of the underlying problem of poor recruitment. Whether stocking will substantially improve the status of black bream in the short to medium term will depend on a range of factors, especially the number of fish stocked and their rate of survival.

There are many questions around the likely effectiveness of stock enhancement. These include the following:

- ❑ Could stocking significantly increase the size of the bream population in the GL?
- ❑ How many fish would be needed?
- ❑ Is current monitoring likely to be able to detect a change if one occurs?
- ❑ Is any effect from stocking likely to be long-lasting?

How effective stock enhancement may be will depend in part on the timing and nature of the current bottlenecks to recruitment. These may be prior to spawning and affect the condition of adults (unlikely given the increased growth rates) or the presence of correct spawning cues (quite possible for a species for which particular salinity conditions are considered to be important for spawning). They may also be in the period between spawning and the first few months of life. It is common for this to be a time of high mortality in fish populations. There may also be a significant bottleneck between the juvenile stage and recruitment to the fishery, due to mortality from cormorant predation. Mortality from cormorant predation has been estimated to exceed the combined mortality from the commercial and recreational fisheries. Stock enhancement is only likely to have a significant effect if it is able to bypass the major population bottlenecks.

How many fish would be needed to significantly add to the natural recruitment is another unknown. Estimates can be made in a variety of ways including:

1. Numbers that are now produced naturally (using estimates from the pre-recruit survey);
2. Back calculated numbers using recent mortality & growth estimates;
3. From the example of the successful stocking in the Blackwood estuary in Western Australia; and
4. At the rule-of-thumb stocking rate of 100-200 fish/ha used for native fish in Queensland.

Estimates from pre-recruit surveys were expanded using swept area methods to the total area sampled. There are many assumptions in this expansion, but the calculations suggest that between 80,000 and 400,000 1 year old black bream have been produced in the years between 1995 and 2004. Such levels of recruitment have apparently been insufficient to sustain the black bream fisheries, and would suggest that stocking of 1 year old fish needs to be at a higher average rate in order to have a significant impact.

Estimates of mortality rates of the 1995 year class were also used to back-calculate the number of 1 year old fish that would be needed to produce 1 tonne of black bream at the LML of 28 cm. These calculations are dependent on the time taken to reach this size. At the growth rate observed for the 1995 year class, it was estimated that 160,000 fish would be needed for each tonne of fish reaching the LML (2,500 fish of 400 g each). Therefore, about 16 million 1 year old fish may be required to maintain a 100 tonne fishery. Faster growth and lower mortality would produce lower estimates than this. For both these methods of estimation, fish to be stocked are likely to be younger than 1 year old, and the numbers stocked would need to be higher to accommodate any mortality between stocking and this age.

Black bream have been stocked successfully in the Blackwood River estuary in Western Australia, using a total of 220,000 fish. This estuary has an area of 12 sq km. To obtain a similar stocking density in the Gippsland Lakes (340 sq km) would require 6 million fish of similar age (an order of magnitude more than recent levels of natural recruitment).

The nominal stocking density that is employed in Queensland for stocking of native fish into various waters (100-200 fish/ha) equates to 3.4 to 6.8 million fish when applied to the Gippsland Lakes. The age or size of fish at which these stockings occurs is unknown.

These calculations are indicative only, but all suggest that the numbers of black bream that would be needed to make a significant contribution to natural recruitment are in the order of several hundred thousand per annum or more.

Monitoring of any stocking is necessary if its impact is to be assessed. Current monitoring programs in the Gippsland Lakes include creel surveys of the recreational fishery, catch rates by research anglers, monitoring of pre-recruits with an annual haul seine survey, and commercial catch and effort data. There is also a new fishery-independent monitoring program being developed aimed at assessing the relative abundance of adult bream in the lakes and the inflowing rivers. All could be used to assess the impact of any stocking program. Existing data could also be used to estimate the magnitude of any change in abundance that is likely to be detectable with a specified level of confidence for each monitoring tool (except for the new fishery-independent survey).

The Future

There are many factors to be considered in any decision about the likely contribution that stock enhancement may make to improving the fisheries for black bream in the Gippsland Lakes. There are now good frameworks outlining the logical steps that should be taken in making such a decision. There are many documented examples of stock enhancement failing to deliver expected outcomes for a variety of reasons, and an analysis of the risks and alternatives should be a part of such a process. A well-designed stocking program has the potential to explore stocking strategies that maximise the benefits from any fish stocked (such as the optimal timing and location of releases, and sizes of fish to be released) and also to assist in understanding the factors that have limited recruitment.

It is clear that stocking could potentially increase the size of the population of black bream in the Gippsland Lakes, but it is likely to require a large number of fish to be stocked over several years to achieve this result. Whether any change from stock enhancement is likely to be long-lasting is much less certain. If the factors that are currently contributing to the poor levels of natural recruitment continue, then stock enhancement is unlikely to have any long-term impact unless it is ongoing. If egg production is currently limiting recruitment, and if stock enhancement could boost the spawning stock to a significantly higher level, then it may produce a long-lasting effect. Ongoing management to maintain these higher levels of egg production would then be necessary. At present, however, egg production is not considered to be the factor limiting recruitment of black bream in the Gippsland Lakes.

In the longer term, habitat and environmental factors beyond the direct control of fisheries management, are probably the key factors in determining the health of the bream population in the Gippsland Lakes and the fisheries it supports. A better understanding of these factors that determine reproductive success and recruitment would help to evaluate and influence alternative broader ecosystem management strategies.

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Using Population Models to Aid the Decisions about the Stocking and Reintroduction of Trout Cod (*Maccullochella macquariensis*)

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Abstract

The decision about where to place hatchery produced fish as part of a stocking or reintroduction program may not be a simple task. The decision making process can be simplified if the different decisions available can be ranked based upon some criteria of success. In this paper we present a summary of information that can be useful for planning threatened species recovery through stocking or translocation. A population model describing the ecology of trout cod in terms of both deterministic and stochastic processes was written to analyse different stocking-reintroduction strategies. These strategies relate to the number of fish stocked, the longevity of stocking and the size of fish reintroduced. Based upon predictions of the model it was concluded that the most effective strategy for minimising the risk of stocking failure was stocking at higher densities, for longer periods and with age 1+ year classes. The methods implemented in this study can be broadly applied to aid the decision making process for other native species for both stocking and reintroductions. Importantly, the processes of constructing a population model for an Australian native fish species identified the extreme absence of information on important population statistics (survival, fecundity, immigration, emigration) that have direct impacts upon the capacity to forecast stocking success.

Introduction

Stocking enhancement for conservation purposes in Australia is often undertaken for the purpose of re-establishing populations of threatened species (eg Brown *et al.* 1998, Crook and Sanger 1999, NSW Fisheries 2004). Those responsible for implementing such a re-introduction are often faced with technical decisions about the number of fish to reintroduce, the timeframe that stocking should occur and the age of the individuals that should be reintroduced. The desired outcome of these decisions is a stocking strategy that maximises the chance of re-establishing a self-sustaining population (i.e. establishing a population that can persist into the future without continual stock enhancement). Unfortunately, the knowledge bank that exists to answer these questions is often limited for many species.

To aid this decision making process, different reintroduction strategies can be examined through the application of population viability analysis (PVA). The population dynamics of reintroduced populations often resemble those of small isolated populations. Chance events such as fluctuations in the vital rates, uneven sex ratios, and inbreeding depression may impact upon these populations and drive them to extinction (Gilpin and Soulé 1986). Assessing the viability of small populations is essential to determine whether the population can sustain such fluctuations. PVA assesses the viability using the projections from a stochastic population model that summarises the demographic information as well as other relevant ecological information about a species (i.e. territoriality, density dependence). Chance fluctuations are included through three main sources of variation in the demographic rates: demographic stochasticity (reflecting the inherent uncertainty due to finite, integer numbers), environmental stochasticity (depicting the temporal variability of the environment), and spatial variability (arising from the heterogeneity of habitat patches in which a population exists) (Todd *et al.* 2001). In considering these random, natural sources of variation in the demographic rates, a model can provide results that are relevant to conservation purposes such as the risk of extinction, the chance of population persistence, expected persistence time, and projected range of population abundance.

