Managing Fish Translocation & Stocking in the Murray-Darling Basin

Statement, recommendations and supporting papers

Workshop held in Canberra
25-26 September 2002

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WWF Australia Report; 03/02

ISBN 1-875941-42-8

Compiled by Bill Phillips, MainStream Environmental Consulting

designed by

Printed and bound by Union Offset Printers

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Acknowledgements

The Managing fish translocation and stocking in the Murray-Darling Basin workshop would not have been possible without the financial support of the Murray-Darling Basin Commission, NSW Fisheries and the Queensland Department of Primary Industries, and WWF Australia and the Inland Rivers Network (IRN) gratefully acknowledges this support.

Many thanks to those who assisted in the organisation of the workshop, particularly Bernadette O’Leary, Bill Phillips, Mark Lintermans, John Harris, Alex McNee, Jim Barrett and Greg Williams. Bill Phillips also skillfully facilitated the workshop, collated these proceedings, and together with Mark Lintermans, who acted as workshop rapporteur, ensured that the outcomes of the workshop were accurately reflected – thanks Bill and Mark.

Thanks also to those who presented papers at the workshop, and to all participants, who contributed towards making the workshop an effective and valuable exercise.

Marie Waschka
WWF Australia
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1. Statement and recommendations

Summary conclusions

1. We, the participants of the Managing Fish Translocation and Stocking in the Murray-Darling Basin workshop held in Canberra on 25-26 September 2002, call upon the Commonwealth and relevant State and Territory Governments, recreational fishing, hatchery and aquaculture interests and other stakeholders within the Murray-Darling Basin to implement the recommendations presented below and address the many issues and opportunities in current fish translocation and stocking practices.

2. The workshop participants acknowledge that translocation and stocking activities are a valuable management action for certain purposes, but that there are risks with conducting such activities. We consider that any stocking and translocation action must be implemented in an ecologically sustainable way.

3. It is also noted that the governments of New South Wales, Queensland, South Australia and Victoria have fish conservation and management responsibilities outside the Murray-Darling Basin, and that for these jurisdictions the management of translocation and stocking practices requires consistent state-wide policies. Harmonising these approaches among the Basin States, and also with the Australian Capital Territory (ACT), presents a significant challenge.

4. The workshop participants acknowledge that while significant progress has been made to address the issues of translocation and stocking within the States and the ACT, current management is generally uncoordinated between these jurisdictions. This management is, in many instances, inadequately resourced and suffers from lack of scientific knowledge and suitable community education and consultation processes.

5. The workshop notes that at present the draft Native Fish Strategy for the Murray-Darling Basin 2002-2012 is available for public comment, and urges that the recommendations provided below be reviewed in finalising the draft and implementing the strategy.

6. The workshop welcomes the acknowledgement in the draft Native Fish Strategy of the need for integrated approaches in restoring native fish populations, and concludes that the proposed restorative actions relating to translocation and stocking need to be fully and effectively coordinated. The recommendations below should be viewed as contributing to these integrated efforts to see native fish populations recover across the Basin.

7. It is further concluded that fish translocation and stocking activities have ecological, commercial, cultural and recreational dimensions and that coordinating these efforts across the Basin will therefore need a balance of ecological, economic and social outcomes and expectations. This will require careful consultations with stakeholders, especially indigenous communities, across the Basin.

8. The workshop participants call upon all Basin jurisdictions, in accordance with the national strategies for ecologically sustainable development (ESD) and biodiversity conservation, to urgently review their policy, legal and administrative frameworks relating to fish translocation and stocking practices to ensure that the precautionary principle is factored into relevant decision making.

9. It is a concern that too few resources are currently available to provide for the necessary best-practice development, community consultation, compliance monitoring, research and education. These needs are summarised in the recommendations below. The Murray-Darling Basin States, the ACT and the Commonwealth Governments are requested to review this untenable situation as a matter of high priority.
Specific recommendations

Implementing the National Policy for the Translocation of Live Aquatic Organisms

The workshop has considered the National Policy for the Translocation of Live Aquatic Organisms (1999), and reviewed progress within the various jurisdictions with its implementation. While it is noted that some jurisdictions have made progress toward consistently and comprehensively implementing this nationally agreed policy, much remains to be done. Therefore, the workshop recommends the following:

10. Those State/Territory Governments without translocation or stocking policies in place are urged to proceed to prepare and/or finalise them as soon as possible, and to ensure that they are consistent with, and complementary to, the National Policy for the Translocation of Live Aquatic Organisms (1999). Ideally, there will be cooperation between the various jurisdictions to result in Basin-wide consistency, or at worst complementarity (see also paragraphs 3 above, and 11 below).

11. To support the implementation of the above recommendation, the MDBC Ministerial Council is requested to commission an audit of implementation of the National Policy for the Translocation of Live Aquatic Organisms (1999) within the Basin States and the ACT to document progress, identify gaps and identify opportunities for harmonised policy development and institutional frameworks.

12. The State/Territory governments are also encouraged to develop appropriate Basin-wide mechanisms for delivery of on-ground outcomes through their translocation or stocking policies once they are in place. Such approaches may include agreed management zones to allow for native species conservation or recreational fish stockings of both natives and salmonids to be managed for specified outcomes. As indicated above (see paragraph 8 above), in the interim, care should also be taken to see that the precautionary principle is being factored into relevant decision making on these issues.

Risk Analysis

Fish translocation and stocking activities can carry with them risks which at present are not always well understood or documented (see paragraph 8 above regarding application of the precautionary principle). More systematic and robust approaches to risk assessment and management are needed across the full range of fish translocation and stocking activities. The workshop recommends:

13. The Governments of the Murray-Darling Basin Agreement are urged to recognise the full potential impacts of inappropriate stocking and translocation practices on fish species and communities and commit to reducing or avoiding such impacts through the introduction of consistent and appropriate risk assessment procedures consistent with the national ESD framework for Australian Fisheries. The MDBC is ideally placed to facilitate this risk assessment.

14. Inter-basin water transfers and the use of live organisms as bait are considered as priorities for risk assessment due to their potential to introduce and spread either diseases or noxious species and the associated negative impacts this may have on ecosystems and the genetic composition of fish communities. Such assessment should consider the scale of the risks associated with the activities, and, where the risks are considered unacceptably high, identify appropriate management measures to reduce the risk.

15. The mandate of the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) should be expanded to include consideration of freshwater pest species, and the MDBC represented in this forum.

16. Under the guidance and leadership of the Consultative Committee on Emergency Animal Diseases (CCEAD), disease preparedness and response arrangements need to be developed for the Murray-Darling Basin, with simulation exercises undertaken to test these approaches.
Quality control and accreditation for hatcheries and aquaculture

The risk of fish stocking activities introducing unwanted biological material (such as fish, frogs, diseases and parasites) must be recognised and the potential for this minimised. The role and operations of hatcheries and aquaculture in translocation and stocking programs has been carefully considered and the following recommendations formulated:

17. A comprehensive quality assurance and accreditation scheme for aquaculture establishments is required within all Basin States and the ACT. This scheme should be consistent and compatible between Basin jurisdictions (refer to the paper, Management of fish stockings in NSW by Sanger and Talbot at section 6.3 in these proceedings, for details of the comprehensive approach being taken in that State). Compliance monitoring must follow on from the development of quality assurance programs (see 19 below).

18. Aquaculture establishments should be accredited for specific purposes to ensure that the operating protocols are appropriate for achieving a suitable level of genetic diversity.

19. More resources are needed for compliance monitoring and for promoting cooperative and responsible codes of conduct among hatchery operators and aquaculturists (see paragraph 9 above also).

Stocking programs to support recreational fishing

The workshop acknowledges the various forms of recreational fish stocking and that these have specific objectives and outcomes in mind which are largely directed at providing improved angler satisfaction. However, this does not remove the need for such stocking activities to be effectively and appropriately managed and the following recommendations are intended to support this view:

20. A more rigorous and sophisticated decision-making process should be developed for all stocking of both native and exotic species for recreational purposes. Such a process needs to include a documented analysis of the social, economic and environmental costs and benefits of the proposed stocking activity (see 27 below also).

21. The aims and objectives for individual stocking programs need to be clearly established to allow meaningful review and the determination of monitoring requirements and performance indicators.

22. Adequate consultation processes must be employed to allow all stakeholder views to be considered when recreational stocking programs are being considered.

23. Recreational stocking programs for rivers, lakes and impoundments should employ appropriately rigorous quality control, genetic and health protocols, as used in conservation stockings (see 29 below also).

24. Stocking programs should be focused on delivery of outcomes for recreational fishing rather than inputs. Appropriate monitoring programs should be established to allow measurement of success or otherwise.

Conservation-directed translocations and stockings

Translocation and stocking programs are also recognised as important management tools for achieving native fish conservation outcomes. As such the following recommendations have been formulated by the workshop participants:

25. Conservation stockings should be conducted in accordance with relevant State or ACT and national recovery plans for threatened fish species, where these exist.

26. State Governments and the ACT must recognise the importance of threatened species breeding programs and resource them appropriately (see paragraph 9 above also).
27. The restoration of fish populations for conservation (and also recreational fishing – see previous section) outcomes should not overlook the need to operate at the level of ecological community in some cases, rather than exclusively at the species level. The potential ecological implications of translocation and stocking activities must also be considered at a broader geographical scale than just the stocking point or waterbody.

28. A coordinated Basin-wide approach to the commercial aquaculture of threatened species needs to be developed.

29. The management of commercial (grow-out) and conservation-focussed aquaculture programs needs to be de-coupled to ensure that the conservation efforts are not compromised by restricted or selected genetic composition of broodfish (see 23 above also).

30. Cost-benefit comparisons of translocation versus stocking as techniques for rehabilitating threatened fish species or communities need to be undertaken to establish the most suitable approach to pursue.

31. Investigation is needed into techniques which can increase the success of threatened species stocking programs.

Community education, participation and support

The workshop considers that a major impediment to seeing more cohesive, Basin-wide approaches to translocation and stocking remains a lack of awareness among community members, and also among some key government and private sector stakeholders with direct responsibilities in this area. The efforts to see awareness raised among these sectors requires urgent attention as a forerunner to more cohesive Basin-wide actions in the future, and also to build support and mobilise stakeholder involvement.

In reviewing these issues, the workshop participants noted that community awareness, understanding and active support could be encouraged through the use of high profile individuals, ambassadors or patrons, as well as fishing magazines and television programs to carry the simple key messages.

Through using positive case studies and drawing attention to negative impacts from ill-informed or careless translocations and stockings, greater profile could be generated for the issues involved with this area of fish management. It was also observed that a range of established mechanisms, organisations and programs exist through which awareness of the risks and benefits of translocation and stocking practices can, and should, be promoted. In particular, the workshop recommends the following:

32. After examining existing communication and education programs across the Basin and nationally, a communication strategy for fish translocation and stocking needs to be developed which clearly identifies target groups, stakeholders, partners, mechanisms and approaches for information delivery. The communication strategy will require a long-term commitment from all involved, with a regular review process established to assess the success, appropriateness and delivery of educational and awareness raising materials.

33. In relation to 32 above, among the immediate priority target audiences for education and information materials are the following (in no particular order); local councils, angling groups, aquarists, aquarium traders, stocking groups, existing and potential aquaculture establishments, aquaculture industry associations, the tackle industry, schools, indigenous groups and government officials.

34. Innovative approaches are also needed in order to engender stronger community ownership for translocation and stocking activities, possibly through the establishment of small scale fisheries or the incorporation of these activities into regional ‘demonstration reaches’ as proposed in the draft Native Fish Strategy. Such demonstration reaches will provide a visible focus and motivating force for community actions.

35. Monitoring data collected in relation to fish translocation and stocking should be readily and freely available and also distributed to the community through a variety of appropriate means and mechanisms.
Addressing the knowledge gaps

The management of fish translocations and stockings would benefit from major investment in research and development directed at the following areas:

36. The development of a register of stocking and translocation information across the Basin (see 35 above also). Information that could be included in such a register includes; species, number, and hatchery source of released individuals, origins of broodstock and genetic makeup of broodstock and progeny.

37. Monitoring programs need to be established to ascertain the success or otherwise of stocking and translocation programs. A consistent monitoring approach across the Basin is needed, with programs designed to build capacity within Basin agencies. Such monitoring programs should also have the capacity to detect or investigate ‘leakage’ of stocked fish from impoundments (see paragraph 39 below also).

38. The impacts of translocation and stocking practices on the fish of the Murray-Darling Basin is scattered or poorly documented at present. Impacts at both the stocking site and in adjacent aquatic habitats need to be considered, with a review and consolidation of the information describing these impacts required urgently.

39. There is a need to develop marking techniques to distinguish wild-bred from hatchery fish. Such techniques must be capable of cost-effective, non-destructive mass-marking of batches of fish.

40. More information is required on the genetic composition of wild fish populations, both as management and evolutionary units, to assist better hatchery management.

41. There is very little known about the parasites and diseases of native fish. Further research is required to understand the effects of parasites and diseases, and their potential hosts and vectors. Such research should include field studies as well as laboratory investigations.

42. The success of stocking programs needs to be examined in economic terms, as well as recreational and ecological terms. Such an economic focus will clarify the costs and benefits from stocking programs for local communities.

43. Whilst acknowledging that the MDBC’s Sustainable Rivers Audit may provide a broad, Basin-wide assessment of the status of fish populations, there is a need to undertake river-valley or more finely targeted assessments of fish populations prior to stocking or translocation activities.
2. Welcomes and introductory statements

2.1 Welcomes

**Matilda House, Ngunnawal People, Welcome to Country**

To open the workshop, Ms Matilda House, welcomed participants to Ngunnawal Country within which Canberra and surrounds lie. She expressed hope that the workshop would be conducted in a positive and constructive way, and welcomed other indigenous representatives to the Country of the Ngunnawal people.

**Bernadette O’Leary, WWF Australia, Welcome to participants from the host organisations**

On behalf of the host organisations, the Inland Rivers Network (IRN) and WWF Australia, Ms Bernadette O’Leary also welcomed participants. Ms O’Leary noted:

- the interests of the IRN and WWF Australia have in biodiversity conservation of inland rivers and wetlands, and that this was the third in a series of workshops which the organisation have hosted – the others being on the impact of weirs (August 2000) and thermal pollution (June 2001)
- that the Murray-Darling Basin (MDB) is one of 200 globally significant ecoregions identified by WWF, and that WWF Australia has a successful MDB program, and in 2000 identified a number of key threatening processes affecting aquatic species in the Basin (fish in particular)
- that the timing of the workshop fits well with the public comment phase of the draft *Native fish strategy for the Murray-Darling Basin 2002-2012*.

Ms O’Leary outlined the structure of the workshop – a mixture of information and focussed discussion sessions, with opportunities to identify gaps for further work. She noted that the workshop discussion and recommendations would be captured in a set of proceedings, to be distributed to participants and relevant others – particularly decision makers.

Ms O’Leary welcomed the range of participants present, and especially thanked the sponsoring organisations – the Murray-Darling Basin Commission, NSW Fisheries and the Queensland Department of Primary Industries.

2.2 Introduction and scene setting

**Kevin Goss, General Manager, Natural Resources, Murray-Darling Basin Commission**

In making his introductory remarks to the workshop, Kevin Goss expressed pleasure that the Murray-Darling Basin Commission was able to again provide financial support to the host organisations for this, the third such workshop on matters of great interest and significance to the Commission, and especially to the issues of native fish management.

The workshop was reminded that at present the draft *Native Fish Strategy for the Murray-Darling Basin 2002-2012* is available for public comment, and that this workshop was very timely to allow one of the key elements of this draft Strategy to be considered in detail.

Mr Goss noted that experts estimate the current native fish population within the Basin to be about 10% of its pre-European levels, and the proposed target for the *Native Fish Strategy* was to see this returned to at least 60% over the next 50 years. He drew attention to the six driving actions set out in the draft *Native Fish Strategy*; one of which is better management of stocking and translocation.
practices. In some quarters stocking is seen as the cure-all solution but this is not realistic, and an integrated range of actions is what is needed. Among these are habitat protection and restoration, managing weirs and dams better, controlling and reducing the impact of alien species and protecting threatened native fish species.

It is very clear that the community and anglers are vitally interested in stocking and translocation programs, however these are actions which need to recognise the associated risks such as the possible introduction or spread of diseases or alien species, and the potential loss of genetic diversity and fitness.

In concluding, Mr Goss stressed that the Murray-Darling Basin Commission will be acting to ensure that implementation of the Native Fish Strategy, once adopted in early 2003, will be done in concert with other initiatives such as the 'Efflows', ‘Hume to the sea’ and the Sustainable Rivers Audit. He looked forward to receiving the outcomes of the workshop and expressed confidence that they would be useful in helping to fine tune the draft Native Fish Strategy.
3. Key note address

Fish stocking and translocation in the Murray-Darling Basin: Issues, Benefits and Problems

Dr John Harris, Senior Ecologist, Cooperative Research Centre for Freshwater Ecology

Introduction

Homogenisation of plant and animal assemblages is amongst the greatest threats to Earth’s biological diversity (Lodge 1993). Species extinction and declining genetic diversity of populations are further global-scale threats. In freshwater environments including the Murray-Darling Basin (MDB) the stocking and translocation of fishes is a potent factor that has invoked these three threats to biodiversity (Moyle and Light 1996; Claudi and Leach 1999; Sala et al. 2000; Georges and Cottingham 2002). Unlike terrestrial ecosystems, where land-use change will probably have the greatest effect on biodiversity, for freshwater ecosystems, biotic exchanges such as fish stocking and translocation are much more important (Sala et al. 2000).

Historic attitudes to introducing new fish species, sometimes still heard today, were expressed by Nichols (1882) (cited in Low 1999, p.55): He who achieves the more difficult task ………. of peopling a barren river with a noble species of fish, should not pass unnoticed by his contemporaries. Fish acclimatisation societies or their more-modern equivalents, the fish-stocking groups, continue to function throughout the MDB, largely driven by desires to enhance recreational fishing opportunities and quality.

Global fish-stock enhancements are estimated to yield about 2 million t/year, mostly from hatchery-based fisheries in fresh waters, where they account for some 20% of capture, or 10% of combined capture and aquaculture production (Lorenzen et al. 2002). Negative environmental impacts may arise from ecological and genetic interactions between enhanced and wild stocks, or from the spread of disease. Outcomes from enhancements are strongly dependent on natural conditions beyond management control. There has been limited perception in Australia, until recently, that fish stocking can be associated with problems and unintended consequences. Davis, Kearney and Beggs (2000) reported that only 17% of respondents in a national survey identified fish stocking as a threat to freshwater ecosystems. In debates on the role of hatcheries in Northern Hemisphere salmon fisheries, the view has grown that ‘hatcheries are a fool’s bargain’ (Smoker and Linley 1997), that they do no more than drive out and replace production by wild-spawning salmon. Certainly, stocking is extremely widespread but has generally been applied uncritically (Welcomme and Bartley 1998). Despite questions that have long been voiced about the effectiveness of fish stocking, fisheries agencies and politicians often pin hopes for the future of fisheries on fish-stocking programs (White et al. 1995).

Each of the five State and Territory governments responsible for administering parts of the MDB has a fisheries agency involved in regulating fish stocking and aquaculture, along with other activities. No MDB State or Territory authority has a consolidated, formal translocation policy. Queensland has a number of policy elements and some protocols, and Victoria is currently developing a translocation policy. Although past management patterns have been inconsistent among agencies, recent moves have been made to produce more consistent management across the Basin, with improved regulation (e.g. Environment ACT 2000). An important component of this has been the adoption of the National Translocation Policy (Ministerial Council on Forestry, Fisheries and Aquaculture 1999), dealt with elsewhere in these Proceedings. Aquaculture is a rapidly developing industry throughout the MDB (Bearlin, et al. 2002) and measures to protect native fish from adverse impact need to keep pace with this development. Releases of genetically restricted or diseased native fish are almost inevitable without appropriate management and codes of practice for the industry.

The intergovernmental partnership of the Murray-Darling Basin Commission has drafted the Native Fish Strategy whose overall goal is to rehabilitate native fish communities in the MDB to 60 percent of their estimated pre-European-settlement levels after 50 years of implementation (MDBC 2002a). The draft strategy, which is now completing the public-consultation stages, seeks to initiate short, medium and long-term actions for rehabilitating native fish, using a holistic approach and providing directions for investment in on-ground management activities through a broad range of government and community collaborations. Thirteen strategic objectives have been agreed on, relating to fish-habitat rehabilitation, improvements in flow regulation and water quality, recovery of threatened species, restoring fish passage, limiting adverse effects from alien and introduced species, and managing fisheries for sustainability, including fish-stocking activities.
In August 2000 the Australian Society for Fish Biology (ASFB) held a two-day national workshop in Albury titled: Stock Enhancement of Marine and Freshwater Fisheries. Papers and workshop discussions dealt with the ecological, genetic, research and fisheries-management aspects of fish stock enhancement and the proceedings are nearing publication (Moore, in press).

The potential for translocated fish to impact on the genetic diversity of the particular species, to introduce disease and to impact on the natural environment and the biodiversity of native species was discussed in detail. At the workshop there was debate about the appropriateness of current fish-stocking practices in view of inter-government policy on ecologically sustainable development. Some questioned the acceptability of hatchery stocking in view of government commitments to sustainability. The New South Wales Government recently began producing an Environmental Impact Statement dealing with its regulation of fish stocking practices.

The MDB boasts a unique community comprising between about 30 and 35 fish species native to the Basin, depending on definitions. Twelve of these species occur nowhere else on Earth. Some of the unique features of the fish community have been lost in the trend towards homogeneity: once-abundant species have declined and species that originated either overseas or in Australian waters outside the basin have become established (Pollard 1990; Harris and Gehrke 1997; Koehn 2002; Georges and Cottingham 2002). Local extinctions have commonly occurred, especially upstream of large dams. No species have yet become extinct in the MDB, but several are perilously close (Morris et al. 2001) and extinction has often resulted from introductions elsewhere (Barlow, Hogan, and Rogers 1987; Courtney and Robins 1989; Harris and Battaglene 1990; Arthington 1991). While there are currently few available data to show the full extent of lost genetic diversity, severe population declines combined with massive-scale releases of hatchery-bred fish must be having significant impacts, as they are elsewhere in the world. We have good cause to be concerned about the condition of that important part of Australia’s biological diversity that is contributed by freshwater fishes.

An eclectic crew: diverse kinds of stocking and translocation activity

Fish stocking and translocation in the basin comprise many diverse activities, summarised in Table 1 below. Government control over some of these activities has improved recently but many remain problematic. Traditionally, propagated or translocated fish have been released into the wild to enhance angling fisheries for native fish or to initiate and maintain them with alien species. Management of recreational fisheries remains by far the greatest source of fish stocking. The recreational fisheries potential of numerous impounded waters in Queensland has been significantly increased by the introduction of the Recreational Freshwater Fishing Enhancement program in 1986 (Holloway and Hamlyn 1998) and by related schemes in Victoria, New South Wales and the Australian Capital Territory. Government and community conservation agencies release fish for species-conservation objectives (e.g. Douglas et al. 1994). Dollar-smart youngsters have bred bait and aquarium species in natural waterways for subsequent sale. Fish farms spill propagated fish from insecure premises or send out batches of fish contaminated with unintended species; breeders of ornamental fish lose their stock when streams flood outdoor ponds. Anglers sometimes release live-bait fish. Inter-basin water transfers relocate species between catchments. Public health bodies spread fish in the hope of controlling mosquito-borne diseases. The sources of fish releases are many and varied.
### Table 1. Sources of fish translocation and stocking

<table>
<thead>
<tr>
<th>Source</th>
<th>Activity/process</th>
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<tbody>
<tr>
<td>Recreational fisheries management</td>
<td>Fish stock introduction, maintenance or enhancement</td>
</tr>
<tr>
<td>Species conservation</td>
<td>Population rehabilitation using relocated or hatchery-bred fish</td>
</tr>
<tr>
<td>Interbasin water transfer</td>
<td>Unscreened hydroelectric and water-supply schemes</td>
</tr>
<tr>
<td>Fish-farm spills</td>
<td>Flooding, pond overflows, inadequate screening controls</td>
</tr>
<tr>
<td>Ornamental fish escapes*</td>
<td>Flooding, pond overflows, inadequate screening controls</td>
</tr>
<tr>
<td>Aquarium-breeding releases</td>
<td>Deliberate release of aquarium species, with or without intent to harvest offspring later</td>
</tr>
<tr>
<td>Mosquito control</td>
<td>Public health agencies deliberately distributing gambusia</td>
</tr>
<tr>
<td>Live-bait releases</td>
<td>Anglers releasing unused baitfish</td>
</tr>
<tr>
<td>Bait-breeding releases</td>
<td>Anglers and/or entrepreneurs using waterways to breed baitfish</td>
</tr>
<tr>
<td>Contaminated hatchery stock**</td>
<td>Inadequate quality control in hatchery ponds and/or shipments</td>
</tr>
<tr>
<td>Illicit stocking</td>
<td>Anglers making covert releases to waterways</td>
</tr>
<tr>
<td>Rains of fishes</td>
<td>Uplift and redistribution through thunderstorm activity</td>
</tr>
<tr>
<td>Farm dam spills</td>
<td>Flooding, overflows, lack of screening in stocked farm dams</td>
</tr>
<tr>
<td>Ballast water releases***</td>
<td>Ships releasing ballast water taken aboard from remote areas</td>
</tr>
<tr>
<td>Inland marine aquaculture</td>
<td>Aquaculture with marine species (e.g. snapper, mulloway, barramundi) using inland warm saline aquifers</td>
</tr>
</tbody>
</table>

* Especially relevant to koi carp breeders.

** Hatchery shipments have been found to be contaminated with redfin perch, tadpoles, carp and banded grunter (Rowland 2001).

*** Ballast water discharge is more likely to cause problems in marine habitats in Australia and is highly unlikely in the MDB.

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### The ecology of aquatic invasions

Many complex factors interact in determining the outcomes from introduction of an aquatic species (Moyle and Light 1996). Invading species and the systems being invaded interact in idiosyncratic ways that are often hard to predict, largely because of the role of environmental variability in determining the outcomes. Moyle and Light (1996) summarised these interacting processes and possible outcomes (Figure 1). In their conceptual model, an existing pool of species, often modified by human interventions varying between regions and through time, experiences the arrival of a new species. Various routes of dispersal as well as human transportation may be involved. The new arrivals confront a range of resistances opposing their successful establishment. Environmental forms of resistance include the extent to which the species’ thermal, chemical and habitat-structure requirements are met, and the availability of abiotic resources such as shade or spawning sites. Biotic resistance relates to factors such as the availability of prey, competition from, or predation by, other species, and the extent of any adverse effects arising from disease and parasitism. Demographic resistance also encompasses autecological factors such as a dependence on schooling behaviour or a critical requirement for minimum-sized aggregations of fish before spawning can occur. It is also relative to the size and nature of the habitat.
If the combined resistances are too great, the arriving species dies out and the invasion fails. If the species can overcome the combined resistances, it becomes established and undergoes a stage of integration into the species pool. Integration is accompanied by various biotic and possibly abiotic responses from the system, including shifts in the realised niches or behaviour patterns of the invaded species, with or without shifts in abundance or their functional roles in the community. Some species may disappear. Functional shifts especially relate to the effects of predation and competition in determining how food and habitat resources are shared among the community. The end result is an altered aquatic community.

Why do some fish become established while other releases fail?

Predicting the outcomes of aquatic invasions is difficult and uncertain, whether it involves distinct genetic stocks produced by hatcheries, translocated fish, or new species. The large number of system components makes modelling particularly difficult and the accuracy of predictions of an organism’s invasive potential depends on knowledge of its biology and the system’s structure; predictive capacity falls precipitously without this knowledge (Moyle and Light 1996; Fuller and Drake 1999). But the conceptual model of invasions provides a basis for understanding how the outcomes from invasions are determined. For

![Conceptual Model of Invasions](image)

Figure 1. Conceptual model of processes and possible outcomes from invasions by new species or genetic stocks of aquatic species (from Moyle and Light 1996).
establishment and integration to occur the arriving animals must be able to overcome the net effects of environmental, biotic and demographic resistance in the particular habitat. To understand and predict the outcomes of aquatic invasions requires knowledge of each of these components and of the species’ behaviour, physiology and ecology, together with the attributes of the aquatic system. Some aspects of this knowledge have been gathered for native fish in the MDB (e.g. McDowall 1996; Schiller and Harris 2001; Allen et al. 2002), but there are many important gaps that limit understanding, prediction and management of fish translocation and stocking practices.

Low environmental resistance may have been a factor in the successful invasions of Australian waters by redfin perch and gambausia. Both these species have limited swimming ability and seldom thrive in fast-flowing habitats, even if their other needs are met. But extensive parts of the MDB have provided suitable habitat for these fish because flow velocities are mostly low in our generally low-gradient streams. Similarly, the range of trout species is strictly constrained by their intolerance of warm conditions but, in the extensive upland and more-southerly areas of the Great Dividing Range where conditions are cool, trout’s chemical and habitat-structure needs are generally provided. So trout are not confronted by strong environmental resistance within this cool region and establishment has regularly resulted from their release in species-introduction and enhancement programs, in Lake Eucumbene for example (Faragher 1992). Work by Roberts and Tilzey (1997); Driver et al. (1997); and Koehn (2002) provides insights into the factors, especially habitat degradation, barriers to migration and declining populations of native fish, that have favoured the immense invasions of common carp in the MDB and other Australian waters.

Little systematic, detailed knowledge is available of the behaviour of MDB fish, making it difficult in many cases to estimate the numbers of fish required to overcome demographic resistance. Breeding aggregations comparable with those of many marine species do not appear to have been observed among native MDB species. In the current MDB community only the carp obviously spawn in groups, while field and hatchery experience suggests many of the native fish mate as separate pairs. Schooling behaviour is more commonly seen among juvenile native fish, and among adults of at least a few species including Australian smelt, silver perch and bony herring. The adaptive value for these fish of grouping together is open to speculation, but it may well improve resistance to predation or increase access to food resources. It is safe to assume that there is real value for schooling species in adopting such behaviour. These behavioural issues, and the associated knowledge gaps, assume practical importance when it is necessary to decide how many individual fish need to be released in stocking programs for conservation or fisheries management. Our limited understanding of native fish behaviour and demography may help explain the apparently poor results so far from conservation-stocking programs for fish such as trout cod. These gaps are particularly important in ecological risk management and in attempts to rehabilitate populations of threatened species.

Rule-of-thumb recommendations for stocking density with juvenile native fish commonly suggest numbers between about 100-300 fish per hectare of habitat surface area. In an impoundment stocking experiment with golden perch and silver perch (Harris, Gordon and Thurstan, in preparation), juvenile fish stocked at 100 per hectare showed good-to-complete survival. But such recommendations are mostly derived from limited, mostly anecdotal data and are based on artificial habitats in impoundments. They should not be regarded as reliable for enhancing wild populations in natural environments without further research data. Stocking densities specifically recommended for particular species and habitats are now becoming available (e.g. Gallagher, Hutchinson and Chilcott 2000; Hutchinson et al. 2002; Simpson et al. 2002). Modelling studies in Victoria (Bearlin et al. 2002) are strengthening understanding of the dynamics of trout cod reintroductions and similar programs.

Native MDB fish communities are dominated by ecological-generalist species (McDowall 1996; Allen et al. 2002) and many of the trophic and habitat resources are poorly exploited. In headwater streams especially, the native fish fauna is extremely limited, with only one, two or three species (mountain galaxias, river blackfish, two-spined blackfish or Macquarie perch) usually being present. It is not surprising that powerful invasive species like trout and, in some areas, gambausia have been so successful in these poorly exploited niches. In the lowlands, the lack of specialist detritivores, or herbivores other than bony herring, further assisted the carp’s rapid progress to dominance of MDB lowland habitats.

Fish invasions in the MDB have also been facilitated through the system’s generally low biotic resistance. The native fish community contains no specialist piscivores. Although fish make up a significant part of the diet of species like golden perch, Murray cod and spangled perch, these are generalist predators and their effectiveness in controlling fish invasions is questionable. In the impoundment stocking experiment (Harris, Gordon and Thurstan, in preparation), golden perch and silver
perch juveniles showed good survival in the presence of predatory fish, even including abundant redfin perch.

Knowledge of fish disease and parasitism in Australian freshwater systems is disappointingly poor (but see Humphrey and Langdon 1986; Langdon 1990), so that their role in providing biotic resistance to new invasions is uncertain, but apparently limited.

Finally, it needs to be stressed that the outcomes from fish releases are strongly influenced by the gross alterations in the MDB’s aquatic environments resulting from human activities. For native fish, especially those that are threatened species, habitat alteration through modified river flows, obstructed migration paths, sedimentation, riparian degradation and coldwater pollution has profoundly affected the condition of populations and communities (Harris and Gehre 1997; Schiller and Harris 2001; MDB 2002b). Invading alien and introduced fish, on the other hand, may be advantaged by the altered conditions (Driver et al. 1997), or at least enjoy the benefits of reduced predation and competition from a declining native fish community.

At this stage it is clear that fish invasions (or stocking/translocation programs, depending on one’s perspective) are likely to succeed in the MDB if environmental resistance is low, if sufficient fish are stocked to overcome demographic resistance, and if the habitat provides resources that are not heavily exploited. These conditions are most often met in the artificial habitats of impoundments.

