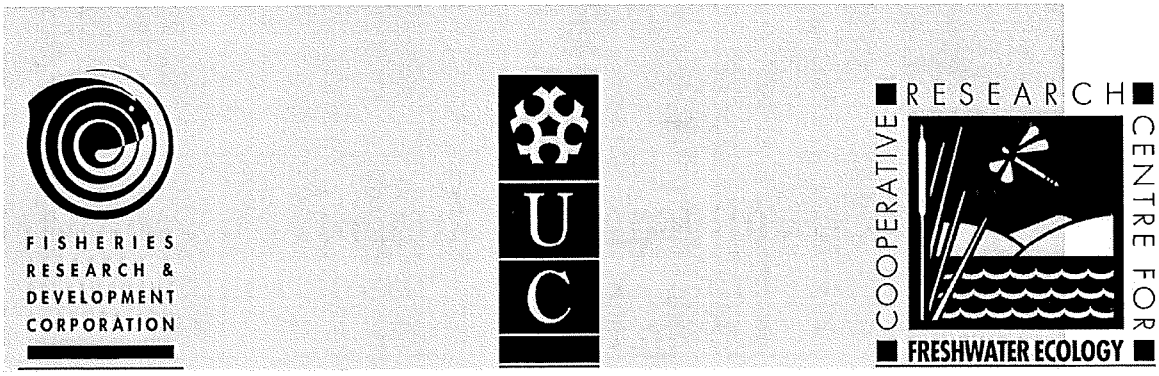
Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies.

R. E. Kearney, K.M. Davis and K. E. Beggs



Project No. 97/142

Final Report

May 1999

ISBN

Table of Contents.

TABLE OF CONTENTS. 3
LIST OF TABLES. 6
LIST OF FIGURES. 6
LIST OF APPENDICES 6

NON-TECHNICAL SUMMARY. 8

CHAPTER 1. INTRODUCTION. 10

BACKGROUND 10
NEED. 10
OBJECTIVES. 11
WHAT IS SUSTAINABILITY? 11
Sustainability. 11
Sustainable development. 12
Ecologically sustainable development. 12
HOW DO WE MEASURE SUSTAINABILITY? 12
HOW DO WE KNOW WHEN WE'VE ACHIEVED ECOLOGICALLY SUSTAINABLE DEVELOPMENT? 12
NATURAL FACTORS AFFECTING THE SUSTAINABILITY OF FRESHWATER FISHERIES RESOURCES. 12

CHAPTER 2. LITERATURE REVIEW. 14

HABITAT DEGRADATION 14
What constitutes Australian freshwater fish habitat? 14
What causes habitat degradation and how does this affect fish? 15
Riparian vegetation degradation. 17
Wetland degradation. 19
Sedimentation. 20
River modification. 22
Forestry/Logging. 22
POLLUTION, WATER QUALITY AND WATER TEMPERATURE. 23
Pollution and water quality. 24
Effects of pollution on freshwater fish. 25
Salinity. 26
Water temperature (thermal pollution). 27
REDUCED ENVIRONMENTAL FLOWS. 28
Effects of changes to the natural flow regime on freshwater ecosystems 29
Other impacts of river regulation 33
BARRIERS TO MIGRATION. 33
Effects of barriers to migration on fish 34
Fishways 34
INTRODUCED SPECIES. 34
Carp 36
FISHING. 37
Effects of overfishing in Australian freshwater ecosystems 38

CHAPTER 3. SURVEYS UNDERTAKEN. 39

NATIONWIDE SURVEY OF ORGANISATIONS INVOLVED WITH FRESHWATER 39
WORKSHOPS WITH THE STEERING COMMITTEE 39
INTERVIEW WITH STATE REPRESENTATIVES 40

CHAPTER 4. MAJOR THREATS TO THE SUSTAINABILITY OF FRESHWATER FISHERIES RESOURCES. 42

INTRODUCTION. 42
METHODS AND RESULTS. 42
Threat mergers 42
Non-weighted results. 43
Weighted results. 43
DISCUSSION. 44
State versus Commonwealth issues 48
Threats within the R&D funding charter of FRDC. 48
Comparison with issues identified in other Australian studies. 50
Comparison with issues affecting freshwater fish worldwide 51
Comparison with issues affecting other sectors in Australia 51

CONCLUSIONS....51

CHAPTER 5. STATE OF KNOWLEDGE OF THE MAJOR THREATS....53

INTRODUCTION....53
METHODS AND RESULTS....53
DISCUSSION....53
CONCLUSIONS....54

CHAPTER 6. PRIMARY CAUSES OF THE MAJOR THREATS....55

INTRODUCTION....55
METHODS AND RESULTS....55
DISCUSSION....55
Causes identified in other Australian studies of the freshwater ecosystem or fisheries....58
CONCLUSIONS....59