The viability of a population is the probability that it will persist at some location over a specified time horizon that is generally predetermined and fixed (Burgman *et al*. 1993). The quasi-extinction risk, defined as the probability that the population falls below a pre-specified abundance at least once during the projection (Ginzburg *et al*. 1982), is a useful summary of the predicted extreme behaviour of endangered populations (Ferson *et al*.1989, Burgman *et al*. 1993; McCarthy *et al*. 1994). Terminal quasi-explosion risk is defined as the probability that the population will be at least some population size at the end of the simulated timeframe. By using these measures each reintroduction strategy can be ranked against each other in terms of its likelihood of establishing a population. Resources available can then be allocated to the most appropriate strategy.

In this paper we present the results from a population model constructed for the critically endangered trout cod (*Maccullochella macquariensis*), to evaluate the likelihood of establishing a population by reintroducing hatchery reared fish. The methods implemented in this study can be broadly applied to aid the decision making process for other native species for both stocking and reintroductions. Importantly, the processes of constructing a population model for an Australian native fish species identified the extreme absence of information on important population statistics (survival, immigration, emigration, mortality) that have direct impacts upon the capacity to forecast stocking success.

Methods

Recovery of Trout Cod

At present only two self-sustaining populations of trout cod are known: a naturally occurring population in the Murray River below Yarrawonga Weir and a translocated population, in Seven Creeks below Polly McQuinns Weir in Victoria (Richardson and Ingram 1989; Ingram *et al.* 1990). Substantial investments have been made by the New South Wales, Australian Capital Territory, Victorian and Commonwealth Governments to recover this species from the brink of extinction (see Douglas *et al.* 1994 and Brown *et al.* 1998).

The re-introduction of populations into the former range through the release of hatchery reared fingerlings, along with addressing the causes for decline have been the major initiatives of the recovery process. The first attempts at reintroduction commenced in the mid 1980s when techniques to produce hatchery reared trout cod were developed (Rimmer 1987; Ingram and Rimmer 1992). Small numbers of juvenile fish have been produced for release into sites within the presumed historical range of the species every year. In a number of locations, stocked fish have survived through to breeding age, but evidence of successful breeding taking place is very limited (Douglas and Brown, 2000, King *et al.* 2005).

Evaluating Reintroduction Strategies

A stochastic model describing the population dynamics and ecology of trout cod (Todd *et al.* 2004) was used to analyse different reintroduction strategies. These strategies relate to the number of fish stocked, their age at release and the longevity of the stocking. Each scenario, encoded into the model, is projected over thirty years and replicated 1000 times to obtain a distribution of the possible population trajectories. This distribution of possible outcomes is then analysed to obtain either quasi-extinction or quasi-explosion risk curves under each scenario. To explore the impact of the different scenario's these curves are compared.

Specifically, we modelled the release of 20,000 fingerlings every year for 3 years, 1,000 yearlings every year for 3 years and 2,000 yearlings every year for 3 years to examine whether the number or size at reintroduction influenced the likelihood of population establishment. Quasi-explosion curves were generated to compare the female adult population size expected after 30 years.

We also modelled the release of 2,000 yearlings every year for 5 years and for 10 years to examine whether the duration of the stocking program influenced the likelihood of population establishment. Quasi-extinction curves were generated to compare the probability of a population falling below 1,000 individuals after 30 years.

Results

Size and Number at Release

The expected population size at the 0.8 probability for the release of 20,000 fingerlings for 3 years was 40 adult females. This compared to 85 adult females for the release of 1,000 yearlings for 3 years and 123 adult females for the release of 2,000 yearlings for 3 years (Figure 1).

Duration of Reintroduction

The probability for the release 2,000 yearlings every year for 5 years being less than or equal to 1,000 adult females was 0.7 and 0.25 for the release 2,000 yearlings every year for 10 years (Figure 2). In other words the probability that the adult female population will be greater than 1,000 at the end of the 30 year projection is 0.3, and 0.75.

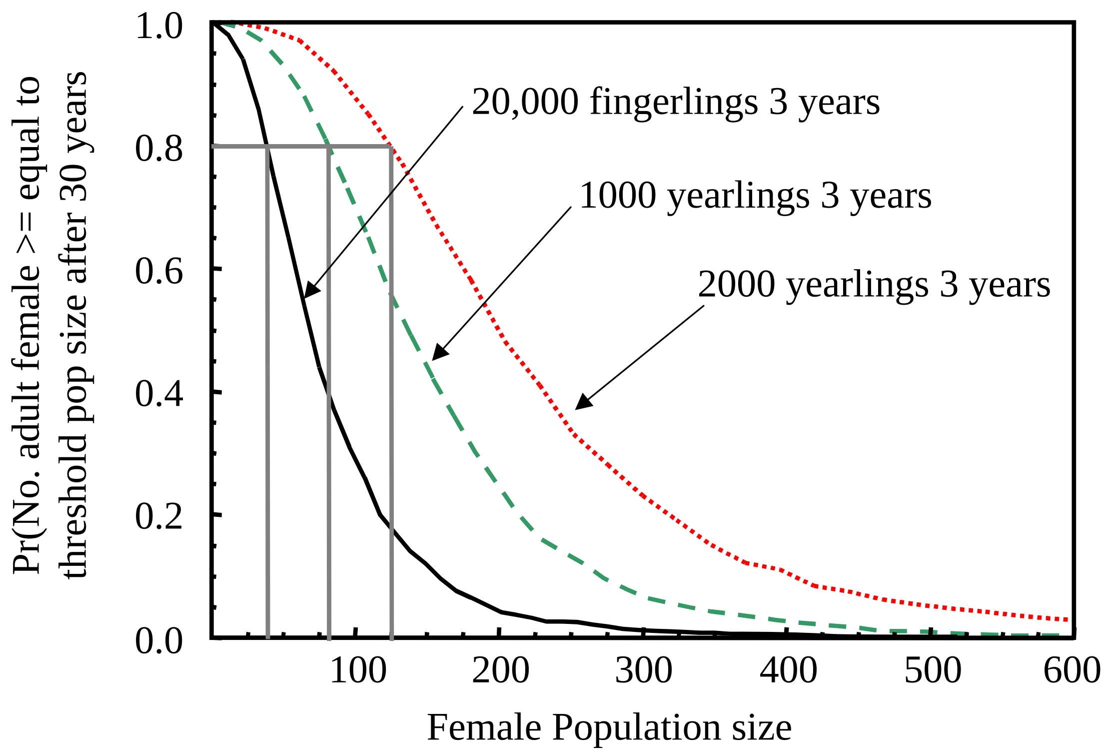

Figure 1: Terminal quasi-explosion curves for the release of 20,000 fingerlings, 1,000 yearlings and 2,000 yearlings