**Outcomes from stocking programs**

Beneficial outcomes from fish stocking are uncertain and inconsistent. Ideally, stocking programs for recreational fisheries should be targeted at the key determinants of angling quality: population density and fish size. Some highly productive recreational fisheries have been developed, at least in the short-to-medium term, in the artificial habitats created by reservoirs (Holloway and Hamlyn 1998; Faragher 1992). Other programs, especially in the open systems of rivers, have failed. Substantial rehabilitation programs stocking propagated endangered species in their former range have so far had little long-term success. In many cases, the outcomes from stocking programs have little or no objective assessment and the various factors controlling their success are poorly understood.

Regrettably few research publications have documented the outcomes from MDB stocking programs although many examples can be found outside the Basin and in international literature. Successful translocations of Murray cod and trout cod (Cadwallader and Gooley 1984) and of Macquarie perch (Cadwallader 1981) have been reported (and see Lintermans, in these Proceedings). Results from MDB trout-cod rehabilitation projects provide some guidance (Douglas, Gooley and Ingram 1994) and some research to test stocking results is currently under way (Robert Faragher, NSW Fisheries, personal communication).

The ASFB national workshop on fisheries stock enhancement (Moore, in press) identified research on the outcomes of fish stocking as a high-priority need for fisheries management. Methods for improving the survival capabilities of hatchery fish following their release into the natural environment have not kept pace with techniques for rearing fish (Olla, Davis and Ryer 1998). Knowledge of the complex interactions between a species and the myriad physical and biological factors a hatchery fish faces upon release is inadequate. Being reared in the psycho-sensorily deprived environment of a hatchery may lessen the innate capability of fish to carry out the basic survival strategy of all fish: to eat and not be eaten. Key behaviours play a role in predator avoidance and food acquisition, and the rearing environment may affect the expression of these behaviours. One of the major causes of mortality in hatchery-reared fish is predation, much of which occurs shortly after release (Baxter, Vallis and Hume 1985; Olla et al. 1998). Anti-predator behaviour in hatchery-reared fish seems imperfectly developed. Deficiencies may also occur in feeding after release, when fish are faced with the shift from hatchery-supplied foods to the capture of live prey. The stresses of handling and transportation add to these deficiencies. Olla et al. (1998) suggest ways that behavioural capabilities in hatchery-reared fish can be improved, including exposure to predators or predatory stimuli, alteration of spatial and temporal distribution of food, mitigation of rearing and transport stress, and control of the social environment. White et al. (1995) considered that post-stocking behavioural problems of hatchery fish appear at least as numerous and damaging as physiological and anatomical problems, and that the problems with stocking are worse in streams. Migration is an important feature of the life cycle of many native species’ behaviour, and population density is likely to be one of the main stimuli for migration (Harris 2001). In cases such as the large-scale experimental stocking of golden perch into a reach of the Murrumbidgee River near Narrandera (Stephen Thurstan, NSW Fisheries, personal communication), the lack of any measurable response may have been at least partly due to the prior existence of a substantial adult population in the river, together with the opportunity for stocked fish to emigrate from the reach in response to increased population density.
Cowx (1999) outlined how stocking and translocation of fish are used to mitigate loss of stocks, to enhance recreational or commercial catches, to restore fisheries, or to create new fisheries. Stocking is widely used for recreational fisheries in MDB water-storage impoundments, and in some streams, but the results are often uncertain. Building on previous research results in Tasmanian fisheries, Davies Sloane and Andrew (1988) found that at 23 out of 27 sites the numbers and total biomass of brown trout were both higher in 1985 than they had been in 1955, despite the cessation of stocking in 1956. Numbers of anglers, total effort and total harvest had all increased in the absence of stocking. Harris, Gordon and Thurstan (in preparation) found experimentally that stocked juvenile fish of golden perch and silver perch survived in impoundments but larvae died. The survival, relative to predation and food availability, of two size-classes (juveniles 30-40mm and larvae that had begun active feeding) was tested. After a year, no larvae had survived, and survival among juveniles was similar for both species. Despite extreme predation pressure in some sites, worthwhile numbers of stocked juvenile fish survived for their first year, indicating the potential benefits of stocking for fisheries enhancement in impoundments, even with strong populations of predators.

Davies et al. (1988) reported that stocking of hatchery-reared trout in Tasmanian rivers that have a self-sustaining trout population is often associated with high mortality of the released fish. Cortes (1996) released hatchery-reared trout in streams to assess interactions between the introduced individuals and the native trout populations. Results showed total trout density and biomass did not significantly change, the native population was impacted and stocking success was strongly limited in space and time. In a study to investigate the costs and benefits of stock enhancement, marked barramundi were released into the Johnstone River in Queensland (Rimmer and Russell 1998). Stocked fish comprised about 20% of barramundi from the relevant size classes in subsequent catches. Cost-benefit analysis indicated that less than 1% of stocked barramundi needed to be recaptured to cover the costs of the stocking program, but whether the resident population was increased by the release of hatchery fish, or whether some of the resident population was merely displaced, was not tested. Weiss and Schmutz (1999) found no significant change in the population size or biomass of wild brown trout populations due to stocking, despite either doubling or trebling the number of large-sized resident fish in two streams.

The effects of stock enhancement can be measured by large-scale sampling of the target population and of unenhanced control populations, together with marking of released juveniles to distinguish them from wild stock (Munro and Bell 1997). New South Wales Fisheries have begun a study of hatchery mass-marking for identifying hatchery fish (Robert Faragher, NSW Fisheries, personal communication). The study aims to assess survival of young hatchery fish after release and to identify fish of hatchery origin among wild populations. Alizarin-based materials are being tested, following on methods using visual implanted elastomer tags (Gallagher et al. 2000), strontium batch-marking (Brown and Harris 1995), oxytetracycline baths and scale-pattern analysis (Butcher et al. 2000), tests with micro-wire tags and other techniques. Collaboration between NSW Fisheries and the Victorian Marine and Aquaculture Fisheries Research has included an experimental release of 46000 alizarin-marked golden perch in each of the Campaspe and Murrumbidgee rivers.

An intensive and detailed study of the effectiveness of fish stocking was undertaken in the Maroochy Estuary, using dusky flathead and sand whiting (Butcher et al. 2000). Unfortunately, resources were insufficient for full assessments of the outcomes from stocking to be completed. Regrettably, while this study involved rigorous sampling and sophisticated analytical techniques, and planned to use independent corroboration of population changes, it suffered from a major flaw that has commonly prevented successful interpretation of this type of research (e.g. Rimmer and Russell 1998). The experiment was uncontrolled, as no independent, unstocked waters were simultaneously sampled to assess background variation in populations. Thus it could not have been reliably determined whether any changes resulted from stocking.

Multiple hazards: displacement, disease and genetic decline

The multiple hazards of fish-stocking practices relate to problems that can be classed as ecological, genetic or disease-related. Ecological problems include the displacement of wild-strain fish by releases of hatchery stock, mostly through competition for food and space as well as predation. This is becoming an increasingly severe issue as wild populations decline to low abundances, as is happening in the MDB (Harris and Gehrke 1997; MDBC 2002b), and as stocking releases expand to ever-larger numbers. Several speakers at the ASFB fish-stocking workshop reported studies in which stocking led to simple replacement of the wild fish by
propagated animals, with no detectable increase in the abundance of subsequent fish populations. Thus wild-stock genetic diversity was lost without producing any fisheries benefits. Ecological issues also include those where stocking or translocation results in alterations to the structure or water quality of the habitat itself, as can happen with benthic-feeding fish like carp (Driver et al. 1997; Roberts and Tilzey 1997). Numerous other responses amongst the whole assemblage of aquatic biota may occur (Courtney and Robins 1989). The potential for tilapia to invade from southeastern Queensland waters poses far-reaching and severe threats of this kind of broad-scale disruption to the ecology of most of the MDB river system. In Queensland, new species are invading waterways from backyard ponds after heavy rainfall. For example, the Ross River now has 13 alien species, all cichlids. Migrant groups are stocking tilapia in dams as traditional food. Translocation of native bunfish species led to local extinction of the Lake Eacham rainbowfish (Barlow et al. 1987). The national regulating authority, the Australian Quarantine and Inspection Service, lists several hundred species approved for import but, even with this extraordinarily liberal control, aquarium breeders in all states are still keeping many unapproved species and there is regular smuggling of banned fish (Low 1999). Hogan (2000) reported extensive stocking in Lake Tinaroo, Queensland, to develop the recreational fishery for barramundi, using a local broodstock strain with appropriate thermal preferences. But stocking for a multi-species fishery there has radically altered the community structure of upper Barron River; fish releases have led to the original total of three species in the catchment now having been increased to a total of 24 species.

Hatcheries producing fish species (in the MDB, mainly golden perch, silver perch, freshwater catfish, trout cod and Murray cod) for recreational fishing, aquaculture and conservation encounter a range of genetic and related stock-management issues. There are profound issues of inbreeding, low heterozygosity and relatively poor fisheries-management value among many hatchery fish (Rowland and Barlow 1985; Dixon 1990; Keenan et al. 1997; Gilligan 2000; Moore 2000 and in press; Bearlin, in these Proceedings). Potential conflicts exist among the objectives of different kinds of breeding programs, with sharp distinctions among the genetic needs of programs for conservation, recreational fisheries and aquaculture (Keenan et al. 1997). Programs conserving threatened species aim to maximise genetic diversity, while commercial aquaculture requires uniformity and enhancement in characteristics such as growth rates. Most stocking programs, especially for recreational fisheries, are undertaken with little knowledge of the genetic diversity of the stocked fish and their relationship to wild populations (Anthony Moore, Southern Cross University, personal communication; Bearlin, in these Proceedings). Market pressures and the need for profitability seriously inhibit progress by commercial hatcheries towards sound genetic practices. In hatcheries there is a lack of selection among young recruits for fitness and viability. While survival from natural reproduction is typically only a few percent, in aquaculture, where all individuals are supported, there is commonly up to 60-80% survival. There is abundant evidence that post-stocking performance (survival and reproduction) of hatchery-produced fish is inferior to that of wild fish, and there is evidence that stocked fish harm wild fish (White et al. 1995).

Hatchery fish with limited genetic variation may reduce the viability of wild populations by affecting growth, survival, recruitment and adaptability to environmental changes. In a recent hatchery-management survey none of the hatcheries responding to the survey managed for the maintenance of genetic diversity (Moore, in press). As a result inbreeding was common, few parents were used and broodstock were repeatedly used over many breeding seasons. The crossing of closely related species was also common (especially among the terapontidae) and fish were selected for breeding on the basis of traits that are valuable to commercial aquaculture, such as growth rate or disease resistance. Broodstock were also sourced from farm dams and were likely to be single-generation siblings. Genetic diversity is very likely to be lost as a result of these poor breeding practices, but they can be rectified to provide much better genetic results and the Model Hatchery Quality Assurance Program under development in NSW Fisheries may provide a basis for the comprehensive scheme of hatchery accreditation across the Basin that has been recommended in the Draft Native Fish Strategy (MDB 2002a). The Southern Cross University survey showed fish were commonly translocated outside their range and between rivers. Farm dam stocking was very common and responding hatchery operators were not concerned about where fish were stocked (Moore, personal communication). Translocating related species like trout cod and Murray cod to new environments can lead to hybridization, possibly with loss of identity for both species (Harris and Dixon 1986; Douglas et al. 1994). Genetic engineering techniques are being developed for salmon in New Zealand and North America, both in hatchery production and for ‘ranching’ of propagated fish in the wild, but the potential for unintended consequences and impacts on wild fish is generating much concern. At the ASFB workshop, a speaker in a discussion session reported that one of the largest commercial hatcheries had been involved in extensive stocking of silver perch for a period of 18 years: all of these fish were the progeny of a single pair of broodstock.
Keenan et al. (1997) and Musyl and Keenan (1992) recommended there should be no translocation or stocking of species between drainage basins (especially between the Lake Eyre, MDB and eastern drainage basins) because of species hybridisation. Keenan et al. (1997) considered that limited stocking may be permitted in riverine habitats, but only if high levels genetic variability were guaranteed. Current practices fail even to approach such guidelines. There should be monitoring of genetic variability in hatcheries, and an inventory kept, aiming to maximise outbreeding and minimise the loss of variation. These recommendations mirror those from previous literature (Rowland and Barlow 1985; Dixon 1990) and emphasise the urgent need for fisheries authorities to take effective, consistent action in protecting the genetic level of freshwater biodiversity.

The severity of both the ecological impacts from stocking and the impacts on gene frequencies depends on the abundance of the stocked fish relative to the receiving wild population. For example, while moderate escapement of inbred hatchery fish over a dam wall into an abundant wild population of the same species downstream may have minimal adverse effects, releasing thousands of the same hatchery fish into a relic wild population, especially in a restricted habitat, may be catastrophic. The more depleted wild stocks become, the more serious will be the effects of poorly designed breeding and stocking programs.

Knowledge of the diseases and parasites of MDB fish is limited and the potential role of hatchery fish as vectors of parasites and disease organisms is poorly known, although both exotic and endemic disease outbreaks have potentially devastating effects on native fish populations (Humphrey and Langdon 1986). However Langdon (1990) reviewed the available knowledge on disease risks arising from fish introductions and translocations. The fatal effects of the virus EHNV (epizootic haematopoietic necrosis virus), spread by redfin perch, provide a sobering example of disease risks. EHNV is acutely fatal to a range of native fish, including the threatened species, Macquarie perch, and only a modest proportion of the MDB fish community has so far been tested for susceptibility (Langdon 1990). Redfin perch have been detected contaminating hatchery shipments, as well as being deliberately translocated. At Queensland University, A. Dove has studied freshwater fish parasites, finding new records for Australia of parasites on weatherloach and impacts of the virulent tapeworm, Bothriocotyle affinis, on western carp gudgeons and other species. Recent developments, especially the inland culture of marine species, raise questions about the potential for new diseases to be introduced among the MDB fish community, for example the possible introduction of BPLV (barramundi picorna-like virus), which may be a virulent pathogen for native fish. Outbreaks of goldfish ulcer disease have occurred in native fish hatcheries. Reviews by J.D. Humphrey (cited in Low 1999) of the disease risk of aquarium imports showed there were few resources and little is being done to control spread of disease by ornamental fish. Some quarantine premises, all of which are operated by the industry, were unsatisfactory, presenting a high risk of transfer of exotic pathogens to fish outside the premises. Laboratory techniques for detecting the carrier state do not exist for many fish diseases. Quarantine procedures and controls were rated by Humphrey as highly unsatisfactory, especially by contrast with those for livestock, birds, and mammal pets. Low (1999) rated the system as ‘farical’, and relying ‘on luck and trust’.

Control of disease outbreaks is extremely difficult. The “Precautionary Principle” needs to be applied and potential sources and risk of disease outbreak determined on the basis that prevention is feasible and cure may be impossible. Initiatives by the Commonwealth Government are leading to progress in the fish-diseases situation. Aquaplan, Australia’s National Strategic Plan for Aquatic Animal Health has been developed, and its relevance to disease prevention and issues of translocation and fish health has been described (Bernoth, in these Proceedings). A disease-simulation exercise is planned for the MDB, with potential involvement of several jurisdictions and numerous water users who could be affected by measures aimed at containing a disease outbreak.

Problems with the ‘stocking panacea’ concept

Many among the MDB’s human community tend unrealistically to regard fish stocking as the solution for fisheries problems. Stocking is seen as a kind of panacea. This attitude has developed because the technology for massive-scale hatchery propagation is well established and pouring large numbers of young fish into waterways appears superficially to be a quick-fix technological way of dealing with difficult problems.

Increasingly the role, benefits and hazards of fish stocking are being debated in recreational fishing circles (Anonymous 2000; Harris 2002). While the general view persists among freshwater anglers that stocking is a panacea for fisheries problems, whether related to fish habitat, food, disease or exploitation, there is increasing awareness of the issues associated with species translocation including the ecological impacts and genetic and disease problems associated with stocking.
Unfortunately, the ‘panacea’ concept often diverts attention and remedial action from fundamental fisheries problems such as overfishing (Kearney 1995; Ye, Jones and Pierce 2000; Davis et al. 2000; Kearney and Kildae 2001), thermal pollution (Phillips 2001), fish passage (Keller and Peterken 2001), river impoundment (Blanch 2001) and alien species like carp (Roberts and Tilzey 1997).

The stocking panacea notion regularly appears when water-management agencies are confronted with the challenges of rehabilitating aquatic ecosystems. Routinely, in seeking solutions for cases like the enormous barrier to fish migration in the Shoalhaven River caused by Tallowa Dam, for example (Greene et al. 1997), or the need to sustain fish passage past Boggabilla Weir, managers have proposed fish stocking as an apparently simple, cheap alternative to solutions for the fundamental problem, in this case the lack of suitable fishways. And equally routinely, when the costs and benefits are thoroughly evaluated, the inadequacy of such proposals becomes plain. Effective stocking solutions would require that all the native species could be propagated (hatchery techniques have been developed for only five of the MDB species and are unlikely to be developed for the smaller, non-recreational species), that wild-strain genetic diversity can be replicated (a major challenge, even for large government facilities), and that only a few stocking releases would suffice (when in fact perpetual releases would be needed for many species). Adequate stocking would also require the release of extremely large numbers of fish, so that hatchery and distribution costs would soon far exceed the cost of more-effective, direct solutions to the problem.

Pressures from angling representatives also drive bureaucratic and political responses based on the panacea notion. Releasing hatchery stock often provides a convenient, populist response to demands for better recreational fishing, whether or not stocking is appropriate. NSW Fisheries has developed the ‘Dollar-for-Dollar’ native fish-stocking program, which involves matching funding for organisations, such as angling clubs and local councils that are raising money to purchase fish from private hatcheries to stock into public waters. The program aims to increase the stocking of golden perch, Murray cod and (in coastal waters) Australian bass, support the efforts of local stocking groups, increase production and sales from private hatcheries in NSW, and enhance recreational freshwater fishing opportunities. Funding is available where the appropriate broodstock are used to produce fry, although no data are available on the compliance with this requirement, which has previously proved extremely difficult for hatcheries. While the program is achieving some of its objectives, it has been criticised by informed angling groups (e.g. Anonymous 2000) as being poorly directed and potentially damaging for fisheries and wild stocks. There have been instances where inappropriate releases have been made in response to political and other pressures.

Another major issue arising from the panacea notion is public’s tendency to equate hatchery-bred fish with individuals of the wild strain. To the average angler, a hatchery-bred Murray cod or golden perch is no different from a wild fish. There is little if any appreciation of the radically different genetic quality, viability and conservation or fisheries values of wild strains. It is important that anglers and other members of the public should appreciate that wild fish possess a unique value, a value that is difficult or impossible to replicate or even approach with mass-propagated hatchery fish. The top priority should be the protection of wild native fish stocks (White et al. 1995).

Natural stocking: stock enhancement without hatcheries

One feature of the ASFB Stock Enhancement of Marine and Freshwater Fisheries workshop in 2000 was the emerging theme of ‘natural stocking’, in which mass releases of hatchery-propagated fish are replaced by efforts to enhance natural recruitment. Proposals included selectively increasing habitat areas for the spawning or nursery stages through special environmental-flow releases, relocating abundant cohorts of larvae or juveniles to protected nursery areas, restoring fish passage past barriers for young migrating fish, translocation of older age-groups threatened species rather than hatchery-based stocking (Linternmans, in these Proceedings) and the use of special-purpose controls on fishing to reduce impacts on spawning aggregations of fish. Publicly promoting the concept of natural stocking could become a powerful tool for increasing the levels of community understanding, for counteracting the stocking panacea notion for fisheries, issues, for negating facile ‘quick-fix’ responses and for strengthening the support of stakeholder groups interested in the condition of fish populations. Natural stocking programs would consider ecological, biological and life-history patterns when forming enhancement objectives and tactics.

Keenan et al. (1997) recommended natural recruitment should be encouraged in preference to stocking. Under the new concept of natural restocking, wild strains of native fish would be supported and encouraged to recruit, grow and migrate by effectively managing the river-flow,
habitats, disease and exploitation issues that have been the primary causes of their declines, and by protecting them from potential adverse effects of hatchery-fish releases. Because anglers expect to maintain close, ‘hands-on’ involvement in managing their fisheries, and since stocking activity has now become the main, firmly entrenched aspect of this involvement, an effective alternative activity will be needed if its role is to be reduced. Some of the suggested natural stocking activities may present opportunities for collaboration between fisheries managers and anglers but they are unlikely to be sufficiently frequent or widespread to fill the need completely. Another activity, designed specifically to meet this need, is the New South Wales Fisheries Department’s Angling Catch Database. This project involves collaboration between the department and angler groups in monitoring the status of recreational fisheries. It provides useful, long-term monitoring data as well as productive involvement for anglers and valuable avenues for feedback, education and liaison. In Queensland and Victoria, departmental liaison with anglers is largely driven through routine consultative meetings based on stocking activities (Holloway and Hamlyn 1998; Breddin, Hamlyn and Cheetham 2000; Ainsworth and Winstanley 2000).

A proper place for fish stocking and translocation in the MDB

A primary goal of fisheries management is to increase population size or growth without harming wild stocks, but stocking is only one of many tools available for restoring depleted populations and should be evaluated together with other tools such as habitat restoration and harvest controls (HepPELL and Crowder 1998). For many late-maturing fish, such as the target native species in the MDB, an artificial increase in juvenile cohort size does not necessarily increase population growth significantly, even if hatchery juveniles survive and grow well and do not adversely affect wild stocks. Management efforts that focus on re-establishing healthy adult stocks and protecting sub-adults may restore declining populations more effectively. Population models and life-history analysis can be very useful for establishing performance criteria and evaluation methods as well as for choosing management options that are likely to be effective (Bearlin et al. 2002).

Cowx (1999), in noting how many stocking programs are carried out without definition of objectives or evaluation of the potential or actual success of the exercise, described a strategic approach to stocking aimed at maximizing the potential benefits, using a procedure that reviews factors such as the source of the fish, the stocking density, the age and the size of fish at stocking, the timing of stocking, and the mechanism of stocking. Similarly, Blankenship and Leber (1997) described a ‘Responsible Approach’ concept for marine fish stock enhancement with ten key components, each considered essential to control and optimise enhancement. The components include many of those already outlined, plus the need to define quantitative measures of success for enhancement programs, to identify released hatchery fish and assess stocking impacts, to use an empirical process for defining optimum release strategies, and to use adaptive management. Jackson (Peter Jackson, Queensland Department of Primary Industry, personal communication) recommended MDB stocking strategies should consider size at stocking, time of stocking (related to availability of food, time for significant growth before winter) locality of stocking (e.g. available cover) and other species present. Hutchinson et al. (2002) and Simpson et al. (2002) provide research results on these issues for stocking impoundments. Ecological, biological and life-history patterns must be considered when forming fish-stock enhancement objectives and tactics. Optimised release strategies and increased fitness for life in the wild are required (Munro and Bell 1997).

Noting that assessment is needed of the environmental costs of stocking, alongside standard economic analyses, White et al. (1995) emphasised that stocking programs should be separated from healthy and potentially healthy wild stocks. This echoes reminders (P. Jackson, personal communication) that impoundments and their fish populations remain part of rivers, and are not isolated except for off-stream storages. The degree of isolation and protection of the river itself depends on the scale and relative storage capacity of the impoundment, expressed through spilling or discharge frequencies, as well as the proportion of the river system upstream of the dam wall. As their size relative to the channel diminishes, weirs are increasingly integral parts of river.

In the light of this expanding knowledge, far-reaching proposals for the future management of the MDB’s fishes have been presented in the Draft Native Fish Strategy (MDBC 2002a). Problems with current fish-stocking practices have been emphasised, as well as the issues of alien species and the threats from further potential invasions. The need for measures to protect wild fish from potential adverse effects from the aquaculture industry is also emphasised. Eight management actions, encompassing management, research and investigation and community engagement are proposed in relation to fish stocking and translocation (MDBC 2002a):
periods, especially those (numbers 1, 2, 3, 5, 7 and 8) that deal with coordinating agency activities and informing and involving the broader community.

Conclusions

Government resources devoted to freshwater fish and fisheries, especially in the States and Territories, are seriously inadequate and some funding programs are in long-term decline. While partner governments’ contributions to the Murray-Darling Basin Commission may go some way towards offsetting these deficiencies, management, education and research programs for freshwater fish resources are severely under-funded and inadequate overall to achieve rehabilitation and sustainability. Program commitments often seem seriously out of balance with the status of freshwater fish as a major component of Australia’s natural resources. Much of the effort and funding has been directed towards short-term political issues rather than towards substantive programs on the resources and their management. Policy is often subjugated to politics. Ethical considerations in altering the fundamental character of MDB aquatic environments have had scant consideration (Georges and Cottingham 2002). Notions of ‘small government’ and the politically dominated, ‘Washminster’-style ‘senior executive service’ have led to failures and inadequacies in public administration and they impede effective management. Such unbalanced, ineffective approaches can only be turned around through the pressures of a well-informed community that values the nation’s unique heritage of freshwater fish and is committed to sustaining it.

Clearly, many issues and problems are associated with fish stocking and translocation in the Basin. Inadequate knowledge, insufficient resources and regulatory deficiencies limit the effectiveness of current management. The full implications of threats from lost diversity at the genetic, population and community levels among native fish, from intrusions of alien species and their impacts on indigenous aquatic communities, and from the spread of diseases and parasites are poorly known. Better knowledge, greater resources and more-effective management are urgently needed to conserve and rehabilitate the Murray-Darling basin’s unique fish communities.

Fish stocking should continue to be used as a valuable tool for managing recreational fisheries for both native fish and trout in artificial impoundments. The efficiency and productivity of this management could be radically improved through skilled research targeting the many outstanding gaps in our knowledge of the dynamics and human usage of these manipulated populations. Consistent guidelines, accreditation and effective supervision are needed to ensure hatcheries are producing viable, disease-free, outbred offspring without compromising their commercial viability. While there are some risks from emigration from impoundments of stocked populations, both upstream and down, these could be offset by sound stocking strategies and by comprehensive, vigorous habitat rehabilitation to enhance the resistance and resilience of relict wild populations of native fish, as proposed in the Draft Native Fish Strategy.

Stocking native fish into streams, especially those with relict native populations, is fraught with hazards and generally provides only short-term benefits for recreational fishing, if any. Trout stocking in streams appears to provide modest and highly variable results, mostly dependent on climatic conditions. It should be restricted to traditionally stocked streams where there are no threatened species of native fauna and where strategic stocking follows a community consensus that has been built on balanced assessments of the benefits and costs. I see no justification for any further introductions of species into the Basin, but there is a pressing need to prevent potential new invasions, most immediately by tilapia from south-eastern Queensland. Programs seeking to rehabilitate threatened fish species have apparently
had little success when hatchery-bred young fish have been released using current methods. Although future surveys may yet disclose so-far-unrecognised successes, new strategies need to be tested in view of international literature, preliminary modelling data and the favourable results from translocating wild adult fish.

The perception among the Basin community that fish stocking is the answer for problems of damaged fish habitats, over-exploitation, alien species or disease need to be reversed. In its place, concepts of natural restocking and the unique value of wild fish need to be developed and promoted to provide a less hazardous, more realistic and positive approach.

Acknowledgments

Material presented in this paper comes from a scoping study on fish-stocking issues funded under the Natural Heritage Trust through the MDB 2001 FishRehab Program administered by Agriculture, Fisheries and Forestry Australia and this support is gratefully acknowledged. I thank representatives of State and Territory fisheries agencies for their extensive consultations and advice about fish stocking matters in their jurisdictions, especially Bill Talbot, Andrew Sanger, Mark Lintermans, John Koehn, Peter Jackson and Wayne Fulton. Mark Lintermans and Peter Jackson kindly provided expert commentary on a draft of the paper.

References


4. Community stakeholder perspectives

4.1 Recreational fishing

Ross Monash, RecFish Australia

Recreational fishers are responsible for the first fish introductions into Australia. Since then, recreational anglers have developed a long-standing tradition of stocking and targeting salmonids.

The first suggestions of introducing trout appear to have come from Tasmania. At the time of European settlement in Tasmania, there were only two angler-worthy species of fish: River Blackfish and Australian Grayling. The River Blackfish was found only in the north of the State and the Australian Grayling was extremely difficult to catch and relatively small. In comparison to England, the country from which many of the early settlers had come, and which at the time had about 40 species targeted by recreational anglers, most Tasmanian waterways were veritable empty buckets.

The first question that comes to mind is 'why not target marine species instead of introducing a new species into Australian waterways?'. At the time, saltwater fishing was still in its infancy. A renowned fishing writer of the time noted a paucity of published information on marine fishing: 'out of considerably more than half a thousand books on angling, only three dealt with the capture of sea fish' (Bickerdyke, 1887).

In the 1800s, 'acclimatisation' was at the height of its popularity, with European terrestrial and aquatic species being introduced worldwide. Reasoning for acclimatisation was twofold, firstly to provide a sense of familiarity for settlers in the new colonies and, secondly, in recognition of the decline of the natural habitat required to sustain populations in their native countries, species were introduced to new environments to prevent their extinction.

The earliest reference to the introduction of salmonids is in the 1840s when several Tasmanian colonists entertained the notion of 'bringing the lordly salmon to grass amongst the picturesque granite hills'.

After several failed attempts funded by keen anglers, and costing in excess of £4000, in 1864 the Norfolk set sail from England carrying 25 tons of ice encasing 181 wooden boxes containing 100,000 salmon and 3,000 trout ova. Four thousand of the salmon ova were retained in Melbourne and the rest shipped to Hobart where they were successfully introduced into the Derwent and other rivers where they rapidly grew. The first salmon introduced into Victoria were bolstered by supplies of trout and salmon from Tasmania and seven years after the first salmon introduction, two recreational fishermen caught 261 trout in two and a half hours on the Hopkins River (Dunn, 1991).

Table 1. 2000/2001 Fish stocking rates in States/Territory found within the Murray-Darling Basin catchment

<table>
<thead>
<tr>
<th>State</th>
<th>Salmonids Government introductions</th>
<th>Salmonids Private introductions</th>
<th>Natives Government introductions</th>
<th>Natives Private introductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria</td>
<td>334 000</td>
<td>400 000</td>
<td>690 000</td>
<td>330 000</td>
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<tr>
<td>NSW</td>
<td>4 409 440</td>
<td>1 991 000</td>
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</tr>
<tr>
<td>Queensland</td>
<td>4 651 470*</td>
<td></td>
<td>4 651 470*</td>
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<tr>
<td>South Australia</td>
<td>-</td>
<td>174 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ACT</td>
<td>177 000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-totals</td>
<td>4 743 440</td>
<td>574 000</td>
<td>7 509 470</td>
<td>330 000</td>
</tr>
<tr>
<td>TOTALS</td>
<td>5 317 440</td>
<td>7 839 470</td>
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</tr>
</tbody>
</table>

* All stocking in Queensland is undertaken by private stocking groups with government support

Results of the yet to be released National Recreational and Indigenous Fishing Survey, indicates that there are 3.4 million recreational fishers in Australia making at least one fishing trip per year. These 3.4 million anglers make a total of 23.3 million fishing trips per year, 4.5 million of which are specifically to freshwater fisheries. Of the trips to freshwater, 2.55 million trips are made to freshwater rivers, 1.7 million trips to public impoundments and 0.24 million trips are made to private impoundments (Pers comm. Gary Henry, August 2002).
are based on direct and indirect expenditure. Direct expenditure includes the purchase of tackle, rods, reels and bait, and indirect expenditure includes the purchase of boats and specialised vehicles, gear/charter hire and accommodation costs (Dominion Consulting Pty. Ltd, 1999).

Such high rates of expenditure create a significant economic injection to rural communities, most of which are located in high unemployment areas. As a result of recreational fishing, jobs are created in the tourism and hospitality industry as well as in bait and tackle outlets.

Benefits of fish stocking can include the obvious such as increased strike rates, larger fish caught, ability to catch species that otherwise may not be present in the area, bolstering of natural populations enabling long term survival and improved regional economies. However, the practice of stocking fish also gives those taking part in stocking activities a sense of ownership over the fish stocked. This sense of ownership equates to a property right which brings with it an increased interest to see that the whole ecosystem upon which the fish depend is managed in a sustainable manner. In my experience, stocking groups often become involved in habitat restoration and the management of the waterways in which fish are stocked. This is in stark contrast to the ‘tragedy of the commons’ that is currently occurring across the Murray-Darling Basin.

In Australia, we currently have both trout stocking and the stocking of native fish. Each has its place and a balance must be struck.

Australian anglers accept that trout impact significantly and adversely on our native fish populations, particularly smaller species such as galaxiads, and gudgeons and where specific native fish populations/species are threatened or under risk of extinction, trout will have to be managed in such a way as not to impact significantly on the native species, even if this means the cessation of trout stocking in those areas or the deliberate removal of trout from the habitats in question.

Trout are a cold water species and as such should be stocked only in cold water impoundments and, to a limited extent, in cold water streams that are marginal or unsuitable for native species. These, mostly highly modified environments, are the main regions in which trout are currently stocked and where they have been stocked, in many cases, for over a century.

Trout should not be stocked where they will significantly impact on native species, particularly threatened native species, which have the realistic potential of long term survival.

Where introduced species such as trout are identified, by peer reviewed scientific studies, as a significant threatening process to a threatened species, they should no longer be stocked in areas likely to enable threatened species’ recovery.

There is a need for fisheries agencies to identify, limit, and set aside areas that are suitable for the stocking of introduced species, particularly trout. Once these ‘trout havens’ have been identified, the stocking of trout in natural and semi natural areas outside the havens should be subject to strict controls and formal management authority approval.