CHAPTER 7. MONITORS AND MANAGERS OF THE MAJOR THREATS....60

INTRODUCTION....60
METHODS AND RESULTS....60
DISCUSSION....60
CONCLUSIONS....61

CHAPTER 8. KNOWLEDGE REQUIRED TO ADDRESS THE MAJOR THREATS....66

INTRODUCTION....66
METHODS AND RESULTS....66
DISCUSSION....66
Knowledge requirements identified in other Australian studies....67
Requirements for an understanding of the ecology of running waters....69
Use of fish as indicators....69
Stock assessment....70
CONCLUSIONS....71

CHAPTER 9. STRATEGIES THAT HAVE ADDRESSED THE MAJOR THREATS....72

INTRODUCTION....72
METHODS AND RESULTS....72
DISCUSSION....72
Strategies which are transportable to other States....72
Strategies identified in other Australian studies....73
CONCLUSIONS....73

CHAPTER 10. STATUS....75

NATIONAL....75
State of knowledge....75
Targeted species....75
Threatened species....77
Knowledge required....78
AUSTRALIAN CAPITAL TERRITORY....78
NEW SOUTH WALES....79
NORTHERN TERRITORY....80
QUEENSLAND....80
SOUTH AUSTRALIA....81
TASMANIA....81
VICTORIA....82
WESTERN AUSTRALIA....82
CONCLUSIONS....83

CHAPTER 11. STRATEGY FOR COORDINATING AND FUNDING NEW RESEARCH....84

INTRODUCTION....84
METHODS AND RESULTS....84
DISCUSSION....85

CHAPTER 12. CONCLUSIONS....86

PROJECT OBJECTIVES....86
PROJECT OUTCOMES....86

BENEFITS....88

BENEFICIARIES 88
BENEFITS 88
FURTHER DEVELOPMENT. **88**
INTELLECTUAL PROPERTY. **88**
STAFF. **88**
ACKNOWLEDGMENTS. **89**
ABBREVIATIONS AND DEFINITIONS. **90**
REFERENCES. **93**
APPENDICES. **115**

List of Tables.

TABLE 1. MAJOR THREATS TO THE SUSTAINABILITY OF AUSTRALIA'S FRESHWATER FISHERIES RESOURCES (BASED ON THE NATIONAL SURVEY, INTERVIEWS WITH STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).....44
TABLE 2. THE SIX MAJOR THREATS IDENTIFIED, IN THE ORDER IN WHICH THEY ARE RANKED, BY EACH OF THE THREE SURVEYS*.....48
TABLE 3. RESEARCH PROGRAMS OF FRDC (FRDC 1996).....49
TABLE 4. KEY INVESTMENT AREAS OF FRDC UNDER WHICH THE MAJOR THREATS IDENTIFIED IN THIS STUDY ARE COVERED.....49
TABLE 5. ISSUES AFFECTING FRESHWATER ECOSYSTEMS AND/OR FISHERIES WHICH HAVE BEEN IDENTIFIED IN OTHER AUSTRALIAN STUDIES.....50
TABLE 6. PRINCIPAL THREATS TO FRESHWATER FISH IDENTIFIED WORLDWIDE (ABRAMOVITZ 1996).....51
TABLE 7. CAUSES IDENTIFIED IN OTHER AUSTRALIAN STUDIES WHICH RELATE TO THE SIX MAJOR THREATS IDENTIFIED IN THIS STUDY.....58
TABLE 8. NUMBER OF AGENCIES IDENTIFIED IN THIS STUDY AS BEING INVOLVED IN THE MONITORING AND MANAGEMENT OF EACH OF THE SIX MAJOR THREATS.....61
TABLE 9. KNOWLEDGE REQUIREMENTS DISCUSSED IN OTHER AUSTRALIAN FRESHWATER STUDIES WHICH RELATE TO THE SIX MAJOR THREATS IDENTIFIED IN THIS STUDY.....68
TABLE 10. STRATEGIES WHICH HAVE BEEN USED IN MORE THAN ONE STATE TO ADDRESS EACH OF THE SIX MAJOR THREATS.....73
TABLE 11. SUMMARY OF THE STATUS OF KNOWLEDGE OF KEY AUSTRALIAN FRESHWATER FISH SPECIES, SPECIES GROUPS AND STOCKS (FROM TABLE 12).....75
TABLE 12. STATUS OF KNOWLEDGE OF AUSTRALIAN FRESHWATER FISH SPECIES, SPECIES GROUPS AND STOCKS (COMMONWEALTH OF AUSTRALIA 1991).....76
TABLE 13. MAIN SPECIES TARGETED BY RECREATIONAL AND COMMERCIAL FISHERS IN EACH STATE.....77
TABLE 14. INFORMATION SUGGESTED BY STATE REPRESENTATIVES AS REQUIRED TO IMPROVE OUR KNOWLEDGE OF AUSTRALIAN FRESHWATER FISHERIES AND SUGGESTIONS OF POSSIBLE FUNDING AGENCIES.....78
TABLE 15. COMMERCIAL CATCH FIGURES FOR FRESHWATER SPECIES TAKEN IN NEW SOUTH WALES WATERS FROM 1975/76 TO 1983/84 AND 1992/93 TO 1995/96.....79
TABLE 16. COMMERCIAL CATCH FIGURES FOR BARRAMUNDI TAKEN IN NORTHERN TERRITORY WATERS FROM 1972 TO 1996.....80
TABLE 17. COMMERCIAL CATCH FIGURES FOR THE INLAND FISHERY (RIVER FISHERY AND LAKES AND COORONG FISHERY) OF SOUTH AUSTRALIA FROM 1976/77 TO 1983/84, 1986/87 TO 1987/88 AND 1994/95 TO 1996/97.....81
TABLE 18. COMMERCIAL CATCH FIGURES FOR CARP AND SHORT-FINNED EEL TAKEN IN VICTORIAN WATERS FROM 1992/93 TO 1996/97.....82
TABLE 19. COMMERCIAL CATCH FIGURES FOR LAKE ARGYLE CATFISH AND BARRAMUNDI TAKEN IN WESTERN AUSTRALIAN WATERS FROM 1976/77 TO 1995/96.....83
TABLE 20. POSSIBLE FUNDING SOURCES FOR PROJECTS INVOLVED WITH THE SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).....84