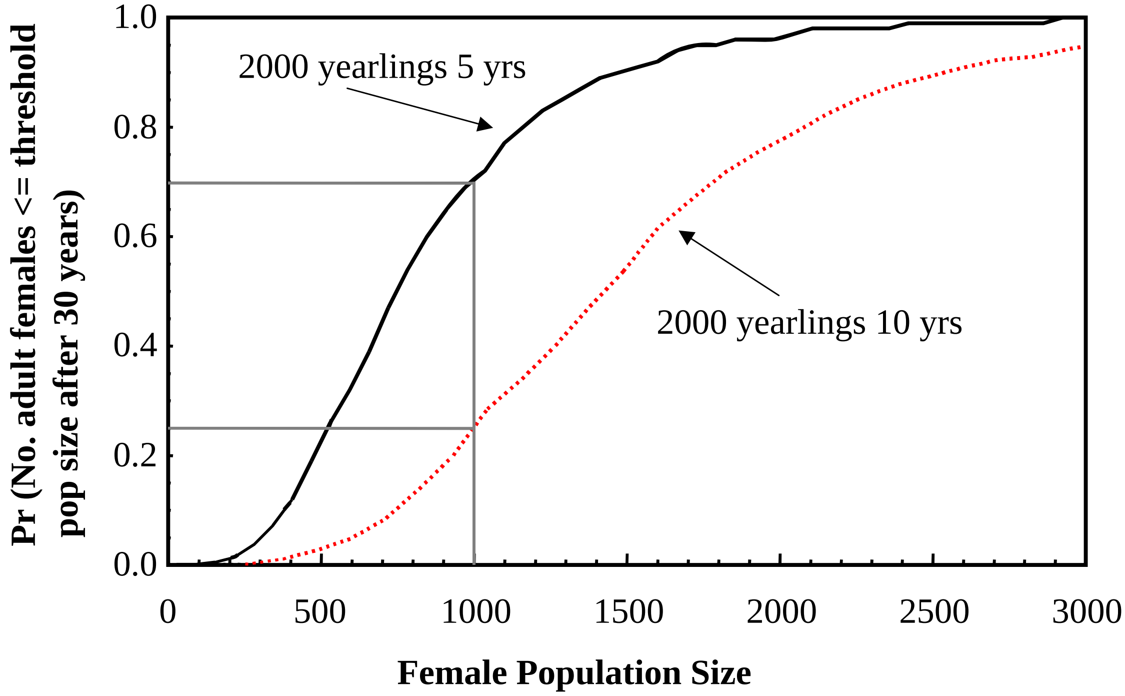

Figure 2: Quasi-extinction curves for the release of 2,000 yearlings every year for 5 years and every year for 10 years

Discussion

In these scenarios, adding the 20,000 fingerlings is a higher risk strategy with little benefit or chance of establishing a new population. In natural populations, the greatest proportion of mortality is thought to occur in the first year and the model has been parameterised to reflect this. If this is also the case for introduced fingerlings then it may be that adopting a fingerling release strategy is not the best use of time and resources.

The release of yearlings was predicted to be the most likely to succeed. The reason for this is that yearlings are thought to have a higher survival rate that is subject to a lower environmental variation when compared to fingerlings. We have not considered, however, that hatchery reared yearlings may have much lower chances of survival. We have made no distinction between hatchery bred yearling survival and innate yearling survival. If rearing trout cod in the hatchery to one year old and releasing them as a reintroduction strategy is to be successful, then some research is required to examine the survival of these hatchery reared fish upon release.

In this analysis, short duration stocking (5 years) did not produce the best conservation outcomes for trout cod in comparison to stocking for 10 years. This indicated that continuous stocking needed to be maintained over a period of years to build an adult population that has the best chance of being viable in the long term.

Sensitivity analysis of the model to small changes to fingerling and yearling survival rates was undertaken. This analysis revealed the outcomes to be insensitive to small changes (±10%) in these survival rates. This indicates that the rank order of the outcomes will be consistent, even if we are unsure about the underlying distribution for these survivorships. The sensitivity analysis undertaken by Todd *et al.* (2004) on the model used in this analysis indicated that predictions (eg. predicted population size) are sensitive to the model structure and the underlying distribution for survivorship. Consequently, whilst the rank order of the scenario's modelled in this paper will be consistent, the predicted population sizes are unlikely to be robust.

A review of the literature revealed that very little information is available to generate reliable survival, immigration, emigration, and mortality estimates for Australian fish species. The sensitivity to model structure and the underlying distribution of these parameters identified by Todd *et al.* (2004) suggests that models of this type should only be used for qualitative rather than quantitative prediction.

Releasing fingerlings as a strategy for trout cod reintroductions may be successful. However, the effort required is perhaps greatly underestimated in that the strategy may need to be maintained over long periods of time and at much higher levels of releases than have so far been conducted. To achieve results predicted under the yearling strategy, 200,000 fingerlings would need to be released annually for ten years. The effort required to produce 200,000 fingerlings per year is not insignificant. On-growing fingerlings to one year old fish is not insignificant either, especially given the uncertainty concerning the survival of hatchery bred fish in the wild. However, in 1999 approximately 1,000 one year old fish were released into the Ovens River indicating that the task is not insurmountable.

Conclusions

The reintroduction program for trout cod has been enhanced by the use of exploratory modelling to help guide decision about the best use of resources for reintroduction. By modelling the release scenarios we have been able to rank order, which release strategy is likely to provide the greatest possibility of success. Clearly, given that the assumptions of the model are acceptable, on-growing 2,000 yearlings is a much better option than releasing 20,000 fingerlings. The process of modelling also made the decision process clear and transparent. Modelling has resulted in each assumption being stated explicitly, which has re-structured the debate on the best age for releasing fish to one concerning specific question about the life-history of trout cod (i.e. what is the survivorship of fingerlings?). This has had the further advantage of providing feedback into our understanding of the system and has directed what questions are priorities for further research or monitoring. The process has also meant that the goals had to be explicitly stated (eg. what is an acceptable level for risk of failure), consequently the results from future monitoring activities will be able to be assessed against our expectations.

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Methods for discriminating between hatchery-reared and wild fish

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A continuing problem for fisheries agencies is the difficulty of discriminating stocked fish from wild fish in environmental monitoring and assessment programs. Fish are now commonly used as biological indicators in river health assessment programs, with the presence, diversity and/or abundance of native fish used as an indicator of the health of native fish populations. Fisheries agencies and recreational fishing clubs also stock large numbers of hatchery-produced fish either to provide improved recreational fishing or establish viable fish populations. Consequently it is vital to know whether captured native fish individuals are wild or from hatchery stocking programs. As part of a project funded by the Murray-Darling Basin Commission under its Native Fish Strategy, a review of existing and proposed methodologies for the discrimination of hatchery and wild fish was conducted (Crook *et al.* 2005). The aim of the review was to assess the potential of the various methods for application in hatcheries in the Murray-Darling Basin (MDB). The following paper provides a brief synopsis of the main findings of the review.

About 25 hatcheries in the MDB produce native fish for release into the wild and in excess of 4 million hatchery-reared native fish are released annually. Golden perch *Macquaria ambigua* comprise ~65-70% of these fish and Murray cod *Maccullochella peelii peelii* and silver perch *Bidyanus bidyanus* make up most of the remainder. The majority of native fish produced by hatcheries are released as fingerlings about 30-50 mm total length, and it is common for hatcheries to produce batches of 100,000 or more individual fish. The large scale of many commercial and government hatchery operations and the small size of the fingerlings place specific limitations on methodologies for discriminating hatchery-reared and wild fish. As a consequence, the review placed particular emphasis on the cost-effectiveness and logistic feasibility of methods for application in current commercial and government hatchery operations. Factors that were considered in this context included:

- Logistics and costs of the marking procedure;
- Effects of the marking procedure on fish;
- Mark retention and longevity;
- Reliability of mark detection;
- Logistics and costs of mark detection;
- Effects of the detection procedure on fish;
- Discrimination capacity of the mark (individual, batch, hatchery versus wild); and
- Demonstrated utility.

There are many methodologies available for identifying groups of fish [see reviews by Parker *et al.* (1990) and Nielsen (1992)]. The utility of a particular technique depends upon the aims of the research or stocking program and the logistical limitations that apply. The ethical treatment of fish is also becoming an increasingly important issue and any methods used in hatcheries will need to meet ethical and legislative standards. Based on the assessment of factors listed above, it was concluded that only a few methods have realistic potential for routine application in MDB hatcheries at present. Many of the methods reviewed (eg. coded wire tags, fin clipping, visible elastomer tags) require handling of individual fish and, therefore, are unsuitable for marking large numbers of hatchery-reared fingerlings. Such limitations are likely to prevent routine use of these methods, particularly in private hatcheries where the production of fish is targeted towards delivering profits to the hatchery owner.

