

Towards responsible native fish stocking

identifying management concerns and
appropriate research methodologies



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Australian Government
Fisheries Research and
Development Corporation



Queensland Government
Department of Primary Industries and Fisheries

Towards responsible native fish stocking: identifying management concerns and appropriate research methodologies

D. J. Russell



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Department of
**Primary Industries
and Fisheries**



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NON-TECHNICAL SUMMARY

2007/057	Towards responsible native fish stocking: identifying management concerns and appropriate research methodologies
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Objectives:

1. Identify the major management concerns regarding the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks
2. Hold a workshop of experts to agree on appropriate methodologies to address the previously identified management issues

Non-Technical Summary:

Outcomes achieved:

A major outcome of this project has been the identification and prioritisation of the major management issues related to the ecological impacts of fish stocking and the elucidation of appropriate research methodologies that can be used to investigate these issues. This information is paramount to development of the relevant research projects that will lead to stocking activities aligned with world's best practice, a requisite for ecologically sustainable recreational freshwater fisheries.

In order to quantify the major management issues allied to the sustainability of freshwater fish stocking, stakeholders from around Australia were identified and sent a questionnaire to determine which particular issues they regarded as important. These stakeholders included fisheries managers or researchers from Federal, Territory and State jurisdictions although others, including representatives from environment and conservation agencies and peak recreational fishing and stocking groups were also invited to give their opinions. The survey was completed in late 2007 and the results analysed to give a prioritized list of key management issues relating to the impacts of native fish stocking activities. In the analysis, issues which received high priority rankings were flagged as potential topics for discussion at a future expert workshop. Identified high priority issues fell into the following core areas: marking techniques, genetics, population dynamics, introduction of pathogens and exotic biological material and ecological, biological and conservation issues.

The next planned outcome, determination of the most appropriate methodologies to address these core issues in research projects, was addressed through the outputs of an expert workshop held in early 2008. Participants at this workshop agreed on a range of methodologies for addressing priority sustainability issues and decided under what circumstances that these methodologies should be employed.

Outcomes achieved (continued)

It is anticipated that future projects will adopt many of these methodologies to address sustainability issues thereby assisting in the refinement of existing assessment and stocking protocols to ensure that they are aligned with world's best practice. This, in turn, will help to ensure that the substantial benefits of fish stocking are continued to be enjoyed by industry and the community.

Stocked fisheries now represent alternative recreational fisheries that simultaneously reduce fishing pressure on marine, coastal and freshwater fish stocks and deliver considerable social and economic benefits. The continued success of freshwater fish stocking in Australia is almost certainly contingent on the use of world's best practice and in demonstrating sustainability under the principles of Ecologically Sustainable Development. This project contributes to this goal by determining what the major environmental issues are and listing appropriate methodologies that can be used to address them in research projects.

During the first phase of the project, a questionnaire was developed for distribution to pertinent stakeholders to satisfy objective 1, 'identify the major management concerns regarding the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks'. Stakeholders were identified either by the steering committee members or through networking with local and interstate colleagues. Initial contact was made with most of these stakeholders by telephone and the purpose of the project was explained. Stakeholders were requested to consider filling out a small questionnaire designed to assist in identifying the pivotal management concerns regarding the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks. Most agreed and these individuals were emailed the questionnaire in late 2007. Of the 36 surveys that were sent out, 29 completed responses were received including 13 and 11 respectively from management and research organisations or personnel and 5 from industry or academia. Responses were received from stakeholders in all States and Territories except South Australia where there is currently minimal freshwater stocking activity. Issues that received high priority rankings were flagged as potential topics for discussion at the workshop. These issues fell into the broad areas of: (i) genetics; (ii) population dynamics; (iii) introduction of pathogens and exotic biological material; and (iv) ecological, biological and conservation issues. A need for stocked fish to be appropriately marked to allow them to be differentiated from conspecifics was also identified.

To meet the second objective, 'to hold a workshop of experts to agree on appropriate methodologies to address the previously identified management issues', a meeting of selected expert researchers and managers was held at the Joondoburri Conference Centre on Bribie Island in southeast Queensland on the 25-26 March 2008. Its broad structure was a series of introductory 'setting the scene' presentations followed by a number of workshop and plenary sessions to decide upon appropriate methodologies.

Using the broad areas of concern identified in the earlier survey of stakeholders as a starting point, delegates first identified specific management issues and then developed a series of prioritized research questions that addressed those management issues. Following this, delegates split into individual workgroups to elucidate the most appropriate methodologies for addressing each of the research issues and rapporteurs later reported their conclusions back to a plenary session.

The final workshop session involved a discussion on the way forward to ensure sustainability of native fish stocking and the continuation of the considerable social and economic benefits that it brings. Potential partnerships, funding sources and resource sharing arrangements were discussed and broad outlines for two priority projects that deserve funding consideration were scoped. These projects will involve work on barramundi stocking in north Queensland and Murray cod stocking in the Lachlan River (or another river) in New South Wales. Both of these projects would address critical management issues and use a multi-disciplinary approach that would incorporate the latest advances in molecular and chemical tagging techniques.

Keywords: Freshwater fish stocking, sustainability, environmental impacts, research methodologies, research techniques.

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BACKGROUND

In Australia, fish stocking activities have resulted in the creation of valuable new 'put and take' fisheries as well as the enhancement of existing wild fisheries (Rowland et al. 1983; Cadwallader & Kerby 1995; Rowland 1995; Holloway & Hamlyn 1998; Ingram et al. 2004). As a result, stocking activities have been of considerable economic benefit to both industry and the community, particularly in rural and regional areas. Recently, questions have been raised about the environmental sustainability of fish stocking activities that will need to be addressed if industry and the community are to continue to enjoy its substantial benefits (see Phillips 2003).

While fish stocking is not new in Australia (trout have been released for over a century), the ready availability of native species due to recent advances in fish breeding technologies has resulted in a huge increase in the magnitude of stocking activities since the late 1970s. In Queensland alone in 2001/02, 1.24 million fish of at least seven species were stocked into 25 impoundments (QDPI&F, pers. comm.). Annual production of Murray cod (*Maccullochella peelii peelii*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) by commercial hatcheries in New South Wales is 5 – 8 million fish (Rowland & Tully 2004). In Victoria between 730 and a million native fish are released annually with golden perch and Murray cod the dominant species (Department of Primary Industries 2005).

There have been many positive outcomes from fish stocking activities. For example, advances in breeding technology for barramundi (*Lates calcarifer*) in the 1980s resulted in the creation of successful "put and take" recreational fisheries for that species in many impoundments including Lake Tinaroo, north Queensland. The increase in visitor numbers that resulted from the creation of the Lake Tinaroo fishery has been of significant economic and social benefit to the local rural community. A cost-benefit analysis of the barramundi stocking program in Lake Tinaroo concluded that each dollar spent on fish stocking generated a potential \$31 of economic benefit to the Queensland economy (Rutledge et al. 1991). Hogan (pers. comm.) estimates the value of the Tinaroo fishery alone to be in excess of \$10 million. There are also many other examples of highly successful stockings that have established large recreational fisheries in impoundments and rivers in New South Wales (Rowland 1995) and other parts of Australia.

As well as impoundment stocking, a number of fish species have been released into many inland and coastal rivers around Australia. Some of these stockings are designed to enhance or promote the recovery of existing fisheries. Barramundi stocking in Queensland is one example where hatchery-produced fish have been released to enhance existing wild fisheries. A long-running study by Russell and colleagues in the Johnstone River in north Queensland examined the efficacy and cost-benefits of barramundi stock enhancement (Russell & Rimmer 1997, 1999, 2000; Russell et al. 2002). The data obtained from this study suggests that, after only moderate stocking activity, stocked fish can contribute between about 10 and 15% of the commercial and recreational catch respectively (Rimmer & Russell 1998). The stocking of Murray cod, golden perch and silver perch has re-established these species in some rivers on the Northern Tablelands of New South Wales (Rowland 1995). Additionally, over the last 20 years, stocking has been used as a tool for the conservation of endangered species including the eastern freshwater cod (*Maccullochella ikei*), trout cod (*M.*

macquariensis) and Mary River cod (*M. peelii mariensis*) (Rowland 1989; Lintermans et al. 2005). In Victoria trout cod are being stocked in small numbers to establish self-sustaining populations thus ensuring the survival of this species in the wild (Department of Primary Industries 2005).

While there are successful stocking programs for freshwater fish, there are some doubts about the degree of success of some programs, the effects of stocked fish on endemic fish populations and effects on other fish species and aquatic fauna and flora. The key question of whether or not stocking is enhancing fish stocks and fisheries or simply displacing natural stocks remains to be answered in some cases.

Potential problems relating to the stocking of native fishes were reviewed by Harris (2003) and discussed at a workshop “*Managing Fish Translocation and Stocking in the Murray-Darling Basin*” (Phillips 2003) held in Canberra in September 2002. Gillanders et al. 2006 reviewed the impacts of native fish stocking on fish within the Murray-Darling Basin and recommended that, given the continued increase in stocking of hatchery-reared fish and the potential for interactions with wild fish, it was essential to take a responsible approach and to monitor and experimentally evaluate stocking programs. In addition, an Environmental Impact Statement (EIS) on freshwater fish stocking in New South Wales (New South Wales Fisheries 2003) noted that a risk assessment of the existing fish stocking activity found that almost all aspects were likely to pose a risk to the environment, in particular to 1) threatened species, 2) unlisted species of conservation concern, 3) areas of conservation significance, 4) genetics and 5) fish health and disease. The EIS also highlighted the lack of specific research into the impacts of stocking on the receiving environment. In Victoria, a series of protocols for the translocation of fish into Victorian inland public waters has been developed (Department of Primary Industries 2005).