As far as future introductions are concerned, Recfish Australia supports the IUCN-World Conservation Union position on the introduction of species and believes that no exotic fish species should be introduced into natural habitats. Introductions into semi natural habitats should only occur if there are exceptional reasons for doing so, and introductions into man-made habitat should only occur after an assessment, to establish the effects on surrounding natural and semi-natural habitats (IUCN, 1987). In the development of a system of Marine Protected Areas (MPA), Environment Australia used the IUCN MPA categories as a basis for its legislation. Through negotiations with stakeholders, Environment Australia is well on the way to developing a system of reserves acceptable to all stakeholders.

The long term future of freshwater angling is dependent on the ability of target species to adapt to substantial and ongoing environmental changes occurring within the Murray-Darling Basin. Stocking with fish of inappropriate genetic stock, which have been translocated, has the potential to inhibit this adaptability.

Currently little, other than economic incentive and the wishes of fisheries stocking management, is in place to prevent inappropriate translocations of species. Native fish for the use of restocking undergo no genetic analysis to determine whether or not they are genetically compatible to the existing stock. Stock is usually sourced from hatcheries close to the point of release but the only incentive for the stocking of fish from nearby sources is financial. Stocking with fish supplied from nearby hatcheries saves significant transport costs. What would happen if the local hatcheries were to close? Fisheries officers could stock ACT waters with fish sourced from as far afield as South Australia or Queensland. The basis for stock selection to be used in fish stocking should be governed by, and only by, genetic compatibility of the fish to be stocked with the fish naturally present.
The precautionary principal states that where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. A lack of scientific understanding of regional and localised genetic characteristics is not an acceptable reason for the ad hoc translocation of native species. The precautionary principal must be applied to the translocation of native fish species as well as for introductions.

In the past, inappropriate stockings of private impoundments have been responsible for numerous species entering our waterways; of particular concern is the spread of Redfin perch. Redfin perch is becoming a more popular angling species, I believe mainly as a result of declining catches of native species.

Recfish Australia would like to propose a ban on the ad hoc stocking of exotic species on private property. Stocking on private property should only take place if sufficient preventative measures have been undertaken to ensure that there is no possibility of the accidental release of introduced species that have can potentially colonise local waterways. Fish stockers stocking private waters should be encouraged to utilise only native species within their range, sourced from genetically secure stock.

Recreational fishers have undoubtedly been responsible for numerous translocations and introductions through the irresponsible use of live bait. Recfish Australia has developed the National Code of Practice for Recreational and Sport Fishing which specifically states that exotic species should not be used as live bait and all captured live bait should be released only into the waters from which it was collected.

As demonstrated by the Code of Practice, the recreational fishing sector is involved in education programs aimed at reducing the number of unplanned releases. The National Carp Task Force has also been very active in educating the public on the impact of carp on the environment. The forthcoming evolution of the National Carp Task Force into the National Carp and Pest (Invasive) Fish Task Force, provides the opportunity for this group to expand into controlling other pest aquatic species.

Conclusions

The future of freshwater fishing in Australia is dependent on healthy aquatic ecosystems and the fish they sustain. Stocking is only one of a number of mechanisms that can be used to conserve fish populations and contribute to the improvement of the recreational fishing experience.

Further decline of our native species targeted by anglers is undoubtedly going to lead to greater pressure by anglers to stock with both native and exotic species. Rigorous stocking guidelines must be developed and implemented as soon as possible.

There is a need for fisheries management agencies to place tighter controls on stocking practices for both native and desired introduced species. Such controls need to specify areas suitable for the stocking of trout and also provide clear guidelines for the stocking of native species to prevent weakening of the gene pool.

Fundamental changes to stocking and translocation practices for aquatic species are required. To get these changes right quickly, I would suggest a top down approach. The basis for the development of appropriate guidelines should start with the IUCN position statement. Public and stakeholder consultation could then be undertaken to develop legislation acceptable to all.

The IUCN Position Statement on Translocation of Living Organisms: Introductions, reintroductions and re-stocking is a good starting point for the development of national guidelines for the introduction and translocation of fish species.

The stocking of native and introduced recreational target species provides benefits not only to recreational fishers but the community as a whole, through tourism and the social benefits inherent in recreational fishing. If stocking and translocation methods are inappropriate, or guidelines inadequate, the programs risk the long term survival of the very species that are being stocked and nurtured. Conversely, if we do it correctly in future, we not only improve biological and recreational fishing outcomes but the wider socioeconomic benefits which accrue to the community from these outcomes.

Footnotes

1 Note: In this paper ‘Introduction’ refers to the intentional or accidental dispersal by human agency of a living organism outside its historically known native range and ‘translocation’ refers to the intentional or accidental dispersal by human agency of a living organism within its historically known native range.
4.2 Central Region Aboriginal Land Council

**Bill Phillips, Chairperson**

Bill Phillips acknowledged the welcome to Ngunnawal Country, as extended to all participants by Matilda House at the opening, and said that he appreciated the opportunity to provide his perspectives about the issues on the table at this workshop on behalf of the Central Region Aboriginal Land Council.

Bill explained to the workshop some of the issues which are of concern to Aboriginal people in his region. Namely issues of access to traditional fishing resources and respecting and understanding the cultural significance which fish and fishing practices have for the indigenous peoples of the central region. He stressed how to these Aboriginal communities fishing was, and continues to be, an important part of passing on cultural heritage between generations and that future management of fisheries needed to be sensitive to this.

In conclusion, Bill said that it was pleasing to see that the workshop organisers had sought to have indigenous peoples issues and ideas incorporated into the workshop and looked forward to working with the others present to have these views reflected in the recommendations of the workshop.

4.3 Conservation

**Dr Paul Sinclair, Director, Healthy Rivers Campaign, Environment Victoria**

*“Murray cod: sustaining memories and sustainable futures”*

River skippers who travelled the Murray River during the late nineteenth and early twentieth century were contemptuous of farmers who thought the Murray started in a hole just above their property and ended at the most immediate downstream bend.

The skippers knowledge of great stretches of the river was unusual. It is unlikely that many people have had an intimate knowledge of the whole of the Murray’s 2570 kilometre length. Most settler Australians have known the river through specific moments and qualities, and by empathising with particular species of flora and fauna. These elements of the river’s larger reality have offered some settler Australian’s columns of light into the emotional, ecological and historical depths of the Murray.

Settler Australians have been particularly attached to Murray cod. These fish have been the focus of many settler Australians memories and stories. They have been the source of metaphors and experiences by which individuals were able to think themselves into the inter-related dimensions of the river’s life.

However these attachments are now threatened by the demise of once abundant Murray cod populations. During the 1940s and 1950s vast numbers of Murray cod were caught by professional and amateur fishermen. For example, in the first week of the 1953 open season on Murray cod, professional fishermen sent up 6 tons of fish from Mildura to the Melbourne markets. This abundance is a stark contrast to the present day condition of Murray cod populations. In August 1997, the New South Wales Fisheries Office of Conservation and the Cooperative Research Centre for Freshwater Ecology released the results of a two year survey of New South Wales rivers. The survey team used the most efficient types of fishing gear but did not, in two years of sampling 20 randomly chosen sites along the Murray River, catch a single Murray cod.

It is now known that the health of Murray cod populations are an indicator of widespread ecological change. The river has been in severe decline since the end of the Second World War, largely because of its regulation by
a series of locks, weirs and dams. Pollution, overfishing and irrigation and urban development have also played a significant part. While concern is regularly raised about the deterioration of the Murray’s water quality and biodiversity, the broader cultural consequences of this decline are rarely considered.

In the past it was generally accepted that the development of the river would exact environmental costs. It was thought that the benefits of river regulation and irrigation would create a new river so bountiful in agricultural, horticultural and viticultural products that the old, unregulated river would soon be forgotten. This story has dominated settler Australian perceptions of the Murray and encouraged them to think of themselves as conquerors of land and water. However river regulation has not provided the unlimited rewards that it promised. Salinity now threatens to destroy the last vestiges of the river’s past by poisoning places, species and qualities of significance to Aboriginal and settler Australians.

The decline of Murray cod has reduced the opportunity for settler Australians to find pathways into the ecological and human history of the river. Murray cod’s presence has bonded individuals to the river, and contributed to some settler Australian’s feeling a sense of moral obligation towards it. People have empathised with Murray cod because they have been a symbol of the river’s essence. Knowledge and experience of Murray cod have allowed settler Australian’s to feel that they have had access to the river’s ancient secrets. These fish made people feel that they belonged to the river.

Individuals who had spent hours waiting in the shallows of a wetland during duck hunting season or had searched the river’s surface for signs of unseen lives often forged strong relationships to places and species. These people’s knowledge and skill as hunters contributed to their sense of belonging to the river. The erosion of the river’s biodiversity now means that these ways of establishing a connection to the river are no longer sustainable.

The ambiguous stories of care and exploitation told by settler Australian fishermen offer valuable insights into the inter-relationships between ecologies, geographies, and histories. The memories of hunters offer more hope than the rhetoric of irrigationists who continue to see the river as a water delivery system and drain. And, unlike the particular brand of environmentalism which thinks that the decline of the river only reveals destruction, the memories of hunters offer a more complex understanding of settler Australians relationship with the Murray.

The fishermen’s memories are more hopeful because, unlike many who casually reap the rewards of the river’s regulation, the death of each fish allowed them to directly witness the implications of their desire to make the river part of their life.

Murray cod had evolved for a river that had ceased to exist by about 1966. In that year, A. Dunbavin Butcher of the Victorian Department of Fisheries and Wildlife reflected on how ‘relatively few of the natural characteristics of the uncontrolled river system remained’. This fact did not curtail fisherman’s dreams of catching one big Murray cod whose age-span could parallel their captors lives and soothe doubts about the overall health of native fish.

Post-war fishermen were connected by ephemeral and eclectic memories to an older, pre-regulation river residually preserved in the present by Murray cod. A mature fish may have been spawned around the same time as its captor was born, and popular and scientific knowledge of the river from which Murray cod had evolved was as fragmented as a fisherman’s own childhood memories. Fishing was an intensely contemplative, personal experience which relied on detailed knowledge of currents and snags; of how subtle changes in the colour of the water would affect the catch or how weather patterns influenced fish. This knowledge was not shared readily. When a professional fisherman who fished a section of river upstream of Swan Hill died recently, no-one knew where to find his nets. It wasn’t until weeks later, after the level of the river had fallen and exposed its banks, that his nets, full of decaying fish, were discovered: a rotting eulogy to the old man’s skill.

Settler Australian’s have, like Aboriginal peoples, claimed that Murray cod is an expression of the river’s soul. In Aboriginal stories Murray cod feature as the creator of the Murray. These stories vary between regions along the river but the general narrative remains similar. One version recounts how a hunter from Creation times chased a giant Murray cod from New South Wales to Lake Alexandrina in South Australia. The bends and reaches of the river were formed as the fish thrashed along the channel. Settler Australian’s, following the Aboriginal lead, have called the fish the river’s “wise old man” and its patron saint.

There is a tradition of settler Australians seeking knowledge about empirical and symbolic relationships between people, the river and its fish from within the bodies of individual Murray cod.

The ability of Murray cod to resume residence of a particular snag months after they left has only recently been determined by radio tracking of individual fish carried out by the Department of Conservation and
Environment Victoria and the Murray-Darling Basin Commission. Transmitters which allowed scientists to track fish for up to three years were inserted into the body cavity of individual fish and a stainless steel wire aerial passed out through the left side of the fishes body. Signals from the transmitter could be tracked from land, boat or aircraft.

An older and less scientifically rigorous effort to understand Murray cod’s habitat patterns is found in stories about its skin map. Some fishermen believe that skin taken from behind the gills revealed a detailed picture of the part of the river where the fish was caught. A slight variation on this story suggests that the tree-like markings on the cod’s swim bladder were an image of the fishes birth place.

The few documented references to this story claim that it originated in the experiences of old bushmen and it seems possible that this story may have been absorbed into settler Australian fishing lore from Aboriginal culture. As the Murray cod bones found near the burial site of the 30 000 year old Mungo Woman attest, Aboriginal’s have been keen hunters of Murray cod for generations. After invasion and settlement, Aboriginal fishing camps continued to exist along the Murray and the capture and sale of native fish provided a valuable source of food and income well into the 1960s. Perhaps settler Australian’s absorbed the cod skin story into their own lives, just as they had done with the idea that Murray cod were the soul of Murray River.

The Murray cod skin map is a mythical guide to the river which allows people to believe they have access to the fish’s otherwise unchartable life. Each individual fish is inscribed with its own unique map created from its specific experience of time and space. Each fish holds within it knowledge of the river that remains hidden until a fisherman, who, by catching the fish, displays some intimacy with its life within the river. The skin map is a popular symbol of the profound association between Murray cod and specific places within the Murray River. So, in a loose way, the skin map pre-empts the discoveries made with the assistance of radio tracking devices implanted in Murray cod bodies.

The skin map story is one of a number of stories Bub Sebastian tells about Murray cod which reveal the ambiguity of settler Australians attachments to the river. Bubs real name is Ivan Murray Sebastian, but he’s been known as Bub since his birth in 1921.

Bub and his wife Flora live up behind the Hume Dam at Mitta Mitta in the foothills of the Australian Alps. Each time I’ve visited Bub I’ve left with two sorts of gifts. Bub makes chutneys and sauces from home grown vegetables. His produce has won handfuls of prizes at the Albury Agricultural Show. Bub bottles his chutneys and sauces in a menagerie of rigorously sterilized peanut butter and coffee jars. Hot wax is poured in to seal the jars contents before a wrist-tight lid is applied. Bub glues his own labels on the jars indicating the type of sauce contained and the date of its production. For example a typical label will have written in copper plate ‘Bub’s Tomato Sauce, 20 March 1995’, or ‘Fruits and Spices Chutney, November 1995’. I’ve always left Bubs house with half a dozens assorted jars of his produce.

Bub’s second gift are his stories. When he tells a story he turns to long dead people, and by changing the tone of his voice, puts words into their dry mouths. His sentences are filled with ‘bloody hells!’ and ‘Oh Jesus!’, said with an incredulous wonder that softens the edges of harsh words. He speaks with a gentle voice and give his stories the rhythm of a recited recipe. Some of his best stories are about Murray cod.

Fishing had been the source of most of Bub’s contact with the Murray and Darling Rivers. As a child, Bub and his brother Ray spent most of their Christmas holidays camping at a place known to them as ‘Tea Trees’. They’d cut saplings and make a crude frame over which wattle tree branches were leant: we used to love being there...I love the bush. Most weekends the brothers spent fishing.

In 1995 Bub’s brother Ray, who had moved to Queensland, was admitted to hospital before they were to leave on a fishing trip to the Darling River. Doctors found a lump as big as an orange behind his heart. Ray decided he did not want to be kept alive on a machine. Bub greeted the news of Ray’s terminal condition with a phrase that resonated with the resourcefulness the brothers had shown in the bush; they’d find a way out of it, said Bub. Ray died soon afterwards. On the wall of the Sebastian’s kitchen is a talismanic photograph of Ray and Bub holding four of the 270 lb of fish they caught on a trip to the Darling River in the early 1960s.

In 1998, as part of a collaborative exhibition with sculptor John Davis and composer Mark Pollard, I wrote a series of vignettes about peoples’ relationships with the river. One of them was loosely based on stories told to me by Bub.

Each Murray cod has a map of its birthplace inscribed upon its skin. Our father told us this. He worked on the dam and on weekends taught us to love the bush. The skin map was hidden within the cod so the desire to find its home cost the fish its life.
My brother and I caught cod in a drum net. Water fell away from the mesh of the net as we pulled it from the river. We brought the cod into our world and made it part of the love we shared between ourselves. My brother killed and cleaned the fish then held its skin map to the sun and searched for his own likeness amongst the red gum snags and deep river holes.

Years later, after my brother had died and only my grief travelled with me into the bush, I returned to our fishing place and saw him again. He was big as a wheat bag and moving through the water with the grace of a warm breeze.

For Bub Sebastian, and those like him who have spent a great part of their life involved with the river, Murray cod are characters woven into memories and life stories. Murray cod are repositories of meaning, at once symbolic of profound social and ecological change, while also deeply rooted in specific times and places. Murray cod are tokens of a way of life. People have fished for them because the act of catching them partially defines who they are and the lives they remember.

The stories Bub tells about fish are complicated because they blend exploitation and care, regret and satisfaction. Bub loves Murray cod, thinks there is no fish to compare with its sweet flavour. For 30 years he went on an annual fishing trip with friends along the Murray or Darling Rivers. He looks back on these trips with a mixture of pleasure and remorse. We wouldn’t even bring yellowbelly home. We were too bloody proud, we only wanted cod...Now I get crook on myself...because no stream could stand the amount of fish [we took]...We only had lines and rods and we caught them legally, but we came back to Wodonga with a quarter of a ton of cod. We had the boat full, we had the back of the utility full of bloody cod...it was unlimited.

Bub knows Murray cod are no longer unlimited. In 1995 John Koehn, Australia’s leading expert on freshwater cod, told the Age newspaper how saving ‘Murray cod goes way beyond conservation. It’s part of our culture’. The trouble scientists like Koehn faced was “that we don’t know anything about this beast that we’re trying to save...There’s obviously something wrong, they’re going down the tube faster than anything else. They’re not going to last the next 200 years unless something drastic is done”.

Efforts are being made to improve the chance that Murray cod will remain living within the river. New South Wales authorities have phased out commercial fishing for Murray cod and some efforts have been made to improve their habitat by leaving snags in the river. In South Australia commercial fishermen still fish for Murray cod and a bitter debate is currently raging at public meetings and on the letters page of local newspapers about their right to do so. Some professional fishermen argue that they, like the fish they catch are part of the river’s heritage. Scientific data collected from New South Wales would suggest that professional’s use of gill and drum nets allow them to target remnant populations of Murray cod.

It is now the time for decisions to be made about which attachments to the river are sustainable, and which are not. The decline of Murray cod raises difficult decisions about the sort of river settler Australian’s want to live with. How can we foster deep relationships with the river while keeping its fish alive?

John Davis, one of Australia’s pre-eminent sculptors passed away recently. John grew up near the Murray and considered Murray cod to be a ghost of his own past. He talked of the river and the adjacent mallee as being his country, and gained deep satisfaction when he was able to collaborate with Koori artists who painted their own stories on Murray cod he’d made from bitumen, eucalyptus twigs and calico. He said it was good to celebrate with other people who claimed the Murray cod as central to their culture and their country.

It’s time that more settler Australian’s started valuing these sorts of connections. We need to start telling stories about the difficult and ambiguous relationships we have with particular species, and acknowledge the ways that their lives interconnect with our own and bind us to a deep past.

4.4 Industry

Bruce Sambell, President, Aquaculture Association of Queensland, Managing Director, AusyFish

Commercial Aquaculture in Queensland

Aquaculture in freshwater in Queensland is developing steadily. The development is strong and sustainable. The variety of species is as diverse as the method of culture. Redclaw crayfish (Cherax quadricarinatus), common yabbies (Cherax destructor), and freshwater shrimp for bait, are the most common invertebrates being cultured.
Silver perch (*Bidyanus bidyanus*), Jade perch (*Se Corpum barcoo*), and Barramundi are the most common fish under culture, however there are a number of other native species showing considerable promise. These include Sleepy cod and Australian bass.

Most of this aquaculture activity has taken place in earthen ponds, however some of the species are also being cultured in Recirculating Aquaculture Systems (RAS). In fact some species are biologically unsuitable for open pond culture. These RAS are high-technology, expensive, and very efficient. They are capable of producing large tonnage of fish in the minimum amount of water. Recently there has also been a move towards cage culture. That is, growing table fish in cages within large ponds. This method is also demonstrating some considerable efficiency.

Native fish hatcheries generally employ the open pond method to produce their fingerlings. Hatcheries that are situated above the one in one hundred year flood level are extremely secure provided reasonable measures are taken to ensure cultured species remain within the licence area.

When considering the approval of an aquaculture licence it is important to consider the culture method to be employed by the proponent. RASs are the most secure form of aquaculture, followed by cage culture then open ponds.

**Queensland Fisheries Service and Aquaculture (QFS)**

Aquaculture in Queensland is well supported by the QFS. QFS Extension Services are available from most regions of the state. QFS officers are based in Cairns, Townsville, Rockhampton, Bundaberg, Kingaroy, Bribie Island and Brisbane. These services include fish health. Experienced officers are involved in the inspection and approval process of aquaculture licences. Other aquaculture centres, such as the research facility at Walkamin on the Atherton Tablelands are also able to offer support to freshwater aquaculture.

Farm security

Freshwater aquaculture can and should be safe from unwanted escapes. Control methods are simple but effective in preventing escapes from a freshwater fish farm. In November 1999 the Aquaculture Association of Queensland, worked with the Department of Primary Industries, to introduce its *Industry Environmental Code of Best Practice for Freshwater Finfish Aquaculture*. Under this plan escape prevention mechanisms must include the following:

- The screening of pond/tank discharge structures with an appropriately sized mesh;
- The screening of farm discharge structures with an appropriate sized mesh.

**Noxious fish and translocation**

Queensland has declared a number of fish as ‘noxious’, including:
- Mosquito fish
- Carp
- Weather loach
- Nile perch
- Electric eel
- Piranha, and others.

All of the above are non-native species, however it is possible for native species to become pests outside their natural range. Last year in NSW the Barred grunter, AKA Banded grunter or Striped grunter, was declared noxious. This is an Australian native species found from the Burnett River, in South-East Queensland, and across the northern parts of Australia. It is likely that the translocation was a result of a contaminated shipment of fingerlings. Similar translocations of this fish have also occurred in South-East Queensland. To the best of my knowledge there have not been any accidental translocations since the introduction of the *Industry Environmental Code of Best Practice for Freshwater Finfish Aquaculture*.

While farm security is the responsibility of the holder of the aquaculture licence, the release of fish into farm dams and public dams is the responsibility of the person or persons actually releasing the fish. Responsible hatchery operators advise property owners who intend to stock their farm dam, on species which are suitable and permitted in their dam. Hatchery operators have less control with fingerling deliveries to stocking groups. The responsibility for stocking the correct species, or strain of fish, is on the holder of the ‘stocking permit,’ this is usually the stocking group. This is a problem area
as members of stocking groups are generally not fish experts and are not qualified to detect shipments which are contaminated with unwanted species. There is a clear need for an education process to ensure the stocking groups and owners of private farm dams are aware of the consequences of stocking ‘the wrong fish.’

Queensland Stocking Program

Stocked Impoundment Permit Scheme

This scheme has operated since 12 July 2000. Queensland fish stocking groups have benefited from more than $809,000 raised since the introduction of the Department of Primary Industries Queensland Fisheries Service (QFS) Stocked Impoundment Permit (SIP) scheme. Since the SIP scheme was introduced in July 2000, $612,000 has been allocated to stocking groups to purchase fish and for other activities aimed at enhancing the fishery. (QFS press release 13/9/2002.)

Currently the Stocked Impoundment Scheme includes 25 dams, these are;

\begin{itemize}
  \item Bill Gunn Dam (Lake Dyer), Lenthalls Dam, Bjelke-Petersen Dam, Leslie Dam, Boondooma Dam, Maroon Dam, Borumba Dam, Moogerah Dam, Burdekin Falls Dam, North Pine Dam, Cania Dam, Peter Faust Dam, Connolly Dam, Somerset Dam, Coolamunda Dam, Storm King Dam, Eungella Dam, Teemburra Dam, Gordonbrook Dam, Lake Tinaroo, Isis Balancing Storage (Lake Gregory), Wivenhoe Dam, Kinchant Dam, Wuruma Dam and Lake MacDonald.
\end{itemize}

Four more may soon be added, Cressbrook Dam and Cooby Dam near Toowoomba, the Glenlyon Dam near Stanthorpe and the Callide Dam near Biloela. Apart from the Stocked Impoundment Permit Scheme there are many stocking groups in Queensland actively involved in stocking public impoundments and a few rivers. More than 200,000 Queenslanders fish in freshwater at least once each year. Many freshwater fishing spots attract a significant number of visiting anglers from outside the local area and are therefore important for those communities.’

Queensland Fish Hatcheries

Aquaculture licence holders who produce fingerlings do not require any special conditions on their aquaculture licence. There are no specific references to genetic management on the aquaculture licence. Fingerlings are sometimes sold to grow-out farms that may then on-sell all or some of these fingerlings. These fingerlings have usually been purchased at a reduced rate due to the grow-out farm’s purchasing position, making this a profitable practice. In some cases it has become practice to sell fingerlings that are non-performers (slow growers) to stocking groups. Grow-out farmers have not been exposed to the same education process as recognised hatcheries. The management of native fish hatcheries would benefit from a ‘hatchery licence,’ or at the very least hatchery accreditation. The production of fingerlings could then be restricted to ‘accredited hatcheries.’ This would allow for a process to better educate fingerling producers. The sale of fingerlings, an activity restricted to ‘accredited hatcheries.’

Summary

Aquaculture in Queensland is diverse and commercially valuable. The stocking program in Queensland is a valuable community asset. The AAQ is eager to work with government and other authorities towards safe stocking, and safe aquaculture. There could be a benefit from either a ‘hatchery licence’ or a ‘hatchery accreditation’ policy.

Education is the most useful tool in preventing unwanted translocations.

About the presenter.

Bruce Sambell is the president of the Aquaculture Association of Queensland Inc., (AAQ) a position held for the past six years. He also sits on a number of Government bodies as an industry consultant including:

- QDAC (Queensland Aquaculture Development Advisory Council)
- QAIF (Queensland Aquaculture Industries Federation)
- Fisheries Regional Development Committee, Hervey Bay
- Fisheries Regional Development Committee, Bundaberg
- Freshwater MAC (Ministerial Advisory Committee)
- MAC sub-committee for translocation
- MAC sub-committee for the stocked impoundment permit scheme
- In 1999 Bruce was made ‘Patron’ for ANGFA ACT. (Australian New Guinea Fishes Association). In 2000 he was appointed to the, ‘working group’ for the Conservation Genetics Inventory Project for Murray Darling River Fish.
As president of the AAQ Bruce is exposed to all aspects of the freshwater aquaculture sector in Queensland, including the hatchery sector. These hatcheries are involved in the stocking of public and private waters in Queensland with native fingerlings. As a member on the Freshwater MAC sub-committee for translocation he is familiar with the approval process for such applications. These are applications made by stocking groups to stock a new species into the impoundment they manage. Bruce is also very familiar with Queensland’s freshwater stocking program. He was instrumental in the formation of the Freshwater Finfish Aquaculture Environmental Code of Practice.

Bruce has had a background in the ornamental fish sector for 25 years. In 1978 he moved from Melbourne to Sydney where he built a chain of retail aquarium shops and a live ornamental fish wholesale business. In 1988 Bruce established a fish farm in Queensland. The farm, on 200 acres is the largest of its type in Australia. An extensive range of Australian native fish are produced at his hatchery, including Silver Perch, Jade Perch (Barcoo Grunter), Golden Perch, Saratoga, Welsh’s Grunter, Sleepy Cod and a few cross breeds. Australian native fish which are suitable for use as ornamental fish are also a major part of the farm’s business.

Bruce is a member of the ‘Pet Industry Joint Advisory Council’ and the ‘Australian New Guinea Fishes Association.’

The Freshwater Ministerial Advisory Committee in Queensland plays a key role in the in the management of Queensland’s freshwater fishes. The Freshwater MAC advises the Queensland Fisheries Service (QFS) on issues relating to the management of the Queensland, “Freshwater Fisheries Management Plan.” This includes general policy issues such as the issuing of permits for any new species to be aquacultured in the western drainages. General policy on the collection of wild stocks for use as brood-stock by hatcheries, movement of species into public impoundments which have not previously been stocked into the impoundment before, issuing of stocking permits to stocking groups, are examples of the duties of the Freshwater MAC. Bruce has been a member of the Freshwater MAC for over 4 years.
5. Government overviews and perspectives

5.1 National

Dr Eva-Maria Bernoth, Manager, Aquatic Animal Health, Agriculture, Fisheries & Forestry – Australia

Abstract

Translocation of aquatic animals can be a useful management tool for the commercial fishing and aquaculture industries as well as for the recreational fishing sector. Like any movement of live animals, the translocation of fish, molluscs and crustaceans includes the risk of spread of disease. However, in aquatic animals – especially in open water systems – disease is much more difficult to detect, identify, contain and eradicate than in land-based animals. Therefore, the adage that ‘prevention is better than cure’ holds especially true in the aquatic environment. Under the Australian Constitution, the Commonwealth Government is responsible for quarantine and international animal health matters. State and Territory governments are responsible for animal disease control within their own boundaries. Acknowledging the need for an across-border approach especially in the aquatic sector, a range of national policies has been developed to provide frameworks and achieve consistency throughout the country.

AQUAPLAN – Australia’s National Strategic Plan for Aquatic Animal Health 1998–2003 was launched in 1999 as a broad, comprehensive strategy that outlines objectives and projects to develop a national approach to disease emergency preparedness and response and to the overall management of aquatic animal health in Australia. Three of its eight programs deal directly with health-related aspects of translocation (‘Surveillance, monitoring and reporting’; ‘Preparedness and response’; and ‘Legislation, policies and jurisdiction’) whilst other programs (e.g. ‘Research and Development’) critically underpin such activities.

This paper provides an overview of AQUAPLAN and of some national policies relevant to fish translocation, e.g. the National Policy for the Translocation of Live Aquatic Organisms (1999) which presents a list of issues and principles and provides guidelines for implementation; and the AQUAPLAN Zoning Policy Guidelines (2000) which specifically address translocation-related disease issues. The paper also explains how a risk analysis process could be applied to the disease risks potentially associated with a suggested translocation.

Whilst the above mentioned policies and approaches may be considered as ‘preventative’ tools, AQUAPLAN also includes the AQUAVETPLAN series of manuals which outline methods and protocols to respond to emergency aquatic disease outbreaks. Furthermore, the presentation introduces the concept of a disease simulation exercise as a tool to test Australia’s capability to quickly and effectively manage a disease outbreak in a complex environment such as the in the Murray Darling Basin.

1. Disease in aquatic animals – a conceptual model

Today’s understanding of the development of disease in aquatic animals goes back to the famous three circles published by the microbiologist Stanislas Snieszko in 1973 (Figure 1 below).
Snieszko 1973). The three circles represent the host (aquatic animal), the pathogen (e.g. viruses, bacteria, parasites) and the environment. If an aquatic animal of a susceptible species is exposed to a pathogen, infection may result. This will inter alia depend on the species, age and general health status of the animal as well as on the virulence of the pathogen. In the graph, ‘infection’ is visualised by the area of overlap (intersection) between the two circles. Infection does not necessarily progress to disease. However, under certain environmental conditions, the situation may deteriorate and disease develops, visualised in the graph by the overlapping area of all three circles. Conducive environmental conditions include changes in water parameters (e.g. reduced dissolved oxygen, change in temperature or pH), access by predators or changes in management (e.g. new feed, increase in stocking densities). Alternatively, a pathogen may be living in an environment (represented by the overlap between pathogen and environment), and establishing a reservoir. In this case, the disease will develop only if a susceptible host is introduced.

2. The role of translocation in spread of disease

With Figure 1 in mind, one can easily imagine how translocating an infected host can inadvertently translocate an infection. A recent, very comprehensive review on transboundary (international) spread of aquatic animal diseases has been published as part of a report of an international workshop on these issues (Fegan et al., 2001).

Two scenarios may be envisaged:

a. the host is clinically sick;

b. the host is clinically healthy

That a clinically sick animal may spread disease is obvious; for many infectious disease agents (e.g. viruses), a sick animal acts like a ‘factory’ continuously producing infective particles and releasing them into the environment. Clinically sick animals should not be translocated. Figure 1 nicely demonstrates, however, that clinically healthy animals may also be infected.

‘Subclinically’ infected animals may be in the incubationary period of their infection (it is too early for clinical signs to develop). Likewise, an animal may be recovering from an infection (it is too late to see clinical signs), but it may still shed the infectious agent. A particularly worrisome group of subclinically infected animals are the so-called ‘carriers’ which may harbour pathogens all their lives. They may be able to transmit those pathogens to susceptible hosts. The true health status of any of these groups of subclinically infected animals cannot be determined without testing.

If the animals that are to be translocated are subclinically infected at the time of translocation, they may transmit the pathogen into the recipient environment and to its resident animals which in turn may become infected (and even diseased); and/or they may succumb themselves to clinical disease in the new environment. Regardless of their own health status, the animals that are to be translocated may become infected by pathogens that are already present in the new environment, either in diseased animals or in healthy ‘carriers’.

3. AQUAPLAN

Jurisdictional responsibilities for animal health in Australia

Under the Australian Constitution, the Commonwealth Government is responsible for quarantine and international animal health matters. The six State and two Territory governments are responsible for animal disease control within their own boundaries (Animal Health Australia 2002).

Development of AQUAPLAN

In the wake of the 1995 pilchard mortality in southern Australian waters, the then Standing Committee on Fisheries and Aquaculture (SCFA) reported to its Ministerial Council that priority should be given to developing a national response mechanism for fisheries and aquaculture emergencies. Subsequently, several comprehensive reviews were formally tabled within Australia; they critically assessed, and made recommendations for, Australia’s national response to fisheries and aquaculture emergencies (Jones 1995), Australia’s quarantine including aquatic animal quarantine (Nunn 1995; Nairn et al., 1996), imported fish and fish products (Higgins 1996), and management of incursions of pests, weeds and diseases (SCARM 1997).

The Australian Government has a strong commitment towards aquatic animal health issues to ensure the effective and sustainable development and profitability of Australia’s aquatic animal industries. In this context, the prevention and management of diseases are of paramount importance. In 1997, following a Cabinet decision relating to the ‘Nairn’ and the ‘Higgins’ reports (see references), the Federal Government allotted $6.7 million dollars over four years to the then Commonwealth Department of Primary Industries and Energy, now Department of Agriculture, Fisheries and Forestry.
Australia (AFFA) to implement the recommendations of both reports. Of the total sum, $2.7m were allocated to develop a comprehensive aquatic animal health plan for Australia and to address management procedures for aquatic animal disease emergencies.