The methods that hold the most promise for implementation in MDB hatcheries are those that do not involve handling of individual fish and do not require significant alterations to normal hatchery procedures. Whilst several intrinsic marks[6] satisfy this requirement, they may not provide the discriminatory power necessary to precisely determine whether an individual fish is hatchery-reared or wild-bred. However, Willett (1996) found that analysis of circuli patterns on scales of silver perch had classification rates of >90% when discriminating between two batches of hatchery fish released into dams. Whether such levels of accuracy can be achieved in open systems such as rivers of the MDB is unclear. The study of Butcher *et al.* (2003) on two species in an open estuarine system, also using scale circuli, has produced quite promising results, however, with classification accuracy between wild and stocked fish of 75-89%.

The analysis of intrinsic chemical marks in otoliths and scales also appears to be one of the more promising of the available methodologies. This method does not require any handling of fish or changes to normal hatchery practices. The results of a pilot study on golden perch (Crook *et al.* 2003) suggest that high levels of discrimination between the otolith chemical signatures of hatchery and wild fish may be possible due to inherent differences in the rearing conditions between hatcheries and the wild (eg differences in water chemistry due to the use of fertilisers in hatchery rearing ponds). On the downside, the use of otolith chemical signatures requires sacrifice of the fish, although analysis of scales rather than otoliths could potentially overcome this problem. Further research is currently being undertaken to determine the utility of this methodology.

The external chemical marking of hatchery fish with calcein or other fluorescent compounds is another methodology that has considerable potential for routine application in MDB hatcheries. Chemical marking does not require handling of individual fish, although the marking procedure does require adjustments to hatchery procedures. With the development of osmotic induction techniques, however, it is possible to chemically mark tens of thousands of fish within 10 minutes. The fact that fluorescent compounds such as calcein can be detected externally using portable detectors means that identification can be conducted under field conditions and does not require sacrifice of the fish. An additional benefit of the technique is that the compounds

[6] Marks that are either naturally present in fish or can be induced in fish without direct application.

also produce a permanent mark on the otolith that can also be used to identify fish. In combination with other chemical marking techniques, such as enriched isotope marking, there are a variety of possibilities for producing hatchery specific chemical markers. Whilst the potential benefits of chemical marking are clear, further research is required to develop and test the utility of these techniques. A trial of the osmotic induction technique to mass mark golden perch fingerlings with calcein and alizarin red S is being conducted by the authors of this paper.

Thermal marking of otoliths and scales is a chemical-free and relatively inexpensive method that certainly warrants further investigation. Discrimination accuracy rates of over 95% have been reported in some instances, and large numbers of fish can be marked using relatively straightforward procedures. Previous work by Willett (1994) suggests that thermal marking of the scales of silver perch might be feasible for large-scale implementation. Since fish holding tanks, recirculation systems and heating systems are widely used and are common features of commercial and government hatcheries in the MDB, opportunities may exist to mark fish without drastic changes to normal hatchery procedures.

Finally, parentage determination using microsatellite analysis has great potential as a means of discriminating hatchery and wild fish. Genetic techniques are now well established and their utility continues to develop as technological advances make analysis both easier to undertake and more powerful. Implementation of genetic identification programs does not require handling of individual fingerlings, although it does require biopsy sampling and accurate record keeping for all broodfish used to produce fingerlings. Sampling from wild populations for genetic analysis does not require sacrifice of the fish. A detailed microsatellite library has recently been developed for Murray cod as part of a project being conducted by PIRVic and limited work has also been conducted to develop microsatellites for other MDB species. This work provides a good platform for the future development of genetic techniques for implementation in hatcheries across the MDB. Whilst some methodological issues would need to be overcome for routine implementation, issues of commitment and compliance currently present the main obstacles to large-scale implementation of genetic identification programs.

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Habitat Restoration – Beyond the Easy Fix for Fish Stocks?

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Abstract

The enthusiasm with which some industry and community stakeholders embrace the stock enhancement potential of fish stocking is often underpinned by perceptions of such strategies as a panacea or 'easy fix' for pressured fish stocks. While the legitimacy of stocking as a stock enhancement tool cannot be denied, there is a danger inherent in misperceptions of its importance or primacy as a stock enhancement tool. Critical habitat management needs underpinning reduced stock carrying capacity or recruitment bottlenecks and the stock enhancement potential of habitat rehabilitation or other fishery management needs may be overlooked. This paper presents a precautionary based review of issues and R&D needs associated with the risks and merits of stocking in comparison to habitat rehabilitation options. Examples of cost effective fish habitat rehabilitation addressing fish passage, flows, thermal pollution, aquatic weeds, instream habitat, riparian vegetation and broader catchment management needs are presented. One of the key constraints on our current ability to identify the need for or to compare the merits of stocking versus habitat rehabilitation stock enhancement approaches is a lack of quantification of the fish stock outcomes of past investments in each strategy. This is nominated to be a key area for further research and development that could lead the way toward more strategic and sometimes integrated use of both stocking and habitat rehabilitation stock enhancement approaches. Improved extension of future and past R & D outcomes concerning the risks and merits of fish stocking and habitat rehabilitation is also identified as a high priority for achieving enhanced fish stock outcomes and ecologically sustainable fisheries management in Australia.

Why not stock?

Given the success of fish stocking for establishing and enhancing recreational fisheries in both Australia and overseas, stocking proponents will often question why socking should not be the first option considered for restoring depleted wild fish stocks. The answers to this question are associated with the risks and cost of stocking and the potential of other stock enhancement strategies particularly habitat restoration to deliver more strategic investment toward more longer term and ecologically sustainable fishery outcomes.

For those who wish to become informed there is ample information concerning the potential downfalls of poorly managed fish stocking although it would be fair to say that the majority of published literature still concerns overseas fisheries despite the increasing emergence of Australian examples. The four main risks associated with fish stocking concern the potential for:

1. Translocation and establishment of non-local species (includes native species above natural fish passage barriers, results in predatory and competitive interaction impacts normally attributed to establishment of feral species);
2. Gene pool impacts (swamping of native diversity, lower vigor populations, mal-adaptation to local conditions);
3. Trophic impacts (overloading of top order predators, predatory impacts on prey or sensitive / endangered species);
4. Disease risks (introduction of hatchery origin diseases to wild populations).

While most Australian jurisdictions have established protocols for dealing with these risks none are fail safe particularly where the capacity or willingness of agencies to enforce appropriate practices on industry and community is limited and examples of management transgressions continue to emerge.

The other issue that needs to be considered in assessing the merits of stocking are cost effectiveness in comparison to other stock enhancement strategies including traditional fishery management tools that provide stock output controls (size slots, bag limits, seasonal or locational closures etc) or habitat rehabilitation that aims to address stock recruitment or carrying capacity constraints of degraded ecosystems.

The costs associated with stocking programs are not inconsequential particularly if the full costs associated with research and development of culture techniques, establishment of hatchery infrastructure and operational costs associated with the production of fingerlings are included. Where such programs are maintained for years or decades the magnitude of the associated capital investment is of an order of magnitude that could potentially translate into viable alternative stock enhancement programs that don't have the concomitant risks associated with stocking. The diversion that the apparently 'easy fix' option provided by stocking provides to fishery management agencies in comparison to addressing more formidable management needs i.e. changes in fishery exploitation levels or habitat restoration is perhaps one of the more significant hazards associated with the pursuit of stocking based stock enhancement strategies.

When is stocking appropriate?

Before developing the case for habitat restoration as a stock enhancement strategy it is important to acknowledge that stocking is an important tool for stock enhancement and that under some situations may be the only viable tool available.

As a stock enhancement strategy the stocking of water bodies with fish fingerlings or fry essentially attempts to deliver increased levels of recruitment to fish stocks. In terms of effectiveness stocking is therefore likely to be most effective where 'recruitment bottlenecks' exist i.e. where natural recruitment is non existent or cannot sustain adult stocks. Recruitment bottlenecks can occur where:

1. There has been a loss or severe degradation of critical breeding or nursery habitat;
2. Where fish passage barriers impacts on the viability of breeding or recruitment migrations; or where
3. Unviable adult breeding populations prevent successful breeding or produce unsustainable recruitment levels.