List of Figures.

FIGURE 1. THREAT MERGERS RESULTING FROM STEERING COMMITTEE INPUT.....43
FIGURE 2. MAJOR THREATS TO THE SUSTAINABILITY OF AUSTRALIA'S FRESHWATER FISHERIES RESOURCES (BASED ON THE NATIONAL SURVEY AND INTERVIEWS WITH STATE REPRESENTATIVES, EXCLUDING INPUT FROM THE STEERING COMMITTEE) – WEIGHTED RESULTS.....46
FIGURE 3. PRIMARY CAUSES OF THE SIX MAJOR THREATS (BASED ON INTERVIEWS WITH STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).....56
FIGURE 4. AGENCIES INVOLVED IN THE MONITORING OF THE SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).....62
FIGURE 5. AGENCIES INVOLVED IN THE MANAGEMENT OF THE SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).....64

List of Appendices.

APPENDIX 1. QUESTIONS DISCUSSED AT THE STEERING COMMITTEE WORKSHOP REGARDING THE MAJOR THREATS IDENTIFIED IN THE NATIONAL SURVEY.
APPENDIX 2. QUESTIONS USED IN THE INTERVIEWS WITH THE STATE REPRESENTATIVES.
APPENDIX 3. THREATS TO FRESHWATER ECOSYSTEMS IDENTIFIED IN THE NATIONAL SURVEY AND ORGANISATIONS CONTACTED.

APPENDIX 4. MAJOR THREATS TO THE SUSTAINABILITY OF FRESHWATER FISHERIES RESOURCES IN EACH STATE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 5. STATE OF KNOWLEDGE FOR THE MAJOR THREATS IDENTIFIED IN EACH STATE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 6. STATE OF KNOWLEDGE FOR THE OVERALL SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 7. PRIMARY CAUSES OF THE MAJOR THREATS (BASED ON INPUT FROM THE STEERING COMMITTEE).
APPENDIX 8. PRIMARY CAUSES OF THE MAJOR THREATS IDENTIFIED IN EACH STATE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 9. PRIMARY CAUSES OF THE OVERALL SIX MAJOR THREATS (BASED ON INTERVIEWS WITH STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).
APPENDIX 10. MONITORS AND MANAGERS OF THE MAJOR THREATS (BASED ON INPUT FROM THE STEERING COMMITTEE).
APPENDIX 11. MONITORS AND MANAGERS OF THE MAJOR THREATS IDENTIFIED IN EACH STATE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 12. MONITORS AND MANAGERS OF THE OVERALL SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).
APPENDIX 13. SUMMARY OF THE AGENCIES INVOLVED IN THE MONITORING AND MANAGEMENT OF THE OVERALL SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).
APPENDIX 14. KNOWLEDGE REQUIRED TO ADDRESS THE MAJOR THREATS (BASED ON INPUT FROM THE STEERING COMMITTEE).
APPENDIX 15. KNOWLEDGE REQUIRED TO ADDRESS THE MAJOR THREATS IDENTIFIED IN EACH STATE, POSSIBLE FUNDING AGENCIES AND MANAGEMENT ACTIONS LIKELY TO RESULT FROM THE ACQUISITION OF THIS KNOWLEDGE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES).
APPENDIX 16. KNOWLEDGE REQUIRED TO ADDRESS THE OVERALL SIX MAJOR THREATS AND MANAGEMENT ACTIONS LIKELY TO RESULT FROM THE ACQUISITION OF THIS KNOWLEDGE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).
APPENDIX 17. SUMMARY OF THE KNOWLEDGE REQUIRED TO ADDRESS THE OVERALL SIX MAJOR THREATS AND MANAGEMENT ACTIONS LIKELY TO RESULT FROM THE ACQUISITION OF THIS KNOWLEDGE (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).
APPENDIX 18. STRATEGIES WHICH HAVE ADDRESSED, OR ARE ADDRESSING, THE MAJOR THREATS (BASED ON INPUT FROM THE STEERING COMMITTEE).
APPENDIX 19. STRATEGIES WHICH HAVE ADDRESSED, OR ARE ADDRESSING, THE MAJOR THREATS IDENTIFIED IN EACH STATE (BASED ON INTERVIEWS WITH STATE REPRESENTATIVES).
APPENDIX 20. STRATEGIES WHICH HAVE ADDRESSED, OR ARE ADDRESSING, THE OVERALL SIX MAJOR THREATS (BASED ON INTERVIEWS WITH THE STATE REPRESENTATIVES AND INPUT FROM THE STEERING COMMITTEE).