AQUAPLAN – Australia’s National Strategic Plan for Aquatic Animal Health 1998-2003 (Figure 2) has been jointly developed by Government and private industry sectors and seeks to build and enhance capacity for the management of aquatic animal health. It has been developed in a manner consistent with existing arrangements in the terrestrial animal sector and, wherever possible, links into existing State/Territory government and industry health management arrangements. Between 1998 and 1999, stakeholders from governments and the private sector signed on to AQUAPLAN which was finally endorsed by Ministers in 1999. AQUAPLAN is available on the AFFA Website.

AQUAPLAN comprises eight key programs under which governments and private sector have identified priority projects to achieve the program objectives. The eight key AQUAPLAN programs are:

1. International Linkages
2. Quarantine
3. Surveillance, Monitoring and Reporting
4. Preparedness and Response
5. Awareness
6. Research and Development
7. Legislation, Policies and Jurisdiction
8. Resources and Funding.

Three of these programs deal directly with health-related aspects of translocation (‘Surveillance, monitoring and reporting’; ‘Preparedness and response; and ‘Legislation, policies and jurisdiction’) whilst other programs (e.g. ‘Research and Development’) critically underpin such activities.

National Policy for the Translocation of Live Aquatic Organisms

In 1996, the then SCFA acknowledged the need for a common approach to the issue of translocation of aquatic organisms and tasked its Environment and Health Committee (EHC) with developing a national approach to translocation. EHC and SCFA’s Aquaculture Committee, in consultation with major stakeholders with an interest in translocation and its impacts, prepared a set of national translocation policy guidelines which were endorsed by the then Ministerial Council on Forestry, Fisheries and Aquaculture (MCFFA) and published in September 1999 as the National Policy for the Translocation of Live Aquatic Organisms – Issues, Principles and Guidelines for Implementation (MCFFA 1999) (Figure 3).
Figure 3: National Policy for the Translocation of Live Aquatic Organisms - Issues, Principles and Guidelines for Implementation 1999. The national translocation policy guidelines explore the different types of translocation that occur, their associated risks, and provide a policy framework and risk assessment process against which translocation proposals may be assessed.

The National Policy for the Translocation of Live Aquatic Organisms explores the different types of translocation that occur, clarifies the issues surrounding translocation, sets out agreed national policy principles and describes guidelines for the development of translocation policies in each state where such policies do not already exist. It also explores the risks associated with translocation and provides a policy framework and risk assessment process against which translocation proposals may be assessed.

In summary, the National Policy for the Translocation of Live Aquatic Organisms:

- Raises environmental, ecological and disease issues;
- Recommends a risk analysis-based approach to translocation;
- Is a set of national guidelines consistent with international provisions;
- Is endorsed by the Commonwealth and State/Territory governments; and
- Is agreed by State and Territory fisheries agencies to be used as a basis from which to develop jurisdiction-specific translocation policies and guidelines.

AQUAPLAN Zoning Policy Guidelines

Increasingly, Australia will be called upon (e.g. by trading partners through World Trade Organization processes) to substantiate its claims of freedom from major diseases in order to support export certification and quarantine import policies. Identifying disease-free areas in a country, and clearly separating them from infected areas, can be beneficial to both export and import. In the case of disease outbreaks in an infected area, exports could still continue from free areas; for imports into free areas, special protective measures can legitimately be applied, for example allowing import only from other free areas. The procedure of delineating such free and infected areas is called "zoning".

The same principles that make zoning a useful tool in international trade provide benefits also in the domestic scene; for diseases with an uneven distribution throughout the country, zoning can help to minimise spread into, so far, uninfected areas.

The development of a policy paper on disease zoning was identified as a priority project under AQUAPLAN. Such a paper should, "explain the generic principles of zoning based on pathogen distribution, the movement principles between zones, and international relevance of national zoning."

The AQUAPLAN Zoning Policy Guidelines were prepared by a small project team in consultation with stakeholders such as the Commonwealth and State/Territory governments as well as the private sector. The AQUAPLAN Zoning Policy Guidelines were endorsed by the then SCFA and the then Standing Committee on Agriculture and Resource Management in April and August 2000, respectively, and were published in August 2000 as the AQUAPLAN Zoning Policy Guidelines (Figure 4). They are available on the AFFA website (http://www.affa.gov.au).
the generic principles of zoning based on pathogen distribution, the movement principles between zones, and international relevance of national zoning. They were jointly developed by the private sector and Commonwealth and State/Territory governments.

In summary, the AQUAPLAN Zoning Policy Guidelines

- define ‘zoning’ as the process of delineating geographic areas (‘zones’) according to the distribution status of a disease agent, with the purpose to minimise the risk of spread of disease;
- acknowledge that zoning is resource-demanding, and hence recommend implementation on an ‘as needed’ basis;
- Are a set of national guidelines consistent with international provisions;
- Are endorsed by the Commonwealth and the State/Territory governments; and
- Are agreed by State and Territory governments to be used as a basis from which to develop specific zoning policies.

4. Risk analysis

‘Risk analysis’ is the technical term for a process that we all conduct several times a day, for example, when we – as a pedestrian – decide whether to cross that four-lane, heavy-traffic street right where we are, or whether to move down to the next set of traffic lights and wait for the green signal.

Basically, a risk analysis is a process by which we try to find answers to a number of questions on a perceived risk with the aim to clearly identify the risk; assess its dimension, likelihood and possible consequences; identify some management strategies; and finally decide whether the risk is acceptable, with or without those strategies, or not at all. Throughout the formal process, maintaining communication is a key issue. ‘Real-life’ questions and the corresponding steps in a risk analysis are lined up in Table 1.

<table>
<thead>
<tr>
<th>Question</th>
<th>Step in the risk analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>What could go wrong?</td>
<td>Hazard identification (what is the risk?)</td>
</tr>
<tr>
<td>How likely is it to go wrong?</td>
<td>Risk assessment (how big is the risk?)</td>
</tr>
<tr>
<td>What would be the consequences of its going wrong?</td>
<td>Risk assessment (what are the consequences?)</td>
</tr>
<tr>
<td>What can be done to reduce the likelihood or the consequences of its going wrong?</td>
<td>Risk management (can we mitigate the risk?)</td>
</tr>
</tbody>
</table>

Table 1: Steps in a Risk Analysis. ‘Real-life’ questions and the corresponding steps in a risk analysis are lined up, using the terminology of the latter. Throughout the formal process, maintaining communication is a key issue.

As mentioned above, the national translocation policy guidelines recommend a risk analysis-based approach to translocation proposals. Clearly, the spread of disease is an identified hazard associated with translocation. The formal steps in ‘hazard identification’ and ‘risk assessment’ could look like this:

Hazard identification

There are several hazards imaginable, and some key hazards may be defined as follows:

i. Animals in a recipient environment become infected and diseased with a pathogen that enters this environment in a translocated, healthy-looking host.

Scenario: Healthy-looking rainbow trout are to be moved to top up stocks in a popular angling spot. There is concern that these trout may be infected with epizootic haematopoietic necrosis virus (EHHV), and that they could transmit this infection to trout already living there. There has never been an EHHV outbreak recorded in these waters before.

ii. The translocated host may become diseased by a pathogen it harbours subclinically at the time of translocation; this pathogen may cause clinical disease in this host because of the stress associated with translocation

Scenario: As above, but in this case, the prime concern is with the new trout which are of particularly valuable strain.
iii. The translocated host may become infected and diseased by a pathogen already residing in the recipient environment.

Scenario: A batch of a rare strain of Murray cod is to be released from a hatchery, but there is concern about the survival chances of these animals, as there have been reports of fish kills in the recipient waters. An infective agent was implicated, but the true cause was never determined.

In order to decide whether these are real hazards in a given situation, or whether they are only theoretical, the following information is required:

• Health status of animals that are to be translocated (‘what could be transmitted?’)
• Health status of animals in recipient environment (‘what is already there?’)

Whilst this approach sounds very straightforward, the necessary fact-finding may turn out to be a huge task. It starts with the realisation that we can only ever test for the presence or absence of pathogens we know. For example, we can conduct tests on the rainbow trout (that are to be translocated) that will give us a certain degree of assurance that they are not infected with EHNV. However, these animals may well harbour viruses as yet unknown.

Second, no matter how many tests we conduct to exclude the presence of EHNV, we can never be 100% sure that those fish are free of the virus. The remaining uncertainty will decrease with the number of fish tested, but even if every fish were tested — and bearing in mind that most tests require lethal sampling —, we would still not be 100% certain, unless we had a test method which does not yield so-called false-negative results. In other words, we would need to be sure that a ‘negative’ test results equates to ‘no EHNV in the sample’ in 100% of the cases (this would be a test with 100% sensitivity). Also, for many disease agents, the time of the year will determine the chances to find an infected animal.

Release assessment … consists of describing the biological pathway(s) necessary for a translocation activity to ‘release’ (that is, introduce) a pathogen into a particular environment, and estimating the likelihood of that complete process occurring.

Exposure assessment … consists of describing the biological pathway(s) necessary for exposure of humans and aquatic and terrestrial animals in the recipient environment to the hazards and estimating the likelihood of these exposure(s) occurring, and of the spread or establishment of the pathogen.

Consequence assessment … consists of identifying the potential biological, environmental and economic consequences. A causal process must exist by which exposures to a pathogen result in adverse health, environmental or socio-economic consequences.

Risk estimation … consists of integrating the results of the release assessment, exposure assessment, and consequence assessment to produce overall measures of risks associated with the pathogen identified at the outset. Thus risk estimation takes into account the whole of the risk pathway from hazard identified to unwanted outcome.

In order to conduct these steps, the following information is required:

• Are the resident animals susceptible to infection with the identified hazard(s) / pathogen(s)?
• Can the animals develop clinical disease under certain conditions?
• Can the animals transmit the disease further?
• Can the animals develop a carrier state, appearing healthy, but remaining infected and infective?
• Can the pathogen establish a reservoir in the environment and survive even without a fish host?

The above questions are only some of the more crucial ones we would need to answer, and, again, there are problems with finding the necessary information. For example, the question whether resident animals (for example, Murray cod) are susceptible to infection with a pathogen that may be harboured by healthy animals of another fish species (e.g. trout) is not that easy to answer: experiments may have to be conducted, where Murray cod are artificially infected with the pathogen in question (e.g. EHNV) and monitored for signs of disease. Problems with interpretation of those experiments arise when the cod do not show signs of disease. Remembering Snieszko’s three circles (Figure 1), we have to accept that clinical disease may develop only under a specific set of conditions.
(which just happen not to exist in our experiment), yet the cod may be infected. We may have picked a relatively resistant strain/age group of cod, and/or we may have picked a relatively benign strain of virus. How many cod do we need to test anyway, and at what stage would we call off the experiment, concluding that Murray cod are not susceptible to this virus?

Dealing with uncertainty

The examples explained above show that underpinning a risk analysis with sound scientific data can be extremely resource demanding. Where scientific data are not available and cannot reasonably be obtained, science policies may be applied to assist dealing with uncertainty.

In her paper on research needs to underpin risk analysis, Bernoth (2001) quotes Walker (1998) who describes the so-called ‘Delaney Clause’ as an example of a science policy for hazard identification; this clause governs approval of food additives under the US Federal Food, Drugs, and Cosmetic Act. It stipulates that any food additive that can cause cancer in laboratory animals is treated as a human carcinogen. Obviously, it would be difficult, if not impossible, to scientifically show that a substance (the hazard) which causes cancer in laboratory animals does not pose a hazard to humans. The Delaney Clause is not scientific in nature, rather it reflects the broader goal of protecting human health, and it reflects a conservative risk management strategy. In the area of risk assessment, the so-called ‘no-effect threshold’ is another example of a science policy: given that it is inherently difficult to establish a safe dose or level of exposure for carcinogens, any level of exposure is considered as posing some risk. A well-known science policy for risk management is the so-called ‘precautionary principle’ which operates by favouring the protection of health and/or the environment when balanced against technical feasibility, economic efficiency, etc. and thus is conservative in nature.

A degree of uncertainty should, however, not automatically trigger the use of science policies such as the so-called ‘precautionary principle’. Reasonable steps should be taken to fill our knowledge gaps to identify and assess risks, and to identify risk management strategies. In the international context, for comparison, successive Australian Governments have maintained a highly conservative but not a zero-risk approach to the management of biosecurity risks. Importantly, the effects of decisions taken on translocation proposals need to be monitored closely, to help filling the gaps in our knowledge for future reference.

5. Disease preparedness and response

Disease emergencies will occur, no matter how many precautions are taken. Therefore, it is prudent to be well prepared and know how to deal with emergencies quickly and effectively, and in a well-coordinated manner. Under AQUAPLAN, two approaches are taken, and they complement each other.

AQUAVETPLAN manuals

Program four of AQUAPLAN – Preparedness and Response – includes the development of AQUAVETPLAN, an aquatic animal disease veterinary emergency plan (Figure 5). AQUAVETPLAN is based on the existing terrestrial animal emergency disease management plan – AUSVETPLAN – which was conceptualised in the late 1970s and became operational in 1991. AQUAVETPLAN comprises a series of manuals outlining emergency preparedness and response and control strategies for aquatic animal disease emergencies in Australia. All published manuals are available on the AFFA website (http://www.affa.gov.au).
There are various categories of AQUAVETPLAN manuals:

**Operational Manuals**

The AQUAVETPLAN Operational Procedures – Destruction and the AQUAVETPLAN Operational Procedures – Disposal manuals were published in May 2002. The AQUAVETPLAN Operational Procedures – Destruction manual provides specific technical information on the rapid harvesting and destruction of aquatic animals. Information is provided that is relevant to finfish, crustacean and mollusc industries. The AQUAVETPLAN Operational Procedures – Disposal manual addresses issues such as safe transport of diseased aquatic animals and the most appropriate methods for safe disposal of diseased aquatic animals. Both manuals are designed to minimise the spread of disease in the face of an aquatic animal disease emergency. The Federal Budget Initiative Building a National Approach to Animal and Plant Health has provided funding for another operational manual, the AQUAVETPLAN Operational Procedures – Disinfection to be produced within the next 12 months.

**Enterprise Manuals**

The AQUAVETPLAN Enterprise Manuals were published in December 2000. The AQUAVETPLAN Enterprise Manuals are aimed at both government and industry personnel who may be involved in emergency disease preparedness and response and are designed to enable decision-makers to access sufficient information on industry practices and environments to be able to create applicable control strategies at short notice. The manuals are also designed to inform industry personnel of the necessary steps and factors taken into account for decision-making under emergency conditions. The AQUAVETPLAN Enterprise Manuals provide brief information on industry practices and structures and then outline approaches which should be considered in the face of an aquatic animal disease emergency.

**Disease Strategy Manuals**

The AQUAVETPLAN Disease Strategy Manual – Furunculosis was published in June 2001. It includes information about the exotic bacterial disease furunculosis, its diagnosis and options for controlling it in case an outbreak is ever suspected or confirmed in Australia. The AQUAVETPLAN Disease Strategy Manual – Furunculosis also sets out an integrated planned approach to controlling furunculosis. The manual is designed for government and industry and provides decision-makers with quick and easy access to the information needed to implement control strategies at short notice. The Federal Budget Initiative Building a National Approach to Animal and Plant Health has provided funding for additional disease strategy manuals for three finfish diseases (viral encephalopathy and retinopathy; viral haemorrhagic septicaemia; whirling disease) and two crustacean diseases (white spot disease; crayfish plague).

**Management Manuals**

The AQUAVETPLAN Control Centres Management Manual was published in February 2002. It outlines the procedures, management structures and areas of responsibility that need to be in place at the local, State and Commonwealth levels in the advent of an outbreak. Specifically, the manual describes the roles of response personnel during the initial stages of an emergency, how to develop and manage disease control centres, and the various activities that need to be undertaken in or around infected areas. The AQUAVETPLAN Control Centres Management Manual can be used operationally, either as the primary manual or as a back up for specific action plans; as a planning tool to help develop more specialised procedures; and as a reference source in training exercises. The Federal Budget Initiative Building a National Approach to Animal and Plant Health has provided funding to support the production of state-specific Control Centres Management Manuals.

**Australian Aquatic Animal Disease Identification Field Guide**

The Australian Aquatic Animal Disease Identification Field Guide was published in March 2000. The Field Guide provides an informative account of the diseases and organisms that threaten Australia’s aquatic animals. It also has information on diseases in other parts of the world and how they could affect Australia if they were to occur here. The Field Guide’s key feature is that it targets the very people whose interests and livelihoods depend on Australia having a healthy aquatic environment, the ones with the day-to-day contact with our aquatic animal life who are well placed to undertake the necessary monitoring and surveillance. The Fisheries Research and Development Corporation (FRDC) Aquatic Animal Health Subprogram is considering an update and publication of the Field Guide on CD ROM.

The Federal Budget Initiative Building a National Approach to Animal and Plant Health has also provided funding for the development of an aquatic animal Exotic Disease Training Manual. Another project funded this way is the development and conduct of an aquatic
animal exotic disease-training course to be held at the CSIRO Australian Animal Health Laboratory in Geelong (Victoria). One output of the training course will be a CD-ROM which will be available as a resource to veterinary practitioners and pathologists. These projects have commenced and are to be completed by June 2004.

Disease simulation exercises

Whilst agreed-upon AQUAVETPLAN manuals are a critical resource for a quick and effective response, their usefulness to a great extent relies on the extent to which involved personnel are familiar with those plans. In addition, not each aspect of a real-life emergency can be fully covered in contingency plans. It is therefore generally accepted that practice in handling disease emergencies, including the use of existing manuals, provides the best training.

There are three avenues to gain experience in managing an emergency response: ‘hands-on’ experience in real-life emergencies; learning from formal debriefs, or post mortems, of such real-life events; and training through incident simulation.

To date, staff from the Office of the Australian Chief Veterinary Officer have conducted disease simulation exercises for government officers and key industry staff in Queensland for the prawn and redclaw crayfish industries, in Tasmania for the Atlantic salmon industry, in Victoria for the trout industry, in South Australia for the abalone industry, and most recently in Western Australia for the non-Pinctada maxima pearl oyster industry. Each exercise was tailored to the needs and aims of the particular jurisdiction and industry and included discussions, tabletop exercises and field days. The Federal Budget Initiative Building a National Approach to Animal and Plant Health has provided funding for further exercises in New South Wales (oysters) and Victoria (abalone).

Whilst the simulation exercises conducted to date were designed to provide individual jurisdictions and industries with training in the management of an aquatic animal disease emergency, the need for inter-jurisdictional cooperation in successful disease control and eradication has not previously been addressed. The Federal Budget Initiative has recently provided funds for the planning of a multi-state exercise, using the Murray-Darling Basin as a case study. The objectives of this new exercise are:

- To develop in consultation with a range of government and non-government organisations, a simulation exercise that will effectively address issues of inter-jurisdictional communication and cooperation in response to an emergency disease incident;
- To engage the States/Territories that share the Murray-Darling Basin in the planning exercise and in doing so, heighten the awareness of these jurisdictions to the potential for incursions of emergency disease; and
- To negotiate funding for the subsequent simulation exercise from a range of participating agencies.
- This new project is to commence in January 2003 and precede the actual running of such an exercise.

6. Conclusions

Like any movement of live animals, the translocation of fish, molluscs and crustaceans includes the risk of spread of disease. However, in aquatic animals – especially in open water systems – disease is much more difficult to detect, identify, contain and eradicate than in land-based animals.

Acknowledging the need for an across-border approach, a range of national policies has been developed to provide frameworks and achieve consistency throughout Australia. Those policies as well as training opportunities should be utilised to facilitate a risk-based approach to translocation.

Acknowledgements

The supply of photos for Figures 2-5 by Kevin Ellard (Tasmanian Department of Primary Industries, Water & Environment) is greatly appreciated.

References


Footnotes

1 Click on Output ‘Product Integrity/Animal and Plant Health’, then go to ‘All Product Integrity/Animal and Plant Health Documents’ and click on ‘AQUAPLAN’.

2 Click on ‘Product Integrity, Animal and Plant Health’ in the OUTPUTS box on the left hand side of the AFFA homepage, then under ‘All Product Integrity / Animal and Plant Health Documents’, click on the folder ‘AQUAPLAN’ and go from there to ‘AQUAPLAN Zoning Policy Guidelines’.

3 Click on ‘Product Integrity, Animal and Plant Health’ in the OUTPUTS box on the left hand side of the AFFA homepage, then under ‘All Product Integrity / Animal and Plant Health Documents’, click on the folder ‘AQUAVETPLAN’.

4 Click on ‘Product Integrity, Animal and Plant Health’ in the OUTPUTS box on the left hand side of the AFFA homepage, then under ‘All Product Integrity / Animal and Plant Health Documents’, click on the folder ‘AQUAVETPLAN’.

5.2 Australian Capital Territory

Mark Lintermans, Wildlife Research & Monitoring, Environment ACT

Introduction

Canberra is the largest inland city in Australia with a population of approximately 320,000 and its residents are only a few minutes drive from the Murrumbidgee River and a number of urban lakes. The ACT is wholly contained within the Murray-Darling Basin. Fish stocks in the natural streams have been affected by a combination of factors including: a rise in the numbers of anglers as Canberra’s population has grown; increased efficiency of angling practices, as modern technology has improved rods, reels and lures; and habitat modification associated with the impact of rural and urban development in the catchments of rivers and lakes.

The stocking of recreational fish species in Canberra’s urban lakes may aid in the conservation of native species by relieving fishing pressure on the more fragile rivers and streams in the Canberra region. Stocking lakes with certain fish species also helps to establish a balanced ecosystem in waters where fish may have been depleted artificially or where pest species are abundant. For example, the heavy metals leaching from the Captains Flat mine killed all the Murray Cod and Golden Perch...
which used to inhabit the Molonglo River. Consequently when Lake Burley Griffin was formed in 1964 there were no large predatory fish species remaining, with the alien Goldfish the dominant species. Stocking of Murray Cod and Golden Perch has restored the fishery in the lake to a more balanced state by providing a predator for other fish species.

The developing needs of fisheries management and changes in community expectations and attitudes is reflected in the National Policy on Recreational Fishing in Australia (National Recreational Fisheries Working Group 1994) which states that ‘Recreational fishing should be managed as part of the total fisheries resource to ensure quality fishing, and to maintain fish stocks and their habitats, for present and future generations of Australians’. The National Policy also emphasises that measures which seek to increase the range and diversity of recreational fishing opportunities throughout Australia should be encouraged, and that community involvement and awareness plays a vital role in fisheries management.

Fish Stocking Plan for the ACT

The development of a fish stocking plan for the ACT was one way of keeping the community informed on the directions and philosophy of fisheries management in the Territory.

The fish stocking Plan for the ACT was released in 1996 and contained a five year program of fish stocking activities in the various waters of the ACT. The plan was updated and re-issued as the Fish Stocking Plan for the ACT 2001–2005 (ACT Government 2000) and it is proposed that the plan will be revised every five years. The plan categorises waters in the ACT into three types: urban lakes, natural streams, and water supply reservoirs.

The Urban Lakes

There are 14 urban lakes and ponds in the ACT managed by the ACT Government, of which four are stocked to provide recreational fishing opportunities (ACT Government 2001). There are two additional lakes in which fish stocking occurs; Lake Burley Griffin which is managed by the National Capital Authority (National Capital Planning Authority 1995) and Googong Reservoir which is jointly managed by the ACT Government and NSW Fisheries. The primary role of urban lakes in Canberra is to provide an environmental buffer and protection for the ACT’s streams from the impacts of urban development, as well as to provide a pleasant aesthetic backdrop for the city centres. Many of these lakes and ponds are on streams too small to support natural recreational fisheries (e.g. Tuggeranong Creek and Ginninderra Creek) or are on streams where upstream uses have severely disrupted or eliminated the natural fish communities (e.g. the impact of heavy metals pollution from Captains Flat mines on the Molonglo River).

Many of the fish species in urban lakes do not encounter the necessary environmental conditions for successful breeding and so they must be maintained by regular stocking. As a consequence, the existing fisheries in Canberra’s lakes have been created artificially by stocking a variety of native and introduced angling species with the aim of providing a mixed recreational fishery which is easily accessible to most Canberrans.

Environment ACT stocks between 30,000 and 80,000 fish each year in Canberra’s lakes, with more than 2 million fish stocked since 1981 (Table 1). In the early years following the establishment of Lake Burley Griffin in 1964, the emphasis was on the introduced species Rainbow Trout and Brown Trout. However, by the early to mid 1980s these species showed poor survival and growth rates in the urban lakes, and as native fish became commercially available the emphasis on stocking trout has declined. The five species currently stocked are shown in Table 1, with experimental stockings in the early 1980s of other species such as Brook Trout and Freshwater Catfish discontinued as these species no longer meet the stocking principles (see below)(Lintermans 2000).

<table>
<thead>
<tr>
<th>Species</th>
<th>Number stocked since 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murray Cod</td>
<td>457,660</td>
</tr>
<tr>
<td>Golden Perch</td>
<td>974,500</td>
</tr>
<tr>
<td>Silver Perch</td>
<td>386,500</td>
</tr>
<tr>
<td>Brown Trout</td>
<td>54,000</td>
</tr>
<tr>
<td>Rainbow Trout</td>
<td>143,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2,015,660</strong></td>
</tr>
</tbody>
</table>

The Natural Streams

The fish populations in the natural streams are what remain of native fisheries that existed at the time of European settlement. Some stocking of introduced species was carried out by acclimatisation societies and individuals in the latter part of the 1800s and early 1900s but stocking of streams is no longer practised in the ACT except in special circumstances (e.g. a release or relocation of a threatened species for conservation...
purposes). The major reasons why stream stocking is not undertaken are:

- The fact that certain fish species are uncommon or have declined in certain rivers may be an indication that there are problems in that river requiring attention. It may be that food resources are limited or that breeding habitats are insufficient. The stocking of artificially bred fish into these systems may mask the true conservation status of the fisheries and destroy an important measure of whether river management is adequate or improving.

- Some rivers in the ACT support remnant populations of threatened fish species such as Macquarie Perch, Silver Perch, Murray Cod, Two-spined Blackfish or Murray River Crayfish. Some of these species are threatened because of loss of suitable habitat or competition from and predation by introduced fish species. The release of large numbers of stocked fish would simply impose further competition and stress on these threatened species and is thus undesirable.

- The ACT has only limited funds for fish stocking and it makes sense to spend these funds where there is the greatest opportunity to effectively augment the fishery.

Water Supply Reservoirs

The three water supply reservoirs located on the Cotter River in or adjacent to Namadgi National Park (Cotter, Bendoora and Corin reservoirs) are not stocked with fish for the following reasons:

- The waters of the Cotter catchment above the Bendoora dam wall (this includes the waters of Corin and Bendoora reservoirs) are managed as a fish conservation zone within Namadgi National Park and fishing is prohibited. These waters contain populations of three threatened fish species: Macquarie Perch, Trout Cod and Two-spined Blackfish.

- The waters of Cotter Reservoir are closed to fishing to protect water quality, and two threatened fish species: Macquarie Perch and Two-spined Blackfish. The Cotter River is one of the few remaining rivers in south-eastern Australia which has neither Carp or Redfin present. The opening of Cotter Reservoir to fishing may facilitate the introduction of these exotic fish species by well-intentioned but ill-informed anglers in order to ‘enhance’ the fishery. The introduction of Carp or Redfin could also introduce significant fish diseases such as Epizootic Haematopoietic Necrosis (EHN) virus which has been shown in laboratory studies to kill a number of native fish species including Macquarie Perch.

Guiding Principles for stocking in the ACT

The Fish Stocking Plan for the ACT 2001–2005 contains a number of guiding principles that are used when deciding whether or not to stock in the ACT. The principles are grouped into five categories that deal with stocking for conservation, recreation or research purposes, and the type of water that the stocking is being proposed for. The guiding principles are:

(A) Urban lakes and Googong reservoir

(i) Fish may be stocked for conservation, recreation and research purposes.

(ii) Both native fish indigenous to the ACT region and/or non-indigenous fish species may be stocked.

(iii) Non-indigenous species will only be stocked for recreational purposes and only Brown or Rainbow Trout will be stocked

(B) Natural streams and water supply reservoirs

(iv) Fish may be stocked for conservation and research purposes.

(v) Only native fish indigenous to the ACT region may be stocked.

(C) Fish stocked for conservation purposes

(vi) Native fish may be stocked for conservation purposes where:

(a) there is a need to maintain or enhance the conservation status of a species;

(b) stocking will not put at risk the ACT conservation status of other fish species; and

(c) there is a reasonable expectation that the fish will survive.

(D) Fish stocked for recreational purposes

(vii) Fish may be stocked for recreational purposes where:

(a) the water to be stocked is a ‘public water’ which is open to recreational fishing;

(b) stocking will not put at risk the ACT conservation status of native fish species;
(c) there is a reasonable expectation that there is suitable and sufficient habitat available for survival and growth; and

(d) the level of natural recruitment is insufficient to support a fishery.

(E) Fish stocked for research purposes

(viii) Fish may be stocked for research purposes where:

(a) stocking will not put at risk the ACT conservation status of other native fish species; and

(b) the stocking is part of a recognised research program.

Conservation stocking

There are two species which have been the subject of stocking or translocation for conservation purposes in the ACT. They are Trout Cod and Macquarie Perch, both nationally endangered species. Trout Cod have been stocked at two locations, Bendora Reservoir on the Cotter River and Angle Crossing on the Murrumbidgee River, as part of a national stocking program coordinated by the National Trout Cod Recovery Team. Stocking of Trout Cod into Bendora Reservoir occurred in 1989 and 1990 with a total of 8741 fish released. A total of 47,000 Trout Cod have been stocked into the Murrumbidgee River in the ACT between 1996-2002 (ACT Government 1999a; Lintermans 2000). The Trout Cod released in the stocking program have been supplied by the Narrandera Fisheries Centre of NSW Fisheries, or the Snobs Creek Hatchery of the Department of Natural Resources and the Environment, Victoria.

Macquarie Perch have been subject to two translocation attempts in the Canberra region. The first, in the Queanbeyan River in 1980 was in response to the inundation of spawning beds after the construction of Googong Reservoir (Lintermans 2000, 2002). The second was in response to the draining of Cotter Dam during the summer of 1985, when it was feared that low water levels and high water temperatures would adversely effect the local Macquarie Perch population (ACT Government 1999b; Lintermans 2000, 2003). The Queanbeyan River translocation has been successful but the Cotter Dam attempt appears to have failed due to thermal pollution issues with the receiving water.

ACT Translocation Policy

The ACT does not have a separate policy on translocation of fish. However, the Fish Stocking Plan for the ACT 2001–2005 only allows native fish species indigenous to the Canberra region, or two widely distributed salmonid species to be stocked. Further controls on translocation are provided in the ACT’s fisheries legislation (Fisheries Act 2000) which prohibits movement of live fish from one water body to another.

Hatchery Protocols

There are currently no hatcheries or aquaculture establishments in the ACT, although a number of proposals to establish aquaculture facilities have been received in recent years. Consequently, there are no hatchery protocols in place. The future development of hatchery protocols for the ACT would require close liaison with other Murray-Darling Basin jurisdictions, particularly NSW. The large commercial aquarium facility in Canberra has permit requirements concerning the import of fish, and also has controls on the treatment and discharge of aquarium water.

Legislation

The primary legislation governing fish in the ACT is the Fisheries Act 2000, although there are provisions for the protection of declared threatened species under the Nature Conservation Act 1980. Section 79 of the Fisheries Act 2000 prohibits the release of live fish into public waters except with the written approval of the Conservator, or unless the fish was taken from the part of the public waters into which it is released. Section 76 of the Fisheries Act 2000 requires persons importing or exporting live fish to have a licence to do so, and Section 85 prohibits the use of live finfish as bait. The Fisheries Act 2000 has provision for declaring noxious fish, but no species have been declared as yet. There were no noxious species listed under the previous ACT fisheries legislation (Fishing Act 1967). It is anticipated that declaration of noxious fish will occur after review of the relevant lists in other Basin jurisdictions.

References

National Recreational Fisheries Working Group. 1994. Recreational Fishing in Australia: A National Policy. National Steering Committee on Recreational Fishing,
5.3 New South Wales

see paper 6.3 Management of fish stocking in New South Wales, Dr Andrew Sanger, Regional Manager, Western region, NSW Department of Fisheries, and Bill Talbot, Principal Manager, Threatened Species, NSW Department of Fisheries

5.4 Queensland

Peter Jackson, Principal Fisheries Scientist, Queensland Fisheries Service

Background

The Queensland Fisheries Service (QFS) supports the stocking of fish into public and private waters for recreation and conservation purposes in accordance with the principle of Ecologically Sustainable Development.

Prior to 1986, stocking of freshwaters was largely for research purposes. Production techniques for species such as Sleepy cod and Sooty grunter were developed at the Walkamin Research Station on the Atherton Tablelands in North Queensland. Fingerlings of these species were released into various river systems and impoundments in north and central Queensland to evaluate their growth and survival.

Stocking to create recreational fisheries began in 1986 when the Queensland Government initiated the Recreational Fishing Enhancement Program. Funds were made available for an initial three-year period to stock artificial impoundments to create recreational fisheries. From the beginning the program was a partnership between the Government and local communities with fish stocking associations being formed for each impoundment. The stocking program was continued beyond the initial three years and has resulted in the development of recreational fishing opportunities throughout the State. The program has had a significant positive impact on rural economies.