In the case of the latter, the causes of non viable adult breeding populations need to be further examined to identify causal factors which may include:

1. Fishing pressure;
2. Limited recruitment; or
3. Habitat impacts on ecosystem carrying capacity.

In all of the cases cited above, habitat impacts underpin all sources of recruitment bottleneck other than the impact of fishing pressure on adult populations. This highlights the potential of habitat rehabilitation as a viable stock enhancement strategy and the continued role for other fishery management tools in the case of the over exploitation of fish stocks. The qualification on the potential of habitat rehabilitation is the fact that some habitat impacts are irreversible under contemporary technical or economic constraints. **The presence of an insurmountable recruitment bottleneck defines the most readily justifiable case for the use of stocking as a stock enhancement tool for natural fish stocks.**

In the case of artificial water bodies such as impoundments the case for stocking as a fish stock enhancement tool is more readily made. Impoundments usually owe their existence to insurmountable fish passage barriers and highly modified hydrological conditions. This negates the possibility of natural recruitment maintaining fish stocks in the case of recreationally popular catadromous fish species (i.e. Australian Bass, Barramundi) or other natives (i.e. Murray Cod, Golden Perch, Silver Perch) that depend on natural flows and hydrological cues for breeding success. However, some smaller impoundments or weir systems that retain natural hydrological cues e.g. Lake Mulwala on the lower Murray River still experience high levels of natural recruitment for recreationally popular species i.e. Murray Cod which negate the need for stocking based stock enhancement.

In noting the justifiable case for stocking based fisheries in the artificial water bodies formed by impoundments it is also important to recognise that there is nothing 'artificial' about the river systems that drain to or from impoundments and that the risks associated with the stocking of 'natural' non-impounded systems will generally apply even though such risks are less readily recognised by community and agencies alike.

When is habitat restoration more appropriate?

Considering the risks and costs associated with fish stocking and definitions of when its use as a stock enhancement tool is most appropriate (above), provides a robust foundation for examining the case for habitat rehabilitation as a stock enhancement strategy. A strong case for habitat rehabilitation as the most cost effective approach to fish stock enhancement can usually be made where one or more of the following conditions apply:

1. When the rate of return (in terms of fish stock recruitment) over the longer term (~10 yrs) associated with addressing habitat restoration needs presents better $ investment than continued stocking;
2. When habitat quality, availability and/or access are the key limiting factors determining stock carrying capacity and/or recruitment success;
3. When risks posed by stocking are too great; and
4. When the collateral ecosystem benefits of habitat restoration / catchment management are significant.

Examples of cost effective habitat restoration?

Although conditions underpinning the case for habitat rehabilitation as a cost effective approach to fish stock enhancement can be identified (above), in practice its merits in comparison to other stock enhancement approaches are generally not quantitatively assessed. This is due to a often limited assessment or capacity for assessment, of the causal factors underpinning the need for stock enhancement and poor measurement or monitoring of the costs and stock outcomes associated with either habitat restoration or stocking based stock enhancement strategies.

The following examples of 'cost-effective' habitat rehabilitation are nominated on the basis of one or more of the conditions underpinning cost effective habitat rehabilitation cited above being met. They include:

1. Fish passage re-instatement;
2. Flow (including tidal) re-instatement;
3. Thermal regime re-instatement;
4. Aquatic weed management;
5. Instream habitat restoration (i.e. macrophytes, snags, channel morphology);
6. Riparian zone and wetland rehabilitation; and
7. Catchment management (especially hydrology, sediment and nutrient loads).

Fish passage re-instatement

		
Low gradient rock ramp fishways (Ragland Ck central Queensland) are a relatively inexpensive means of reinstating fish passage pass low structures. Cost effective investment in fish passage reinstatement needs consideration of the stock enhancement merits of addressing numerous small passage barriers versus single large barriers.	Vertical slot fishways have been extensively developed in Australia to meet the needs of Australian species. Although relatively costly they facilitate fish passage pass large main river stem structures up to 6m in height (Photo MDBC).	The vast majority of river systems within Australia's intensive land use zone have weirs or dams presenting impassable fish passage barriers for catadromous and migratory species which constitute the majority of recreationally targeted species.

Where feasible, reinstatement of fish passage past structural barriers represents perhaps one of the most cost effective examples of habitat restoration based stock enhancement. This is because in the best case examples works need only to provide access to existing suitable habitat and where recruitment process remain viable stock size will be subsequently enhanced by the carrying capacity of the newly accessible habitat.

Structural means of facilitating fish passage have been well researched and developed in Australia though some outstanding R & D needs are associated with large structures, access to off river (floodplain water bodies) and non-structure passage barriers presented by weed infestations and poor water quality. What has not been as well pursued is the subsequent monitoring of fish movement and quantification of stock outcomes associated with fish passage reinstatement. This is required to answer questions concerning the strategic and stock enhancement merits of addressing one large versus numerous small passage barriers within a region or river system and to quantify the rate of return of fish passage re-instatement versus other stock enhancement strategies such as stocking in the case of large fish passage barrier structures.

Given the large number of Australian freshwater fish species beyond those targeted by fishers that require free movement within river systems, the collateral ecosystem benefits of reinstating fish passage are also generally large and can include re-instating access for ecological cornerstone species (e.g. mullet key detritivore and prey species) that have been excluded from ecosystems due to passage barriers. Conversely fish passage re-instatement can have negative consequences in the case of feral species (redfin, carp, tilapia) which have their range limited due to existing fish passage barriers.

The benefits associated with re-instating fish passage are dependent upon the area and suitability of accessed habitat. In the case where accessed habitat is degraded and unsuitable for recruiting fish or has significant constraints on adult carrying capacity the benefits of reinstating fish passage may be limited.

	
Fish passage barriers caused by the physical and water quality impacts of aquatic weed infestations are an issue that requires further R & D.	Insurmountable fish passage barriers presented by large impoundments (Burdekin Falls Dam Qld) provide a ready justification for stocking based stock enhancement subject to appropriate risk assessment.

Flow Regime Re-instatement

	
Sustained inundation of Barmah-Millewa floodplain forest generated by a small flood being supplemented by a released environmental flow in 2005. Monitoring of the environmental response of this ecosystem indicated a significant recruitment event for several key freshwater fish species targeted by inland fisheries. Further quantification of fish stock outcomes associated with dedicated environmental flow re-instatement is required to support the case for such releases in an increasingly competitive water market (Photo MDBC).	Dead barramundi in a dried lagoon basin (Woolwash Lagoon central Qld). Previously considered a near perennial lagoon with a 1 in a 100 yr drying frequency this system has dried or near dried several times in the last decade highlighting the possible emergence of climate change associated wetland impacts. Such threats underline a heightened importance for securing flow re-instatement based habitat restoration options in future water resource management planning.