Non-Technical Summary.

97/142 Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies.

PRINCIPAL INVESTIGATOR: Professor R.E. Kearney

ADDRESS: School of Resource, Environmental and Heritage Sciences
University of Canberra ACT 2601
Telephone: (02) 6201 5785 Fax: (02) 6201 2328

OBJECTIVES:

- To identify the major threats to the sustainability of freshwater fisheries resources in each State and Territory.
- To identify probable primary causes for the most significant threats in each State and Territory.
- To assess which threats could be approached by a national or State by State cooperative strategy for research.
- To propose a strategy for coordinating and funding new research relevant to ensuring the sustainability of Australia's freshwater fisheries resources.

NON-TECHNICAL SUMMARY:

The plight of our freshwater systems necessitates urgent action. It is significant that the comments provided in 'Australia: State of the Environment' (SoEAC 1996) confirm that commonly used indicators of each of the ten key threats to sustainability show continuing deterioration. While most of the threats to freshwater systems have been the subject of at least some research, knowledge of the interrelationships between fisheries and freshwater ecosystems remains seriously inadequate. Urgent requirements at the commencement of this project included:

- a current review of the factors which influence the productivity of Australia's inland fisheries;
- correlation of cause and effect for the major threats identified;
- correlation of cause with the relevant management or regulatory authority;
- an assessment of data and knowledge needed to facilitate management action;
- an assessment of areas where research is most likely to lead to significant management action;
- an evaluation of strategies that have worked, or are working, in one or more State or Territory and assessment of the likelihood of success from broadening or transporting these strategies; and
- an assessment of potential cooperative approaches to commissioning and supporting priority research.

The present study identifies the six major threats to Australia's freshwater fisheries resources as:

- habitat degradation;
- pollution/water quality/water temperature;
- reduced environmental flows;

- barriers to migration;
- introduced species/carp; and
- fishing.

Each of these threats is examined in more detail in the report to provide answers to the requirements listed above.

All of the six major threats were found to be of nationwide significance and to fall within the R&D funding charter of FRDC to some extent. Several causes were identified for each, with numerous causes being implicated in more than one threat. A number of the causes were determined to be of concern nationwide.

With the exception of fishing, both the monitoring and management of the major threats were found to be fragmented. Such fragmentation has led to ineffective data collection and management of the major threats.

Knowledge required to address the major threats was identified. It was determined that all of the requirements are best approached on a cooperative basis with inter-State coordination providing obvious benefits. For several issues national coordination appears advantageous.

Several strategies which have addressed, or are addressing, the major threats were also identified. All are likely to be transportable to other States and would benefit from at least a State-by-State cooperative approach.

It was found that few States currently have adequate data relating to the sustainability of their fisheries resources. Necessary data include biological data (e.g. information on stock structure and size, productivity of the resource and catch history), environmental data (e.g. reaction of species to natural and anthropogenic changes in their environment, the importance and position of a species in the food web and the interdependence of species) and economic data (e.g. fishing effort, profitability and valuations of the environmental resource). Further data from the commercial, recreational and indigenous sectors is required to improve the management of freshwater fisheries. There also needs to be greater recognition of the existence and cultural significance of an indigenous freshwater fishery.

In general, there needs to be more emphasis on communicating the outcomes of research to managers and better documentation of adaptive management successes and failures by managers. This requires improvement of the research/ management/ policy interface.