At a federal level, the Department of the Environment, Water, Heritage and the Arts is assessing a proposal that the introduction of live native or non-native fish into Australian watercourses that are outside their natural geographic distribution be considered as a key threatening process under the Environment Protection and Biodiversity Conservation Act 1999. This proposal has obvious implications for the future of fish stocking activities within Australian watercourses. There has also been speculation that introductions of novel fish predators, either accidental or intentional, would place at risk significant amphibian and crustacean assemblages, particularly in high mountain streams of the wet tropics (Burrows 2002). Burrows (2002) cites European and North American examples where there have been significant reductions, even localized extinctions, of frog populations as a result of the introduction of novel predators. Other studies suggest that novel predators can influence the distribution, size structure and behaviour of prey species even though the prey species have endemic predators. These issues highlight the need for quality scientific data on the environmental impacts of fish stocking activities.

The need for genetic management during stock enhancement programs is recognised worldwide. Genetic diversity is positively correlated with fitness (Reed & Frankham 2001). The fitness of enhanced populations can decline due to overall loss of genetic diversity and out-breeding depression. Genetic diversity may also progressively fall in an enhanced population when hatchery fingerlings outnumber and possibly out-compete endemic conspecifics. This can be a major problem because hatchery progeny

are usually derived from few parental broodstock and are therefore highly related. Subsequent generations of stocked fish will consequently have a higher incidence of inbreeding, leading to lower genetic diversity within the enhanced population. This can result in populations with less resilience to disease and a reduced ability to meet environmental challenges, such as climate change and environmental degradation by urbanization and agriculture. The lowering of genetic diversity within hatchery progeny is inevitable without the guaranteed contribution of a large number of brood-stock and appropriate breeding programs for the production of offspring. Out-breeding depression occurs when the offspring of hatchery and wild endemic fish have a reduced ability to survive compared to pure endemic strains. It occurs when (1) the genotype of hatchery/endemic hybrids is comparatively dysfunctional (breakup of co-adapted gene complexes), and (2) the hybrids inherit a gene (or genes) whose frequency has been artificially increased in the hatchery but which are detrimental to survival in the wild (introgression). Natural selection in the wild will remove individuals with low fitness, but the net effect is death and decline in the overall population size. These effects have been documented (Makaira Pty. Ltd. 1999) for some species. In one example from Spain, the genetic effects of stocking hatchery-reared brown trout into wild populations included (1) stocked fish failing to reproduce, (2) wild brown trout populations experiencing substantial introgression from hatchery stocks and (3) virtual extinction of local endemic populations (Garcia-Marin et al. 1991; Garcia-Marin et al. 1999). Inbreeding depression and loss of genetic variation from bottlenecks (very small effective population size, N_e) have also been documented in Atlantic salmon and several trout species (Waples and Drake 2004). Genetic monitoring of enhanced populations is therefore critical and can be achieved by (1) measuring genetic diversity and gene frequencies through time in stocked populations, and (2) genetic testing for hybrids. Informed management decisions on the levels and types of stocking activities can then be made on the basis of this information.

To address concerns associated with hatchery production and stocking of native fish, in particular genetics, disease and trash fish, the NSW Department of Primary Industries developed a Hatchery Quality Assurance Program for Murray cod, golden perch and silver perch (Rowland & Tully 2004). This program which involves accreditation and auditing of hatcheries is being implemented through a Hatchery Quality Assurance Scheme and will be in place in NSW by August 2008.

Most of the information on sustainability of fish stocking in Australia is in the form of desktop studies using information gleaned from overseas work which may or may not be relevant. It would be unwise to excessively extrapolate the outcomes of cold water and temperate fish stocking studies in the northern hemisphere to temperate, tropical and sub-tropical ecosystems in Australia where species assemblages and ecological characteristics differ significantly. If the benefits of fish stocking to the community and industry are to continue, then mechanisms need to be put in place to ensure that it is carried out in an ecologically-sustainable manner. This project outlines a roadmap to achieving this goal.

NEED

Better understanding of the impacts of stocking was flagged as a key national issue at the recent FRDC-sponsored “National Workshop on Research, Development and Extension Priorities for Stock Enhancement, Fish Stocking and Stock Recovery (FRDC project 2005/323)”. Stocked fisheries now represent alternatives to traditional recreational fisheries that simultaneously reduce fishing pressure on marine, coastal and freshwater fish stocks and deliver considerable social and economic benefits. An aging human population and increased leisure time for workers will create additional demands for fishing in the future. The continued success of freshwater fish stocking in Australia is contingent on demonstrating that it is sustainable under the principles of ESD. The impacts of fish stocking on recipient ecosystems and wild fish stocks are poorly understood and these activities have drawn adverse criticism from conservation groups and environmental management agencies.

On a national scale, the Department of the Environment, Water, Heritage and the Arts (DEWHA) are driving sustainability issues via the Environment Protection and Biodiversity Conservation Act 1999 (EPBC), with introduction of live native or non-native fish into Australian watercourses that are outside their natural geographic distribution currently being assessed as a key threatening process. Within Queensland, all native fish stocking applications are assessed on their risk to local aquatic communities; other States have similar procedures. However, the decision-making processes are poorly supported by data related to the likely ecological risks of the proposed stocking activities. These data cannot be obtained solely from desk-top studies that draw largely on overseas literature. What is urgently needed is pertinent Australian research to address key data deficiencies including impacts of stocking fish outside their natural range, displacement of natural populations and effects on genetic diversity. To do this effectively and to promote world’s best practice in our stocking programs, the issues first need to be succinctly defined and then appropriate methodologies developed to fully investigate them in research projects.

OBJECTIVES

1. Identify the major management concerns regarding the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks.
2. Hold a workshop of experts to agree on appropriate methodologies to address the management issues identified in Objective 1.

METHODS

To clarify the major management concerns related to the sustainability of native freshwater fish stocking activities in Australia, key stakeholders were polled for their views. These stakeholders included fisheries and environmental managers, researchers from Commonwealth, State and Territory agencies and Departments and representatives from industry. Stakeholders were identified by either the steering committee members or through networking with local and interstate colleagues. Initial contact was made with most of these stakeholders by telephone to explain the purpose of the project and also to request the completion of a small questionnaire (see Appendix 3) designed to assist in identifying the pivotal management concerns regarding the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks. Most agreed and these individuals were emailed the questionnaire and asked to respond before mid November 2007. Those that hadn't responded by that date were sent a reminder about two weeks later. The questionnaire had an explanatory section and a series of both closed-ended (answer choices provided) and open-ended (allow respondents to provide answers in their own words) questions. In most of the closed-ended questions, participants were asked if they strongly agreed (1), agreed (2), disagreed (3), strongly disagreed (4) or had no opinion on an issue (5). Questions were posed in both positive and negative terms and adequate space was left under each closed-ended question to let respondents elaborate or make further comments thus allowing for the capture of valuable additional information. To ensure the veracity of the survey design, it was developed in close consultation with a QDPIF communications specialist and biometrician. The responses were entered into a Microsoft Access Database and the average responses for each closed-ended question (where positive opinions were given by respondents) were calculated. In addition to the pooled data, the information was also analysed according to the affiliation, job description and geographic location of the respondent. An analysis of variance and pair-wise tests between means using the LSD procedure were used to compare the responses from each of these groups. Responses to the open-ended questions and the comments were compiled to ensure that the coverage of the issues was as complete as possible.

A two day expert workshop involving selected fisheries experts from most States was held at the Joondoburri Conference Centre on Bribie Island in southeast Queensland on the 25-26 March 2008 (Fig. 1). This workshop was organised to determine the most appropriate research techniques and methodologies for addressing the sustainability issues identified in the abovementioned survey. The steering committee identified potential workshop participants based on their expertise in a range of specialist areas including genetics, population dynamics and modelling, ecological impact assessments, freshwater aquaculture and freshwater fish stocking. The workshop program (Appendix 4) was divided into seven sessions. There were a number of "setting the scene" presentations on the first morning with the remainder of the workshop structured to allow maximum time for discussion in plenary and workgroup sessions. The actual sustainability issues that were to be discussed in the workgroups were decided upon early and varied only slightly from the broad categories identified in the earlier survey of stakeholders. These key sustainability concerns were genetics, ecological and conservation issues, stocking effectiveness and optimal stocking densities and each was discussed in detail during the workgroup sessions. These

sessions identified the respective management and research issues and existing techniques that could be used to address them in research projects.

The final two workshop sessions were dedicated to discussing implementation, potential collaborative arrangements, funding sources and developing recommendations. In addition, time was set aside to identify areas that needed immediate attention and to develop project outlines to address them.

RESULTS/DISCUSSION

Stakeholder survey to identify management issues

Relevant stakeholders, including fisheries and environmental managers, were polled to determine what they viewed as the major management concerns related to the impacts of native freshwater fish stocking activities on recipient ecosystems and wild stocks. Of the 36 surveys that were sent out, 29 (81%) completed responses were received including 13 and 11 respectively from management and research personnel and 5 from industry or academia. Responses were received from stakeholders in all States and Territories except South Australia. Average rankings for the closed-ended questions ranged between 1.5 and 3.2 where 1 is maximum agreement and 4 is maximum disagreement.

In the analysis, issues which received high priority rankings were flagged as potential topics for discussion at the workshop. These fell into five broad areas: 1) the need for appropriate marking techniques to identify stocked fish; 2) genetics effects; 3) population dynamics; 4) introduction of pathogens and exotic biological material; and 5) ecological, biological and conservation issues. Specific high-priority sustainability issues that were identified by participants in the survey as needing further investigation included:

- information on appropriate stocking rates and carrying capacities for a variety of species under changing environmental conditions, including fluctuating storage levels;
- the ecological impacts of stocking on aquatic communities including the possible effects of stocking predators;
- loss of genetic diversity in wild populations as a result of stocking activities.