The initial aims of the program were to:

- Stock and restock inland water storages with native species (that is native to Australia);
- Create an inland recreational fishing resource and tourism attraction;
- Reduce pressure on saltwater estuary fishing.

Today about seventy stocking groups regularly stock suitable impoundments throughout the State as well as some river systems. Fish stocked include; Murray cod, Golden perch, Silver perch, Australian bass, Barramundi, Saratoga and Sooty grunter. The majority of the fisheries are “put, grow and take” fisheries with no natural recruitment so that annual stockings of fingerlings have to be undertaken.
Recent telephone surveys commissioned by QFS have shown a significant increase in the percentage of anglers targeting impoundment fisheries between 1996 and 2001.

Funds to stock impoundments come in part from the government and partly from funds raised in local communities by fish stocking groups. In the past three years the QFS has allocated $168,000 annually for the purchase of fingerlings. In 2000 the Stocked Impoundment Permit Scheme was implemented. The scheme applies to the taking of fish from 25 specified stocked impoundments in Queensland. After administration costs all funds raised by this scheme are directed to fish stocking.

The majority of fingerlings for stocking are purchased from private hatcheries. The QFS provides some Barramundi fingerlings from its northern fisheries centre in Cairns and fingerlings for stocking the endangered Mary River cod are produced at Lake MacDonald Hatchery in Cooroy with funds provided by the Noosa Shire Council and QFS.

Extent of stocking and translocation

In the 2000/2001 season about 1,663,800 fingerlings were released into impoundments and other waterbodies throughout Queensland. These numbers are expected to increase in future years with the advent of the Stocked Impoundment Permit Scheme.

In the Queensland portion of the Murray-Darling Basin a total of 597,547 fingerlings were released in 2000/2001. The species stocked were Golden perch, Silver perch and Murray cod. The number of fingerlings stocked each year since 1996 is shown below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden perch</td>
<td>588832</td>
<td>588917</td>
<td>558416</td>
<td>792056</td>
<td>563981</td>
</tr>
<tr>
<td>Silver perch</td>
<td>46200</td>
<td>31000</td>
<td>33100</td>
<td>20900</td>
<td>1000</td>
</tr>
<tr>
<td>Murray cod</td>
<td>21141</td>
<td>17850</td>
<td>30850</td>
<td>21283</td>
<td>32566</td>
</tr>
<tr>
<td>Total</td>
<td>656173</td>
<td>637767</td>
<td>622366</td>
<td>834239</td>
<td>597547</td>
</tr>
</tbody>
</table>

Under Schedule 5 of the Fisheries (Freshwater) Management Plan 1999 translocations are not permitted into the Queensland portion of the Murray Darling Basin. However there is still a requirement to ensure appropriate genetic variability in the hatchery-produced fingerlings so that there are no impacts on wild genetic stocks.

Management

Stocking in Queensland waters must be undertaken in accordance with the requirements of the Fisheries Act 1994, the Fisheries Regulation 1995 and the Fisheries (Freshwater) Management Plan 1999, the QFS Translocation Policy for Freshwaters and the National Policy for the Translocation of Live Aquatic Organisms

Translocation Policy

Fish stocking in Queensland freshwaters are carried out according to the following principles:

- Stocking public or private waters with translocated species or non-indigenous genetic stocks of a species will be considered only where a clear potential economic, social or conservation benefit can be demonstrated, and where no alternative native species in the drainage basin have similar potential.

- Translocations will not be permitted in catchments where:
  a. the integrity of native fish communities remains substantially intact and/or
  b. there are one or more threatened species of fish (conservation priority catchments), and/or
  c. there are several native fish species of value (translocation unnecessary catchments)

- Translocation of species accorded threatened status because of habitat loss or other factors is supported. Here, the emphasis should be on the establishment of breeding populations, carried out in accordance with the principles of the draft Australian and New Zealand Environment and Conservation Council Policy for the translocation of vertebrate animals in Australia.

  - With the exception of threatened species, preference will be given for translocating species that will not reproduce in their target environment.

  - Where a basin or river system is contiguous with another State, the agreement of that State will be obtained before any translocation can take place. Queensland will seek reciprocal arrangements with other states.
Managing Fish Translocation and Stocking in the Murray-Darling Basin

To stock public waters, impoundments or river systems, an application must be made by a community-based stocking group. An application from an individual will not be considered. A standard application form is provided and if the application includes a translocation an additional form must be completed listing the justification of the proposed translocation, details of the receiving environment, likelihood of the translocated species reproducing and potential impacts on native species.

To ensure a more strategic approach to fish stocking, Stocking Group Liaison Officers from the Queensland Fisheries Service meet with individual stocking groups to establish five year impoundment management plans. These plans outline the species to be stocked and in what numbers they will be stocked. The stocking schedule from the management plan is attached to the application.

If an application is straightforward and does not involve a translocation it is considered by the Queensland Fisheries Service only. All applications involving a translocation, or where there is any concern about the species or number of fish to be stocked, are considered by the Stocking and Translocation Subcommittee of the Freshwater Fisheries Management Advisory Committee. The Subcommittee has membership from stocking groups, relevant government agencies and conservation representatives.

Applications are considered according to standard stocking and translocation protocols. Further information may be requested from the applicant if necessary. The recommendation of the subcommittee and any other relevant information are considered by the Queensland Fisheries Service in reaching a decision on the application.

Under the Fisheries Act 1994 the applicant may appeal the decision through the Fisheries Tribunal. Grounds for appeal include the decision being contrary to the Act, manifestly unfair or causing personal hardship to the applicant.

Issues

There are a number of emerging issues related to fish stocking in Queensland. These are:

- Fish stocking in Queensland was initiated to create recreational fisheries in artificial impoundments but has becoming increasingly directed towards river systems. A precautionary approach is required to ensure that stockings do not impact on natural fish populations.
Little data are available on the significance of movement out of impoundments into river systems. Can we separate recreational stockings from conservation stockings or is there significant “leakage” from impoundments to require all stockings to be considered as conservation stockings?

Although the Queensland Translocation Policy requires the consideration of genetic stocks there remains a lack of hatchery protocols to ensure the appropriate maintenance of genetic variability in hatchery-bred fish.

In the case of the Queensland portion of the Murray-Darling Basin, legal translocation at the species level is not an issue as it is not permitted. However, there is a significant amount of stocking undertaken both in artificial impoundments and rivers. Appropriate management remains an issue at the genetic stock level.

5.5 South Australia

Jon Pressor, Principal Fisheries Manager
Department of Primary Industries and Research

Regulations

The South Australian Fisheries Act 1982 (s.50) prohibits the release into any waters any exotic fish, any farm fish, or any fish that have been kept apart from their natural habitat. Under the definitions in the Act, ‘waters’ means any sea or inland waters including any body of water or watercourse of any kind occurring naturally or artificially created.

It is an offence, therefore, to release any cultured fish (restocking) or translocate fish from their natural habitat unless the Director of Fishery has approved an exemption to s.50 of the Act for this activity to occur.

Stocking Policy

South Australia does not have a current formal written policy for the management of fish stocking programs and translocation of fish in rivers and streams. Generally, fish stocking programs are not encouraged but are considered on a case-by-case basis.

There are no Government owned hatcheries for stocking purposes, although hatchery facilities exist with a number of Government agencies (South Australian Research & Development Institute – Aquatic Sciences Centre) and universities. There are a number of privately owned hatcheries, predominantly used for aquaculture businesses.
Exemptions to the regulations have been approved for projects to establish artificial refuge populations and/or for enhancing local populations of critically endangered small native fish species. In recent years, these have been approved for programs developed by the CRC for Freshwater Ecology with the Department of Environmental Biology, University of Adelaide.

Exemptions have also been provided to organisations such as SARDI Aquatic Sciences and the Adelaide City Council to translocate, for stocking and recreational fishing purposes, native freshwater fish species from the River Murray and private hatcheries to several water impoundments, including the Thordon Reservoir and Torrens Lake in the Adelaide metropolitan region.

Stocking of trout

A long-standing arrangement (30 years) exists with the South Australian Fly Fishermen’s Association (SAFFA) to allow them to operate a small privately-owned hatchery in the Adelaide Hills to hatch trout eggs from Tasmania and release fingerlings in various streams and rivers in South Australia enhance trout numbers for recreational fishing purposes. The Association annually release trout under an exemption approved by the Director of Fisheries in the following streams and rivers:

- Broughton
- Light
- Wakefield
- North Para
- Torrens
- Onkaparinga
- Cox
- Finnis
- Currency
- Hindmarsh
- Inman
- Bull
- Hay Flat
- Meadows
- Scotts
- Little Para

However, trout are still considered to be an exotic species under the Fisheries Act, and it is alleged that trout have established feral populations in at least 8 streams throughout the State. Some of the streams that contain trout also harbour resident populations of rare and threatened small native fish species and other aquatic organisms, as well as other exotic fish species including carp, redfin and mosquito fish.

In recent years, consideration has been given to remove brown trout (Salmo trutta) and rainbow trout (Onchorhyncus mykiss) from the exotic species list and declare it as ‘valuable introduced species’. It is proposed that specific regulations managing the culture and release of these trout species be developed so that this fishery can be managed as a valuable recreational fishing resource and tourism opportunity. These proposals are currently being progressed under the current review of the Fisheries Act, with a specific project underway to review the management of trout stocking and the impact of this activity on native fish populations.

Associated with the trout restocking program, a general exemption is provided to land owners every year who purchase fingerlings from or through the SAFFA to allow them to stock farm dams for their own purposes and not for sale.

If a land owner wants to stock dams with the intention of selling fish, then they require a land-based aquaculture licence issued under the Aquaculture Act 2001. The stocking of these aquaculture enterprises is then managed separately as a commercial activity.

Broodstock Collection

Policies have been drafted for the collection of broodstock for aquaculture purposes. Associated with this are the strict guidelines and protocols developed for the aquaculture industry that prohibit the re-release and translocation of broodstock, the prevention of escapements of cultured fish, and the management of disease and parasites.

5.6 Victoria

Tarmo A. Raadik, Freshwater Ecology Research, Arthur Rylah Institute for Environmental Research, Co-operative Research Centre for Freshwater Ecology

Background

The stocking of hatchery produced fish, and the translocation of wild-caught fish, into public and some private waters in Victoria is commonplace. These activities fall into two distinct categories: intentional releases, where a decision has been made to release a particular species; or unintentional releases, where fish are accidentally released. Examples of approved intentional releases are the stocking of native and exotic species into public or private waters for recreational angling, and conservation oriented restocking or re-establishment of native species. Examples of illegal intentional releases are the stocking or translocation of exotic species to broaden their geographic range, such as Carp (Cyprinus carpio), Gambusia (Gambusia holbrooki), and other exotic coarse angling species (Roach Rutilus rutilus). Another intentional release is the dumping of unwanted
‘bait-bucket’ fish, though sometimes the activity can be in ignorance of the environmental consequences.

Unintentional releases may occur through agricultural or other land-management practices, such as water transfer infrastructure (inter-Basin water transfers), where fish are able to access and potentially colonise new waterways. Other accidental releases can occur from aquaculture facilities or escape or release of aquarium species. These examples can also be intentional activities, for example, five cichlid species established in the warmwater Hazelwood Pondage in Gippsland.

Fish stockings and translocations are mainly undertaken by State government agencies (Department of Natural Resources and Environment – NRE), some fisheries client groups (eg. Rex Hunt Futurefish Foundation, recreational angling clubs), semi-government agencies (eg. Melbourne Water), private groups (eg. Native Fish Australia, Victoria), consultants, and also by individuals (either deliberately or in ignorance).

The Victorian Department of Natural Resources and Environment is the lead agency for the management of fish stocking and translocation, and is “…responsible for the integrated management of Victoria’s natural resource base, including resource development and utilisation, and the protection, conservation and management of Victoria’s natural environment”. Within NRE two divisions have involvement in fish stocking and translocation issues:

- Fisheries Division (Fisheries Victoria), with the focus of managing fish stocks to meet commercial and recreational needs in a balanced manner, and developing a viable and sustainable aquaculture industry.
- Parks, Flora and Fauna Division, who oversee the management of Victoria’s land and resources, including biodiversity (flora and fauna), for their environmental, conservation and recreational values.

Stocking and translocation decisions were previously made by the Fisheries Division, and by both divisions since the establishment of Parks, Flora and Fauna in the mid 1990’s.

Legislation, Policies and strategies, and decision making

Numerous legislation, policies, strategies and other documents are available to guide stocking and translocation decision making in the state (Table 1). Decisions are increasingly being made with due consideration of the obligations and recommendations contained within the majority of these documents.

<table>
<thead>
<tr>
<th>Legislation</th>
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<tbody>
<tr>
<td>• Victorian Flora and Fauna Guarantee Act 1988</td>
</tr>
<tr>
<td>• Victorian Fisheries Act (1968) 1995</td>
</tr>
<tr>
<td>• National Environment Protection Biodiversity Conservation Act 1999</td>
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<table>
<thead>
<tr>
<th>Strategies</th>
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<tbody>
<tr>
<td>• Victorian Inland Fisheries Strategy 1997</td>
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<tr>
<td>• Victorian Biodiversity Strategy 1997</td>
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<tr>
<td>• Victorian River Health Strategy 2002</td>
</tr>
<tr>
<td>• Bendigo Region Fisheries Management Plan 2002</td>
</tr>
<tr>
<td>• Goulburn Eildon Fisheries management Plan (in prep.)</td>
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<table>
<thead>
<tr>
<th>Policies</th>
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<tbody>
<tr>
<td>• Native Fish Stocking Policy (public waters)</td>
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<tr>
<td>• Trout Stocking Policy (public waters)</td>
</tr>
<tr>
<td>• Fish in Farm Dams Policy (private waters)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recovery Plans</th>
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</thead>
<tbody>
<tr>
<td>• Trout Cod Research Recovery Plan (Douglas et al. 1994)</td>
</tr>
<tr>
<td>• Barred Galaxias Research Recovery Plan (Raadik 1995)</td>
</tr>
<tr>
<td>• Silver Perch Recovery Plan (Clunie and Koehn 2001)</td>
</tr>
<tr>
<td>• Freshwater Catfish Recovery Plan (Clunie and Koehn 2001)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Flora and Fauna Guarantee Action Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Action Statement No. 38, Trout Cod, Maccullochella macquariensis. (Reed 1993)</td>
</tr>
<tr>
<td>• Action Statement No. 65, Barred galaxias, Galaxias olidus var. fuscus (Koehn and Raadik 1995)</td>
</tr>
<tr>
<td>• Action Statement No. 42, Variegated Pygmy Perch, Nannoperca variegata. (Fisher 1993)</td>
</tr>
<tr>
<td>• Draft Action Statement: “Introduction of live fish into public or private waters...”</td>
</tr>
</tbody>
</table>

Two important conservation conditions of the Native Fish Stocking Policy are that:

1. Waters will be stocked if they are within the former known range of the species, except where special management or research needs arise;
2. Waters will not be stocked if the conservation status of other native fish species or unique faunal assemblages are put at risk.

An important conservation condition of the Trout Stocking Policy is that waters will not be stocked if release of fish is considered a threat to a population of a species of special concern, or where a unique faunal assemblage occurs. Both of these policies are currently under review.

**Stocking/translocation proposals**

Fisheries Victoria undertakes an annual consultative process, which is in its seventeenth year, with meetings held once a year in all NRE regional offices. This process provides a forum for discussion on recreational fish stockings, fish population surveys, and other related fisheries management issues, and is used to review the current year’s stocking plan and to draft the next year’s plan (eg. Ainsworth and Hayes 2002). The meetings are open to broad representation from DNRE, water management authorities, catchment management authorities, and fisheries client groups.

Other fish stocking or translocation applications, either for recreation, conservation, or aquaculture, are received during the year and fall outside of the Fisheries Victoria consultative process, and until recently have been handled in an ad-hoc manner. As an initiative, Parks, Flora and Fauna recently (2001) established an Aquatic Translocation Review Committee to review conservation fish stocking/translocation proposals. The panel also reviews and provides advice, via Parks, Flora and Fauna Division, on recreational and aquaculture proposals being considered by Fisheries Victoria, for an OneNRE decision.

The committee has developed a risk assessment protocol based on the national translocation policy (Anon 1999), and assesses proposals on a range of risks, including risk of escapement, within or outside natural range, likelihood of establishment, and potential environmental impact, and compliance with other departmental policies.

NRE is also developing a department-wide risk assessment process for assessing translocation of live aquatic organism, also based on the national translocation policy. A guideline for the assessment of proposals is currently under way.

**Conservation and recreational stocking/translocation programs**

Five native species of fish have been stocked or translocated within Victoria for conservation reasons over the past ten years (Table 2). Macquarie perch and trout

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Main reason for stocking/translocation</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Macquaria ambigua</em></td>
<td>Golden perch</td>
</tr>
<tr>
<td><em>Macquaria australasica</em></td>
<td>Macquarie perch</td>
</tr>
<tr>
<td><em>Bidyanus bidyanus</em></td>
<td>Silver perch</td>
</tr>
<tr>
<td><em>Maculolocheilla peeli peeli</em></td>
<td>Murray cod</td>
</tr>
<tr>
<td><em>Maculolocheilla macquariensis</em></td>
<td>Trout cod</td>
</tr>
<tr>
<td><em>Macquaria colonorum</em></td>
<td>Estuary perch</td>
</tr>
<tr>
<td><em>Macquaria novemaculeata</em></td>
<td>Australian bass</td>
</tr>
<tr>
<td><em>Tandanus tandanus</em></td>
<td>Freshwater catfish</td>
</tr>
<tr>
<td><em>Gadopsis marmoratus</em></td>
<td>River blackfish</td>
</tr>
<tr>
<td><em>Galaxiella pusilla</em></td>
<td>Dwarf galaxias</td>
</tr>
<tr>
<td><strong>Exotic Species</strong></td>
<td></td>
</tr>
<tr>
<td><em>Salmo trutta</em></td>
<td>Brown trout</td>
</tr>
<tr>
<td><em>Oncorhynchus mykiss</em></td>
<td>Rainbow trout</td>
</tr>
<tr>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>Chinook salmon</td>
</tr>
<tr>
<td><em>Salmo salar</em></td>
<td>Atlantic salmon</td>
</tr>
</tbody>
</table>

Table 2. Fish species stocked or translocated under approved programs, into Victorian public waters during the last 10 years. H – hatchery produced; W – wild-caught.
cod have been produced in hatcheries, and large numbers have been released in catchments in the Murray drainage in Victoria. More recently, smaller scale translocation of wild-caught native species have been undertaken to re-establish populations in selected areas.

In addition, five other native species have been stocked to augment recreational fisheries in rivers, lakes or impoundments, with golden perch and Murray cod the most abundant species stocked. Four species of exotic salmonids have also been stocked to create or enhance recreational fisheries, also in rivers, lakes or impoundments. Brown and rainbow trout continue to be the main species stocked.

A commercial freshwater eel fishery exists in the state, which is guided by the Victorian Eel Fishery Management Plan 2002. Of interest is a wild-caught component of the fishery, where stock enhancement is undertaken using elvers and small adult eels, which are stocked into lakes in the coastal western district for on growing. It is unclear what process was undertaken to select these waters.

Hatchery protocols

Given the reliance on hatchery production to produce fish for recreational stocking programs, there are no detailed, formalised or documented hatchery protocols governing fish production. Currently all trout cod production, and a small quantity of Murray cod production is undertaken at the DNRE hatchery at Snobs Creek, with stocks of other native fish and all salmonids purchased from private hatcheries. There is a small joint venture program with DNRE and private industry to produce Australian bass for stocking within the Gippsland Lakes catchments.

In general, for some species, protocols follow existing general practices, but except for trout cod production, which is governed by protocols established in the recovery plan (Douglas et al. 1994), other documentation is lacking. Some general practices are listed below:

- **Murray cod** – brood stock are replaced on death, spawnings are generally monitored to avoid dominant males, broodfish are rotated amongst ponds, and progeny is mixed before stocking.

- **Golden perch** – progeny must come from at least five females.

References


6. Other key note papers

6.1 Conservation genetics of Murray-Darling Basin fish; silver perch (Bidyanus bidyanus), Murray cod (Maccullochella peelii), and trout cod (M. macquariensis)

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Abstract

Approximately 8% of Australian freshwater fishes are threatened with extinction, and 25% are considered to have either significantly declined in distribution, or occur in restricted areas. Many Australian fish species that are depleted in the wild are also produced in aquaculture. Information obtained on the genetic population structure and levels of genetic variability of captive and wild fish populations, will enable improved conservation and broodstock management including decisions on translocation and stocking.

To assess the genetic variability of captive and wild populations of three depleted fish species of the Murray-Darling Basin, approximately 450 base pairs (bp) of the 5’ end of the control region of mitochondrial DNA (mtDNA) was sequenced in silver perch (Bidyanus bidyanus), Murray cod (Maccullochella peelii) and trout cod (Maccullochella macquariensis) tissue samples. Outgroups, which include other members of the Australian Percichthyidae, were sequenced to obtain an indication of among species variability for this gene. The outgroups include: Mary River cod (Maccullochella peelii macquariensis), Clarence River cod (Maccullochella ikei), golden perch (Macquaria species), Australian bass (Macquaria novemaculeata), river blackfish (Gadopsis marmoratus), eel-tailed catfish (Tandanus tandanus), Nile perch (Lates niloticus), barramundi (Lates calcarifer), Welch’s grunter (Bidyanus welchi), jade perch (Scortum barcoo), sleepy cod (Oxyeleotris lineolatus), and Macquarie perch (Macquaria australasica).

We present preliminary impressions of landscape genetics and intraspecific genetic diversity for silver perch, Murray cod and trout cod using mtDNA sequences as the genetic marker. This information will aid conservation and hatchery managers to make informed decisions to improve hatchery, restocking, translocation and conservation practices of freshwater fish in the Murray-Darling Basin.

Introduction

Over the past hundred years there have been significant impacts on Australia’s natural waterways. Large scale modification and destruction of habitat has lead to the dramatic decline of many native freshwater species. Hatcheries are playing an increasingly important role in the management of fish species in the Murray-Darling Basin, particularly through restocking programs. Most Australian stocking programs are currently undertaken with little knowledge of the genetic diversity of, or the relationship between, the broodstock and natural populations. With the continuing decline of many fish species in the wild, both the importance and frequency of restocking programs is expected to increase.
Captive breeding programs usually have at least one of three major goals:

1) reintroduction of critically endangered or extirpated populations,
2) bolstering effective population size and genetic variation of existing populations, and
3) adding individuals to economically important, yet declining game species populations.

Captive breeding, however, can result in detrimental genetic effects in the captive populations, such as: inbreeding depression, the loss of genetic variability via genetic drift, or domestication selection (Allendorf & Ryman, 1987). The concern is that these genetic problems may be introduced (via gene flow) into natural populations when captive animals are released. Unidirectional gene flow alters and finally replaces the genetic composition of a natural population when hatchery stocking continues over a long period of time. In particular, population fitness maybe jeopardised if the genetic composition of the donor individuals differs from that of the receiving stock.

Freshwater fish species are generally subdivided into genetically discrete populations (Avise & Smith 1974; Avise, 1975; Avise et al., 1975; Stein et al., 1985; Powers et al., 1986; Cashner et al., 1988). In Australia, the existence of genetically discrete populations within freshwater fish species has only recently been documented (Keenan et al., 1995; Musyl & Keenan, 1992). However, despite the growing scientific evidence for this type of population subdivision, little is known about the level of population subdivision within the Australia’s largest freshwater drainage basin, the Murray-Darling River system. This project was designed to develop and apply genetic markers to assist the definition of management units, review current breeding programs within hatcheries, and to understand genetic relationships between hatchery and wild populations for three important native species within the Murray-Darling Basin.

The genetic definition of aquaculture stocks is a fundamental requirement for any culture program whether it is directed at producing a commercial product, or rehabilitation of natural fish populations. At a commercial level, breeders may require a genetic identification system to tag or place proprietary stamps on their product (Ferguson, 1994). Furthermore, recognising the degree of similarity (or difference) among strains allows the fish breeder to act upon minimising the deleterious effects of inbreeding. As not all strains are equally suitable for crossbreeding, informed choices of whether to employ a donor strain can be assisted with the knowledge of the genetic status of each of the strains and the level of their genetic relatedness to each other.

The ability to discriminate among hatchery stocks is no less important in rehabilitation aquaculture. One common action in restoration aquaculture is to stock cultured fish into waters where natural populations have declined as a result of anthropogenic impact. Evaluation of such a program would include recognition of strains with favourable survival and reproduction performance, so that future stocking efforts can concentrate and benefit from further production of that strain. The reproductive success of stocked hatchery fish can only be determined with the use of diagnostic genetic markers among source stocks. The aim should be to approximate natural composition, rather than to maximise numbers stocked by using a highly productive strain.

Fish reared in the Australian government and private sector hatcheries have been used to maintain wild stock and private water populations since the late 1970’s and for growout since the mid 1980’s. There is growing concern amongst the scientific community that the aims of breeding programs may be conflicting. Breeding fish for conservation, particularly of threatened species, aims to achieve natural levels of genetic diversity, while commercial aquaculture requires uniformity and enhancement of selected characteristics (e.g., growth rates) for efficient production, whilst maintaining genetic variability to improve characters such as disease resistance.

This study reports a general review of hatchery broodstock management practices, as well as provides key recommendations to improve genetic management of broodstock targeted at producing freshwater fish for stocking in the Murray-Darling Basin. In addition, this study aimed to achieve an understanding of genetic variation within hatcheries producing silver perch, Murray cod and trout cod for food production and/or stocking for conservation and recreational purposes. We established that mtDNA control region sequences were highly effective as a species marker, and examined the application of mtDNA as a genetic marker for landscape genetics (population structure) for silver perch, Murray cod and trout cod within the Murray-Darling Basin.

Methods

Definition of a Management Unit

The primary role of conservation biology is to retain evolutionary diversity, flexibility, and as a result, long term viability of the species (Baverstock et al., 1993). That is, to maintain the full array of differently adapted geographic variants within a species (Moritz, 1994a). In this context, an important aspect of conservation
management is to recognise any subdivision within a species, and the geographic scale of these units such that they can be monitored and managed (Baverstock et al., 1993). There is an eclectic approach in the literature to the definition and terminology of intraspecific units for economic and/or conservation management. Intraspecific units may be defined by life history, morphology, behaviour, genetics, geography or a combination of these (Barlow et al., 1995; Moritz et al., 1995). Equally difficult to qualify is the term ‘stock’. In fisheries management, the aim of recognising fish stocks is to ensure that they are harvested in such a manner that genetic diversity is maintained (Larkin, 1981). A fish stock is a genetically or otherwise distinct population with a common breeding ground (Larkin, 1981). Under this definition, fish from a single location (i.e., population) may be comprised of several stocks (Larkin, 1981; Dizon et al., 1992).

Evolutionarily Significant Units (ESUs) can be recognised as monophyletic clusters on mtDNA phylograms, and show significant divergence of allele frequencies at nuclear loci (Moritz, 1994a; 1994b; Moritz et al., 1995). ESUs therefore, emphasise historical population structure rather than current adaptation and short term conservation requirements (Moritz, 1994a). Defining ESUs ensures that evolutionary heritage is recognised and protected, and that evolutionary potential inherent across the set of ESUs is maintained (Moritz, 1994a; 1994b; Moritz et al., 1995). Management Units (MUs) are recognised as populations with significant divergence of haplotype (allele) frequencies at nuclear or mitochondrial loci, irrespective of the phyletogenetic distinctiveness of the haplotypes (Moritz, 1994a; Moritz et al., 1995). That is, populations that do not show reciprocal monophyly for mtDNA alleles, yet have significantly diverged in allele frequencies, are significant for conservation in that they represent populations connected by such low levels of gene flow that they are functionally independent (Moritz, 1994a; Moritz et al., 1995). MUs are identified to aid short-term management of ESUs (Moritz et al., 1995). Moritz (1994a) suggests that the term ‘stock’ be restricted to short-term management issues (e.g., harvesting) and in relation to genetics, be treated synonymously with MUs.

With respect to this study, MUs are defined initially by geography (regional and catchment scales), the scale of the MUs will be determined by the samples, and lastly, the MUs will be defined by their genetic distinctiveness. The term ‘stock’ refers to the populations of fish within those MUs, and the terms ‘stock’ and ‘population’ are interchanged. The term ‘population’ may refer to any unit of fish above an individual. ‘Sample’ refers to the individuals taken from a population for genetic analyses.

Selection of a Genetic Marker

MtDNA fulfills the requirements for an effective population molecular marker which should have the following features:

1) the information obtained is consistently scoreable and comparable,
2) it is polymorphic with relatively low mutation rates,
3) it is neutral, and
4) it can be developed using the method of the Polymerase Chain Reaction (PCR).

The method of PCR facilitates use of a small sample that does not require sacrificing the specimen, the sample can be stored in ethanol, and does not require the sample to be of the highest quality. Allozyme markers, although they are effective population markers, have the main limitations of:

1) requiring repeatable standards,
2) requiring sacrifice of the specimen, and
3) the samples must be of high quality, and
4) must be preserved and stored at -80°C.

MtDNA and microsatellites are both effective markers that possess the aforementioned desirable qualities. Microsatellites are considered superior population markers to mtDNA, though they are more time consuming and less economic to develop. MtDNA was chosen since it is both economic and effective in providing sufficient resolution for population assignment enquires.

Species of Interest

Silver perch, Murray cod and trout cod are all Australian freshwater fish species that are depleted in the wild, as well as being produced successfully in aquaculture. They were selected as little or nothing was known of their genetic structure or variability, and it was considered that this information would benefit their aquaculture through broodstock management, and for management of stocking and translocation.

Silver perch were included as possibly the most genetically altered in the wild through extensive stock enhancement and translocation programs over the last 25 years. Silver perch in the wild have undergone a dramatic decline in abundance, and are extensively cultured and the most immediately in need of a program to prevent inbreeding. Silver perch hatchery operators have a high requirement for the identification of new and suitable populations to source broodstock.
Trout cod were included as an endangered species with a current recovery program in place. They are held at Narrandera and Snobs Creek hatcheries and exist at two sites in the wild, the Murray River and Seven Creeks. Additional introduced populations exist in the Murrumbidgee River and Ovens River which are routinely sampled. Trout cod represent a severely limited population, the restocking programs for which are controlled through the Trout Cod Recovery Team, and the fish for restocking are supplied through two State government hatcheries.

Given the close taxonomic relationship to trout cod, and in consideration of the technical aspects of developing molecular markers for related species (i.e., new genetic markers often need to be developed for less related species), Murray cod were chosen as the third species of interest. Murray cod are a flagship species in that they are very popular for angling, and are becoming increasingly important as an aquaculture species. The distribution of Murray cod throughout the basin is broad and there is a clear need to investigate the population structure of this species.

Specific objectives

• Obtain a hatchery survey of broodstock management. Obtain estimates of genetic variation captured by hatcheries.
• Establish the landscape genetics of the wild populations using mtDNA sequences as a genetic marker.
• Develop a Geographic Information Mapping System (GIS) for the Murray Darling Basin. That is, an electronic geographic specific distribution of genotypes (landscape genetics).
• Provide information to enable Best Practices for stocking and translocation.

Sample Collection

The sampling strategy was to obtain 30 individuals of each species from each of the hatcheries registered as producing the species of interest, and 30 individuals from each natural ‘population’.

We also capitalised on the -80°C tissue bank established by Keenan et al. (1995) held at the Bribie Island Aquaculture Research Centre, Queensland Department of Primary Industries (BIARC, QDPI).

Hatchery fish populations

All hatcheries within the Murray-Darling Basin registered as housing the species of interest were contacted as part of a hatchery survey and visited to take samples, usually during the spawning season when hatchery operators were handling their broodstock. When it was not possible to take fin clips from the broodstock particularly for Murray cod which were often pond spawned, we obtained samples from the fingerlings.

Natural fish populations

Government fishery officers and research biologists undertaking fish census studies, were approached to obtain samples from the natural populations. Collection of samples was undertaken under existing ethics committee permits or newly lodged permits where they were required. The method of collecting fish was generally via boat-electrofishing by qualified researchers and State agencies. The fish captured were anaesthetised using Alfaxan CD RTU and a biopsy removed. The fish were recovered in a saline bath (salinities 5 to 10 ppt reduces stress and deters infection) and returned to the site where they were captured. Targeted sampling was undertaken where wild populations were identified as being under-represented. This sampling was undertaken by professional fishing guides that had undergone fish handling training.

Genetic Analyses

Biopsy sampling

The method of collection of a biopsy from fish for DNA analysis usually involved taking a fin clip at the base of the dorsal fin, or between the rays of the tail fin. Using fine sharp scissors and fine forceps, a section of tail fin between the rays was clipped. The clips were then preserved in vials containing absolute (AR grade) ethanol, and ultimately stored at 4°C. The biopsy site was swabbed with an antiseptic (Betadine) to deter infection, and the fish were released (if wildstock), or allowed to recover in a saline bath.

Some of the samples were sourced from an archive of muscle tissue stored at -80°C existing from a former study on the population structure of silver perch and other Australian fish species using allozyme genetic markers (Keenan et al., 1995).

Preparation of tissue for DNA extraction

A section of tissue from the frozen samples were used directly in the following DNA extraction protocols. However, if the sample was stored in ethanol, it was
initially soaked in H2O for a couple of hours, or overnight (O/N) for rehydration. Rehydrating the tissue increases the efficiency of the proteolytic enzyme.