In reducing the 41 threats identified in the national survey to a prioritised list of the six major threats, the inter-relationships between component threats are emphasised. This provides research and funding agencies with a mechanism of cross-referencing current and potential projects and relating them to the six primary threats. It therefore represents a framework for a nationally coordinated grid of six programs (the six key threats) with multiple projects. It must also be stressed that the knowledge requirements identified for each of the six major threats are relevant to the 41 component threats identified in the national survey. For example the knowledge requirements for pollution (major threat number 2) are relevant for the components water quality, nutrient levels, algal blooms, urbanisation and acid sulfate soil. This identification of commonality of knowledge requirements and therefore broad relevance of subsequent research is a major output from this analysis. It allows funding agencies to gain national perspective on research projects, ongoing or proposed, on any of the 41 component threats. It should greatly facilitate the development of a national strategy for coordinating and supporting future freshwater fisheries research in Australia.

KEYWORDS: freshwater fisheries, threats, sustainability, research priorities.

Chapter 1. Introduction.

Background.

At Board Meeting 22 FRDC endorsed the need to "commission an application to undertake a review of the strategic issues relating to the status of the Fresh Water Fishery in an R&D context using existing information". The principal investigator and the CRC for Freshwater Ecology were contacted by FRDC and requested to submit an application on this theme giving emphasis to nationwide perspectives. This report represents the conclusion of the project which resulted from that application.

Australia's freshwater fish resources underpin significant commercial and recreational activities. Unfortunately, many of our native fish resources are in serious decline (Harris and Gehrke 1997); in some cases to the point where even the survival of the species is threatened (Wager and Jackson 1993). On the other hand, a number of introduced species continue to thrive, in some areas supporting major recreational and commercial activities (e.g. salmonids, Davies and McDowall 1996) and in others posing serious threats to valued ecosystems (e.g. carp, Arthington and McKenzie 1997; Harris and Gehrke 1997).

It is accepted that threats to the sustainable use of our native fish species are complex and not primarily resulting from targeted commercial and/or recreational exploitation (Wager and Jackson 1993; SoEAC 1996). 'Australia: State of the Environment' (SoEAC 1996) lists the following as the key issues for the sustainability of inland waters: dryland salinity, wetlands, over-allocation of water to consumption, irrigation, endangered species, nutrients, water weeds, sediments, monitoring and data. Australians concerned specifically with the fish component of our fresh water systems could add at least the following: barriers to migration, availability of spawning grounds, resource ownership, resource access including Aboriginal rights and entitlements, interaction between native and introduced species, pollution, impact of commercial, recreational and indigenous harvest, fish disease and the effects, including genetic, of manipulating populations by stocking. While most of this broad spectrum of issues has been the subject of some research, our knowledge of the inter-relationships between fisheries and freshwater ecosystems remains seriously inadequate.

There is currently little coordination of Australia's freshwater fisheries management and research is dominated by perceptions of individual States or Territories. Many water management agencies, other than those with specific responsibility for fisheries, influence the major issues impacting on the sustainability of fisheries. The CRC Program, particularly through the CRC for Freshwater Ecology, and organisations such as the Murray-Darling Basin Commission (MDBC), have greatly increased communication and cooperation between agencies and water users, but a national strategy for freshwater fisheries conservation remains to be developed.

This project is relevant to several components of FRDC's Operational Objective:

- to be influencing the development of fisheries R&D strategies at Commonwealth, State, regional, fishery and species levels;
- to be influencing collaborative R&D between researchers and between researchers and stakeholders.
- to be influencing the R&D expenditure of other funding agencies;

Need.

It is accepted that the plight of our freshwater systems necessitates urgent action. FRDC identified the need for this project.

It is significant that the comments provided in 'Australia: State of the Environment' (SoEAC 1996) confirm that indicators of each of the ten key threats to sustainability show continuing deterioration.

While most of the threats have been the subject of at least some research, our knowledge of the interrelationships between fisheries and freshwater ecosystems remains seriously inadequate. Urgent requirements at the commencement of this project included:

- a current review of the factors which influence the productivity of Australia's inland fisheries;
- correlation of cause and effect for the major threats identified;
- correlation of cause with the relevant management or regulatory authority;
- an assessment of data, knowledge and research needed to facilitate management action;
- an assessment of areas where research is most likely to lead to significant management action;
- an evaluation of strategies that have worked, or are working, in one or more State or Territory and assessment of the likelihood of success from broadening or transporting these strategies; and
- an assessment of potential cooperative approaches to commissioning and funding priority research.

Objectives.

This study aimed to identify the key threats facing the sustainability of Australia's freshwater fisheries resources and suggest strategies for addressing those of highest priority.

The objectives of the study were to:

- identify the major threats to the sustainability of freshwater fisheries resources in each State and Territory;
- identify probable primary causes for the most significant threats in each State and Territory;
- assess which threats could be approached by a national or State by State cooperative strategy for research; and
- propose a strategy for coordinating and funding new research relevant to ensuring the sustainability of Australia's freshwater fisheries resources.

To achieve these objectives three surveys were undertaken (Chapter 3) and a review of the literature performed (Chapter 2).