When the responses of stakeholders with differing affiliations (eg. conservation agencies, Fisheries Departments and industry) were statistically compared, there was considerable consensus, but also some disagreement. For example, although there appeared to be general dissatisfaction from all respondents about the current protocols for determining fish stocking rates (average ranking of 3.04), significantly fewer ($P < 0.05$) respondents from conservation agencies than fisheries departments disagreed that the present protocols for determining stocking rates are appropriate. Similarly, there was disagreement amongst the various stakeholder groups about whether fish stocking actually reduced pressure on fish stocks in nearby coastal areas. Significantly more ($P < 0.05$) respondents from conservation agencies (average ranking of 3.25) than from Fisheries Departments (average ranking of 2.11) did not think this was the case. Conservation agencies were also concerned about disease transference, displacement of native fish, and leakage of stocked fish from intended stocking locations.

As might be expected, the geographic location of respondents did influence the issues that they regarded as important. For example, Queensland respondents indicated that the leakage of stocked barramundi into environmentally-sensitive areas such as the Great Barrier Reef and Wet Tropics World Heritage areas was of concern. Other leakage-related issues that were identified included stocked silver perch impacting on remnant natural stocks in the Murray-Darling Basin (MDB) and stocked golden perch and Murray cod moving from impoundments into MDB rivers.

There was general agreement amongst survey participants that stocking was an appropriate mechanism to rescue threatened stocks, for example the eastern freshwater cod and the Mary River cod. Many also added a caveat that stocking was just one tool that recovery programs can utilize and stressed the need to investigate, and if possible mitigate, the underlying causes of the stock declines. Where such recovery stocking programs are implemented, stakeholders suggested that the recovery be closely monitored. For example, the genetic diversity of stocked fingerlings should adequately represent the genotype frequencies of the remnant population and that care is taken not to exceed carrying capacity for that species. This is discussed further in the 'Effectiveness of stocking activities' section.

There were a number of new management issues, in addition to those incorporated into questions on the survey, which were identified by respondents. These included the need to:

- understand how stocking programs can be adapted to deal with the effects of climate change such as reduced freshwater inputs or drought;
- implement adaptive management as a tool for fine tuning ongoing stocking programs;
- be able to accurately quantify the contribution of hatchery-bred fish to the fishery;
- evaluate ecosystem services models for assessing the need for stocking activities;
- involve social scientists in stocking programs and to improve communication and education about stocking issues;
- develop enhanced hatchery protocols to minimize the spread of disease and 'trash' species.

While these last three issues are undoubtedly important, the steering committee regarded them as beyond the scope of the present project and suggested that they not be discussed in detail at the following workshop.

Workshop

After the results of the questionnaire were analysed and then compiled, the steering committee met to plan the structure of the workshop and to develop a draft agenda that would deliver the planned project outcomes (see Appendix 5). Its broad structure was a series of introductory "setting the scene" presentations (see Table 1) followed by a number of workshop and plenary sessions to decide upon appropriate methodologies.

Table 1. Workshop presentations

John Russell (Qld)	Setting the scene, general introduction
John Russell (Qld)	Results of the questionnaire sent to managers and other stakeholders
Neil Loneragan (WA)	Global trends in marine stock enhancement and restocking
John Russell (Qld)	Stocking in Queensland
Stuart Rowland (NSW)	Hatchery production and stocking of native freshwater fish in NSW
Greg Jenkins (WA)	Stocking/restocking programs in WA
Michael Hutchinson (Qld)	Ecological and conservation impacts of fish stocking
Brett Ingram (VIC)	Stocking native fish in Victoria
David Crook (VIC)	Non-lethal detection of stocked fish from the lab to the field
Jenny Ovenden (Qld)	Genetics issues
James Smith (NSW)	Modelling carrying capacity for Australian Bass

The first presentation was a detailed report on the results of the survey of key stakeholders to identify the main issues associated with native fish stocking. These results formed the basis for much of the discussion for the rest of the workshop. The remaining presentations in Session 1 (see Table 1) gave background information on:

- 1) the current status of freshwater fish stocking in Queensland, New South Wales, Victoria and Western Australia;
- 2) the latest marking techniques for juvenile stocked fish;
- 3) specific background information and knowledge gaps related to genetic, ecological and carrying capacity impacts resulting from freshwater fish stocking.

The presentations were followed by a plenary session to finalise which critical sustainability issues would be discussed in detail over the remainder of the workshop. The starting point for these discussions was the broad management issues identified in the earlier survey: (1) the need for appropriate marking techniques to identify stocked fish, (2) genetic effects, (3) population dynamics, (4) introduction of pathogens and (5) exotic biological material and ecological, biological and conservation issues. To make the workgroup discussions as focused as possible and to eliminate ambiguities these issues were further refined to:

- Genetic management
- Ecology and Conservation
- Stocking Effectiveness
- Optimal Stocking Densities
- Biosecurity

Workgroups were formed to address each of these topics (with the exception of Biosecurity which was discussed by all workshop participants) and challenged to a)

identify specific management issues and to b) develop a series of prioritized research questions that addressed those management issues (see Table 2). Once that was achieved, the workgroups were then asked to comprehensively document techniques that could be used in projects developed to answer the abovementioned research questions. These workgroups were given the remainder of Session 2 and Session 3 to deliberate. Rapporteurs were then asked to report the results of those deliberations back to a plenary session (Session 4). A summary of these discussions follows.

Table 2. Management and research issues.

Management Issues	Research Issues/Questions
Impacts on aquatic communities	Is stocking affecting predator/prey balances?
Impact of leakage of stocked fish	How to determine if leakage is occurring and, if so, what the consequences are?
How to manage genetic diversity	How to determine if there has been an overall loss of genetic diversity and inbreeding depression in a wild population that has been enhanced with stocked fish? Detect outbreeding depression in a wild population that has been enhanced with stocked fish. How to measure and maintain species-specific N_e (effective population size)? Use of genetic markers in monitoring.
What is the optimal stocking density?	How to estimate optimum stocking density and/or carrying capacity? How to incorporate physical and environmental parameters such as water level fluctuations (richness, relative abundance) when determining carrying capacity? The need for modelling capacity to predict the effectiveness/impacts of stocking new species?
What is stocking effectiveness?	Do stocked fish displace rather than enhance natural populations (eg barramundi)? Does stocking overcompensate for natural recruitment? Does efficacy vary with size-at-stocking? What should post stocking surveys do and can they be standardised across State borders? How to effectively mark stocked fish?



Figure 1. Workshop session at the Joondaburri the conference centre.

Genetic Management

The high priority genetic management issues were:

- How does stocking compare to other options for enhancement and species recovery;
- How to weigh the relative merits/performance against stocking objectives;
- How to manage genetic diversity of wild populations and limit outbreeding and/or inbreeding depression from stocked individuals.

The associated research issues and methods to address those issues were:

- a) How to determine if there has been an overall loss of genetic diversity in a wild population that has been enhanced with stocked fish

This was the biggest question to come out of the workshop relating to genetic management. Despite decades of restocking into wild fisheries, there have been no solid studies undertaken to date that have specifically attempted to quantify if restocking is lowering and/or changing genetic diversity of native fish populations. Three of the issues preventing these studies in the past were an absence of 1) fine-scale historical data on genetic diversity within river catchments, 2) genetic profiles of broodstock and subsequent hatchery fish batches used for restocking, and 3) powerful

genetic markers. The workshop participants agreed that for two of the major Australian stocked fish species (ie barramundi and Murray cod), some of these impediments to genetic studies may be overcome because of 1) good historical restocking records, 2) archival tissues suitable for historical genetic analyses and 3) the availability of powerful suites of species-specific microsatellite and mitochondrial DNA markers. Changing allele and haplotype frequencies between historical and present day populations could potentially be used to provide a measure of the loss of genetic diversity. Participants also believed that the widespread adoption of appropriate hatchery protocols (including the use of adequate numbers of broodstock) at facilities that supply fish for stocking was an essential step in preventing loss of genetic diversity in wild populations. As an example, the literature suggests that an N_e (effective population size) of 50 be the absolute recommended minimum used in the hatcheries to maintain genetic diversity in wild populations. This would be made up of 25 pairs of male and female fish that are all making equal contributions to the progeny thus limiting inbreeding to below 1% per generation.

While not specifically discussed at the workshop, there are some situations where fish stocking may have a positive effect on genetic diversity. For example, stocking activities (with fish obtained from hatcheries using appropriate genetic protocols as discussed above) could potentially arrest a slow, natural drift towards inbreeding depression in fish populations isolated through the construction of instream barriers.

- b) Detect outbreeding depression in a wild population that has been enhanced with stocked fish

Participants at the workshop thought that outbreeding depression was unlikely to be a major research issue in Australia and could not recall any instances where it had been studied in fish populations. The workshop agreed that priority should go to understanding loss of genetic diversity and long term loss of fitness in hybrid populations over time. As fitness is a function of the number of offspring and the number of these that survive and reproduce, for many long-lived fish species this would require a protracted and probably expensive field experiment.

- c) How are hatchery practices impacting on species specific N_e and how can it be measured and maintained

Normal hatchery practices used in aquaculture situations have the potential to dramatically further erode the genetic diversity initially captured in broodstock populations (Frost et al 2006). For example, differential family survival and size grading can create genetic bottlenecks which would tend to reduce N_e from that originally produced by mating broodstock. Before effective genetic management of wild populations through restocking can be understood, there is a requirement to understand how hatchery processes impact on the retention of genetic diversity for each species so that more effective management protocols can be developed that ensure as much genetic diversity as possible is captured in progeny destined for enhancement programs. It is also necessary to determine the current N_e in wild populations so that an estimate can be made on what the minimum N_e should be in hatchery populations to prevent significant loss of genetic diversity. A first step to addressing this research issue would be a project to undertake a genetic audit of the broodstock at all hatcheries

where fish for stocking purposes originate. This is already happening in some jurisdictions and would provide information necessary to identify hatchery fish in wild populations and the genetic pedigree of fish in stocked populations. Population genetic audits of wild populations to determine natural N_e are also required.

d) Use of genetic markers in monitoring

Technology is now available to utilise DNA markers as a natural biological tag in many species. The use of nuclear, co-dominant markers such as highly variable microsatellite DNA repeats can be applied to determine the pedigree of stocked fish and to assign them back to their broodstock parents. This technology can be used in marking studies instead of more traditional tagging methods such as chemical and physical tag types. Recent technical advances have made this type of tagging methodology more affordable, even for relatively large scale studies.