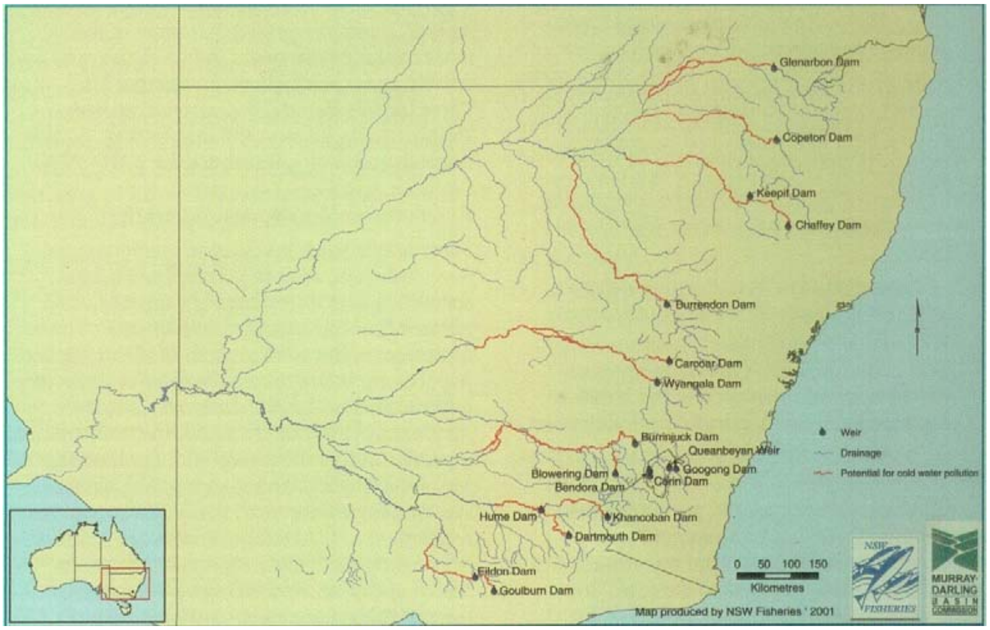
In a continent with the seasonality of rainfall that Australia experiences stream flow events are often a critical cue for the stimulation of fish breeding events and recruitment movements. Hence flow alteration associated with river regulation is one of the key impacts affecting natural recruitment success of native freshwater and coastal fish species. Other forms of flow based impact on fish recruitment and ecosystem carrying capacity include alienation of flows to floodplain and supra tidal habitats from river and estuarine systems due to flow regulation and structures such as levees, bund walls and tide gates. In a naturally highly seasonal environment flow based impacts can also be associated with the loss of seasonality where regulated flows or tailwater generate perennial instead of seasonal flows with concomitant impacts to the primary productivity of floodplain wetlands and increased weed infestation and water quality risks.

In some regulated river systems such as those of the MDB the entire adult population of some key fishery species may be affected in terms of reduced breeding and recruitment success so flow regime rectification if successful can potentially deliver significant enhanced stock outcomes. The challenge in addressing such flow based impacts is cost. The environment is now competing for access to costly, over allocated and subject to climate change, diminishing water resources. For flow regime rectification to be proven as a cost effective fish stock enhancement strategy the science has to be water tight. Work within the MDB is leading the quantification of flow regime based fish stock outcomes though is still in its infancy. Fish stocks are competing against hard export currency in the water markets of regulated river systems and there is still much R & D that needs to be progressed in improving the fishery case for flow regime reinstatement.

In the case of floodplain and supra-tidal habitats alienated from natural flows, fish habitat benefits and recruitment outcomes must also compete directly with agricultural industry uses of land. While there has been a significant amount of work done on reinstating tidal flows into coastal floodplains particularly by NSW DPI in central and northern NSW, quantification of fish stock outcomes has still been relatively poor. Again this needs to be a key focus for R & D if the economic benefits of fish stock outcomes are going to compete successfully with other industry uses of these key habitat areas.

One of the key merits of flow regime reinstatement that does contribute toward its potential cost effectiveness is the significant collateral ecosystem benefits. However, although such benefits are widely recognised they remain poorly quantified and these need to be an ongoing and complimentary R & D focus to fish stock outcomes to justify the level of economic and political commitment that is required to reinstate beneficial flows in Australia's highly regulated river systems.

Thermal regime re-instatement



River reaches of the Murray Darling Basin with probable thermal pollution impacts (NSWF & MDBC).

Thermal pollution is similar to flow regime based impacts in that it impacts habitat suitability and breeding cues for native fish in regulated river systems downstream of major impoundments. Significant lengths of river reach within the MDB (figure above) and other regulated river systems are affected by the cold water released from the lower thermal strata of large water storages. Mitigating thermal pollution impacts is a current research focus of the MDBC native fish management strategy but to date no known thermally polluted sites have been rectified. One area that has not yet been specifically researched is the likely response of native fish stocks in terms of stock carrying capacity and recruitment levels resulting from thermal pollution mitigation. This is a key R & D need.

	
Popular tailrace fisheries for introduced salmonids are a source of ardent opponents to thermal pollution mitigation. Better quantification of the native fish stock enhancement merits of thermal pollution mitigation may help change fisher community support for such initiatives (Photo MDBC).	Reduced habitat suitability for exotic predators and other feral fish species is an as yet poorly quantified collateral ecosystem benefit of addressing thermal pollution impacts.

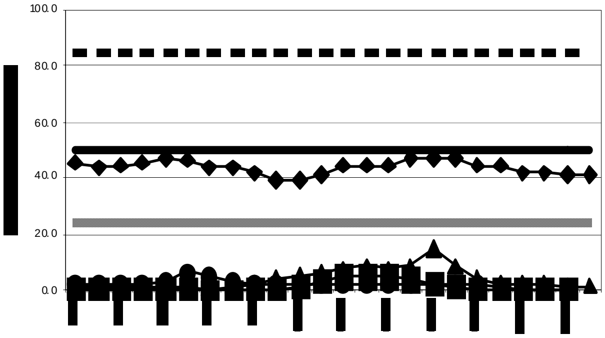
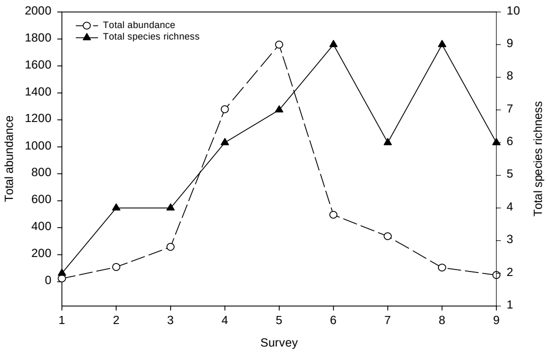
Mitigating thermal pollution requires structural works on the outlets of impoundments that have a relatively large price tag of the order of several million dollars for the more innovative and 'cheaper' options. However, such 'big ticket items' are also likely to have a large positive impact on native fish stocks if the result is that existing native fish populations within hundreds of kilometers of thermally affected river reach become effective breeding populations producing recruits to the broader MDB system. Better quantification of these stock enhancement merits is crucial if the opponents and cost prohibitions to thermal pollution mitigation are to be overcome. The forgone fish stock production costs associated with the existing thermal pollution regime is certainly significant.

Again the balancing issue in favour of rectifying thermal pollution impacts is likely to be the large although as yet poorly quantified collateral ecosystem benefits another priority area for research. Such collateral benefits will extend to realising the full potential of other fish habitat initiatives (i.e. instream snagging, fish passage) that are currently constrained by the overarching habitat limitations set by thermal regimes imposed by upstream impoundments.

Aquatic weed management

		
Deepwater lagoon (Burdekin Delta north Queensland) completely covered in floating mat of aquatic weeds dominated by water hyacinth. Water quality under such weed mats is lethal to fish populations.	Mechanical removal of floating weed mat utilising weed harvester and bank based excavator rake.	Lagoon post weed harvest. Water quality conditions improved to above lethal conditions within days and significant fish community re-establishment occurred within six month.

Weeds are a ubiquitous NRM issue in Australia including for fish habitat management. The problem for fish stocks is most prevalent in developed tropical Australian floodplains where thousands of hectares of highly productive floodplain wetland are severely impacted by aquatic weeds. A range of habitat impacts are caused by weeds including loss of riparian vegetation and native macrophytes but the most significant concern degradation of water quality.

	
Dissolved oxygen conditions rapidly recovered from below lethal conditions (lower grey line) to sub lethal conditions (middle bold line) following aquatic weed harvesting operations in the lower Burdekin River Delta (from Perna 2004).	Native fish species diversity increased and exotic *Gambusia* abundance decreased following weed harvesting operations in the lower Burdekin River Delta (from Perna 2004).

Where aquatic weeds completely occlude the water surface water quality conditions particularly dissolved oxygen becomes lethal for fish populations. This not only impacts the insitu floodplain fish communities but can cause fish passage barriers affecting access to all suitable upstream habitats for migratory species. Species affected include the recreationally and commercially important barramundi. Floodplain habitats are the natural nursery and prey production areas for barramundi and many other species so impacts extend to recruitment levels and broader ecosystem carrying capacity with concomitant impacts on regional fisheries.