It was decided not to include the Australian Capital Territory as a separate State as it is geographically encapsulated in New South Wales and to include it separately would give undue weight to one regional area. However comments from the Wildlife and Research Monitoring Unit of Environment ACT were included among the inputs.

What is sustainability?

Sustainability.

Sustainability is 'the degree to which the earth's resources may be exploited without deleterious effects' (*The Chambers Dictionary* 1993).

In the fisheries context sustainability refers to the fisheries and ecosystems which sustain them and to the continuing efficiency of commercial, recreational and subsistence fisheries. Sustainability requires that the ecosystems on which the fisheries depend are

conserved and that the interrelationships between the environment, habitat, resource and fisheries be recognised (Commonwealth of Australia 1991).

Sustainable development.

Sustainable development is 'designed to meet present needs while also taking into account future costs to the environment and depletion of natural resources' (Delbridge et al. 1991). It aims to 'meet the needs of the present without compromising the ability of future generations to meet their own needs' (SoEAC 1996).

If development is to be sustainable it must take into account social, economic and ecological factors; living and non-living resources; and the short and long term advantages and disadvantages of alternative actions (Harden Jones 1994).

Ecologically sustainable development.

Ecologically sustainable development (ESD) involves using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and in the future, can be increased (Commonwealth of Australia 1991; NS ESD 1992; Harden Jones 1994; SoEAC 1996; FRDC 1997).

Ecologically sustainable development of Australian fisheries requires acknowledgment that fish stocks are part of the larger aquatic ecosystem and that these systems need to be used sustainably (Commonwealth of Australia 1991).

How do we measure sustainability?

Biological, environmental and economic data are required to ensure that the fisheries resource is well managed, this information enables managers to set fishing limits which are compatible with ecologically sustainable and economically efficient harvests (Commonwealth of Australia 1991). Biological data include information on stock structure and size, productivity of the resource and catch history (Commonwealth of Australia 1991). Environmental data relate to the reaction of species to natural and anthropogenic changes in their environment, the importance and position of a species in the food web and the interdependence of species (Commonwealth of Australia 1991). Economic data include fishing effort, profitability and valuations of the environmental resource (Commonwealth of Australia 1991).

How do we know when we've achieved ecologically sustainable development?

Features distinguishing a sustainable approach to development are the consideration of economic, social and environmental impacts of our decisions and actions, and taking a long-term, as opposed to a short-term, view when considering actions and decisions (NS ESD 1992).

The National Strategy for Ecologically Sustainable Development (NS ESD 1992) states that 'Governments recognise that there is no identifiable point where we can say we have achieved ESD'. However, we can help ensure ecologically sustainable development by making changes in the way we think, act and make decisions (NS ESD 1992)

Natural factors affecting the sustainability of freshwater fisheries resources.

Together with anthropogenic factors there are several factors related to the basic state of Australia which affect the sustainability of Australia's freshwater fisheries. These factors are largely outside our control and include highly variable, low levels of precipitation; highly variable, low levels of runoff; and considerable variability of flow in rivers (SoEAC 1996; Crabb 1997).

Australia is the driest inhabited continent in the world; more than one third of the country is classified as arid, receiving lass than 250mm of rainfall per year, another third is classified as semi-arid, receiving 250-500mm of rainfall per year (SoEAC 1996). These are mean annual rainfall figures and there are large fluctuations in rainfall from year to year

and great variability in the rainfall through out a year. A large proportion of the annual rainfall for an area may fall in a few days leaving the rest of the year very dry (SoEAC 1996).

The mean annual runoff is about 12% of precipitation, or 397 000 gigalitres. In contrast in Europe and North America runoff is about 40% of precipitation. The low proportion of runoff experienced in Australia is mainly due to high levels of evaporation (Crabb 1997). The runoff is also not evenly distributed throughout the continent. The Western Plateau drainage division, 32% of the landmass, has no significant runoff (SoEAC 1996). Variability in runoff is greater in Australia than any other continental area in the world (Crabb 1997).

Due to the low rainfall and runoff there are relatively few large rivers and freshwater lakes in Australia. The rivers which do occur are generally slow flowing because of the flat landscape; the difference between the highest and lowest points of Australia is the lowest of any continent, due, at least in part, to geological stability (SoEAC 1996). There is a high degree of variability in the flow of Australian rivers both between and within years (Crabb 1997). The Murray-Darling system, the largest drainage basin in Australia, has a very low flow volume when compared with other large river systems around the world (SoEAC 1996). With the exception of infrequent periods of heavy rain, there is little runoff from about 86% of the Basin (Crabb 1997).

As already mentioned the highly variable nature of the rainfall, runoff and river flow are natural events beyond our control. There is little point undertaking research to 'solve' these natural features of Australia. The native fish have evolved with these features and survive them well. Indeed, many rely on the floods to provide cues for migration and spawning (Cadwallader and Lawrence 1990; Gehrke et al. 1995). However this natural variability is also a factor determining the baseline carrying capacity of the aquatic ecosystem.