Stocking fish derived from the same evolutionary significant units as fish in the receiving area was also regarded as very important but since this principle is now widely incorporated into protocols (e.g. Rowland & Tully 2004) it was not discussed in detail at this workshop.

Ecology and Conservation

In this category the following primary management issues were identified in the group plenary session:

- Impact of the leakage of stocked fish;
- Impacts of stocked fish on aquatic communities.

Other management concerns that were given lower priorities by the workshop participants included how to decide upon the most appropriate species for stocking and if conservation stocking achieves its objectives. While these two lower priority issues were not specifically addressed by the workgroup, they acknowledged that many of the survey and marking techniques they recommended for investigating other issues could also be applied in research projects on these two concerns.

The workshop identified two principal research issues:

- 1) measurement of the leakage of stocked fish from intended target stocking locations; and
- 2) impacts on aquatic communities including the determination of predator/prey balances.

1) Impact of leakage of stocked fish

Depending on the circumstances such as whether or not the species occurs naturally in the area, a suite of different techniques can be used to determine leakage of stocked fish from intended target locations. The workgroup suggested that a first step would be to assess which areas are most likely to encounter problems if leakage of stocked fish occurs. Criteria for this assessment could include proximity of the stocking location to environmentally sensitive reserves or presence of known refuges for threatened species. One such example might be Koombaloo Dam on the Atherton Tablelands which is adjacent to the environmentally sensitive Wet Tropics region in north Queensland.

Existing databases, for example those held by various State Environmental Protection Agencies, could be accessed to provide data on the known ranges of threatened species.

On occasions where a fish has been stocked outside its natural range (e.g. where a catadromous species has been stocked in an impoundment), standard presence/absence surveys can be used to see if it has moved into other locations. These standard surveys include electrofishing, gill netting, seine netting, trapping, visual surveys, fyke nets, trammel nets, fish trawls or hydroacoustics in deeper, lacustrine areas. Under very exceptional circumstances, local Animal Ethics Committees (in conjunction with and the approval of other relevant agencies) may authorize the limited use of poisons such as rotenone to survey some locations. In situations where a measure of absolute or relative abundance, rather than simply presence/absence is required many, but not all, of the standard survey methods may be applicable. When used in conjunction with fishing effort, most of the standard techniques mentioned above can be used to give an estimate of relative abundance. Tag–release and recapture programs and hydroacoustic surveys can be used to give estimates of absolute abundance.

In circumstances where the species does occur naturally at the intended stocking location, other means of differentiating the stocked fish from wild populations are necessary. Usually this involves the stocked fish being marked using an appropriate methodology such as elastomer tags, gene tags, microwire tags or chemical tags. Where larger fish are being stocked then conventional tags such as external dart, anchor, carlin, spaghetti, loop, Petersen disc, internal anchor or even acoustic or radio tags may be employed. Survey techniques include those described immediately above although, depending on the marking technique, additional measures may be needed to detect the presence of the tag. For example, in the case of genetic tags a tissue sample preserved in alcohol or another suitable media will be required to facilitate later analyses.

2) Impacts on aquatic communities

The research sub-issues and methods to address them are as follows:

a) *Intra-specific impacts*: These cover a range of effects including overstocking, displacement of conspecifics and loss of genetic diversity (See ‘Genetic management’ section on page 18 for further discussion). Tools for measuring intra-specific impacts include:

- Measuring temporal or spatial (between a stocked system and control) changes in fish condition factors.
- Measuring temporal or spatial (between a stocked system and control) changes in growth rates.
- Standard fishing surveys including post-stocking surveys. Techniques used in these surveys are outlined above in the ‘Impact of leakage of stocked fish’ section.
- Hydroacoustics techniques linked with video surveillance can be potentially used for assessing impacts on pelagic species
- Before-After-Control-Impact (BACI) design experiments where the impact is stocking of fish. The literature (Leber et al. 1995) suggests that there is potential for stocked fish to displace conspecifics, particularly where overstocking has resulted in carrying capacity being exceeded. The workgroup noted that one of the potential difficulties with this type of experiment is obtaining suitable “before” data and a comparable control site.

b) *Effects on threatened species:* Where there is habitat overlap, stocking activities do have the potential to impact on threatened species. Tools and techniques that may be used to measure or predict the likelihood of impacts occurring include:

- BACI design experiments where the impact is stocking of fish. See comments in ‘Intra specific impacts’ section above on potential pitfalls of using this method.
- Gut analyses to detect if rare, threatened or endangered species are being predated. During the discussion on this technique it was acknowledged that, because these prey species are, by definition, not particularly abundant they may be very difficult to detect in gut contents.
- Analytical techniques to determine if the stocked species occupies the same habitat space as the threatened species. Multivariate statistical techniques can be used to explore habitat preferences and requirements of stocked species.
- Specifically monitoring the relative abundance of focal species immediately after a stocking event. Depending on individual circumstances, this could be done using the traditional fisheries sampling methodologies (see ‘Impact of leakage of stocked fish’ section above).
- Use genetic analyses to monitor N_e . (see ‘Genetic Management’ section above)
- Laboratory or microcosm trials designed to determine general feeding preferences of fish before stocking is undertaken. It would be unlikely that threatened species would be part of such experiments, but they may reveal which general taxon would be likely to be predated.

c) *Impacts on water quality:* Workshop participants identified deleterious effects on water quality in impoundments or rivers as a potential effect of stocking some fish species. These management issues are most likely a result of changes in nutrient concentrations and associated alterations in productivity although other events such as fish kills may also impact on water quality. Where there is evidence or a suspicion that stocking is affecting water quality, a number of investigatory tools may be employed including:

- Replicated laboratory-based trials to investigate specific water quality issues.
- Experimental monitoring of the biomass of phytoplankton, zooplankton and cyanobacteria before and after stocking.
- Conducting a meta analyses of nitrogen and phosphorus levels in existing stocked storages cross-referenced against known stocking levels and densities.
- In lakes and impoundments where water quality has been shown to be a function of fish biomass, hydroacoustic surveys may be used to estimate fish biomass.

d) *Impacts on prey species:* In rivers and impoundments, high densities of stocked predatory species have the potential to cause declines in populations of prey species. Some techniques (or indicators) that could potentially be used to detect or measure such declines are:

- Slow growth of stocked fish relative to fish in a control system or in systems where fish have been stocked at low densities.
- Loss of condition of stocked fish relative to fish in a control system or systems where fish have been stocked at low densities.

- Changes of the relative catch per unit effort (CPUE) or absolute abundances of prey species
- Using hydroacoustic techniques to determine the biomass of prey species in lakes and impoundments.
- Comparative studies with reference impoundments/streams that have not previously been stocked.
- Short-term laboratory microcosm experiments.
- Reductions in the size-at-first maturity of stocked species compared to fish in a control system or systems where fish have been stocked at low densities.
- Changes in RNA/DNA ratios compared to fish in a control situation.
- Population modeling using software such as the Ecosys/Ecopath/Ecospace models. These models have the capacity to predict the probable impacts of stocking on prey species.

e) *Impacts on intra- and inter- specific competition:* Higher densities as a result of stocking may result in more competition for resources between both conspecifics and between species at a similar trophic level. Inter-specific competition may occur when individuals of two separate species share a limiting resource in the same area. When one of these species is stocked at high levels, the unstocked species may be adversely impacted through increased inter-specific competition for the limiting resource. Indicators of significant competition include changes in biology and population parameters, for example, lower fecundities, growth rates, size-at-maturity and increased mortality. In some circumstances increased competition may cause emigration to other areas as individuals are displaced into sub-optimal habitat types due to the competitive pressures described above. Specifically, measuring if disproportionate competition is occurring can be done using methods including:

- Laboratory microcosm experiments to determine the effects of various stocking densities.
- Measuring changes in one or more indicators of population stress for either the stocked species or competitor species, relative to a control site or the condition of the populations before the stocking event. These indicators could include condition factor, growth rates and size/age-at-first maturity.
- Comparing shifts in diet and habitat preferences of both stocked species and competitor species. This may be done temporally (before and after stocking) or spatially (using a reference system where no stocking has been undertaken).

Where there is concern about potential inter-specific competition between a stocked fish and another native species, an analysis to determine the likelihood of trophic niche overlap may be appropriate prior to the commencement of stocking activities.

f) *Productivity:* Fish stocking activities have the potential to directly impact on the productivity on aquatic systems. Theoretically, stocking of piscivorous fish can cause a reduction of the biomass of planktivorous fish which, in turn, can increase primary production in impoundments and lakes. Similarly, increases in secondary production can be caused by an increase in biomass of planktivorous fish. There are instances in the literature where primary productivity has been artificially increased to increase the carrying capacity of reservoirs so that they may support higher densities of stocked fish

(Welcomme & Bartley 1998). Techniques that can be used to assess or measure changes in productivity include:

- Targeted hydroacoustic surveys to determine changes in biomass in lakes and impoundments.
- Quantifying increases in primary productivity (in the absence of blue-green algal blooms) through structured water quality surveys to measure chlorophyll A. Another method of determining primary productivity is the C¹⁴-radiotracer method which measures the assimilation of dissolved inorganic carbon by phytoplankton to estimate the rate of photosynthetic production of organic matter in the euphotic zone. Less sensitive methods (eg. Winkler method) use the production of dissolved oxygen by phytoplankton to estimate primary production. This latter method is predicated on the relationship between dissolved oxygen evolution and carbon fixation.
- Structured water sampling programs to measure the concentrations of nutrients, particularly phosphorus, which are drivers for primary production
- Developing conceptual models may be a useful means for understanding the linkages between productivity changes and fish stocking activities. While these models may provide insights into how the system functions, before they are used for policy or protocol development, workgroup participants agreed that it is essential that such models are first validated.
- Estimating fish biomass by sampling populations using traditional fish surveys such as those listed above in the 'Impact of leakage of stocked fish' section.