**Extracts using Chelex-100**

Using 1.5 mL tubes, approximately 2 mm² section of tissue was added to 500 µL of 10% slushy (or 5% dry) Chelex-100 (Biorad) in H2O, containing 5 µL Proteinase K (20 mg/mL). The digestion mix was vortexed briefly, and incubated at 55°C until the tissue was visibly digested. If the lysate was not clear, the incubation was extended often O/N, with additional 5 µL aliquots of Proteinase K added, along with a brief vortex at intervals throughout the incubation to promote efficient enzyme activity. The samples were then vortexed briefly before an eight minute incubation at 100°C on a heat block, and then vortexed immediately after for about 20 seconds.

The samples were stored at 4°C if in frequent use (rather than freezing at –20°C and then thawing frequently, which damages sample integrity), and re-vortexed and spun briefly (touch spin at 10,000 rpm), each time before a 1 to 2 µL aliquot was taken for a Polymerase Chain Reaction (PCR).

**PCR conditions**

A standard PCR contained: 1 x PCR buffer, 2 mM of MgCl₂, 0.17 mM of each dNTP, 0.32 µM of each primer, 0.75 units of Taq polymerase, and 1.5 µL of undiluted Chelex-100 prepared DNA. PCRs were performed in a Hybaid PCR Express thermal cycler using the following program: one cycle of 94°C for 2 min; six cycles of 94°C for 15 sec, 50°C for 45 sec, 72°C for 1 min 30 sec; 30 cycles of 96°C for 30 sec, 50°C for 15 sec, and 60°C for 4 min. To precipitate the sequencing reaction, 26 µL of 1:26 premixed, 3 M Na Ac (pH 5.2); absolute ethanol, was added. The mixture was mixed by pipetting and incubated at room temperature for 15 min. The mix was then centrifuged for 15 min at 13,000 rpm. The supernatant was aspirated gently, and the pellet washed with 250 µL of 75% EtOH. The pellet was dried by incubation at 37°C for 15 min, then mailed to a contractor to run the sequence (Molecular Biology Facility, Griffith University, Nathan, Queensland, or the Australian Genome Research Facility, University of Queensland).

**TGGE analysis**

To facilitate mass screening of samples, PCR amplimers for silver perch, Murray cod, and trout cod were genotyped by comparing standards alongside new samples using the temperature gradient gel electrophoresis (TGGE) system with heteroduplex analysis either with a divergent ingroup, or highly related outgroup (Elphinstone & Baverstock, 1997; Campbell et al., 1995).

The heteroduplexed PCR amplimers were visualised on gels by silver staining and the haplotypes (a haplotype or genotype is a unique DNA sequence) scored by the differential rate of migrated hetero- and homo-duplexed bands. Sequencing was carried out to verify haplotypes as a routine check, and to ascertain novel haplotypes. Also note that there were some TGGE co-migrating haplotypes for Murray cod and trout cod, which are indicated where relevant as “one ‘or’ the other”.

**Analytical Methods**

In order to determine relatedness amongst the mtDNA haplotypes, sequences were subjected to parsimony treatment via the software program PAUP (Swofford, 2002), and population genetics data analysis via Arlequin (version 2.000) (http://anthro.unige.ch/arlequin). The program AMOVA in Arlequin (Weir & Cockerham, 1984; Excoffier et al., 1992; Weir, 1996) enabled a nested analysis of samples which tested pre-determined geographic areas which maybe considered as logistical management units. Effectively AMOVA provides us with a means of hypothesis testing. The AMOVA treatment is insensitive to the occurrence of haplotypes in low frequencies (‘rare haplotypes’) which could be regionally specific, and perhaps deserving of a stronger weighting than the nested treatment provides. This is where the pairwise population comparisons (Arlequin, version
2,000) were deemed appropriate in recognizing unique catchments, or units for management.

Results

Results of Sample Collection

Samples were collected from 195 unique locations across the Murray-Darling Basin including 555 hatchery broodstock, 862 offspring and 952 wild fish samples. Seventeen species are represented in the tissue bank (Table 1).

Table 1. Tissue Bank collected by this study. Number of each species collected and type of sample represented.

<table>
<thead>
<tr>
<th>Species</th>
<th>Broodstock</th>
<th>Offspring</th>
<th>Wildstock</th>
<th>Grand Total</th>
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</thead>
<tbody>
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<td>Australian bass</td>
<td>13</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banded grunter</td>
<td>11</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barcoo grunter</td>
<td>1</td>
<td>2</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>Blackfish</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Eel-tailed catfish</td>
<td>16</td>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Golden perch</td>
<td>18</td>
<td>18</td>
<td>42</td>
<td>78</td>
</tr>
<tr>
<td>Jewfish</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Macquarie perch</td>
<td>1</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Mary River cod</td>
<td>1</td>
<td></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Murray cod</td>
<td>102</td>
<td>685</td>
<td>271</td>
<td>1058</td>
</tr>
<tr>
<td>Silver perch</td>
<td>399</td>
<td>154</td>
<td>248</td>
<td>801</td>
</tr>
<tr>
<td>Sleepy cod</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Spangled grunter</td>
<td>11</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spangled perch</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TC/MC hybrid</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Trout cod</td>
<td>55</td>
<td>3</td>
<td>*199</td>
<td>257</td>
</tr>
<tr>
<td>Welshs grunter</td>
<td>15</td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>576</td>
<td>862</td>
<td>867</td>
<td>2305</td>
</tr>
</tbody>
</table>

* Note: At least 26 of the trout cod wild fish included in this total are suspected to be previously stocked fish sampled from the Ovens and King Rivers in Victoria.

In total, 2399 samples comprising 16 species from 35 hatcheries and 133 unique locations throughout the Murray-Darling Basin were analysed (Figure 1). For silver perch, trout cod and Murray cod; 801, 257 and 1058 samples were collected respectively.

Crosses indicate sites of wildfish sample collection, and the shaded areas indicate catchments. Note that all samples localities outside of the nominated catchments were not included in the phylogenetic analysis. Four regions were nominated with the following catchments:

North region
(a) Condamine & Maranoa Rivers above Beardmore Dam
(b) Macintyre, Severn & Dumeresq Rivers above Goondiwindi
(c) Gwydir, Horton & Mehi Rivers above the Barwon confluence
(d) Namoi, Manilla, Macdonald, Peel & Mooki Rivers above Barwon confluence

Central region
(e) Lachlan and Murrumbidgee Rivers
(j) Darling & Lower Murray

South region
(f) Upper Murray between Hume Dam & Torrumbarry Weir
(g) Ovens & King Rivers
(h) Goulburn & Broken Rivers.

West Region
(i) The Paroo & Ambathala Ck.

In order to assess the genetic variability of captive and wild populations of three depleted fish species of the Murray-Darling Basin, outgroup species were sequenced in order to obtain an indication of among species variability for this gene. Outgroups included other members of the Australian Percichthyidae as listed in Table 2.
Table 2. Species sequenced for mtDNA. Where there was more than one haplotype, the consensus sequence was considered.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>silver perch</td>
<td><em>Bidyanus bidyanus</em></td>
</tr>
<tr>
<td>Welch’s grunter</td>
<td><em>Bidyanus welchi</em></td>
</tr>
<tr>
<td>Murray cod</td>
<td><em>Maccullochella peeli</em></td>
</tr>
<tr>
<td>Mary River cod</td>
<td><em>Maccullochella peeli</em> macquariensis</td>
</tr>
<tr>
<td>Clarence River cod*</td>
<td><em>Maccullochella ikei</em></td>
</tr>
<tr>
<td>trout cod</td>
<td><em>Maccullochella macquariensis</em></td>
</tr>
<tr>
<td>golden perch</td>
<td><em>Macquaria Murray-Darling sp.</em></td>
</tr>
<tr>
<td>golden perch</td>
<td><em>Macquaria Lake Eyre sp.</em></td>
</tr>
<tr>
<td>golden perch</td>
<td><em>Macquaria Dawson River sp.</em></td>
</tr>
<tr>
<td>jade perch</td>
<td><em>Scortum barcoo</em></td>
</tr>
<tr>
<td>sleepy cod</td>
<td><em>Oxyeleotris lineolatus</em></td>
</tr>
<tr>
<td>Australian bass</td>
<td><em>Macquaria novemaculeata</em></td>
</tr>
<tr>
<td>river blackfish</td>
<td><em>Gadopsis marmoratus</em></td>
</tr>
<tr>
<td>Macquarie perch</td>
<td><em>Macquaria australasia</em></td>
</tr>
<tr>
<td>eel-tailed catfish</td>
<td><em>Tandanus tandanus</em></td>
</tr>
<tr>
<td>barramundi</td>
<td><em>Lates calcarifer</em></td>
</tr>
<tr>
<td>Nile perch</td>
<td><em>Lates niloticus</em></td>
</tr>
</tbody>
</table>

*Clarence River cod sequence was provided by Cathy Nock, Centre for Animal Conservation Genetics, Southern Cross University, Lismore.

In general, we found that sequences were too divergent to align with the exception of Mary River, Clarence River and Murray cod; and silver perch to Welch’s grunter. These sister species which were easily aligned, were included in phylograms constructed for the species of interest (Figures 2 & 3). Sequences for the other species are anticipated for submission to GenBank (http://www3.ncbi.nlm.nih.gov/BankIt/) as part of a peer reviewed manuscript in preparation.

Figure 2. Mitochondrial DNA haplotype tree (dendogram) of silver perch. This is one of three equally parsimonious Neighbour Joining, unrooted trees found by PAUP, using a heuristic search and Nearest Neighbour Interchange with steep descent. The numbers on the branches refer to number of steps (distance) between the haplotypes. The numbers prefixed by ‘sp’ refer to haplotype numbers, for which there are 26 for silver perch. WGcon refers to Welch’s grunter consensus sequence.

Figure 3. Mitochondrial DNA haplotype tree (dendogram) of Murray cod. This is one of two equally parsimonious Neighbour Joining, unrooted trees found by PAUP, using a heuristic search and Nearest Neighbour Interchange with steep descent. The numbers on the branches refer to number of steps (distance)
between the haplotypes. The numbers prefixed by ‘mc’ refer to haplotype numbers, of which there are 13 for murray cod. Co-migrating haplotypes genetyped using the TGGE system are designated ‘mc5or6’ and ‘mc8or9’.

**Nature of polymorphism in mtDNA control region**

Relatedness among individuals, families, populations and species, can be measured by DNA sequence composition. The general philosophy of population and systematic genetics is that the more closely related two organisms, the more similar their DNA sequence. Other than identical twins which have identical DNA, each individual has a unique DNA sequence, a ‘molecular fingerprint’. However, there are sections of DNA or genes that will be identical among some individuals. The level of resolution obtained to examine population genetics will be determined by the genetic marker chosen. With respect to non coding, non repetitive regions of DNA, divergence in DNA sequence is generally characterised by the following pattern of mutations or polymorphism; the most frequently occurring mutations being 1) transitional changes (Adenine (A) exchange for a Guanine (G) base, or Thymine (T) for Cytosine (C) base), then 2) transversional changes (all other base combinations), and then 3) indels (insertions or deletions). As there was a high transition to transversion ratio, and a suggested rate variation (i.e., presence of substitution hot spots) observed among the haplotypes, a Tamura-Nei (Tamura & Nei, 1993) correction was used on the sequence data to accommodate for this pattern of substitution.

**Table 3. Genetic separation between sister species.**

Note only species specific polymorphisms have been considered, and that four mutation events (hence four ‘polymorphisms’) maybe responsible for the 45 indels shown by the Clarence River cod, therefore the lower value of the % difference is likely to be the more indicative. ‘Length’ refers to the total number of base pairs (bp) aligned between species.

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Length (bp)</th>
<th># H</th>
<th>Polymorphism (sites)</th>
<th>ts</th>
<th>tv</th>
<th>indels</th>
</tr>
</thead>
<tbody>
<tr>
<td>silver perch</td>
<td>370</td>
<td>474</td>
<td>26</td>
<td>26</td>
<td>20</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Welch’s grunter</td>
<td>14</td>
<td>469</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Murray cod</td>
<td>71</td>
<td>284</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Mary R cod</td>
<td>7</td>
<td>282</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clarence R cod*</td>
<td>4</td>
<td>293</td>
<td>4</td>
<td>42</td>
<td>1</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>trout cod</td>
<td>89</td>
<td>328</td>
<td>11</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

*Clarence River cod sequence was provided by Cathy Nock, Centre for Animal Conservation Genetics, Southern Cross University, Lismore.

**Silver Perch**

From 801 silver perch samples genetyped, 26 haplotypes were identified (Figures 2 & 4). Parsimony trees showed that there is considerably more structure to the cladistics of silver perch with 7 steps (less than 1% divergence) being the greatest separation between any two haplotypes (Figure 2). The phylogeography of silver perch also reveals significant differentiation between regions largely attributable to differences between the frequencies of the occurring haplotypes rather than the occurrence of region specific combinations of haplotypes *per se* (Table 5). At the catchment level unique combinations and population specific haplotypes seem apparent. In particular the Condamine (a), Macintyre (b) and Cataract Dam (k)

**Table 4. Intraspecific polymorphism.**

‘Length’ refers to the total number of alignable base pairs (bp) amplified by the control region primers within a species. A haplotype (H) is a unique DNA sequence, where more than one individual can share a haplotype. Transitions (ts), transversions (tv) and indels are forms of polymorphism. N refers to number of individuals sequenced as opposed to those genetyped via TGGE.

<table>
<thead>
<tr>
<th>Species</th>
<th>Difference (%)</th>
<th>Length (bp)</th>
<th>Polymorphism (sites)</th>
<th>ts</th>
<th>tv</th>
<th>indels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welch’s grunter vs silver perch</td>
<td>5%</td>
<td>474</td>
<td>22</td>
<td>17</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Murray cod vs Mary R. cod</td>
<td>7%</td>
<td>284</td>
<td>21</td>
<td>18</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Clarence R. cod* vs Murray cod</td>
<td>6 or 20%</td>
<td>295</td>
<td>60</td>
<td>16</td>
<td>1</td>
<td>43</td>
</tr>
<tr>
<td>Mary R. cod vs Clarence R. cod*</td>
<td>1 or 15%</td>
<td>293</td>
<td>45</td>
<td>4</td>
<td>0</td>
<td>41</td>
</tr>
</tbody>
</table>

*Clarence River cod sequence was provided by Cathy Nock, Centre for Animal Conservation Genetics, Southern Cross University, Lismore.
populations are displaying strongly divergent groupings (Table 5).

Table 5. Population pairwise comparisons of silver perch populations (within four regions).

<table>
<thead>
<tr>
<th>Location</th>
<th>Central (j)</th>
<th>North (a)</th>
<th>North (b)</th>
<th>North (d)</th>
<th>Cataract Dam (k)*</th>
<th>Central (e)</th>
<th>South (f)</th>
<th>West (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>-</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(f)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(g)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(h)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(i)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(j)</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Where:

**North region**
(a) Condamine & Maranoa Rivers above Beardmore Dam  
(b) Macintyre, Severn & Dumeresq Rivers above Goondiwindi  
(c) Gwydir, Horton & Mehi Rivers above the Barwon confluence  
(d) Namoi, Manilla, Macdonald, Peel & Mooki Rivers above Barwon confluence

**Central region**  
(e) Lachlan and Murrumbidgee Rivers  
(j) Darling & Lower Murray

**South region**  
(f) Upper Murray between Hume Dam & Torrumbarry Weir

**West Region**  
(i) The Paroo & Ambathala Ck.  
(l) *Warrego River*

**Eastern drainage**  
(k)* Cataract dam (captive population).

Figure 4. Silver perch haplotype frequencies.
Table 6. Genetic diversity for six populations of silver perch in the Murray-Darling Basin. The allele frequencies at three polymorphic loci as found by Keenan et al. (1995), and the actual number of haplotypes for mtDNA as found in this study.

<table>
<thead>
<tr>
<th>locality code</th>
<th>site</th>
<th>status</th>
<th>N</th>
<th>Mean heterozygosity</th>
<th>mean # alleles</th>
<th># polymorphic loci</th>
<th>N</th>
<th># haplotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>Pindari Dam</td>
<td>stocked</td>
<td>20</td>
<td>0.100</td>
<td>2.00</td>
<td>3</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>G1</td>
<td>Leslie Dam</td>
<td>stocked</td>
<td>18</td>
<td>0.056</td>
<td>1.33</td>
<td>1</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>Y9</td>
<td>Cataract Dam</td>
<td>stocked</td>
<td>46</td>
<td>0.166</td>
<td>2.00</td>
<td>3</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td>K2</td>
<td>Wyangala Dam</td>
<td>stocked</td>
<td>13</td>
<td>0.000</td>
<td>1</td>
<td>0</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>N1</td>
<td>Torrumbarry Weir</td>
<td>wild</td>
<td>48</td>
<td>0.125</td>
<td>2.00</td>
<td>3</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>H1</td>
<td>Cunnamulla</td>
<td>wild</td>
<td>31</td>
<td>0.147</td>
<td>2.33</td>
<td>3</td>
<td>31</td>
<td>13</td>
</tr>
</tbody>
</table>

Analysis of hatchery holding for silver perch showed that broodstock collections are generally missing several available haplotypes and are dominated by relatively few haplotypes: sp1, sp5, sp13, and sp18 (Figure 5 and Table 7). As one example, a detailed comparison between broodstock held at Grafton Research Centre as ‘Cataract strain broodfish’ and the source populations at Cataract Dam show that the broodstock collection is significantly under-represented. Analysis of broodstock revealed only one haplotype (sp1) from the Grafton hatchery sample of at least five possible haplotypes (sp1, 5, 6, 8 and 24) known to be present in Cataract Dam.

Figure 5. Haplotype frequencies of silver perch comparing hatchery broodstock to wildstock.
Table 7. Silver perch haplotypes and frequencies represented in the broodstock collection at each hatchery.
The identities of the 23 hatcheries surveyed are withheld and represented here by the letters ‘a’ to ‘y’. The absence of any recorded haplotypes for a hatchery indicates ‘missing data’ (samples not analysed to represent this hatchery).

| mtDNA haplotype | a | b | c | d | e | f | g | h | i | k | l | m | n | o | p | q | r | s | t | u | v | w | x | y |
| sp1             | 2 | 21| 2 | 7 | 11| 1 | 5 |
| sp5             | 3 | 6 | 1 | 1 | 1 |
| sp10            | 5 |
| sp13            | 10| 2 | 2 | 4 | 1 | 1 | 5 |
| sp17            | 1 |
| sp18            | 1 | 6 | 13| 4 | 1 |
| sp26            | 3 |
| sp27            | 1 |
| sp28            | 1 | 7 |
| sp29            | 4 |
| # haplotypes    | 0 | 3 | 8 | 0 | 1 | 1 | 1 | 3 | 3 | 0 | 3 | 0 | 0 | 2 | 1 | 0 | 5 | 0 | 0 | 3 | 1 |

Murray Cod

Haplotypes were compared for the 1058 samples of Murray cod (Figure 3). Of the 13 haplotypes, parsimony analysis indicated that the Murray cod haplotypes were generally separated by one or two base pairs (less than 1% differentiation). However, the mtDNA marker showed excellent resolution at the species level, with Mary River cod and Clarence River cod indicated as sister species to Murray cod. The phylogram based on mtDNA data shows that Mary River cod and Clarence River cod are the more closely related species, diverging at approximately the same time from Murray cod (Figure 3). Interestingly, preliminary analysis using two microsatellite loci indicated that both Mary and Clarence River cod have subsets of the broader allele range of Murray cod, supporting the hypothesis of Murray cod as the source species (C. Nock, personal communication, data not shown).

Phylogeographic analyses of samples showed that, as expected, the frequency distribution of haplotypes is highly skewed, with one haplotype (mc1) dominating most populations (Figure 6). The most frequently occurring and most widely dispersed haplotype is probably a plesiomorphic (ancestral) haplotype that has managed to squeeze through one or more bottlenecks (Avise et al., 1979). Molecular analysis of variance (AMOVA) and pairwise comparisons showed that several of the populations explored were significantly different on the basis of the frequency and type of haplotypes found in the various regions (Table 8).
Wildstock, hatchery broodstock, and fingerling production are represented from nine hatcheries participating in Victorian State government stocking programs.

Table 8. Pairwise comparisons of Murray cod catchments of the North and South MDB regions (see Figure 1). Matrix of significant Fst P values (+) as calculated by Markov chain method (10,000 steps) at a significance level of 0.05 and 1023 steps.

<table>
<thead>
<tr>
<th>Location</th>
<th>Condamine</th>
<th>Gwydir</th>
<th>Macintyre</th>
<th>Namoi</th>
<th>Broken</th>
<th>Murray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gwydir</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macintyre</td>
<td>-</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Namoi</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Ovens/King</td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Analyses of hatchery broodstock showed that across the Murray-Darling Basin, hatchery holdings of Murray cod generally reflect the distribution and abundance of haplotypes in the wild (Figure 6). Closer inspection of offspring stocked into Victorian waters in the years 2001/2002 revealed that the stocked fish were not representative of the receiving populations, both in terms of number and proportions of haplotypes (Figure 7). Six of a possible 11 haplotypes were present and one haplotype (mc7) was introduced to the population where it was not found in the wild by this study.
Murray cod fingerlings were stocked into tributaries of the Murray River during the 2001/2002 Victorian State government stocking program.

**Trout cod**

MitDNA sequences were compared for the 291 trout cod representing three populations (Figure 8) with 11 haplotypes identified. Parsimony analysis showed that the greatest distance between any two haplotypes was 4 steps (approximately 2% divergence) (Figure 9).
Phylogeographic analyses of trout cod samples showed that the remnant population in the mid-Murray region between Yarrawonga and Tocumwal contained the highest genetic diversity. All 11 haplotypes were present in this population. Only two haplotypes, tc1 and tc2, were found representing the 47 samples collected from Seven Creeks, Victoria, a finding consistent with the origin of this translocated population. From 26 samples collected from the stocked Oven and King Rivers, six haplotypes were found. These samples are assumed to be derived from fish originally bred in captivity and released as part of the threatened species recovery program. Statistically, the populations from Seven Creeks and the Ovens and King catchment were not significantly different from one another, however both were significantly different to the Murray population ($\phi_{ST}=0.047$, $p=0.05$).

Analysis of both Snobs Creek and the Inland Fisheries Research Station (Narrandera) hatchery broodfish showed that each hatchery is missing several haplotypes, however together they capture all 11 haplotypes. Comparison between hatchery holdings and the Murray population (source of most broodfish) suggests that the frequency of haplotype occurrence in the hatchery broodstock collections is divergent from that in the wild (Figure 10). Trout cod haplotype tc1 is over-represented while tc3 is absent from the wild, indicating either absence, incomplete sampling or relative rarity of this haplotype in the Murray River population. Whereas haplotypes tc7 and tc10 are absent from hatchery samples.
Discussion

There is structure to the populations of native fish in the Murray-Darling Basin. The geographic patterns of diversity found for silver perch, Murray cod and trout cod as reported in this study, represent significant new information for management of these species. However, the impression of landscape genetics that we have obtained are preliminary, and we suggest that further effort be applied to obtain the level of information required to adequately audit and manage genetic diversity. Of particular concern was the issue of scale dependency when exploring for population differentiation. We employed two scales, regional and catchment. The number of samples available was the criteria for how the scales were selected, rather than management units determined via genetic (or other appropriate) criteria. The difficulty of defining units for management is an ongoing problem for conservation managers and population geneticists, as the qualities used to designate units for management, that is MU and ESUs, have not been fully resolved (refer to the Methods section on Definition of a Management Unit).

Supplemental stocking of declining populations of native fish in the Murray-Darling Basin has become a popular management tool over the past 40 years. It is now recognised that the use of fish culture techniques to mitigate rather than solve decline will not be sufficient to safeguard genetic resources of wild populations through supplementation by captive broodstocks (Storfer, 1999). Only if substantial progress is made in addressing the underlying causes of population decline concomitantly with (or in lieu of) initiating captive broodstock programs, is it plausible to expect long-term, sustainable increases in population abundance. Developing an understanding of the genetic structure of native fish populations is critical to the facilitation of appropriate management of breeding genetically appropriate stocks used to supplement wild populations.

Landscape genetics

Phylogeography is the term coined by Avise et al. (1987) to describe the association of genealogical lineages with their present day and historical geographic distribution. Differences in phylogeographic patterns between species are often associated with their vagility and the past and present fragmentation of their environment (Avise, 1994). ‘Landscape genetics’ is a term interchangeable with ‘phylogeography’.

Dates since divergence among species and populations can be estimated along with historical biogeographic events by considering the ‘molecular clock’ for the genetic marker of interest. In the hypervariable section (HVR-1) of the control region (5’ end) the rate of substitution can range from 1% to 10% per million year (Myr) as reviewed by Tikel (1997). Estimating a molecular clock is enabled by obtaining fossil data to estimate divergences among species, or by known vicariant events such as an emergent geological barrier. Using a molecular clock estimate for allozymes, Rowland (1993) reported the divergence from a common ancestor among the Murray, Mary River and Clarence River cods to range from 1.7 to 0.8 million years ago (Mya). Assuming this divergence is correct, the molecular clock for the mtDNA marker employed in this study can be extrapolated to the estimate of 1 and 4% per Myr. On the other hand, if we considered a molecular clock range of 1 to 10% per Myr for the mtDNA marker employed in this study, then the divergence since a common ancestor among the cod would range from 3.5 to 0.3 Mya.

As illustrated, single base polymorphisms or genetic diversity take thousands to millions of years to generate. Consider if we were to observe all of the haplotypes to be separated by one or two steps on a phylogram (equivalent to less than 1% diversity), with the maintenance of a high level of low frequency or rare haplotypes, the existing fish populations may be considered to have evolved within a relatively stable environment. A stable environment from a genetic aspect would be a large population size devoid of large contractions.

Alternatively, if there were an absence of intermediate steps among haplotypes (sequences separated by more than 1 to 2%), accompanied by the geographic sharing of those haplotypes among populations, alerts the researcher to introgression or a population bottleneck. Population bottlenecks are also signalled by the loss of low frequency haplotypes. Whereas a sequence divergence between populations approaching, or greater than 8% alerts the researcher to a potential new species (see Table 3).

The transition:transversion:indel ratios for both Murray cod and silver perch indicate a higher relatedness among individuals within a species, relative to the pattern of polymorphism obtained for trout cod (Table 4). The saturation of transitional and transversional polymorphism in the mitochondrial control region in trout cod suggests that either this gene region has undergone a different rate of evolution (molecular clock) compared to the same gene for Murray cod and silver perch, or that the mtDNA marker is signalling a significant bottleneck or introgression for the trout cod. The other possibility, are nuclear copies of mtDNA (pseudogenes) for trout cod.

The greater the sharing of haplotypes among populations, the greater the presumed gene flow. A haplotype unique...
to a geographic region should be sufficient to gazette that area as a MU. However, if there are rare haplotype(s) in the presence of shared haplotypes of greater frequency, then there will be little statistical power provided for genetic differentiation of that population. Obviously, the probability of sampling a low frequency haplotype within a population will be strongly linked to sample size, and how representative the sample. That is, was the sample randomly collected from all geographic areas within the population?

The following specific findings and recommendations obtained through analysis of the landscape genetics of Murray cod, silver perch and trout cod, although informative, would be better supported by larger sample. We recommend that this pilot study be further advanced by targeting areas which are under represented in sample size, such as the wild fish populations of the western areas of the Murray-Darling Basin.

**Silver perch**

Once widespread, silver perch numbers are now greatly reduced and are listed as vulnerable under threatened species provisions of the *Fisheries Management Act 1994*.

Allozymes were used as a genetic marker to examine seven populations of silver perch by Keenan *et al.* (1995). Only three from 36 loci were reported to be polymorphic in silver perch, compared to seven polymorphic loci in golden perch and eel-tailed catfish (Keenan *et al.*, 1995). Similar levels of genetic variation were found by Keenan *et al.* (1995) in two wild-caught samples, and a varying levels of genetic variation for a captive (Grafton hatchery) and four stocked (Pindari, Leslie, Cataract, and Wyangala Dams) samples. Three of those stocked samples had a significant reduction in all measures of genetic diversity (i.e., mean heterozygosity, mean number of alleles, and polymorphic loci) when compared to the wild-caught populations and the other two stocked populations (Table 6). In contrast to the lack of genetic differentiation among the wild-caught samples, Keenan *et al.* (1995) reported significant variation between the five stocked samples at two loci. In summary, Keenan *et al.* (1995) found three of the stocked samples had very low genetic variation (Leslie Dam, Wyangala Dam, Grafton hatchery) in comparison to the two wild-caught samples (Torrumbarry Weir and Cunnamulla) (Table 6), and concluded that there is reduced genetic diversity in the stocked silver perch as opposed to the wild populations.

This study verifies the conclusions by Keenan *et al.* (1995) of a reduction of genetic diversity in stocked populations of silver perch, compared to wild populations. The stocked populations captured less than half of the number of mtDNA haplotypes compared to the wild populations. Furthermore, the mtDNA marker has provided additional resolution over allozymes to highlight the reduction of genetic variation in stocked populations (Table 6).

Considering an apparent 96% reduction of silver perch in the wild, and that the serial stocking events over the last 40 years would have provided numerous opportunities to bottleneck genetic diversity, the diversity of haplotypes in silver perch (26 in 801 individuals genotyped) was an unexpected finding. It is possible that because of the high performance in aquaculture, the level of haplotypic diversity in silver perch appears to not have degraded. However, note that the comparisons in haplotypic diversity were made relative to the diversity observed for Murray cod and trout cod, as we had no record of the historical haplotype diversity for silver perch.

An unexpected finding, considering the frequent interchange of broodstock among hatcheries (anecdotal information), was the genetic structuring among the hatcheries indicated by the dominance of different haplotypes between hatcheries. In summary, it appears that hatcheries in their entirety, have captured a significant proportion of the genetic diversity (haplotypes).

However, a hatchery on its own, does not have a complete representation of haplotypes (see the *Grafton Hatchery Case Study* for an example), which emphasises the requirement for a hatchery registrar and review of broodstock practices. Of 46 hatcheries surveyed, only one hatchery (non-government) PIT tagged their silver perch broodstock and maintained pedigree records. The record keeping and pedigrees were reflected by the mtDNA marker.

As mtDNA is not the highest resolution marker for contemporary population dynamics, if there is the slightest hint provided by mtDNA haplotypes of limited gene flow, such as a haplotype unique to a population, this should be further investigated. An example for silver perch, is the presence of a population specific haplotype “sp2” to the Paroo River system. The absence of this haplotype elsewhere in the Murray-Darling Basin suggests that the Paroo system may be a separate MU, which should be further investigated with a higher resolution genetic marker (such as microsatellites). We advise against translocation with the Paroo system populations.

We have expanded upon the findings of Keenan *et al.* (1995) by establishing support for genetic differences between wild breeding populations in four of the catchments we explored (Macintyre, Condamine, Mid-Murray, and Lachlan Rivers). The presence of genetic
differentiation of these catchments has implications for current breeding and stocking practices with particular reference to the stocking of impoundments, given that gene flow downstream is possible.

**Welch’s grunter**

During a hatchery survey conducted through this study, the question was frequently raised as to whether Welch’s grunter and silver perch were actually separate species, and if it would be considered to be a problem to hybridise them, presumably as a hatchery practice to investigate hybrid vigour.

We present a sequence separation of approximately 5% using mtDNA sequences (Figure 2, Table 3), which supports separate species status. It was expressed, that in light of the well defined genetic separation of the species, that if there were intentional or unintentional release of the hybrids into the wild, both species may have reduced genetic fitness or viability through introgression (Rhymer & Simberloff, 1996).

**Grafton hatchery case study**

The NSW government run fish hatchery in Grafton, currently managed by Stuart Rowland, provided three of their silver perch genetic strains for genotyping with mtDNA. These strains include: 1) GRC expected to be predominantly of Murrumbidgee River, 2) Cataract Dam, and 3) Murray River strain.

The GRC strain at Grafton, was originally sourced from the Murrumbidgee River and maintained at the NSW government hatchery at Narrandera during the late 1970s and 1990s. At Narrandera, the GRC strain has potentially been mixed with silver perch from other populations. The question was “how true to the Murrumbidgee River population is the GRC strain?” In the absence of a representative sample, we are unable to approach this question. However, the GRC strain had three haplotypes (sp1, sp5, sp18), two of which defined it from the Murray River strain (sp1, sp10, sp13) and through the absence of distinguishing haplotypes, from the Cataract Dam strain of Grafton hatchery (sp1 only). Haplotype sp1 is widespread and common. Haplotype sp5 is also widespread and particularly common in the Paroo system and Cunnamulla populations. Haplotype sp18 was common among hatcheries, yet appeared in very low frequency in Leslie Dam, Cataract Dam, Warrego River, and the Murray River (Tocumwal). The distribution of haplotype sp18 shows quite how effectively mtDNA haplotypes can signal a founding event such as the collection and introduction of broodstock (often less than 10 fish) into a hatchery. This founding event would then be followed by increase by the hatchery with the collected broodstock, and the distribution of those fingerlings to other hatcheries which would then be used as broodstock. In summary, a haplotype observed in very low frequency in the wild could easily dominate in captive breeding programs. The concern is that these fish are ultimately used for stocking, no longer representative of the mixture of a wild population, may potentially alter the genetic composition of the wild stocks.

The Cataract Dam sample collected and analysed by Keenan et al. (1995) had greater haplotype diversity than the Cataract Dam holdings recorded for Grafton hatchery. A recommendation for the Grafton hatchery is to source additional broodstock from the Cataract Dam in attempt to capture those missing haplotypes. However, before commencing the addition of new broodstock, the hatchery objectives for that strain should be clearly defined, with perhaps most sensibly, two lines generated: 1) intentionally inbred for growout production, or 2) intentionally outbred for conservation and recreational production. The interest in maintaining an intentionally inbred line would be to protect against the loss of genetic characteristics captured by the inbred pedigree that are favourable to domestication for growout production. It is possible, that in adding new broodstock (and genotypes) to the Cataract Dam strain, the particular genetic characteristics favourable to that genetic line, could be lost or hidden through breeding and the introduction of new genetic material.