Addressing aquatic weed infestations is a costly exercise, though cost effectiveness can be improved significantly by investment in ongoing weed control maintenance programs as opposed to period costly exercises targeting 'neglect' infestations. However, 'neglect' weed infestations are still prevalent throughout tropical and sub-tropical Australia and more cost-effective and ecologically sustainable means of tackling such infestations and the benefits of doing so remain a high priority for R & D. Again better quantification of fish stock responses to weed management initiatives, existing foregone fishery production costs and likely collateral ecosystem benefits at a regional scale would be likely to provide a potent argument for further investment in such fish habitat restoration initiatives.

Instream habitat restoration

	
Resnagging of river channels is the best developed instream habitat restoration technique in Australia and has been found to have a direct impact on reach fish stock carrying capacity, though warrants further monitoring and assessment (Photo MDBC).	Erosion and sedimentation of stream channels (Richmond River NSW) is probably Australia's most widespread fish habitat issue and the most significant in terms of fish stock impacts. It is also the most poorly served in terms of R & D.

If fully quantified instream habitat impacts would most likely be the most widespread fish habitat issue in Australia and the most significant in terms of the total impact on fish stocks. Instream habitat issues are also probably the most poorly served in terms of existing habitat restoration capacity.

Instream fish habitat includes physical and biological features such as snags, bed condition, channel form, aquatic plants and water quality though the latter is more often considered a management focus for catchment based initiatives (see below). Instream habitat condition is tightly coupled to catchment land use and condition and the extensive clearing of Australia's native vegetation for agricultural purposes within the intensive land use zone and the widespread use of the remainder of the continent for pastoral production are responsible for the widespread nature of instream fish habitat impacts.

To date the most successfully developed instream habitat restoration initiatives in Australia involve resnagging of river channels. These activities have been pursued in many Australian jurisdictions but monitoring of fish stock responses has generally been poor. An exception includes recent work undertaken by the Arthur Rylah Institute concerning the endangered trout cod. This species is known to be highly dependent on the physical habitat provided by snags and monitoring following resnagging activities has found river reach carrying capacity for trout cod to have been increased. Numerous other Australian fish species are also recognised to have equivalent dependencies on snag habitat and this research points toward the potential fish stock benefits of further investment is such habitat restoration.

The key priority area for further R & D in instream habitat restoration concerns river channel geomorphology and bed form restoration. Sedimentation of river channels and deepwater habitats is widespread across the highly erosion prone Australian continent. Understanding the instream habitat interactions with catchment scale geomorphic process drivers is the key to the strategic pursuit and success of instream habitat restoration. Further R & D would better serve the use of both hard i.e. structural and soft i.e. revegetation approaches to reinstating instream habitats. Aquatic macrophyte re-establishment is also a closely related issue in that their occurrence is usually closely related to channel stability and sediment inputs.

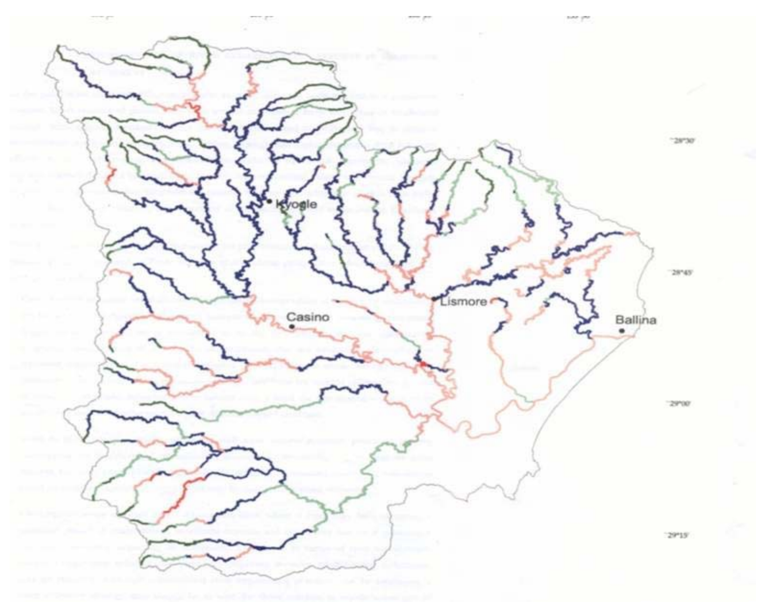
The distribution and availability of deepwater habitats and particular bed forms is known to be critical to the abundance and recruitment capacity on many Australian fish species and application of research findings could deliver significant fish stock enhancement and broader ecosystem benefits.

Riparian zone rehabilitation

Riparian zone rehabilitation primarily involving revegetation is perhaps the most widely practiced form of community based fish habitat rehabilitation in Australia. It is often pursued for many other purposes besides fish habitat restoration i.e. erosion control, water quality improvement, wildlife corridors and fish habitat is usually only one of the collateral ecosystem benefits provided, the full suite of which is usually sufficient justification for pursuing such activities. However, riparian zone rehabilitation can be a costly and labor intensive activity and targeted restoration is required.

In terms of specifically providing fish habitat and stock enhancement outcomes, response times will depend on the strategicness of actions. This is a key area for R & D to guide the large resources that are currently invested into community based riparian zone rehabilitation to better meet specific fish habitat objectives. As discussed under instream habitat needs above, understanding interactions with catchment scale geomorphic process drivers is the key to the strategic pursuit and success habitat restoration associated with river channels including the riparian zone. Riparian revegetation that is cognizant of upstream catchment conditions and pursued in areas with high geomorphic recovery potential will deliver fish habitat and stock outcomes more rapidly than those that have low recovery potential.

The other key R & D area for riparian zone rehabilitation concerns the development of methods that move away from costly and labor intensive approaches to tree planting toward the managed succession of riparian vegetation communities using broad acre tools such as direct seeding, fire regime and grazing management to deliver catchment scale revegetation outcomes.



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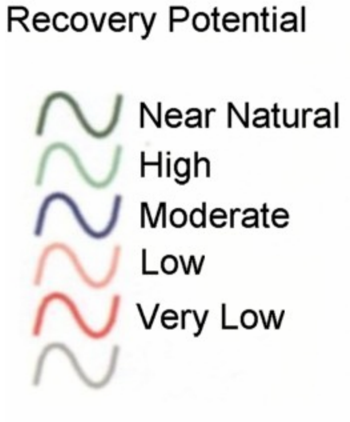
<tr><td colspan="3">
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<tr><td colspan="3">Recovery potential of Richmond River basin reaches based on an assessment of geomorphic processes and drivers (from NSW DLWC 1999)</td></tr>
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<tr><td>Example of low recovery potential river reach affected by upstream sediment slug.</td><td>Example of a moderate recovery potential river reach within a bedrock controlled valley where revegetation will deliver high quality fish habitat and associated stock improvements within a shorter period of time.</td><td>The endangered Eastern Cod, a focus for strategically targeted riparian zone rehabilitation within the Richmond River basin.</td></tr>
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Wetland rehabilitation

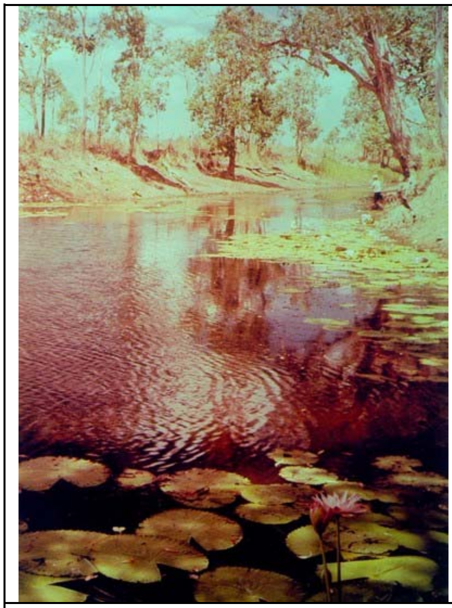
	
Constructed wetland excavated in low lying area of sugar cane farm providing floodplain habitat rehabilitation on the Tully River north Qld. A greater diversity of freshwater fish species is now recorded from this site than remnant 'natural' lagoons.	Constructed wetland Tully River floodplain. This site now hosts a self recruited barramundi population and resident estuarine crocodiles. Broader collateral benefits also accrue in terms of water quality and flood mitigation functions and habitat provision for waterbirds and terrestrial fauna. Very limited R & D has occurred in relation to the optimal design of constructed wetlands or their fish stock benefits.