Effectiveness of stocking activities

A key management issue for both stakeholders and workshop participants was determining the effectiveness of stocking activities from an economic, social and ecological point of view. A number of key principles for measuring stocking effectiveness including the capacity to manage genetic diversity in wild stocks, the delivery of socio-economic benefits for the broader community, minimizing the level of ecological impacts and demonstrating the enhancement of existing fisheries or creation of new fisheries were identified.

Some discussion was devoted to answering the question ‘When Should We Stock?’ The workshop participants agreed that fish stocking should not be seen as a panacea or a quick, short-term fix for management problems but be part of an integrated approach that carefully considers the reasons for stock decline from all perspectives. Stocking should be one of multiple management options for recovery/enhancement programs. Importantly, before stocking is considered as an option, the root causes for the declines need to be fully investigated and if possible addressed. Those causes could potentially be environmental, habitat related and/or fisheries pressures. Depending on the cause, ways to address stock declines include translocation of spawners, facilitating fish passage into impoundments, managing fishing effort (input and output controls), removal of alien species, habitat rehabilitation (e.g. restoration of woody debris, environmental flows and riparian zones and fencing to minimize disturbance from farm animals) and fish stocking.

Once the decision is made to stock, then issues that need to be determined up front include:

- The objectives of the stocking program;
- Performance indicators for assessment of the stocking program;
- Establishing reference points such as knowing when and where to stock and knowing when to stop.

Appendix 7 contains a suggested decision tree for determining if stocking is an appropriate action. A 2003 Australian Society for Fish Biology workshop on stock enhancement also developed a similar decision tree.

Blankenship & Leber (1997) outline a series of procedures to ensure responsible stocking.

The associated research issues and methods to address the above issues are as follows:

1) How to mark stocked fish

In order to develop research projects to investigate stocking effectiveness, there is an imperative to be able to identify hatchery-reared fish. This is particularly important when stocking fish into areas that are inside their natural range (i.e. for enhancement or recovery purposes) as it enables hatchery fish to be differentiated from wild conspecifics. Even when fish are stocked outside their natural range, there may be a

need to mark fish before release to investigate various aspects of stocking effectiveness, for example, to determine optimal size for stocking. Techniques that can be used to mark fish before release are dependent on the size of fish and the type of information that needs to be recovered when the fish is recaptured and include chemical, molecular, coded wire, elastomer, conventional external dart, anchor, carlin, spaghetti, loop, Petersen disc, internal anchor and radio and acoustic tags. While most stocked fish that are currently released are not marked, there are some exceptions, e.g. between 1993 and 2005 every one of the more than 200,000 barramundi that were stocked into the Johnstone River near Innisfail, north Queensland as part of a long-term research program were marked with either a coded wire tag or, for larger fish, a dart or anchor tag.

2) Do stocked fish displace rather than enhance natural populations?

A number of methods can potentially be used to address this research question. There are examples in the literature involving experimental work where the abundances of fish in stocked and unstocked habitats are compared. For example, Leber et al. (1995) used this type of experimental approach in Hawaii to demonstrate that stocking striped mullet enhanced wild populations in coastal habitats. Similarly, BACI style experiments may be appropriate to determine if stocking is enhancing natural populations. However, depending on the species of fish that is being stocked and the natural variation in the abundance of wild populations, BACI experiments may require a commitment to long-term projects.

3) Does stocking efficacy vary with size-at-stocking?

Larger stocked fish tend to have higher survival rates than smaller fish but, conversely, they are much more expensive to produce. A benefit-cost analysis where survival of fish of different sizes is related to their cost to produce (or purchase) is an effective means of determining the most cost-effective stocking size. This is generally done in a large-scale manipulative experiment where batches of different size class fish of a known cost are released and their survival measured over a period of time. Russell et al. (2002) conducted this type of experiment to determine the most cost-effective size for stocking barramundi into open river systems.

4) Does stocking overcompensate for natural recruitment?

The impacts that overstocking can have on aquatic communities and how they might be assessed, is discussed in the 'Impacts on aquatic communities' section above. However, these assessments may not always be appropriate, as fish stocking activities are often associated with data-poor systems where little information presently exists. In this type of situation, simulation tools may be an effective way of assessing the effectiveness of stocking activities and determining if stocking overcompensates for natural recruitment. Existing simulation tools (eg. the Lorenzen Enhancefish model) (Lorenzen 2004) may be suitable or alternatively, there may be a need to develop new models that can be effectively used in data poor systems.

5) How can post stocking surveys be made more effective and, where appropriate, be standardized across State boundaries?

The primary objectives of most post stocking surveys are:

- to determine if and how well stocked fish survive after being released, and
- to monitor the ongoing health of the stocks and the viability of the fishery.

Additionally, stocking surveys may also collect data on the reproductive viability and condition of stocked fish and the contribution that they are making to the overall fishery. Once the issue of identification of stocked fish has been resolved (see above section ‘How to mark stocked fish?’) catch rates provide an excellent metric of the health of the fishery. Catch rates can be obtained using either regular fisheries dependant and/or fisheries independent surveys. The methodologies that can be used in fisheries independent surveys are varied and dependent upon the species being monitored. The various fisheries techniques that may be used and how they can be standardised using measurements of effort are outlined in the ‘Impact of leakage of stocked fish’ section above. Apart from relative abundance data, fisheries independent post-stocking surveys may also collect information on population parameters and movements. Fisheries dependent surveys including log books (voluntary or compulsory), catch cards, phone surveys and creel censuses can also be used to capture catch and effort data on stocked fisheries.

Workshop participants concurred that it would be advantageous to have an agreed uniform national monitoring and assessing standards for post-stocking surveys. This is particularly desirable where fisheries transcend State borders (e.g. the Murray-Darling system). While the means for achieving this is beyond the scope of this project, workshop participants agreed that it would be a useful issue to pursue with their individual managers.

Optimal stocking density

The quantification of optimal stocking density was considered by workshop participants as a critical management issue to minimize the possible adverse impacts associated with overstocking. Potentially, such adverse impacts include the displacement of conspecifics and predators, stunting and even the local extinction of some prey species. It would be unusual for managers administering stocking programs to have access to comprehensive assessments of the carrying capacity of target waterways, therefore other methodologies must be employed to estimate optimal stocking densities. Specific research issues that were identified included:

- How to estimate optimum stocking density and/or carrying capacity;
- How to incorporate physical and environmental parameters like water level fluctuations when determining carrying capacity;
- The need for a modelling capacity to predict the effectiveness/impacts of stocking new species.

Methodologies that could be potentially used to address these research questions include:

1) Modelling

Models that utilize the ecological and environmental characteristics of target ecosystems and species can potentially be used to estimate stocking densities. The literature suggests that this methodology is feasible and that there are a number of different modelling approaches that can be used (Luo et al. 2001; Fayram et al. 2005; Maes et al. 2008). Parameters that can be incorporated into these models include habitat availability, primary production and organisms available for consumption and the predatory impact of recruits. A variation of this type of approach that allows appropriate stocking density to be estimated at the outset of each stocking event has been applied to mulloway stocking in New South Wales estuaries (Taylor & Suthers 2008). Their model uses instantaneous estimates of key organism abundances in the target ecosystem, growth and population parameters and habitat specific parameters such as temperature and forage production capacity.

In the United States, stock-recruitment models have been used to estimate optimal stocking rates in lakes for species such as walleye (Fayram et al. 2005). They suggest that data to estimate optimal stocking rates can be obtained in a relatively short amount of time by sampling similar populations over a few years. These authors note that whether the goal of stocking is endangered species recovery or supplementation of recreational fisheries, accurately determining the optimal stocking rate is of ecological and financial importance.

2) Experimental stocking

Experimental stocking programs or pilot studies can also be used to determine optimal stocking densities although, for some Australian species, calculation of these may necessitate a commitment to long-term and perhaps complex programs. These experiments will need to include variables such as stocking rate, frequency of stocking and size-at-stocking. The workgroup that discussed these experimental stocking programs considered that there may already be enough information available for some species that are currently being stocked (eg. barramundi and trout cod) to considerably reduce the lead-in time for these type of experiments. Furthermore, they suggested that some of the variables derived from these experiments could also be used to feedback into the above mentioned models.

3) Physical and environmental parameters

A related management issue is the imperative for integrating fluctuations of physical and environmental parameters to give realistic estimates of stocking densities. The current (2008) drought in south-east Queensland, which caused water levels in impoundments to fall, in some cases to critical levels, was given as an example of where there is a need to dynamically adjust stocking densities to suit local conditions. Decreases in available habitat and likely declines in the abundances of prey species suggest that optimal stocking densities under such conditions are somewhat less than what they would be when the impoundments are full. Various solutions suggested to address this question included use of empirical multiple regression techniques and Ecosim and/or Ecopath modeling (Pauly et al. 2000.). The latter models may also have utility when investigating the probable impacts of stocking new species.

Biosecurity issues

Biosecurity issues associated with stocking activities including pathogen transfer from hatcheries to wild populations and the unintentional translocation of ‘trash’ species into new catchments or drainages were identified as important management concerns both by stakeholders who participated in the initial survey and by the workshop participants. ‘Trash’ species were defined as native or exotic fish that had contaminated batches of fish released as part of authorized stocking activities. However, during the course of the workshop no specific research issues were identified and participants considered that this management question is being addressed through tighter quality assurance regimes in hatcheries and through existing State protocols.