**Macullochella species**


Using morphological data, and electrophoretic data from 19 loci, Rowland (1993) defined Mary River cod, to be a subspecies of the indigenous Murray (River system) cod, separated by a genetic identity of 0.72. The Clarence River cod from the Clarence River system, to be a separate species to the Murray cod defined by a genetic identity of 0.85. The clear separation of the species and subspecies among the cod were attributed to stream capture events in the eastern drainage ranging from 1.7 to 0.8 Mya (Rowland, 1993). This date is too recent for the more obvious geographic barrier for a vicariance event; the vertical uplift associated with the Great Dividing Range which occurred before the Miocene (26 Mya) (Rowland, 1993). Furthermore, the small founding populations, and vastly different habitats in the coastal river systems compared to the western drainages, would
have contributed to rapid divergence and speciation of the Clarence River cod and the Mary River cod (Rowland, 1993).

Jerry et al. (2001) in a phylogenetic study using mitochondrial 12s rRNA sequence data, that Mary River cod and Clarence River cod are actually sister taxa, and not Mary River cod and Murray cod as shown by Rowland (1993). Furthermore, Jerry et al. (2001) found that Mary River cod and Clarence River cod were indistinguishable using the 12s mtDNA marker. The monophyly of Australian Percichthyidae (with potential exception of Gadopsis) support recent speciation events occurring within in the last few million years (Jerry et al., 2001).

We verify and support the findings by Jerry et al. (2001) with mtDNA control region data. In addition, we distinguish Mary River cod and Clarence River cod with mtDNA control region sequences as a species marker (Figure 3).

Murray cod

The range of the Murray cod are now significantly reduced, and the numbers have declined dramatically over the last 40 years, but formerly they were abundant throughout the Murray-Darling Basin. Murray cod are the largest and most popular native freshwater fish capable of growing to over 100 kg. Closed season, size and bag limits for anglers targeting Murray cod has helped to increase their numbers.

Murray cod phylogeography across the Murray Darling Basin is unreported prior to this study. Population structure is suggested for the Murray cod, but the relationship is unclear. The nested AMOVA analyses did not support differentiation (data not shown), whereas we found differentiation between populations when pairwise comparisons were made within regions (only North and South regions nominated for Murray cod, see Table 8). The extent to which the differentiation between catchments is an accurate depiction of natural and ancestral population structure is uncertain. However, there is a suggestion that all the eastern drainages (Gwydir, MacIntyre and Namoi) are differentiated to each other more so, than the western catchment (Table 8). That the three catchments of the north have been identified as significantly different from each other should be explored in detail to ascertain the potential impacts that barriers and anthropogenic introductions (i.e., through stocking and/or translocation) may have on these populations.

The data obtained through this pilot study may be affected by sampling artefacts, as the eastern section of the Murray-Darling Basin was better sampled than the wild populations representing the western section. Also, the inclusion of hatchery data is likely to cloud the wild stock landscape genetics, despite the assumption that the hatcheries would be representative of local wild populations. The results therefore, should be considered as preliminary with a recommendation to expand sample collection to the western part of the Murray-Darling Basin.

Northern Rivers Murray cod Case Study

The northern end of the Murray Darling Basin including the Gwydir River, upper Macintyre and the Severn River, were severely reduced in the earlier part of this century in the distribution and abundance of Murray cod, golden perch and silver perch, through various heavy anthropogenic activity (Rowland, 1993). Cod were probably extinct in the Richmond and Brisbane River systems by the end of the 1930s (Rowland, 1993). In the absence of a voucher specimen (Queensland Museum, Brisbane, personal communication) it is not known if the cod of the Richmond or Brisbane Rivers was a Murray cod, Mary River cod, Clarence River cod, or even another sister species.

In response to the reduction of native fish numbers, the northeastern rivers were stocked in the first half of the 1900s with native fish, and rainbow and brown trout by local hatcheries (Reynolds, 1988). The assessment of genetic types between the hatcheries of these catchments and the wild stocks is not in conflict with the stocking history. It is likely that the local hatcheries perhaps unintentionally, employed the ‘conservative clause for stocking’ which is to source local broodstock, produce fingerlings which are then stocked back to the same populations where the broodstock were taken.

Trout cod

Phylogeography for the trout cod is unreported prior to this study. Anecdotal evidence suggests that trout cod are have undergone a massive contraction in numbers since white settlement, and there has been a significant reduction in their range. Trout cod now only occur in lowland rivers and lakes around the mid to upper Murray in Victoria, the Murrumbidgee River in the Australian Capital Territory (Rimmer, 1988), and there are a few anecdotal reports of trout cod in the upland headwaters in some rivers of the abovementioned areas. In addition, there is a stocked population of trout cod and Murray cod hybrids in the Cataract Dam, which were introduced prior to the First World War (Rimmer, 1988). Behaviour of trout cod within the aquaculture environment is very similar to Murray cod, though trout cod are more
aggressive and therefore more susceptible to angling pressure. Only the last 30 years reflect any consistent acknowledgment of trout cod requiring conservation attention, and by this stage the damage was done. Trout cod are now listed as an endangered in NSW under the Fisheries Management Act 1994, and as endangered under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999. They are also listed as threatened in Victoria under the Flora and Fauna Guarantee Act 1988 and totally protected under the ACT (under the Nature Conservation Act 1980) and South Australia (under the Fisheries Act 1982). The IUCN (International Union for the Conservation of Nature) has listed trout cod as endangered on its international Red List of threatened flora and fauna.

**Seven Creeks Case Study**

The mid-Murray population is considered to be the remnant population of an originally much wider distribution for trout cod. The Seven Creeks population is believed to owe its origins to one or several undocumented translocation events in the early 1900s. The lower haplotypic diversity in the Seven Creeks population, relative to the Murray River population, is consistent with a series of founding events, or stocking with genetic similar fish. Given the observed lower genetic diversity of the Seven Creeks population, it’s apparent role as a ‘back up’ or ‘genetic reserve’ to reduce risk for the Murray River is called into question.

Perhaps a management program of genetic diversification should be undertaken such that the Seven Creeks population better resembles the Murray River? Alternatively, further exploration of this population may be warranted to explore for localised adaptation that may have occurred since the separation from the remnant population in the Murray. In either case, the role of hatcheries for this endangered fish will continue to be of paramount importance.

Differences in haplotype frequencies are manifested clearly in the re-introduced population sampled from the Ovens and King River catchments in Victoria. This population shows much greater affinity with hatchery stock, and lacks several of the haplotypes of the remnant trout cod population of the Murray River. The trout cod landscape genetics clearly reflect the value of applying genetic tools to the evaluation of hatchery holdings. The representativeness of hatchery stocks may be monitored, and relationships between broodfish and offspring explored, to identify when selection for genetic diversity is inadvertently occurring either during broodstock procurement or during breeding.

**Genetic typing for broodstock management**

Although up to 30 individuals per population can reveal a significant amount of information with respect to the landscape genetics of a species, realistically hundreds to thousands of fish should be genetically tagged in order to obtain sufficient information for ongoing monitoring, and to provide the type of information which is truly useful to conservation and industry managers. That is, the level of genetic information that enables assessment of the genetic status of captive broodstock, and the genetic diversity and landscape genetics of the wild populations (source of broodstock). As a result of these objectives, a non-destructive, informative, cost-effective, high throughput genetic marker, has become the ambition for geneticists.

There are genetic methodologies available that fulfil all the requirements, other than ‘cost-effective’. It costs approximately AUD$50 to genetically type an individual fish with an established genetic marker (which includes the cost of the researcher). Ideally, the cost per individual should be less than AUD$1 to make it feasible for a genetic assessment program. Generally, there are four aspects to the costing of high throughput typing of samples:

- Collection of the samples
- DNA extraction
- Application of the genetic marker of choice.
- Technician and/or researcher’s time to obtain the sample, genetically type the individuals, and to produce a report summarising the significance of the results.

In this study, we have employed the method of Chelex-100 extractions of DNA, and the application of mtDNA genetic marker typed using the method of TGGE. TGGE reduced the cost of typing individuals from that estimated AUD$50 per individual to approximately AUD$2 per individual. If a hatchery were to type 30 individuals of each genetic line using the mtDNA marker and the method of TGGE presented in this study, this would reduce the cost from the estimated AUD$1500 to an affordable AUD$100. Note that the TGGE analysis approach is a method highly effective for Murray cod and trout cod, though silver perch by virtue of it’s high number of haplotypes, would require some additional research and development to establish effectiveness of the same assessment method. Furthermore, mtDNA is highly informative for landscape genetics, and may provide a hatchery with an understanding of the proportion of genetic diversity it has captured. However, as a haploid maternally inherited marker that is less informative for contemporary population dynamics; that is, a marker useful for year to year individual management.
Microsatellite markers on the other hand can provide the level of resolution required for individual broodstock management. There are two loci available known to be polymorphic for Murray cod, Mary River cod, Clarence River cod and trout cod (C. Nock, personal communication). Ideally, 10 to 15 loci are required to obtain sufficient information for an understanding of population dynamics. And although microsatellites are an attractive marker, there are additional research and development costs, and the cost per individual generally remains at approximately AUD$50 per individual.

There have been some recent developments in high-throughput genotyping including an inexpensive and high-throughput silica based DNA extraction method for population studies developed by Elphinstone et al. (in press), which combines a 30 minute ‘do-it-yourself’ single tube purification of genomic DNA in a 96-well format. This quick, easy and economic extraction method produces DNA of quality on par with commercial kits for 1/10th of the cost (i.e., AUD$4 to AUD$0.40). In addition, early stages of microsatellite loci development can be economically facilitated by the use of a universal primer to fluorescently label PCR products (Elphinstone & Nock, submitted). Traditionally the approach has been to purchase a fluorescent primer which can total AUD$100. Considering that generally 10 to 15 microsatellite loci are used in a population study or broodstock analyses, and that often it is difficult to predict the suitability of the primer until it is applied, the production of unsuitable primers can be very costly. The potential redundancy of the primer through lack of suitability, or because the minimum volume purchased can be more than required (limitation provided by the oligonucleotide manufacturer) can be significantly reduced by employing the method by Elphinstone & Nock (submitted).

An example of an attempt to approach economic genotyping for genetic stock assessment of an Australian fishery, is currently underway by the Queensland Department of Primary Industries (Ovenden et al., 2002b). Ovenden et al. (2002b) are using a biopsy lure to remote sample Spanish Mackerel, and apply microsatellite markers targeted at genotyping at AUD$5 per individual, in order to estimate harvest rates for this commercial fishery.

Genetic markers are highly informative for contemporary and historical population dynamics, but their research and development is highly expensive, as is the continued monitoring. Tagging and continual monitoring is unlikely to be feasible unless supported economically by industry. Australian government may be able to initiate research and development, but to be able to capitalise on that funding for conservation genetics projects even within government research institutions is becoming increasingly difficult. An interesting yet difficult exercise currently underway is an attempt to compare an estimate of the monetary value of the Murray-Darling Basin including: agriculture, forestry, tourism and recreation, culture, and water resource, to national and state support via research and development (Larry Kirk, personal communication).

Regardless of the genetic marker employed, this study has reduced the cost of sample collection through establishment of the Native Fish Tissue Bank, thereby benefiting future projects.

Native Fish Tissue Bank

There are two collections from which this study benefited, a -80°C storage of allozyme tissue samples collected for protein electrophoresis studies by Keenan et al. (1995), and an ethanol preserved collection stored at 4°C collected by this study. Both tissue banks are currently kept with a backup alarm system at the Bribie Island Aquaculture Research Centre, Queensland Department of Primary Industries in Queensland.

The funding that supported the collection of this material was provided by the Australian Natural Heritage Trust. The intellectual property, which in this case is a Native Fish Tissue Bank, is of national interest. We recommend that there be continual development of the existing Native Fish Tissue Bank to benefit future research.

We propose that the existing known tissue banks (held at the BIARC and South Australian Museum) continue to be housed in their respective locations and operate as ‘nodes’ of a central registrar. We suggest that the central registrar be developed, administered, and maintained from a location that is made publicly available via a website. Access to the material should be directed by a group of advisers for the respective tissue banks. With respect to the material stored at BIARC, the group of advisers should be the steering committee of this project. With respect to the South Australian Museum freshwater fish collection, Steve Donnellan as curator would be an adviser, as well as Mark Adams, who is a major user and procurer of that collection (approximately 15,000 fish are represented). The cold storage (-80°C) at the South Australian Museum is managed by a part time position at a charge of cost recovery (labour cost for sub-sampling only, which does not include recovery for collection or maintenance). Steve Donellan and Mark Adams have been approached to seek interest in supporting a central registrar.
Currently, there is a proposal in progress for financial support for the central registrar of the Native Fish Tissue Bank to be held at the Centre for Animal Conservation Genetics laboratory at the Southern Cross University, Lismore, NSW. There is strong interest by one of the authors (Daniela Tikel) and the Pro Vice Chancellor of Research (Peter Baverstock) to eventuate projects from the tissue bank material. In addition, the access to the registrar could be facilitated through the Southern Cross University website.

The Arthur Rylah Institute for Environmental Research (ARI), Department of Natural Resources and Environment, Victoria, conducts research and surveys to assist in biodiversity conservation and ecologically sustainable development. It provides authoritative information on flora, fauna and biodiversity conservation to land managers, and the Victorian public. The ARI collected samples for this project, and also has a strong interest in continuing to capitalise on the material collected to date. Furthermore, the monitoring focus of the ARI and opportunities for collections in Victorians waterways by researchers in this institution would continue to benefit the national Native Fish Tissue Bank.

Recommendations

Assess whether stocking or translocation is required.
It may be deemed that the habitat requires rehabilitation, in which case the expected outcomes of any stocking event should be clearly specified.

Conduct a risk assessment of the stocking or translocation event.
There is clear support for the designation of stock management zones (conservation areas) as proposed by Keenan et al. (1995), and supported by this study. Interbreeding distinct populations contains the risk of reduction of fitness, or even extinction through hybridisation and introgression (Rhymer & Simberloff, 1996).

Assess the containment of the receiving populations. That is, will the receiving population leak into other waterways? This may be of particular relevance when stocking impoundments or exchange of broodstock among hatcheries with potential leakage to downstream streams or rivers.

How pristine is the neighbouring waterway? It may be of importance to prohibit stocking and translocation immediately surrounding ‘pristine natural populations’.

The risk assessment should be inclusive of an Environmental Impact Study. If stocking occurs, is there a possibility of disrupting the existing ecology and food chain?

Ensure adequate genetic character for release
Genetic character of the fingerlings released into an existing population should match that of the receiving population, and as such, should be as diverse in genetic complement as possible.

Translocation should only happen among genetically same populations.

Adopt conservative stocking practice.
In the absence of genetic information, it is best to adopt a conservative approach to stocking. That is, local stocking from hatcheries using locally sourced broodstock, where ‘local’ is considered as within a connected catchment (devoid of significant barriers). The assumption being that the movement and gene flow of native fish within a catchment is expected.

Where stocking or translocation will occur into a water body without connection to a pre-existing fish population, as many unrelated broodstock as possible should be utilised to produce fish for stocking. To facilitate this, novel approaches to broodstock management such as annual rotation of broodstock between hatcheries or stocking a proportion of fingerlings from many local hatcheries could supply the same receiving population within a year. Genetic character of stocked fish should be sampled and monitored via a gene-bank registry.

Reduce outbreeding depression by sourcing broodstock from genetically similar populations.

Stocking catchments and impoundments should adopt the same broodstock management and stocking methodologies as employed in stocking of open systems because of: 1) leakage from impoundments into connected waterways, 2) impoundments have been sourced (or may need to be sourced) for broodstock, and 3) gene-flow downstream is possible.

Implement genetic monitoring
One of the most difficult decisions facing managers designing a conservation program is the identification of triggers for action, as well as establishing the criteria for selection of ‘reserves’ (Harvey et al., 1998). The International Union for the Conservation of Nature (IUCN) have initiated the concept of conservation units, and Allendorf et al. (1997) have developed criteria for conservation units based on the IUCN model. The definition of MUs was further explored as reviewed above in Definition of a Management Unit (Methods).
Not only is it important to understand the units for conservation management, but in order to do genetic monitoring, it is necessary to first achieve an assessment, so that it is possible to monitor change. That is, it is imperative to obtain baseline data in order to detect when there has been a change in the genetic structure, or loss of genetic diversity. Generally, all the concerns return to the issue of how to recognise triggers that are able to signal or predict the loss of genetic diversity.

Loss of genetic diversity, and the extensive theory supporting how this occurs is exhausted in the literature (for example, as reviewed by Frankam et al., 2002; Carvalho & Pitcher, 1995; Tave 1993; Lutz, 2001). Essentially the issues include inbreeding, loss of heterozygosity, loss of allelic diversity, effective population size, and outbreeding depression (hybridisation and introgression).

Inbreeding leads to increased homozygosity through the interbreeding of closely related individuals (loss of diversity). Inbreeding depression is the result a higher probability of deformities being exhibited due to the expression of deleterious recessive alleles. Loss of genetic diversity can be signalled through the loss of heterozygosity (or increase in homozygosity), and/or the reduction of allelic diversity, where allelic diversity is the number of possible variants at a polymorphic site or locus. The extent to which loss of diversity can occur is strongly dependent on the effective population size. Outbreeding depression can result in the loss of genetic diversity through hybridisation sterility or introgression. This occurs when genetically divergent stocks are mixed.

Loss of immunity and general health are strong triggers for genetic degradation. Acting on a trigger alerting the loss of genetic diversity is one aspect of monitoring. Taking the appropriate action is the next difficult step in decision making for managers. Each stocking and/or translocation event should be assessed on its’ own merit. Knowing when to mix particular genotypes, or when to separate or protect a particular population are all case specific decisions. This doesn’t alleviate the difficulty in decision making, but it would be foolish to generalise management techniques from a species level, to these particular scenarios.

Furthermore, management should be dynamic; open to new information whether genetic or otherwise. It is of course, all the while extremely important to maintain or preserve the genetic resource, and to be manipulating artificial populations, thereby the loss of genetic diversity in instances is affordable because it can be replenished from the ‘back up’ population.

It may be apparent at this stage for the realisation that experimentation is essential. For example, impoundments stocked with known frequencies of genotypes of a particular species, should be monitored annually to examine fluxes in allele frequencies to better understand and predict the likely outcome if a natural population were to be stocked.

Explore government versus industry production

In the United States of America (USA) conservation and aquaculture production has been separated. This enables regulation of conservation broodstocks to be managed more easily and removes responsibility for conservation breeding from the aquaculture industry. This in turn allows the aquaculture industry freedom to pursue line breeding and strain improvement without risk of compromising genetic qualities of wild stocks.

Conservation stocking (supplementation) that recognises and preserves stock structure for native fish species requires a very large investment in infrastructure and procedures to maintain separation between stocks used to breed for different geographic areas. The international experience suggests that the cost of this infrastructure is not easily met in a commercial environment. The additional costs of monitoring the outputs of commercial hatcheries undertaking such work further add to the cost of production and infrastructure.

As primary consumers of fingerlings produced for stocking into the Murray-Darling Basin, the governments involved have a right and responsibility to explore the best options for production of a quality product.

National conformity in policy

The Murray-Darling Basin covers an area including five Australian State or Territory governments: Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia. The issues of access to broodstock, and now of access to broodstock of appropriate genetic quality, are complex and are made more difficult by State specific legislation and policy.

Establish a central genetic register

The development of consistent policy, a register of broodstock, and the use of genetic typing for all new broodstock, would be major advances to significantly improve the provision and monitoring of broodfish in the aquaculture industry. This would address several issues such as illegal procurement, mis-identification, and lack of rotation of broodfish.
Such a register would also form the basis for stock improvement and domestication for commercial grow-out operations, without compromising stocks that are maintained for the purposes of conservation breeding and stocking. Stuart Rowland of the NSW Fisheries, Grafton, is currently conducting a Hatchery Registrar Quality Assurance Program for NSW to achieve these objectives.

Conclusions

Genetic population structure exists for Murray-Darling Basin native fish species. We have presented a case study for each species of interest that we recognised as having some very obvious and immediate management issues.

This has been an ambitious pilot study (two year investigation supported by the Australian Natural Heritage Trust) for which not all the genetic data have been fully explored or sufficiently reported. Under preparation are a series of more detailed reports which will be submitted to peer reviewed journals. It has been challenging to make specific recommendations, as we feel there should be further research and additional sampling to improve representation of the western populations of the Murray-Darling Basin.

The Recommendations should be considered by managers in order to improve current hatchery, stocking and translocation practices. The success of genetic management of Australia’s native fish species remains with the hatcheries, and it is the hatchery responsibility to consider the genetic status of their fish and the objectives of why those fish are being produced (i.e., commercial verses conservation).

The stocking and translocation workshop for which this document was prepared, is imperative to facilitate communication between government, industry and community, as well as inviting the various States of the Murray-Darling Basin to conform in priorities and policy. We need to continually remind ourselves that the native flora and fauna of the Murray-Darling Basin do not recognise State borders.

Acknowledgments

This work is part of the Conservation Genetics for Murray Darling Fish Project, funded by the Natural Heritage Trust (NHT), Murray-Darling Fish Rehabilitation 2001 Program, and administered by the Department of Agriculture Fisheries & Forestry of Australia. The project is coordinated by a steering committee consisting of: Bruce Malcolm (representative for the commercial, native fish hatchery industry), John Koehn (Victorian Department of Natural Resources & Environment (DNRE)), Andrew Bearlin (DNRE), Clive Keenan (QDPI, BIARC), Daniela Tikel (QDPI, BIARC), and Stuart Rowland (NSW Fisheries).

We thank the collectors of samples, and volunteers for this study including: industry (hatchery) operators, government fishery biologists and restocking organisations, and specifically: Adrian Collins (QDPI, BIARC), Brett Herbert, Peter Graham, & Mal Pearce (QDPI, Walkamin), Cathy Nock (Southern Cross University), Simon Apte, Katie Sumner, and Brett Jasch.

References


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### 6.2 Development of a Riverina-Murray Aquaculture Strategy: ensuring a balance between fish production and conservation

**Graeme Bowley, Aquaculture Planning Officer, NSW Department of Fisheries**

**Background**

Aquaculture is one of the fastest-growing industries in the world. Already 25% of the seafood consumed worldwide is produced through aquaculture. According to the United Nations’ Food and Agriculture Organisation, this is projected to rise to 40% by the year 2010, as a result of increasing demand for seafood which wild capture fisheries can no longer meet.
While many types of aquaculture are still in their infancy in Australia, the same global trends that are driving aquaculture internationally are evident here. As the total value of Australian fisheries production has tended to stabilise over the last five years, the contribution of aquaculture has grown – by 12% in 1997/98 and by 80% over the course of the 1990’s. The national value of aquaculture production reached over $600 million in 1998/99 – 26% of the total value of Australian fisheries production – and the industry is expected to increase in size four-fold to $2.5 billion over the next decade.

New South Wales is poised to capture a significant proportion of this projected growth. A growing number of viable aquaculture investment opportunities are being generated by the drive to satisfy increasing domestic and export demand, and by the competitive advantages (both natural and man-made) which this state offers.

Compared with many overseas locations, New South Wales offers a clean growing environment for most forms of aquaculture. It does not suffer from a number of diseases that have caused losses among aquaculture industries overseas. Strict national and State-level controls have been established to maintain our freedom from some of the worst exotic diseases. New South Wales also offers reliable supplies of good quality water.

Why the need for the Strategy

It is vital that a long-term strategic view of aquaculture development is taken to ensure that investment is ecologically, economically and socially sustainable in the local and regional environmental context. Both industry participants and the NSW Government’s regulatory agencies are very conscious of the need to ensure that the development of the aquaculture industry in New South Wales proceeds in a manner that does not jeopardise its ecological sustainability.

Both industry and government continue to invest heavily in research, technology and management practices to provide for the ecologically sustainable growth of this sensitive industry. Both recognise the environmental benefits arising from aquaculture, as well as the environmental qualities aquaculture needs for it to operate successfully to ensure the continuing high quality of its products.

Development of the Riverina-Murray Sustainable Aquaculture Strategy

The Riverina–Murray Sustainable Aquaculture Strategy (RMSAS) is one of seven land-based aquaculture...
strategies applying to pond, raceway and tank aquaculture which are being prepared for NSW. The North Coast Strategy is presently the only completed strategy and is being used as a blueprint for the development of the remaining 6 strategies including the RMSAS.

To ensure aquaculture is developed in a manner that is ecologically, economically and socially sustainable, NSW Government’s regulatory agencies have come together to provide a whole of government approach in the development of the aquaculture strategies. Regional Steering Groups responsible for developing the region’s strategy comprise of representatives from NSW Fisheries, PlanningNSW, Environment Protection Authority, Department of Land and Water Conservation, National Parks and Wildlife Service, Department of State and Regional Development, NSW Agriculture, and is chaired by Premier’s Department regional coordinators.

The RMSAS once completed will apply to three types of intensive land based aquaculture, namely:

- Saline pond and raceway aquaculture,
- Freshwater pond and raceway aquaculture, and
- Tank based high intensity recirculation aquaculture (saline or fresh water).

The RMSAS will provide an environmentally sound framework for interfacing the technical provisions of the Aquaculture Industry Development Plan (AIDP) for Land-based Aquaculture in the Riverina-Murray under the provisions of the Fisheries Management Act 1994. The AIDP will identify best management for business planning, species selection, site selection and design, planning and operation of the facility and includes the performance requirements for relevant environmental regulations.

The RMSAS will incorporate a whole-of-government approach. It will present a clear message to the existing aquaculture industry as well as new investors as to the environmental performance objectives expected.

The information in the AIDP represents current best practice. However, the RMSAS will encourage continuous improvement in environmental and economic performance and approaches which provide outcomes superior to those outlined in the AIDP are encouraged.

Aquaculture Industry Development Plans

The best management component will provide the basis for the Aquaculture Industry Development Plans (AIDP) for Land-based Aquaculture in the Riverina-Murray under the provisions of the Fisheries Management Act 1994. The AIDP will identify best management for business planning, species selection, site selection and design, planning and operation of the facility and includes the performance requirements for relevant environmental regulations.

The AIDP will incorporate a whole-of-government approach. It will present a clear message to the existing aquaculture industry as well as new investors as to the environmental performance objectives expected.

The information in the AIDP represents current best practice. However, the RMSAS will encourage continuous improvement in environmental and economic performance and approaches which provide outcomes superior to those outlined in the AIDP are encouraged.

Integrated Approvals and Assessment

Integrated approvals and assessment are achieved through a combination of the existing and new provisions under the EP&A Act. This assessment and approval framework provides for efficient assessment, appropriate development controls and holistic decision making. This framework complements and implements the AIDP.

Based on best practice in the AIDP for the location and operation of aquaculture enterprises a ‘Project Profile Analysis’ will be established to provide an up-front preliminary assessment of the likely level of risk to the environment from an aquaculture development proposal. This will lead to environmental performance criteria that form the basis for ‘risk’ profiles and based on these profiles, a streamlined approval process for particular types of development shall be established in the State Environmental Planning Policy (SEPP) 62 – Sustainable Aquaculture. The SEPP:

1. makes aquaculture permissible use on certain land in the local government areas providing it meets “minimum locational performance criteria”;

2. utilises the best practice in the AIDP to establish risk criteria in a ‘Project Profile Analysis’ which can lead to the ranking of development which is considered low risk as Class 1, moderate risk as Class 2 or higher risk as Class 3 Designated Developments.
As a result, development which may be currently designated development (and need an Environmental Impact Statement (EIS) under Schedule 3 of the EP&A Regulation) may be de-designated. Other development currently not designated may become designated based on criteria specific to the region.

These provisions will ensure that the level of assessment matches the level of impacts of a development proposal. Class 1 and 2 development applications will need to be accompanied by a Statement of Environmental Effects (SEE). Class 3 developments will require an EIS to accompany the development application.

Under the integrated development approvals provisions of the EP&A Act, almost all aquaculture proposals will be considered to be integrated development, as they will require at least one approval under the following legislation:


In developing the best practice and environmental performance criteria in the AIDP, consideration has been given to the requirements of the above legislation as well as the legislation listed below which may also apply but are not included in these provisions. This will ensure a whole-of-government approach is taken from the outset in establishing sustainable performance and integrated approvals for the environmental management of aquaculture.


As the best practice in the AIDP will include all key issues for an integrated approval, obtaining subsequent approvals should not be onerous. To achieve this objective, where ever possible the development approval will incorporate the general terms of approval relating to all relevant legislation for the establishment of the project.

In addition, an integrated compliance monitoring provisions of the development consent will integrate the requirements of all approval authorities. This will streamline the post-approval monitoring and reporting requirements and ensure that the aquaculture enterprises are established and operated in a sustainable manner.

Extensive consultation will be undertaken with local government, the aquaculture industry, environmental groups and other stakeholders in the development of the RMSAS. This consultative approach will be continued in the implementation, monitoring and review of the Strategy.

Implementing the Strategy

The implementation of the RMSAS will require a partnership between government, industry and the community. In order to maximise efficiencies and competitive advantages, inter-agency and local government cooperation is essential in facilitating ecologically sustainable new and expanding aquaculture projects. The application of the RMSAS will avoid unnecessary duplication of effort by applicants and agencies. It also will ensure that project approvals can be streamlined when appropriate. This approach offers significant benefits to industry, the community and the environment, the most important being:

- In terms of economic development and employment opportunities, there is clear support for the location of ecologically sustainable aquaculture enterprises in the Riverina-Murray Region. This strategic approach will provide a competitive advantage in attracting sustainable employment to the region;

- In terms of development applications, there is more up-front certainty for applicants and the community as to the environmental requirements and criteria to be met. The approach also provides clear incentives to industry to adopt best environmental practice at the outset; and,

- In terms of the environment, consideration of environmental impacts at the strategic level offers a more appropriate indication of environmental sustainability relative to individual project impact assessments. The consideration of cumulative impacts at the strategic level addresses shortcomings associated with individual impact assessment in isolation.

NSW Fisheries is the key agency responsible for delivery of the on-the-ground outcomes in these four action areas. The other key player is the consent authority (council or PlanningNSW) with responsibility for development consent and integrating approvals. NSW Fisheries and the consent authority will be supported by a Riverina-Murray Regional Aquaculture Steering Group that will provide technical assistance with regard to legislative
requirements, performance standards and monitoring protocols to ensure that a whole-of-government approach is reinforced in each action area.

Monitoring and review of the Strategy

The focus of the strategy is on individual land-based aquaculture projects. However, it is recognised that cumulative impacts may occur when a series of aquaculture enterprise developments are established within a catchment or sub-catchment. NSW Fisheries along with other agencies will be responsible for making recommendations to the Riverina-Murray Regional Aquaculture Steering Group on the need to review and update any aspects of the RMSAS as a result of cumulative or other changes in the catchment.

NSW Fisheries will monitor the performance indicators in the AIDP and will trigger a review if those indicators show that cumulative impacts could be occurring. The RMSAS will be periodically reviewed, and aspects can be reviewed if triggered by a performance indicator.

Linkages and outcomes

NSW Fisheries is also developing in conjunction with the sustainable aquaculture strategies a number of other initiatives to ensure an ecologically sustainable aquaculture industry. These initiatives include:

- An aquaculture compliance program which establishes multiple approaches to achieve a high level of compliance by aquaculture facilities. It will provide a structure to support maximum voluntary compliance with effective checks and deterrents against illegal activity. Program components include information materials, self-audit, systemised inspection audits and the creation of a central data base to manage aquaculture administration and compliance throughout NSW;

- A hatchery quality assurance program to ensure that stock produced is appropriate for the end use, be it aquaculture, recreational stocking or conservation stocking; and,

- NSW Fisheries translocation policy which provides guidance on the permissibility of translocation of fish species into aquaculture facilities and associated design and operational criteria, which are included in the aquaculture strategies.

The RMSAS recognises the importance of the role of NSW Fisheries in extension and compliance. In addition to NSW Fisheries Officers being available to provide up-to-date information as a result of research programs and advice on best practice in aquaculture management, they will be in the front line in ensuring best practice is followed and approvals are complied with.

In addition to the increasing understanding of pond culture, improvements in recirculation and filtration technology has resulted in an expanding ‘boutique’ tank-based industry located in industrial zones in towns supplying high quality fish principally to the restaurant and tourist trade.

The RMSAS will provide a common basis to plan for the future growth of aquaculture in the Riverina-Murray Region. The outcome of the strategic planning approach will be increased aquaculture opportunities and related employment through:

- facilitating the growth of existing sustainable aquaculture industries;
- attracting new aquaculture industries to the region;
- attracting aquaculture related industries and jobs to the region.

Aquaculture has the potential to be a significant employer in regional areas as well as having flow-on employment and export opportunities.

The way forward

The implementation of the RMSAS when completed will require effective collaboration between government, industry and the community. The RMSAS brings together the interests of economic development, land use planning and development control to form a partnership that can lead to ecologically sustainable aquaculture and employment generation in the Riverina–Murray Region. The RMSAS can result in:

- improved environmental outcomes with cumulative issues providing better indicators of sustainability;
- improved development outcomes with greater certainty and a simplified assessment and approval approach;
- improved community outcomes with the development of environmental performance criteria and encouraging employment in the region; and,
• improved outcomes for the Region with co-ordinated assistance in attracting ecologically sustainable aquaculture investment.