By and large wetland rehabilitation involves most of the other discussed fish habitat restoration initiatives with the main distinction being a focus on off river water bodies as opposed to main river and steam channel habitats. The imperative for addressing wetland rehabilitation as part of fish stock enhancement initiatives is important. Wetlands are recognised to be critical breeding and/or nursery areas for many fish species and a major driver of river basin primary productivity and consequently fish stock carrying capacity. In the intensive land use zone of Australia most floodplains have now lost greater than 50% of their wetland areas.

As for most fish habitat restoration methods, quantifying the fish stock responses to targeted wetland rehabilitation initiatives is a priority for R & D required to assess the merits of wetland management programs in comparison to other fish stock enhancement strategies. Another key R & D area concerns constructed wetlands. There has been strong community interest, particularly in tropical Australia in the construction of artificial wetlands on agricultural floodplains that have lost most of their natural wetlands. Such 'artificial' wetlands are often treated as poor cousins to remnant natural ones by NRM management agencies despite the fact that some preliminary assessment has found that constructed wetlands can often have better water quality characteristics and support higher fish diversity. Fish stock benefits are also apparent in that areas that were previously terrestrial farmland now support self recruiting populations of key prey and fishery species such as barramundi.

Very limited R & D has been applied in the design and development of these constructed wetland systems and the prospects that applied research could improve their fish habitat and other catchment functional values for water quality and flood mitigation are high.

Catchment management

	
The author fishing for barramundi at the Round Waterhole Sheepstation Ck lower Burdekin River Delta 1970.	Same site in 1999. The only site based management change has been the removal of cattle grazing. Other impacts are due to changes in management of catchment scale processes.

In its full definition integrated catchment management (ICM) can span the full suite of all fish habitat restoration issues discussed in this paper. As a distinctive focus though, catchment management as discussed here is concerned with the management of sites and processes that occur or extend beyond the actual fish habitat areas. While management of land use practices may seem far removed from the task of fish stock enhancement the reality is that the ecosystem processes that underpin good fish habitat and successful habitat (and stock) restoration connect to the catchment and its users management practices. As discussed above, strategic habitat restoration of any type often requires full consideration of upstream process drivers which may often determine the rate of response of habitat works conducted at a site scale.

As a management concept ICM has been with the Australian NRM community for at least two decades and is often applied as a framework when developing NRM strategies. However, the full application of ICM as a framework for delivering improved fish habitat outcomes has scope for development. Some of the key R & D needs have already been touched on above and include improved understanding of catchment sediment and nutrient loads particularly their sources, sinks, fish habitat impacts and effective mitigation strategies. Potentially as important for fish habitat management is the need for an improved understanding of catchment hydrology particularly groundwater interactions with site scale water quality and other habitat values and the influence of flows characteristics on fish movement, recruitment and floodplain habitat access.

Key R &D / extension issues

In identifying the key R & D and extension issues associated with habitat restoration as a stock enhancement strategy and its merits in relation to the perceived 'easy fix' option of fish stocking, the four general question around which this paper has been developed provide as useful a framework as any:

1. Why not stock?
2. When is stocking appropriate?

3 When is habitat restoration more appropriate?
4 What are examples of cost effective habitat restoration?

R&D - Why not stock?

This question addresses the risks that are known to be associated with stocking which to date are largely drawn from overseas examples. This is a result of possibly better stocking management practices in Australia (culture and stocking techniques for most of Australia's stocked fisheries have been developed relatively recently and we have sought to avoid the mistakes made elsewhere) and due to limited research elucidating the full costs of the mistakes that Australia has made with past and even current stocking programs. As an example, exotic salmonid stocking has been occurring in Australia for over a hundred years and quantification of competitive interactions with native fish and other impacts on aquatic ecosystems associated with this stocked fishery are rudimentary to say the least and the source of ongoing debates that could be resolved through targeted research. Key associated R & D issues include:

1 Ecological impacts of translocated and stocked exotic species?
2 Ecological vigor of stocked populations?
3 Carrying capacity of open systems?
4 Impacts of diseases carried by stocked populations (e.g. EHN)
5 Consequences of stocked impoundment population overflows to open systems.

R&D - When is stocking appropriate?

This question acknowledges that under some conditions, stocking is the most appropriate stock enhancement strategy but also recognises that many stocking programs have been implements and pursued without adequate assessment of the need, merits or outcomes of such programs. Key associated R & D issues include:

1 What constitutes a rigorous decision making processes?
2 Assessing the stock outcomes (c/f inputs) of stocking?
3 What is the nature and casual factors underpinning the fish stock recruitment bottleneck that will be addressed by stocking?
4 Undertaking cost benefits analysis of stocking versus other stock recovery strategies incl. habitat restoration and other fishery management tools.
5 What are the potential ecosystem benefits of stocking? i.e. does reinstating top order predators through stocking provide a useful feral fish population control measure?

R&D - When is habitat restoration more appropriate?

This question is based on the recognised potential of fish habitat restoration to be a more cost effective stock enhancement strategy than stocking but acknowledges that the case can only be made if there is research that provides better quantification of the costs and fish stock outcomes associated with habitat restoration in comparison to stocking. Key associated R & D issues include:

1 What are the cost / benefit ratio comparisons between habitat restoration and stocking approaches to stock recovery?
2 When is habitat the key limiting factor on stock size?
3 When are risks posed by stocking too great?
4 What are the collateral ecosystem benefits of habitat restoration / catchment management approaches to stock recovery?

R&D and <u>extension</u> priorities – Examples of cost effective habitat restoration?

This question follows on from the preceding but more specifically addresses the need to demonstrate good examples of cost effective habitat restoration based fish stock enhancement and also recognises that further R & D is required to develop the strategic pursuit and cost effectiveness of fish habitat restoration approaches. Key associated R & D issues include:

1 What are the most effective methods / approaches for re-instating fish habitat? (R & D needs for individual fish habitat restoration approaches identified in preceding discussion)
2 What is the return (number of recruits to fish stocks for $ invested) of difference habitat restoration options?
3 How to monitoring and quantify fish stock outcomes.
4 <u>Extension</u> – convincing the stocking 'clients' that habitat restoration is more often the prerequisite as well as a viable alternative to stocking based stock enhancement programs.

Conclusions

Fish stocking is not a silver bullet when it comes to addressing the problem of stressed fish stocks. Fish stocking has a legitimate role in stock enhancement but also a range of associated risks that are not necessarily perceived to be significant by the fishing industry or community in Australia due to a combination of good management to date, good fortune and possibly the limited research that has been pursued on the full costs of some of our less that ideal past stocking practices. Assessing all risks and alternative fish stock recovery options including habitat restoration needs to be a prerequisite to proceeding with fish stocking in Australia if we are to pursue the most cost effective stock enhancement strategies and deliver ecologically sustainable outcomes. Fish habitat restoration presents the opportunity for the permanent remediation of environmental carrying capacity and recruitment bottleneck constraints affecting fish stocks and is a more appropriate investment option that poorly conceived stocking programs which at their worst represent a perpetual diversionary band aid justified by input rather than output measures. While habitat restoration is a proven stock enhancement tool the stock enhancement benefits need to be better quantified and communicated to the fishing community to compete with stocking's 'easy fix' appeal. Ultimately there is a need for integrated approaches to stock recovery in which stocking will have legitimate role to play in conjunction with habitat rehabilitation initiatives.

Macquarie Perch an endangered species that requires an integrated mix of habitat restoration and culture and stocking technique development to serve its conservation.