Model Systems

The final workshop session involved a discussion on the way forward to providing managers with the extra information required, where necessary, for them to refine their stocking protocols to bring them up to world’s best practice. This would ensure the retention of the considerable social and economic benefits that native fish stocking provides. Potential partnerships, funding sources and resource sharing arrangements were discussed and broad outlines for two priority projects to investigate sustainability issues related to ongoing fish stocking activities were developed. Projects were scoped on two species; barramundi stocking in north Queensland and Murray cod stocking in the Lachlan River in New South Wales. Both of these projects were recommended as model systems to test a multi-disciplinary approach that would incorporate the latest advances in molecular and chemical tagging techniques.

Murray Cod

Recent research has identified discrete populations of Murray cod and suggested that stocking may influence the genetics of some populations in the Murray-Darling Basin (Rourke 2008). However, the effects of stocking programs across the basin are not clear, and the contribution of stocked Murray cod and natural recruits to various populations and the effects of stocking on their genetic integrity are not known. Workshop participants suggested that there was a need to clarify this situation.

Study site: The Lachlan River was suggested as a potential site for this experimental study. It is a semi-closed system about 500km long that is bounded by weirs at both ends and includes an impoundment. It has the added advantage of having had fish communities sampled routinely as part of an existing NSW Department of Primary Industries Species Richness Assessment (SRA). There is potential for the SRA to provide both historical data and for it to collect new information for the proposed experiment. Another potential site is the Dumaresq River on the NSW/Queensland border. This river has been extensively stocked and there are now concerns of overstocking and possible stunting of cod. It is not known if the cod population is based on stocked fish, natural recruits or a combination of both.

Methods

In scoping this project, the workgroup suggested the following methodologies could be employed:

- Development of a strategic sampling program over the first year of the project to assess the existing genetic structure of the population. The primary fish sampling technique would be a boat mounted electrofisher.
- The experimental design to include provision for both the river and impoundment to be intensively stocked with Murray cod. It is planned to have one initial stocking during the first year with the possibility of a second stocking at a later date. These fish would be chemically tagged fish to detect possible leakage over the impoundment wall.
- As genetic markers for Murray cod already exist, it is proposed to use these data to investigate the proportions of stocked fish within the existing population and to monitor post-stocking changes in allele frequency. The sampling program will be facilitated through the collection of genetic samples obtained as part of the NSW quality assurance program. This information will be used to track what is happening with the stocked fish throughout the life of the sampling program. Where fingerlings are sourced from a private hatchery, a genetic audit of the broodstock in that hatchery will be conducted prior to stocking.
- Annual censuses will be conducted to determine the proportion of stocked and natural fish in the 0+ (young-of-year) age group.

Duration: At least 5 years and there was discussion over whether to run the project in 1 or 2 phases.

Potential funding sources: Murray-Darling Basin Commission, ARC linkage grant.

Barramundi

There are ongoing concerns from conservation groups and some Government agencies that barramundi stocking, particularly in open river systems, is having 1) undesirable impacts on the genetic diversity of wild stocks and 2) adverse ecological effects. Of particular concern is the unsubstantiated possibility of stocked fish moving from intended stocking locations into environmentally sensitive areas where they may impact on threatened species.

Study sites: The Johnstone River, near Innisfail in north Queensland, has an accurate history of stocking activities spanning the past 15 years. All stocked fish that have been released into this river system have been marked with coded wire tags to facilitate subsequent identification. A tropical impoundment, possibly Tinaroo or Koombaloomba Dam may also be selected for the study. Both of these impoundments are adjacent to the environmentally-sensitive Wet Tropics World Heritage Area.

Methods:

- Determine the capacity for stocked fish to move into environmentally-sensitive areas using a) replicated riverine and impoundment releases of microtagged fingerlings and b) radio tracking adult barramundi.

- Monitoring the movements of these stocked fish will be done through electrofishing surveys and by accessing the Suntag recreational fishing database.
- Non-lethal dietary analysis of the stomach contents of stocked fish to look for evidence of cannibalism and/or the presence of rare / endangered species.
- Assess the genetic effects that fish stocking has had on wild populations in the Johnstone River using pre-existing DNA sources to develop microsatellite genotype profiles.
- Investigate the displacement of wild populations with stocked fish through a Before-After-Control-Impact (BACI) experiment.
- Explore the possibility of predator-prey imbalances and competition in an experiment comparing the condition and growth of stocked fish relative to wild fish in a comparative control system.

Duration: At least 3 years.

Potential funding sources: FRDC, ARC Linkage Grant

BENEFITS

Currently, fish stocking around Australia delivers considerable social and economic benefits directly to recreational fishers. In addition, stocking has played an important role in the conservation of threatened species. Stocking programs have indirect downstream spin-offs to support industries that are dependent on the ongoing prosperity of the fishing industry. Rural and regional communities in particular, have derived considerable benefits from the establishment of recreational fisheries in inland waters. There is a pressing need for pertinent research to address key data deficiencies related to fish stocking sustainability issues in Australia.

By identifying and quantifying the core management issues related to sustainability of fish stocking activities, this project will benefit both managers and researchers by providing them with a document listing critical areas that require further attention. The outputs from this current project will directly benefit researchers by providing them with access to a comprehensive listing of the most up-to-date and appropriate methodologies that can be used to address many major sustainability issues related to the impacts of fish stocking in research projects. The results of these projects, in turn, will assist management to refine existing assessment and stocking protocols to ensure that they are aligned with world's best practice. The end-users, i.e. the fishing industry, will ultimately benefit through the development of these protocols and guidelines for fish stocking thus ensuring its future.

FURTHER DEVELOPMENT

The delegates at the workshop fully endorsed the conduct of further research into fish stocking sustainability issues and to this end, encouraged the continued support of funding agencies including FRDC. Areas where further development should be considered include:

- 1) Implementing projects to address fundamental knowledge gaps so that Australian fish stocking protocols can be brought up to world's best practice. Many of the claims being made by interest groups, while unsubstantiated, are being given considerable weight and need to be tested in a rigorous scientific manner. At the workshop, two projects that addressed critical knowledge gaps related to barramundi and Murray cod stocking issues were scoped. Because of the generation times of these species and the complexity of the work that needs to be done, it was acknowledged that these projects may take longer than the normal maximum project time of three years to achieve. In these cases, consideration should be given to funding longer term projects, perhaps up to five years duration.
- 2) Holding a similar workshop to address issues related to stocking/translocation of alien species, for example salmonids. As this current workshop was restricted to discussing issues related solely to the translocation of native freshwater fish species, delegates felt there was value in undertaking a similar exercise for alien species. Such a workshop would update and build upon some of the earlier work on translocation of alien species (Cadwallader 1996; Lintermans 2004)
- 3) Determining further what common actions are being taken internationally to lessen the environmental impacts of fish stocking. This could take the form of a comprehensive literature search of strategies being implemented by overseas agencies involved in fish stocking to ensure that their activities are ecological sustainable. Also first hand contacts with agencies that have already gone through the process of implementing best practice stocking protocols would be highly beneficial. Transfer of their knowledge and experiences in this area could be accomplished through mechanisms such as exchanges or study tours.
- 4) Investigating socio-economic effects of fish stocking activities around Australia. Delegates agreed that the quantification of socio-economic impacts had been largely neglected.

In acknowledgement of the growing national importance of freshwater (including stocked) fisheries, workshop delegates encouraged FRDC to consider proactively supporting the establishment of a more formal, multidisciplinary advisory group(s) drawing together expertise from across Australia to advise on freshwater fisheries-related issues (including fish stocking) and applications.

PLANNED OUTCOMES

The planned outcomes for this project were the identification and prioritisation of the major management issues related to the ecological impacts of fish stocking and the elucidation of appropriate research methodologies that can be used to investigate these issues. The identification of these issues and the appropriate methodologies to effectively address them is paramount to development of relevant research projects that will lead to stocking activities aligned with world's best practice, a requisite for ecologically-sustainable recreational freshwater fisheries.

In order to quantify the major management issues allied to the sustainability of freshwater fish stocking, stakeholders from around Australia were identified and sent a questionnaire to determine which particular issues they regarded as important. These stakeholders included fisheries managers or researchers from Federal, Territory and State jurisdictions although others, including representatives from environment and conservation agencies and peak recreational fishing and stocking groups were also invited to give their opinions. The survey was completed in late 2007 and the results analysed to give a prioritized list of key management issues relating to the impacts of native fish stocking activities. In the analysis, issues which received high priority rankings were flagged as potential topics for discussion at a future expert workshop. These fell into five core areas: marking techniques, genetics, population dynamics, introduction of pathogens and exotic biological material, and ecological, biological and conservation issues.

The next planned outcome, determination of the most appropriate methodologies to address these core issues in research projects was addressed through the outputs of an expert workshop held in early 2008. Participants at this workshop examined all of the priority sustainability issues identified in the earlier survey and then agreed on a range of methodologies for addressing those issues and in what circumstances that they should be used.

Future projects that adopt these methodologies when addressing sustainability issues will assist in the refinement of existing assessment and stocking protocols to ensure that they are aligned with world's best practice. This, in turn, will help to ensure that the substantial benefits of fish stocking are continued to be enjoyed by both industry and the community. Two such projects, one on barramundi in northern Australia and the other on Murray cod in southern Australia are currently in the development phase.

CONCLUSION

The project consisted of two linked phases; the first was a survey of stakeholders to gauge opinions on the major management issues related to freshwater fish stocking activities while in the second phase experts from around Australia were asked to decide upon methodologies that would be appropriate to use in research projects investigating those management issues.

There was considerable agreement amongst stakeholders regarding what were the major management issues related to sustainability of fish stocking activities. These were:

- the need for more information on appropriate stocking rates and carrying capacities for a variety of species under changing environmental conditions including fluctuating storage levels;
- the ecological impacts of stocking on aquatic communities including the possible effects of stocking predators
- loss of genetic diversity in wild populations as a result of stocking activities.