The extremely variable rainfall leads to both floods and droughts which are a feature of the Australian environment (SoEAC 1996; Crabb 1997). The building of large reservoirs has been a common measure taken to mitigate the effects of droughts. These reservoirs also have the effect of reducing downstream small to medium sized floods while not impacting to the same extent on extreme events (Walker 1992; Maheshwari et al. 1995; Mussared 1997). Other measures, such as protective levees, are taken to reduce the effects of floods (Crabb 1997). Such measures have an impact on the fisheries resource (discussed further in Chapter 2). It is possible, and worthwhile, to research these anthropogenic impacts, to try and find solutions for the problems caused through taking measures to reduce the effects of natural events.

Chapter 2. Literature Review.

In this chapter we present a review of the literature pertaining to the overall six major threats to the sustainability of Australia's freshwater fisheries resources, as identified in Chapter 4, as well as a brief review of research priority setting. In this review each threat is defined, the main causes of the threat are identified, and the impacts of each threat on fish production are discussed.

Although these threats to freshwater fish are discussed separately, the processes leading to the decline of freshwater fish are inter-related. No one factor is solely responsible for the decline of fish population. The overall six major threats are discussed in order of priority as presented in Chapter 4.

This review is not intended to be exhaustive, the subject is extremely broad. Rather an effort has been made to concentrate on the most recent, Australian information. Where possible, review papers and reports have been used.

Habitat degradation.

Habitat degradation has been identified as a major cause of loss of diversity and decline in populations of freshwater fish, not only in Australia, but globally (Allen and Flecker 1993; Wager and Jackson 1993; Abramovitz 1996). This section considers the habitat requirements of Australian freshwater fish, the ways in which habitat has become degraded and the known or likely effects of such degradation on fish production.

The following threats were identified as distinct issues affecting the sustainability of freshwater fish, however they are closely related to, or represent a specific form of, habitat degradation: degradation of riparian vegetation, wetland degradation, sedimentation, river modification and forestry/logging. Consequently, these issues are addressed in this section.

What constitutes Australian freshwater fish habitat?

Australian freshwater fish are found in both lotic (flowing) and lentic (still) environments. Particular habitats are required for spawning, feeding and refugia. Some species require different habitat types at different stages of their life history. Therefore, specific habitat requirements may vary within as well as between species, however, some general characteristics are recognised; these are discussed below.

Instream habitat features are recognised as strong determinants of fish assemblage structure (Pusey et al. 1995). A variety of instream features serve as habitat for fish. Firstly, there is a range of flow conditions in streams with pool–riffle sequences providing habitat for fish and their food organisms (Brooks 1994). Some species, such as Macquarie perch (*Macquaria australasica*), may inhabit deep pools for much of the year but move upstream to shallow water to spawn (Cadwallader and Lawrence 1990). A number of instream habitat features are associated with streamside (riparian) vegetation. These include large woody debris (snags), undercut banks, leaf litter, overhanging vegetation and submerged root mats. Snags are particularly important habitat in lowland rivers for both fish and invertebrates (Harmon et al.1986; O'Connor 1992; Wager and Jackson 1993). Snags contribute to stream structure and habitat complexity by forming debris dams which help produce complex current patterns (i.e. backwaters, eddies and side channels) (Gregory et al. 1991; Gippel et al. 1992). Snags also provide shelter from fast currents and retain sediment (Gippel et al. 1992). Fish use snags to avoid predators (Koehn and O'Connor 1990); for feeding, as they are sites of high invertebrate biomass (Walker et al. 1992; Everett and Ruiz 1993); and as spawning sites, with a number of species including Murray cod (*Maccullochella peeli*), trout cod (*Maccullochella macquariensis*) and freshwater blackfish (*Gadopsis marmoratus*) known to deposit eggs inside submerged hollow logs (Cadwallader and Lawrence 1990; Koehn and O'Connor 1990). In general, snags create more complex habitat for fish and invertebrates which presumably increases overall

biodiversity within a river (Gregory et al. 1991; Gippel et al. 1992; Campbell 1993; Gippel et al. 1996).

Riparian vegetation stabilises banks by holding the soil together, thus enabling undercut banks to form and persist (Wilson et al. 1996). In addition, the streamside vegetation becomes part of aquatic habitat during flooding. By being part of the floodplain it may provide important feeding and refugia habitat for spawning fish and/or juveniles (Campbell and Doeg 1989). Riparian vegetation influences stream ecology and function and, in turn, fish, in other important ways; these will be discussed later.

Floodplains are areas of relatively flat land covered by water during major floods and they are built from layers of nutrient rich sediment deposited by the river during flooding (Mussared 1997). They are important components of freshwater fish habitat. Many invertebrates and plankton undergo aestivation stages as eggs or larvae in dry floodplain sediments (Boulton and Lloyd 1992). These organisms emerge during inundation and become a major food source for the juveniles of many fish species including golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and Murray cod (Lloyd et al. 1994; Boulton and Lloyd 1992; Wager and Jackson 1993).