The Strategy provides a clearly defined framework to facilitate the entry of new aquaculture industries into the Riverina-Murray Region and the continued growth of existing businesses. This strategic framework will provide a competitive advantage for the Region as it provides a tailor-made decision making process and a streamlined approval regime resulting in up front certainty without compromising environmental outcomes.

6.3 Management of fish stocking in New South Wales; 
Dr Andrew Sanger, Regional Manager, Western region, NSW Department of Fisheries, and 
Bill Talbot, Principal Manager, Threatened Species, NSW Department of Fisheries

Abstract

New South Wales Fisheries is responsible for the management of fish stocking in New South Wales. This responsibility extends to fish produced at both Government owned and privately operated hatcheries.

NSW Fisheries has been breeding fish for the purpose of enhancing recreational fishing since Gaden Hatchery opened in 1953. During the 1970s and 1980s the department developed techniques for breeding native freshwater fish at Narrandera Fisheries Centre, the Brackish Water Fish Culture Research Station (now known as the Port Stephens Fisheries Centre) and the Grafton Research Centre.

Over the past 20 years the department has improved technology and substantially increased the output of fry and fingerlings. During this period stocking policy has also evolved. Current practices involve stocking fish for both conservation and stock enhancement purposes. The consideration of environmental factors is a major part of stocking decision making, and genetic issues are considered in both government hatcheries and the licensing of private operations.

The next few years will involve an even greater rate of change. Recent amendments to the Fisheries Management Act require the development of a management strategy for stocking activities in NSW. Prior to its finalisation, the draft strategy must undergo environmental assessment under the provisions of the Environmental Planning and Assessment Act to test its sustainability in terms of environmental management. This comprehensive environmental impact assessment report must be prepared and publicly exhibited.

Hatchery operations are also under review. In addition to government hatchery operations, the private hatchery industry has grown to a point where it produces around 7 million fish annually. Many of these fish are used for enhancing recreational fisheries and stocking farm dams. Poorly managed hatcheries can create significant problems associated with inbreeding (e.g. abnormalities, low survival, slow growth), genetics (e.g. low levels of variation, stocking of siblings), diseases and the translocation of non-endemic fish. To address these issues, the department is developing a Hatchery Quality Assurance Program (HQAP) for inland native fish hatcheries.

Introduction

Stocking of fish into freshwater environments in New South Wales is managed by the State Government through its fisheries management agency, NSW Fisheries. Stocking is undertaken for both recreational fisheries enhancement and biodiversity conservation goals. Both public (i.e. Government owned) and private hatcheries produce fish for stocking. There are also a number of small hatcheries owned and operated on a not-for-profit basis by community groups, such as angling clubs, that produce fish for stocking.

Regulation of the stocking activities of both Government and the general public has evolved as the understanding of the potential impacts of stocking has increased, and the potential range of species available for stocking has increased.

Initial attempts by early colonists to establish familiar sport and table fish from Europe into Australian waters saw a number of successful introductions including common carp, salmonids and redfin perch. Many of these species remain abundant in NSW and elsewhere in Australia and most are sustained by natural recruitment. For the salmonids, which are held in high regard worldwide as sports and table fish, ongoing stocking programs developed very early on, and remain in place today to sustain important recreational fisheries.
Initially the only species available for stocking were salmonids, principally brown and rainbow trout, which were produced at hatcheries owned and operated by trout acclimatisation societies. These fish were stocked out into suitable cool water streams and lakes with little knowledge about their own growth and survival, or the potential for these introduced fish to impact on native species. The main regulatory controls on stocking at that time were more aimed at achieving an orderly distribution and equitable allocation of fish for restocking rivers and lakes.

As techniques for efficient hatchery production of other species developed, regulatory instruments and policies were developed to provide for growth in the private hatchery industry, greatly enhanced recreational fisheries in lakes, and protection of natural biodiversity at the bioregional or catchment level. The main elements of this current policy are:

- All stocking into public waters requires a permit;
- Stocking is permitted for fish within their natural range;
- Salmonids are only permitted in waters that have been traditionally stocked;
- Golden perch and silver perch are permitted in farm dams in the eastern drainage located above the 1/100 year flood level and in Hunter River impoundments;
- No other introductions or translocations of native or non-native species without environmental assessment and public consultation.

This policy has ensured that no further legitimate introductions of alien fish or translocations of native fish have occurred for many years in NSW. However, accidental or illegal introductions of a number of species such as oriental weatherloach and banded grunter have occurred and this remains a problem for biodiversity conservation.

The State of NSW has a range of freshwater environments in which stocking is carried out. These include rivers and impoundments (lakes) in montaine, slopes and lowland environments, on both sides of the Great Dividing Range and including almost all river catchments in the State.

History of trout hatchery facilities

Brown and rainbow trout were successfully introduced to NSW waters over 100 years ago. The combination of the great popularity of trout fishing, the early success with initial introductions into many areas, and the relatively simple technology required to produce trout in hatcheries saw the establishment of a large number of private and community owned and operated hatcheries in the early 1900’s.

The most successful facilities were those operated by what came to be the trout acclimatisation societies. The trout acclimatisation societies were formally recognised by government as the producers of trout for restocking purposes, and were assisted in their voluntary operations with government funding.

Many of these facilities struggled to consistently produce fish, often because of one or more of the following factors: poor water quality/quantity, inappropriate sites, lack of funds and inadequate labour (voluntary or paid). Most of these facilities ceased operation prior to about 1950, although some continue in one form or another today.

In the 1950’s the government of the day recognised the difficulties that acclimatisation societies faced in operating trout hatcheries. The government took control of two of the remaining hatchery sites, employed permanent staff and has continuously produced trout and salmon at these sites since then. The acclimatisation societies remain recognised by government as a partner in the stocking of trout into suitable waters in NSW. This represents a strong cultural link with the original voluntary groups who pioneered the development of trout fishing in NSW.

History of native fish stocking programs

The breeding biology of the freshwater native fish of importance to recreational fishing was very poorly understood prior to the 1960’s. Research carried out in the 1970’s and 1980’s in NSW at what is now the NSW Fisheries Narrandera Fisheries Centre, broke through many of the barriers to hatchery production of Murray cod, golden perch and silver perch – the main recreational species in lowland rivers of the Murray-Darling Basin. Hormone induced stimulation of spawning, hatchery-based incubation of fertilised eggs, and plankton pond grow out from young larvae to fingerling stage established the basis for both a private farm dam stocking program and a public recreational fisheries enhancement program in the government owned large impoundments.

Technology transfer to private industry saw many inland native fish hatcheries establish. These private facilities
now provide all stock for private farm dams, and a large number of fish for community funded river stocking programs.

The focus of the fish breeding program at Narrandera Fisheries Centre has shifted from technical research to production of large quantities of fish for restocking programs in recent years. This has been made possible by upgrading of the facilities at Narrandera over many years and improved technical knowledge.

Current status of stocking programs

NSW has a very large commitment to both government-funded and community-funded stocking programs at present. There are five State-owned facilities that produce freshwater fish for stocking. These facilities are located in coastal, mountain and western drainage regional locations. In addition, private hatcheries are located throughout the State and produce fish for stocking both public and private waters.

The stocking programs are strongly supported by major clients. While there is scientific debate about the relative value of stocking programs versus other methods of fisheries enhancement, there is no doubt that public opinion is overwhelmingly in favour of maintaining, or increasing the numbers of fish and number of locations that are stocked.

Conservation stocking program

Four threatened freshwater fish species have been stocked into NSW waters. These are eastern cod, trout cod, silver perch and Macquarie perch. Currently only eastern cod and trout cod are stocked as part of a recognised recovery program. Silver perch are stocked into impoundments to enhance recreational fishing opportunities and stocking of Macquarie perch has been discontinued for the time being due, in part, to the technical difficulties of hatchery production of this species.

Genetic management protocols have been introduced for the eastern cod and trout cod stocking programs. These protocols are designed to minimise the loss of natural genetic diversity in the hatchery breeding program. For eastern cod, the protocols stipulate a number of requirements, as outlined below.

- The eggs from each pair must be incubated separately;
- Larvae from 5 pairs are to be stocked into each plankton production pond, or the fry from 5 pairs/ponds should be pooled after harvest;
- The same number of offspring from each pair should be stocked into the wild;
- Single cross matings (1 Female x 1 Male) are required;
- No individuals bred from more than once per season;
- Broodfish are to be collected from 3 or more sites.

Similar protocols are used for production of trout cod for stocking.

Recreational fishing stocking program

Salmonids

The salmonid stocking program is resourced with fish produced at two Government hatcheries, Gaden hatchery at Jindabyne and Dutton Hatchery at Ebor. Four species are produced at the hatcheries - brown trout, rainbow trout, brook char and Atlantic salmon. The majority of fish are released as advanced fry (25 to 35 mm in length) to streams, and fingerlings (70 to 100 mm in length) to lakes. Approximately 4.5 million fry and fingerlings are released from the two hatcheries on an annual basis. Smaller numbers of yearlings and surplus broodstock are also released.

Acclimatisation society branch members from the New England, Orange, Central Tablelands, Southern Highlands and Snowy Mountains regions assist with the stocking of trout fry into streams and lakes in a cooperative arrangement with NSW Fisheries. An agreed list of stocking sites, numbers of fish and species is negotiated each year prior to the production season at the two hatcheries.

Factors taken into consideration in stocking approvals include the possible impact of stocked trout on threatened species, public access to the proposed locations, and the environmental suitability of the site for growth and survival of the stocked trout.

Native fish

There are two native fish stocking programs in NSW waters – one resourced primarily from Government hatcheries, the other from privately operated hatcheries.

Government hatcheries produce fish for stocking of impoundments throughout the State. The primary species are Murray cod, golden perch and silver perch in Murray Darling Basin and Australian bass in coastal drainages. Approximately 2.5 million fingerlings are stocked annually.
A broodstock management protocol is employed to minimise the potential for undesirable genetic consequences of releasing hatchery-reared stock into the wild. These protocols are similar to those used for conservation stocking as outlined above. Sourcing appropriate broodstock to support these protocols is expensive and difficult. This is likely to be a major consideration in expansion of the native fish stocking program, or introduction of a hatchery quality assurance program (see below).

Production techniques for native fish are continually being refined. They are now fairly reliable but still subject to climatic and biotic factors. As a consequence, there can be significant variation from year to year in production levels from the hatcheries.

Angling clubs and other community organisations have for many years undertaken to fund stocking of rivers with native fish sourced from private hatcheries. This activity now receives dollar for dollar support with funds provided from the sales of recreational fishing licences. Approximately 1 million fingerlings are stocked annually under this program at present.

The species that are supported under this program are Murray cod and golden perch in the Murray-Darling Basin and Australian bass in coastal drainages. These three species are the most popular native freshwater fish for recreational fishing in NSW, and are widely available from private hatcheries located throughout State.

To participate in the scheme, hatchery operators must agree to certain conditions on broodstock management and quality control for stocked fish. Most of the stocking locations approved under this program are in rivers. Applicants are encouraged to consider the need for the stocking, and must source their stock from a participating hatchery.

The dollar for dollar stocking program has a number of advantages over the previous ad hoc stocking of rivers by community groups. The scheme provides incentives for greater compliance with regulatory requirements, for both hatchery operators and stocking groups. NSW Fisheries believes this has improved the quality of reporting of stocking activity. The scheme also provides the ability to influence private hatchery procedures in regard to quality control and broodstock management through financial incentives.

Future management of stocking in NSW

NSW Fisheries is preparing a draft Fisheries Management Strategy for fish stocking. The draft Fisheries Management Strategy will regard fish stocking as an activity that has the potential to have an impact on the environment. Consequently it will be subjected to environmental impact assessment in accordance with guidelines laid down by Planning NSW, the agency responsible for administering the provisions of the Environmental Planning and Assessment Act.

This will be the most comprehensive assessment of the environmental impact of fish stocking in Australia, and the resultant final Fisheries Management Strategy will underpin stocking activities in NSW for the foreseeable future.

The environmental assessment will consider a range of factors that are relevant to stocking. These include:

- The impacts of stocking on the broader aquatic ecology, habitat and the environment;
- Ensuring the protection of key habitats and protected or threatened species;
- The influences of other activities on fish stocking activities;
- Social and economic issues associated with the stocking

In relation to the biophysical environment, the environmental assessment will specifically:

- Identify key biodiversity and habitat characteristics within catchments or stocking zones, including important areas and/or features;
- Identify at a catchment level any adverse or beneficial implications on biodiversity and aquatic habitats from stocking;
- Consider the effects of stocking on trophic structure;
- Assess the implications of fish stocking on the genetic composition of stocked and wild populations;
- Identify management or mitigation measures (current or proposed) to mitigate, rehabilitate and/or compensate for adverse impacts of stocking on aquatic species;
- Indicate levels of confidence that management measures would achieve predicted outcomes and effectively manage impacts and associated risk.
Preparation of the Draft Fisheries Management Strategy and Environmental Impact Statement involves a lengthy process that includes:

- A period of internal compilation of information and articulation of objectives, strategies and actions proposed for the draft Fisheries Management strategy;
- Consultation with a range of stakeholder groups, including advisory committees, angling groups, the conservation movement, indigenous communities, the aquaculture industry and State and Commonwealth government agencies to refine the draft Fisheries Management Strategy;
- Assessment of the environmental impact of the objectives, strategies and actions in the Draft Fisheries Management Strategy by qualified experts;
- Preparation of a draft Environmental Impact Statement based on these assessments;
- Peer review of the draft Environmental Impact Statement;
- Further consultation with the stakeholder groups outlined above in relation to the content of the Environmental Impact Statement;
- Preparation of a ‘final’ draft Fisheries Management Strategy and Environmental Impact Statement;
- The general public will then be asked to comment on the draft strategy during a public exhibition period;
- Further consultation with stakeholder groups about the public comments on the draft documents;
- Finalisation of both documents for consideration and determination by the relevant government Ministers.

The process outlined above is expected to be complete by the end of 2003. The numerous opportunities for stakeholder input into the Fisheries Management Strategy before the process is completed will ensure that all viewpoints are considered, and appropriate checks and balances are built in to guide the future management of stocking in NSW.

Hatchery Quality Assurance

A key component of ensuring that the ongoing stocking program in the Murray-Darling Basin (and elsewhere in NSW) meets best practice standards is the development of a hatchery quality assurance program (HQAP). A project to develop such a program is being undertaken by NSW Fisheries. Consultation with other State agencies about the development and implementation of the program is occurring.

The main outcomes of the project are:

- A detailed hatchery manual for production of Murray cod, golden perch and silver perch.
- A written HQAP that:
  
  (i) defines conditions for the design and operation of hatcheries;
  (ii) is based on Hazard Analysis Critical Control Point procedures;
  (iii) can be used as basis for accrediting and auditing hatcheries;
  (iv) links with existing legislation and policies; and,
  (v) can be used as a template for hatcheries of other species groups.

It is proposed that there will be on-going certification and monitoring of NSW hatcheries in line with the HQAP.

Matters for consideration in the HQAP include issues to do with the facilities (e.g. site selection, design, equipment), environmental issues (e.g. water quality, chemical use, effluent management), production considerations (e.g. broodstock management, artificial breeding protocols, genetics and breeding programs production of fingerlings, disease and health management), end use considerations (e.g. stocking methods, translocation policies), and administrative issues (e.g., records keeping, auditing and compliance monitoring and inspections).

All of the matters considered will be done within a Hazard Analysis Critical Control Point procedures framework to ensure risks are identified and managed to meet acceptable standards.

Conclusions

NSW contains unique freshwater ecosystems that support valuable and diverse recreational fisheries. Many species are endemic and nearly all of the 86 native freshwater fishes found in south-eastern Australia are found nowhere else in the world.

Some native species such as Murray cod have highly significant ecological and cultural values. As targets of recreational fishing activity they help support many regional economies. Introduced trout species also provide benefits in regional areas by creating highly sought after recreational fishing opportunities.

Stocking will remain a major tool in enhancing recreational fishing and conserving some threatened...
native fish populations. A host of initiatives are underway including the implementation of changes to planning laws, as well as initiatives such as the hatchery quality assurance project. These initiatives will ensure ongoing improvements in both the environmental performance and the contribution to recreational fisheries for private and publicly funded stocking programs in NSW.

6.4 Stocking policies for freshwater fish in Victoria

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(*Paper presented on the day by Wayne Fulton, Department of Natural Resources and Environment, Victoria)

Introduction

The stocking of freshwater fish in Victoria is primarily the responsibility of the Fisheries Division of the Department of Natural Resources and Environment with some input from the Division of Parks, Flora and Fauna. There is an annual process for reviewing proposed recreational fish stockings which involves input from relevant Departmental, industry and community stakeholders.

This paper considers the issues relevant to fish stocking and the development of a translocation policy in Victoria under the following headings:

- Legislation and strategies
- Current stocking arrangements for freshwater fish
- Translocation challenges
- Current Victorian directions

Legislation and strategies

Several Acts and strategies provide the framework for the protection and management of Victoria’s aquatic flora and fauna and their associated habitat, as follows:

Fisheries Act 1995

The Fisheries Act 1995 (Vic) and fishing regulations provide the main framework for the sustainable use of living aquatic resources, protection of fish habitats, promotion of sustainable quality recreational fishing opportunities, facilitation of access for a range of uses and community involvement in fisheries management.

As set out in the first objective of the Act, the overriding principle in the management of Victoria’s fisheries is that they should be managed on an ecologically sustainable basis.

Flora and Fauna Guarantee Act 1988

The Flora and Fauna Guarantee Act establishes a legal and administrative structure to enable and promote the conservation of Victoria’s native flora and fauna, including aquatic species. The legislation provides for the conservation, management or control of flora and fauna and the management of potentially threatening processes.

Victorian River Health Strategy

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

Current stocking arrangements for freshwater fish

Conservation stockings

These stockings are identified in Action Statements developed under the Flora and Fauna Guarantee Act 1988. Conservation stockings in Victoria are currently focussed on trout cod, freshwater catfish and river blackfish with some consideration of Macquarie perch and dwarf galaxias. These can include stockings via translocation of adults as well as the release of juvenile fish.

Several issues are considered when undertaking conservation stockings:

- The need to maintain or enhance the conservation status of a species;
• The need to be within the known former natural range of the species, except where special management or research needs arise or exist;
• There is a reasonable expectation that the fish will survive, grow and reproduce;
• The conservation status of other native fish species or unique faunal assemblages are not put at risk.

Commercial aquaculture stockings

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

Recreational fish stockings

The most extensive and routine stockings of fish in inland waters are for the purposes of maintaining and enhancing recreational fisheries. Both native fish and salmonid species are released with some similar and some unique criteria for each group.

Native fish stocking for recreational fishing

Stocking of native freshwater fish for recreational purposes is mainly focussed on golden perch and Murray Cod. This is primarily undertaken in lakes and impoundments although there is some stocking of these species in rivers. Limited stocking with Australian bass, estuary perch and silver perch is also undertaken. Currently about 50 waters are stocked on a regular basis. Around 1 million native fish fingerlings are currently released each year, in addition to limited quantities of on-grown Murray Cod.

A number of factors are considered in determining whether a water will be stocked with native fish;
• Is the habitat suitable for survival and growth;
• Whether natural recruitment is insufficient to support a fishery;
• Are the fish accessible to anglers;
• Will enough anglers fish the water to justify the expense involved;
• Is the stocking within the known former natural range of the species;
• The conservation status of other native fish species or unique faunal assemblages will not be put at risk.

Stocking of salmonid fish species for recreational fishing

Brown trout and rainbow trout are the main species of salmonids stocked with some limited releases of Chinook salmon and Atlantic salmon. These are primarily released for recreational anglers in lakes and impoundments. Salmonids are not normally stocked in rivers and streams. The stocking of trout and salmon species is largely undertaken with yearling fish as this enhances their survival prospects and reduces lead-time between release and potential recapture. Currently about 80 waters are stocked on a regular basis. Approximately 350 000 salmonids are released each year.

As with the native fish stockings a number of factors are considered in determining whether trout are released into certain waters. Firstly, stocking with trout is excluded from waters:
• Where the released fish may constitute a threat to a population of a species of special concern or where a unique faunal assemblage exists;
• Where natural reproduction adequately supports a fishery;
• Waters east of the Snowy River catchment;
• Those waters identified as unacceptable habitat.

In the case of salmonid fish, waters will be considered for stocking when:
• Sufficient habitat for the maintenance and growth of the fish exists;
• Natural reproduction of salmonids is insufficient to support a fishery;
• The fish are accessible to anglers and there is a reasonable expectation that enough anglers will fish the water.

Translocation challenges

There are many challenges that need to be met to prepare a translocation policy that is acceptable to all stakeholders. In addressing these challenges the social and economic benefits the community gains from fish stocking need to be considered in conjunction with an assessment of the impact such stockings can have on biodiversity values.

Proposals for fish releases need be subjected to a risk assessment process with a range of risk thresholds identified under the following broad categories:
• intolerable risk - where impacts are simply not acceptable;
• tolerable risk - where impacts can be accepted under certain circumstances or for certain defined benefits;
• acceptable risk – where no significant impacts are expected.

In many cases stocking programs are maintained because they are well-established practice which are widely accepted and supported by the community even if the impacts are not well defined. In the case of new releases involving new species, or existing species into new areas, it could be argued that the inherent risk is greater than the continuation of an existing long-standing practice.

Managing according to risk will always be a challenge in terms of where to draw the line between what is an acceptable risk and what is not. Regardless of this, ensuring the environmental considerations associated with translocation will not be addressed solely by introducing new regulatory measures. Community education will be critical to ensuring any new arrangements and associated decisions are understood and accepted by those members of the community who have either a commercial or recreational interest in fish stocking programs.

Current Victorian directions

Victoria presently is well progressed in developing a Translocation Policy that will adapt the National Policy to the local situation. The State Policy provides guidelines for assessing translocation of live aquatic organisms in Victoria that will be subject to staged implementation. The policy will focus on the Department of Natural Resources and Environment working with peak stakeholders and external experts to find an effective solution with a major focus on establishing protocols to address translocation proposals of similar type and risk. The process would see the establishment of an ‘Expert Evaluation Panel’ that would probably be overseen by an independent chair.
7.1 The use of local translocations and re-introductions in the conservation management of threatened freshwater fish

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Abstract

Translocation of fish within and between catchments was a common technique for establishing fish populations until the 1960s. The development of techniques for artificially breeding native fish in the late 1960s and early 1970s led to an emphasis on stocking hatchery produced fingerlings as the accepted mechanism for establishing fish populations. Today, local translocations (the movement of fish within rather than between catchments) are rarely used, yet they have some obvious benefits, particularly in the management of threatened or declining fish species. This paper outlines the case for increasing the use of local translocations, and provides a case study of a successful application.

Introduction

The Murray-Darling Basin contains approximately 36 species of native fish of which 16 are listed as threatened at either the State/Territory or national level (Table 1).

Recent attempts to establish, or re-establish, populations of threatened fish in mainland Australia have largely concentrated on the stocking of hatchery-bred individuals into waters within their natural range (see Brumley 1987; Douglas et al. 1994; Simpson & Jackson 1996; Brown et al. 1998; NSW Fisheries 1999). A similar emphasis on hatchery stocking programs for the recovery of threatened fish populations is evident overseas (Andrews & Kaufman 1994; Brown & Day 2002). Although such programs have resulted in short-term survival of a proportion of stocked fish, with survival past the first few days post-release being critical, the establishment of self-supporting populations of these fish has been infrequent. For example the critically endangered Trout Cod Maccullochella macquariensis has been the subject of a national restocking program since the late 1980s with approximately 1 million individuals released at numerous sites in NSW, the Australian Capital Territory (ACT) and Victoria, but no self-supporting population has been established. Local translocation as a means of re-introducing threatened fish species has rarely been used in mainland Australia, but has some significant advantages over a conventional hatchery-stocking approach. This paper provides a case study of a successful translocation, and discusses the potential for wider use of this technique.

Table 1. Threatened fish species of the Murray-Darling Basin

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EPBC = listed under Commonwealth Environment Protection and Biodiversity Conservation Act 1999
ASFB = listed on Australian Society for Fish Biology threatened fish list
P = conservation status supplied by Michael Hammer (unpublished)
CE = critically endangered; E = endangered; E Popns = endangered populations; V = vulnerable; DD = data deficient
Case Study

The Queanbeyan River catchment lies in New South Wales to the east of the ACT. The Queanbeyan River is a major tributary of the Molonglo River in the upper Murrumbidgee River catchment (Figure 1).

Figure 1: The upper Murrumbidgee catchment showing the location of the study area containing the Queanbeyan River and Googong Reservoir.
The need for an additional domestic water supply reservoir for Canberra resulted in the construction of Googong Dam on the Queanbeyan River in 1978. There was a small population of the threatened fish Macquarie Perch *Macquaria australasica* (Figure 2) in the Queanbeyan River prior to the construction of Googong Dam.

A fish monitoring program between 1978 and 1980 revealed that Macquarie Perch were present in the reservoir, but were not recruiting (Figure 3), with the future of the population appearing grim.

Figure 2: Macquarie Perch *Macquaria australasica*

Figure 3. Length frequency (total length) of Macquarie Perch captured in Googong Reservoir between October 1978 and November 1980.
It is believed that the filling of the reservoir flooded all available Macquarie Perch spawning sites, and the population is unable to access the spawning habitats in the river above the reservoir because of a natural barrier posed by a waterfall (Curleys Falls). Curleys Falls is at the upstream limit of the impounded waters and consists of a series of small (1-3 m) drops through a small rocky gorge. In November 1980, 57 adult Macquarie Perch (Figure 4) were netted from the reservoir and transported upstream, past the barrier of Curleys Falls, and released at two sites on the Queanbeyan River. It was hoped this action would allow the species to access suitable spawning sites and ensure the survival of the population in the Queanbeyan River.

![Figure 4: Length frequency (total length) of Macquarie Perch translocated past Curleys Falls in 1980](image)

Monitoring of the release sites between 1981 and 1985 did not detect any Macquarie Perch and it was feared the relocation attempt had failed. However, from the mid to late 1980s, anglers occasionally reported catching Macquarie Perch at one of the release sites. A preliminary survey of the release sites in 1991 revealed the presence of a small population of Macquarie Perch. A comprehensive survey of the population was conducted in 1996 and 1997, with at least four age classes of perch present (Figure 5). A breeding population is now established (Linternans 2002).

![Figure 5: Length frequency (total length) of Macquarie Perch captured in the Queanbeyan River in 1996 and 1997.](image)
The importance of a long-term monitoring strategy is apparent, with the original five-year monitoring program failing to detect either adult survival or recruitment.

What are translocations?

The IUCN defines translocation as ‘the movement of living organisms from one area with free release in another’ and lists three major classes of translocation: Introduction; Re-introduction; and Re-stocking (IUCN 1987). The IUCN definitions of the three translocation classes are:

- **Introduction** of an organism is the intentional or accidental dispersal by human agency of a living organism outside its historically known native range;
- **Re-introduction** of an organism is the intentional movement of an organism into a part of its native range from which it has disappeared or become extirpated in historic times as a result of human activities or natural catastrophe;
- **Re-stocking** is the movement of numbers of plants or animals of a species with the intention of building up the number of individuals of that species in an original habitat.

This paper specifically considers the second class of translocation defined by the IUCN (1987), that is, re-introductions.

History of local translocations

Local translocations of native fish were commonplace prior to the development of native fish breeding programs in the late 1960s and early 1970s, and movement of adult fish was an accepted practice for establishing new populations or expanding a species range (see Wilson 1858; McCoy 1885; Stead 1913; Cadwallader 1981; McKay 1989; Harris & Battaglene 1990). In fact, the only successful attempt at establishing a population within the Murray-Darling Basin of the critically endangered Trout Cod occurred in Sevens Creek, Victoria, when ~100 individuals were translocated from the nearby Goulburn River by an angling club between 1921 and 1922 (Cadwallader & Gooley 1984; Douglas et al. 1994).

Fortunately, many of the early translocation attempts failed as the species involved were often being moved well outside their normal distributional range, with little thought given to the consequences for the receiving fish community. An example of an inappropriate early translocation is the only other self-sustaining translocated population of Trout Cod in Cataract Reservoir, where the species has hybridised with Murray Cod *Maccullochella peeli* (also translocated) with no ‘pure’ Trout Cod remaining. As there was often little knowledge of the composition or structure of the receiving fish community, and rarely any detailed monitoring of the early translocation attempt, few concerns were expressed about the potential impacts of translocation.

Advantages of local translocations

This paper advocates the cautious use of local translocations (or re-introduction under the IUCN definitions) as a tool with particular application to the management and recovery of threatened fish species. Before any translocation exercise is attempted, a formal and comprehensive risk assessment is absolutely essential. The IUCN Position Statement on the Translocation of Living Organisms provides a comprehensive account of the planning and information requirements necessary when translocations are being considered, and the National Policy for the Translocation of Live Aquatic Organisms provides the basis for implementing translocation actions within Australia.
Local translocation has a number of advantages as a recovery technique over other potential management actions such as hatchery releases.

• It can provide a useful interim management action to facilitate the survival of localised populations whilst addressing habitat degradation or threatening processes impacting the donor population.
• It can be used to expand a species range or establish secure populations above natural or artificial barriers, where the provision of fish passage might facilitate invasion by unwanted species such as trout, Carp or Redfin Perch.
• It removes the potential for ‘domestication’, or establishment of other non-natural behaviours of fish (such as disturbed patterns of feeding and predator avoidance) before release.
• Its use within drainages generally lessens the potential concerns about genetic issues that may arise from stocking hatchery bred fish.
• It can allow the rapid establishment of a mixed-age population structure should this be required (whereas stocking with hatchery bred fish usually only introduces a single age-class per year).
• It can be used with species which are not artificially bred (for example small species like pygmy perch, galaxiids, gudgeons), or which are difficult to breed.
• It can involve fish of a larger size-class which has the benefits of:
  (i) reducing predation risk on newly released fish;
  (ii) decreasing the time between re-introduction and potential breeding; and
  (iii) facilitating collection of certain ecological information through radio-telemetry or tagging (that is often not possible with small fingerlings).

The desirability of stocking larger fish has been recognised, even for hatchery bred fish, but often is not possible within commercial hatcheries because of competing demands for the use of grow-out ponds, as well as the cost involved in supplementary feeding. The use of local translocations utilises the natural stream environment as the grow-out facility and so avoids these commercial issues.

Issues and future investigations

The Googong translocation of Macquarie Perch involved adult fish as the effect on the donor population was not an issue; the donor population was doomed by its lack of accessible spawning sites. Where a translocation is to extend the range of a population, or to establish a new population without compromising the donor population, consideration should be given to using juvenile or immature fish.

The advantages of using smaller individuals are:

• there is minimal effect on the adult donor population;
• there is usually a larger number of smaller individuals available; and
• a significant proportion of juvenile fish would be expected to be lost to the donor population through natural mortality, so it is a relatively low-risk intervention.

The disadvantages of using small fish are the higher proportion of individuals that may be lost through natural mortality, and increased predation risk, particularly from alien predators.

Many previous local translocation attempts have failed to adequately monitor the outcomes of the translocation, either through insufficient resources being devoted to monitoring, or the inappropriate temporal scale of monitoring. Consequently, potentially valuable insights into the factors involved in the success or failure of these management interventions has been lost. A recent modelling exercise involving Trout Cod has demonstrated that even with the optimum reintroduction strategy and a rigorous long-term monitoring program, environmental stochasticity and monitoring imprecision severely limits the capacity to detect the success of the reintroduction program (Bearlin et al. 2002). Re-introductions require a long-term commitment of resources if we are truly to ‘learn by doing’. If used in an ‘adaptive management’ framework and rigorously monitored over an appropriate timescale, local translocations provide a useful addition to the toolkit for threatened species management.

References


Lawrence, C. 1993. *The introduction and translocation of fish, crustaceans and molluscs in Western Australia*. Fisheries Management Paper No. 58. Fisheries Department of Western Australia.


7.2 Trends in fish hatchery practices within New South Wales: What do they tell us about the maintenance of genetic diversity in fish stocking programs?

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Abstract only provided

In the past we have tended to breed and stock fish indiscriminately, with little regard to the receiving population. As a result fish stocking programs have had mixed outcomes. One reason for these mixed results may be the loss of genetic diversity through inappropriate hatchery and stocking practices.

We surveyed hatcheries throughout NSW, which revealed very few parental stock are used to produce large quantities of progeny, and that inbreeding is common. These practices are likely to reduce genetic diversity within captive-bred fish and in the receiving population.

Genetic diversity gives a population an adaptive mechanism to deal with a changing environment including new or evolving predators, competitors, and parasites as well as changing landscapes and climatic conditions. Therefore a reduction in genetic diversity is likely to reduce adaptive potential.

Inbreeding has been shown to severely reduce fitness and in some cases lead to the functional extinction of domestic animal populations. Our survey also indicated that most hatchery operators have very little knowledge of the deleterious consequences of poor genetic management. Additionally, it was revealed that stockings into waters outside the species’ range or local population are common. These stockings are likely to increase the chance of hybridisation and introgression among congeners and homogenise evolutionarily distinct populations. The end result is likely to be a significant reduction in both genetic diversity in restocked populations and biological diversity within and across species. Restocked populations may also have reduced viability to persist over evolutionary timescales.
### 8. List of participants

<table>
<thead>
<tr>
<th>Number</th>
<th>Participant</th>
<th>Position/Institution</th>
<th>Contact Information</th>
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<tbody>
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WWF is one of the world’s largest and most experienced independent conservation organisations, with almost 5 million supporters and a global network active in more than 90 countries.

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