The leakage of stocked fish into environmentally-sensitive areas where they could potentially have a range of impacts, for example on aquatic ecosystems or on threatened or endangered species was considered as an important issue in some parts of the Murray-Darling Basin and in north Queensland. Respondents also expressed concern about transference of diseases and trash fish and displacement of native fish by stocked fish. There was general agreement amongst stakeholders that fish stocking was an appropriate mechanism for rescuing threatened stocks with the caveat that the underlying cause of the decline in the wild populations should be first investigated and, if possible, remedied before stocking is considered.

The workshop brought together experts from a range of disciplines including geneticists, fisheries modellers, biologists, ecologists and biometricians. The major management issues that were addressed in the workgroups were leakage of stocked fish from intended stocking areas, effects on aquatic communities, genetic impacts, determining optimal stocking densities and assessments of the effectiveness of stocking activities. While biosecurity was regarded as important, no research issues were identified and the workshop participants considered that this management question was already being addressed by tighter quality assurance regimes in hatcheries and through existing State protocols.

There are a wide variety of approaches, both direct and indirect, that can be adopted when seeking to investigate the potential impacts of stocking activities. The choice of which one(s) are appropriate very much depends on the experimental design and the questions that need to be answered. To be able to adequately design experiments to assess the impacts of fish stocking, it is important that stocked fish can be identified when recaptured. To do this they can be marked using a variety of techniques including chemical, gene, elastomer and microwire tags, or for larger fish, an array of more traditional external and internal marking techniques (see above description in 'Ecology and Conservation' section) may be employed. Specialist marking systems such as radio and sonic tags can be used to answer specific questions about movements. The direct approaches include field and microcosm experiments that seek to quantify various impacts relative to a control situation. BACI design field experiments may be

potentially used when seeking to determine if stocked fish are displacing conspecifics or other competitors. Other field experiments can be used to measure changes in relative or absolute abundances of stocked species, their competitors or prey. Measures of abundances can be made by using traditional survey techniques such as electrofishing, netting, trapping or trawling that have been standardized using a measure of fishing effort. Some lesser known techniques such as hydroacoustic surveys may provide measures of absolute or relative abundances in the deeper waters of lakes and impoundments that may be more difficult to sample using traditional techniques. Changes in population parameters such as declining growth rates, condition, age/size-at-first-maturity, fecundity and increasing mortality are indicators that fish stocks are under stress and can be measured relatively easily. Depending on circumstances, a range of methodologies can be employed to assess leakage from intended stocking areas including use of standard fisheries survey and marking techniques. Radio or sonic tags can be used to track the movements of larger stocked fish while structured surveys employing traditional fish sampling techniques can be used to monitor the movements of smaller, marked stocked fish. Tools that can be used to investigate genetic issues include highly polymorphic microsatellite markers and maternally inherited mitochondrial markers.

Modelling techniques that utilize ecological and environmental characteristics of target ecosystems and species can be used to estimate optimal stocking densities in aquatic ecosystems. Stock-recruitment models can also be employed to estimate carrying capacity. A variety of techniques are available to determine if stocked species are impacting on rare, threatened or endangered species. Gut content analyses can assist in determining the diet of stocked species, while habitat preference analyses are useful in ascertaining if hatchery-reared and wild stocks occupy the same trophic niche.

The final workshop session involved a discussion on the way forward in providing managers with the extra information required, where necessary, for them to refine their stocking protocols and bring them up to world's best practice. This would ensure the retention of the considerable social and economic benefits that native fish stocking provides. While beyond the scope of the current project, it was acknowledged that the practicalities of introducing world's best practice may be considerable. For example, depending on what needs to be changed, the transition could involve considerable costs to hatcheries, industry, government and the community. Careful planning of the implementation of the changes is critical and a consultative and open approach needs to be adopted to fully explain the rationale for any proposed measures thereby minimizing resistance from one or more of the client groups.

Potential partnerships, funding sources and resource sharing arrangements were discussed and broad outlines for two priority projects to investigate sustainability issues related to ongoing fish stocking activities were developed.

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APPENDIX 1

Intellectual Property Identify the intellectual property and/or valuable information arising from the research.

n/a

APPENDIX 2

Staff List

Steering Committee:

D. J. Russell (Project Leader)
R. Officer
J. Ovenden
P. Kind
A. Butcher
M. Hutchison

Other QDPI&F staff involved in conference organisation:

P.A. Thuesen
D. Smith
P. Palmer
K. O'Brien
S. Brooks

APPENDIX 3

Questionnaire

The Fisheries Research and Development Corporation is interested in identifying what fisheries managers regard as the main environmental impacts of fish stocking. Based on your response, an expert workshop will be convened to develop appropriate research methodologies to address those issues. To assist in identifying the main issues, we would be grateful if you would complete this questionnaire. Please note that this survey is for native fish only. We also invite you to append more detailed comments on a separate document to be returned with this questionnaire.

1. I am concerned that stocking of native fish in areas where they occur naturally could displace rather than enhance existing local fish populations

Strongly agree Agree Disagree Strongly disagree No opinion

Comments:

2. I need more information about the carrying capacity of impoundments and rivers during drought periods where overstocking may cause environmental damage

Strongly agree Agree Disagree Strongly disagree No opinion

Comments:

3. Stocking is a common mechanism for transferring unwanted biological material such as disease, parasites and other organisms from hatchery environments into the wild

Strongly agree Agree Disagree Strongly disagree No opinion

Comments:

4. Leakage of stocked fish from intended target stocking locations into other areas is an important issue that we need more information on

Strongly agree Agree Disagree Strongly disagree No opinion

Comments:

5. I need more information about the leakage of stocked fish into environmentally sensitive areas where they could have a deleterious impact on threatened and endangered species including amphibians

Strongly agree Agree Disagree Strongly disagree No opinion

Comments:

6. If you have agreed with either Question 4 or Question 5 please nominate the species, area and give details of the issue/s

7. Where endangered fish populations are a concern, do you agree that (choose one):

a) It is generally appropriate to release hatchery produced fish to rescue threatened stocks

- b) Release of hatchery produced fish is appropriate provided actions have been taken to minimise any potential side effects (eg. a decline in genetic diversity) on the endemic population.
- c) It is not appropriate under any circumstances
- d) No opinion
- Comments:

8. Stocked native fish can have a positive effect on habitat and water quality

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

9. The present protocols for determining stocking rates are appropriate and I'm not concerned that stocking at those rates is causing environmental damage

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

10. Fish stocking overcompensates for natural recruitment

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

11. In your view, does stocking provide,

- (a) A valuable means of rescuing, enhancing and/or creating fisheries
- (b) Has little impact
- (c) No opinion
- Comments:

12. Stocking of native fish in areas where they occur naturally is likely to decrease the genetic diversity of wild stocks?

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

13. Stocked fish need to be from the same genetic stock as the receiving population

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

14. I need more information on how stocking of predators potentially alters food chain dynamics and trophic cascades

- Strongly agree Agree Disagree Strongly disagree No opinion
- Comments:

15. Stocking can restore the predator/prey balance near high density angling population areas where exploitation is high

Strongly agree Agree Disagree Strongly disagree No opinion
Comments:

16. It is important to understand how fish stocking could potentially affect resident aquatic communities

Strongly agree Agree Disagree Strongly disagree No opinion
Comments:

17. In coastal areas, freshwater fish stocking reduces fishing pressures on nearby marine fish stocks

Strongly agree Agree Disagree Strongly disagree No opinion
Comments:

18. Are there other management issues related to environmental impacts of stocking that you think are important in your jurisdiction but poorly understood? Please list.

- 1)
- 2)

19. Do you think that your organisation should be represented at the upcoming FRDC workshop on developing research techniques to assess the environmental impacts of stocking? If yes, please nominate a suitable individual preferably with a fisheries or aquatic research background.

Yes No No opinion

Name: _____

Any further comments (please attach another page if necessary)

Please indicate which of the following best describes who you represent:

Government Department

Member of the public

Other management agency (describe)

Industry group (describe)

Academic

Other

(describe) _____

**Contact details
(optional):**

Name: _____

Address : _____

Telephone: _____

Email: _____

If you are a private individual and have chosen not to give contact details, please state your post code. This is for statistical purposes only.

Postcode: _____

Please return your completed questionnaire by email or post to John Russell, Northern Fisheries Centre, PO Box 5396, **CAIRNS**, Queensland, 4870 by the **16 November 2007**.

APPENDIX 4

Workshop Program

Towards responsible native fish stocking: Identifying management concerns and appropriate research methodologies (26-27 March, 2008)

Day 1

8:30- 10:30 SESSION 1: PLENARY SESSION

08:30-08:40 Welcome, introduction of participants, House Keeping - Rick Officer

08:40- 09:10 Results of the Questionnaire sent to managers and other stakeholders
John Russell

09:10-09:30 Global trends – what are environmental impacts are occurring elsewhere
Professor Neil Lonergan

09:30-10:30 Issues from around Australia
Queensland (John Russell)
New South Wales (Stuart Rowland)
Victoria (Brett Ingram)
Western Australia (Greg Jenkins)

10:30-10:45 SESSION 1: QUESTIONS AND GROUP DISCUSSION –
ADDITIONAL STATE ISSUES

10:45-11:25 Morning tea

11:15-12:15 SESSION 1: CONTINUATION OF TALKS

Ways of identifying stocked fish in wild populations (Dr David Crook)

Genetics issues (Dr Jenny Ovenden)

Biology/ecology/conservation issues (Dr Michael Hutchison)

12:15-12:45 SESSION 1: ADDITIONAL ISSUES AND GENERAL
DISCUSSION OF ISSUES RAISED DURING SPECIALIST
TALKS (Facilitator)

12:45-13:30 LUNCH

SESSION 2: DECIDING THE PERTINENT ISSUES

13:30-14:30 Brainstorming session on issues raised in the morning sessions. Decide on the workgroup topics; Prioritizing the issues.

- 14:30-1530** **SESSION 2: SPLIT UP INTO INDIVIDUAL WORK GROUPS** – Developing research objectives and methodologies for key areas of concern
Each Group to be given a prioritized list of topics
Group Leader (to be nominated from each group)
Rapporteurs (to be nominated from each group)
- 15:30-1600** AFTERNOON TEA
- 16:00-1700** **SESSION 3: CONTINUATION OF WORKGROUP DISCUSSIONS**
- 1700-17:15** **SESSION 3: DISCUSSION AND SUMMING UP OF DAY 1 AND DIRECTIONS FOR TOMORROW**
- 1715-1745** Tour of the Bribie Hatchery (Paul Palmer)
- 19:30-** WORKSHOP DINNER
- Day 2**
- 8:30-10:30** **SESSION 4: PLENARY SESSION – RAPPORTEURS REPORTS**
- 10:30-11:00** Morning tea
- 11:00-12:30** **SESSION 5: PLENARY SESSION**
 Will these techniques/objectives answer the pertinent questions about impacts?
 Outputs/outcomes – what will it tell us and is that suitable?
 Which techniques need more basic research and how can that work be funded?
 Will these techniques/objectives address the concerns given by managers?
- 1230-13:30** **LUNCH**
- 13:30-14:30** **SESSION 6: IMPLEMENTATION**
 Identifying potential partnerships, funding sources and resource sharing arrangements
 What are priority species?
 Develop project outlines for priority species
- 1430-1500** **SESSION 7: SUMMING UP & IDENTIFYING COLLABORATIVE PROJECTS**
 - Recommendations to FRDC
 - Where to from here?
- 1500-15:30** AFTERNOON TEA

APPENDIX 5

Table 3 Delegate list for expert workshop

Attendee	Affiliation
Vlad Matveev	CSIRO
Matthew Barrett	Sunwater
Adam Butcher	DPI&F Queensland
Michael Hutchison	DPI&F Queensland
Michael Macbeth	DPI&F Queensland
Paul Palmer	DPI&F Queensland
Paul Thuesen	DPI&F Queensland
Peter Kind	DPI&F Queensland
Rick Officer	DPI&F Queensland
John Russell	DPI&F Queensland
Jenny Ovenden	DPI&F Queensland
David Crook	DSE, Victoria
Brett Ingram	DPI Victoria
Stuart Rowland	DPI NSW
Andy Moore	BRS, Canberra
Ben Cook	Griffith University
Greg Jenkins	Challenger TAFE, Western Australia
Neil Lonergan	Murdoch University, Western Australia
Dean Jerry	James Cook University
Rob Doupe	James Cook University
Cathy Nock	Southern Cross University
Glen Wilson	University of New England
James Smith	University of New South Wales

APPENDIX 6

Table 4. Workshop presentations

John Russell (QLD)	Setting the scene, general introduction
John Russell (QLD)	Results of the Questionnaire sent to managers and other stakeholders
Neil Lonergan (Global)	Global trends in marine stock enhancement and restocking
John Russell (QLD)	Stocking in Queensland
Stuart Rowland (NSW)	Hatchery production and stocking of native freshwater fish in NSW
Brett Ingram (VIC)	Stocking native fish in Victoria
Greg Jenkins (WA)	Stocking/restocking programs in WA
David Crook (VIC)	Non-lethal detection of stocked fish from the lab to the field
Jenny Ovenden (QLD)	Genetics issues
Michael Hutchinson (QLD)	Ecological and conservation impacts of fish stocking
James Smith (NSW)	Modelling carrying capacity for Australian Bass

APPENDIX 7

Press releases and publicity (Queensland *Sunday Mail*, 4/5/08)

FISHING

WITH HARRY BLIGH

Sunday Mail 4/5/08

Boffins study stocks

FISHERIES scientists from around Australia are better armed to assess the impact of native fish stocking after a recent two-day workshop on Brisbane Island.

Fish stocking of waterways and impoundments has economic and social benefits, so it is vital for the scientists to ensure it is sustainable into the future, and that the environment is protected.

Workshop convenor John Russell, a Department of Primary Industries and Fisheries principal biologist based in Cairns, said the workshop was an outstanding success, with 24 participants from around Australia.

Funded by the Fisheries Research and Development Corporation, the workshop was designed to identify the best and most appropriate ways of investigating environmentally related fish-stocking issues.

"Many of the scientists who attended the workshop were national or international experts in a broad range of fields, from fish genetics to population modelling and ecology," Russell said.

"The workshop heard a range of talks on topics including the latest developments in marking small hatchery-reared fish and novel ways to determine sustainable stocking rates for various species."

Hundreds of thousands of fish are stocked annually in rivers and impoundments around Queensland alone.

Species produced commercially for stocking in freshwater areas included

'Fish stocking is delivering social and economic benefits'

JOHN RUSSELL

Mary River cod, saratoga, silver perch and sooty grunter.

"Some of these species have been used to create exciting new recreational fisheries in freshwater impoundments or to enhance existing fisheries," Russell said.

"There is little doubt that fish stocking is delivering enormous social and economic benefits around Australia, particularly to rural and regional communities.

"It shouldn't be seen as a panacea, but as one of many tools that is available to managers.

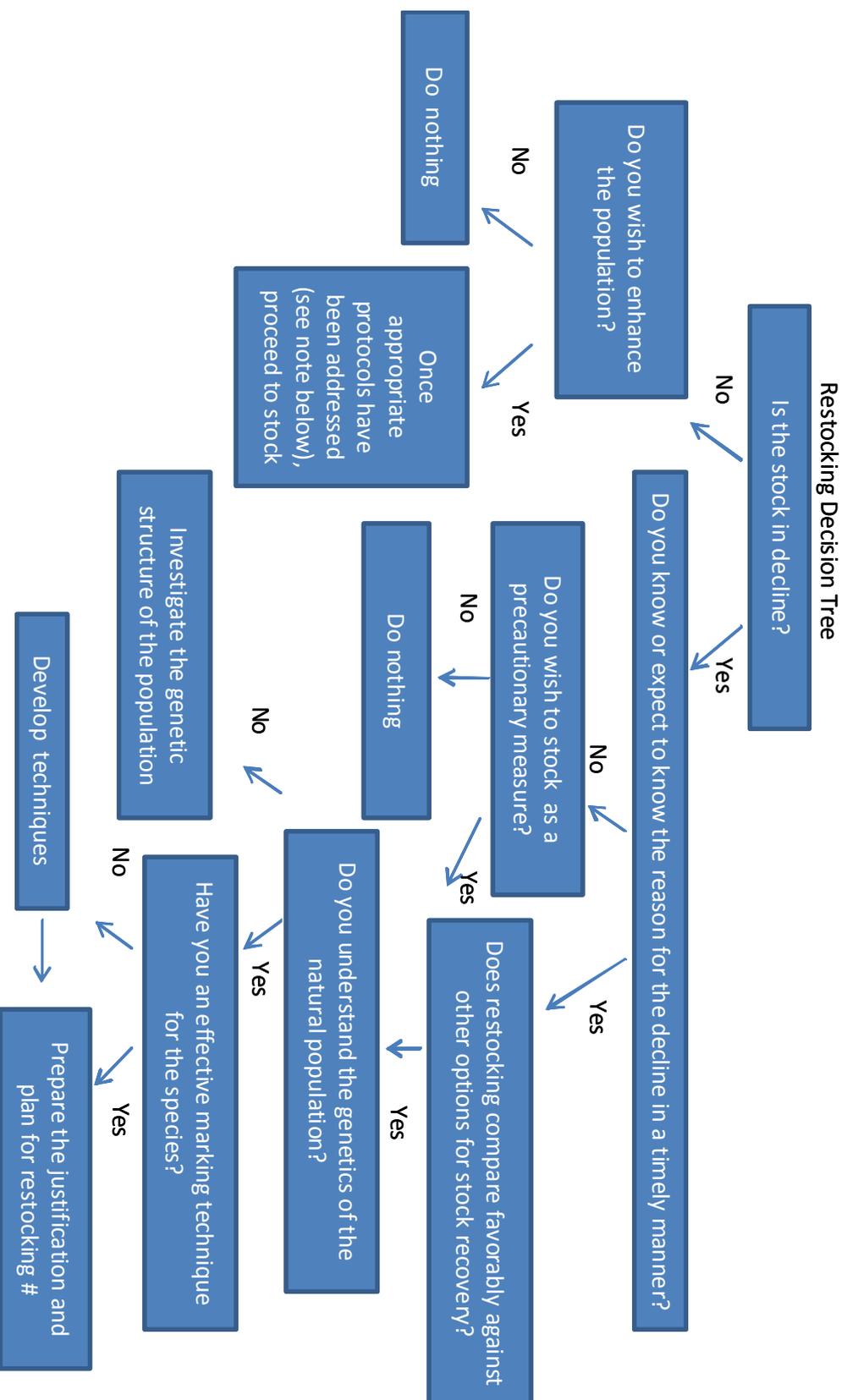
"We need to ensure fish stocking is conducted in a sustainable manner. To do that, we need to be confident the most appropriate tools are used to assess any potential impacts."

Russell said this work needed to be done to provide "best-practice" advice to community stocking groups and government management agencies.

"This will ensure the environment is protected, and that the economic and social benefits that fish stocking has provided will continue into the future," he said.

A final report on the outcomes of the workshop

APPENDIX 8



Decision tree for determining if stocking should be undertaken (as designed by Greg Jenkins).[#] *Note that the restocking plan needs to include or take into account: stocking objectives, hatchery protocols, carrying capacity, stocking densities, a monitoring plan, a trigger for when to cease stocking and measurements of stocking success.*