Other significant features of instream habitat are submerged and emergent vegetation, filamentous algae and the substratum (Rozas and Odum 1988; Savino and Stein 1989; Lake 1994). The substratum, which may be comprised of boulders, cobble, pebble, gravel, sand or silt, provides important habitat for feeding as many invertebrates live within the streambed (the hyporheic zone) (Lake 1994). The substrata also serves as spawning sites for species such as Macquarie perch which deposit their eggs in shallow water over boulders, pebbles or gravel (Cadwallader and Lawrence 1990).

Lentic waters, such as dams, lakes, swamps, wetlands and billabongs, provide habitat for freshwater fish, especially during periods of low river flow (Bayley and Li 1992; Horwitz et al. 1998). These waters are generally deeper and clearer than lotic waters, and although some species can live and breed in non-riverine conditions, they may prefer streams (Caughley 1990). Aquatic plants (macrophytes) may be particularly important in lentic environments as they provide food and shelter (Arthington et al. 1992).

The freshwater and brackish regions of estuaries are also important habitat for freshwater fish as many species, e.g. Australian bass (*Macquaria novamaculeata*) and migratory galaxiids, utilise these areas at some stage of their life cycle. Thus they are critical to the recruitment of fish (Lake 1994).

The freshwater habitats described above are important not only for fish, but also invertebrates, which are a major food resource for fish (Campbell and Doeg 1989; Arthington et al. 1992).

The physicochemical properties of freshwater ecosystems (e.g. dissolved oxygen, pH, salinity, suspended sediment, temperature and flow velocity) are important aspects of the environment in which fish live, but are not habitat characteristics as such and therefore will be addressed in the 'Pollution, water quality and water temperature' section of this review.

What causes habitat degradation and how does this affect fish?

It has been suggested that a high level of habitat diversity within a river leads to high species diversity (Pusey et al. 1995; Welcomme 1995; Pusey and Kennard 1996). Any process that removes or alters the habitat features described above may result in habitat simplification and hence degradation. Habitat can be degraded through many processes and the majority of these are associated with land use practices (agriculture, forestry, industrial/urban development) and river regulation. Habitat degradation may also result from the clearing of catchment and riparian vegetation, gravel extraction and introduction of exotic species (both aquatic and terrestrial plants/animals) (Bruton 1995; Cullen and Lake 1995; Jackson 1997). These processes can alter flow regimes and cause bank erosion,

eutrophication, sedimentation and salinisation. Consequently, fish habitat may be degraded because of the resultant changes in stream morphology, chemistry, physical conditions, biology and ecology.

Habitat degradation may have a detrimental effect on fish directly by making areas inaccessible or unsuitable, or indirectly through similar effects on their food organisms. Effects may be short or long term, and localised or widespread.

A major cause of reduced habitat availability is river regulation. Many native fish species undertake extensive migrations (upstream or downstream) to spawn and structures built for river regulation (i.e. dams, weirs, etc) impede these migrations and may effectively isolate fish from their spawning habitat (Cadwallader and Lawrence 1990; Wager and Jackson 1993; Pollard and Hannan 1994; Wasson et al. 1996). This is discussed further in the section on 'Barriers to migration'. Dams and other impoundments have also caused habitat loss through the conversion of lotic areas to lentic waters (Arthington et al. 1992). Furthermore, floodplains become the ideal habitat for the juveniles of many native species during flooding and hence river regulation and flood mitigation measures (e.g. levee banks) which prevent the inundation of floodplains can also lead to a reduction in habitat availability (Cadwallader and Lawrence 1990; Wager and Jackson 1993).

Habitat simplification is another major form of degradation. This may occur when important habitat attributes are lost e.g. pools filled in by sediment, snags removed, undercut banks lost because of the clearing of riparian vegetation (Cadwallader and Lawrence 1990; Arthington et al. 1992; Jackson 1997).

Overall, habitat degradation may impact on native fish in a variety of ways. Habitat degradation may lead to native fish becoming isolated in marginal habitats and this may cause changes at both the population and community level (Allan and Flecker 1993). With less habitat available, intra- and inter-specific competition may be increased, spawning success reduced and fish populations may decline because of subsequent reductions in recruitment (Allan and Flecker 1993). In addition, fish community structure may be altered as 'sensitive' species become rare or are lost, and 'tolerant' species become relatively more abundant (Bruton 1995). Habitat degradation may also lead to an increased prevalence of exotic species (Allan and Flecker 1993; Harris 1995).

Effects of agriculture and mining on freshwater fish habitat

Agricultural activities have significantly altered the catchment areas of many Australian river systems and have also placed high demand for water on these rivers. Consequently, the impacts of agriculture on freshwater ecosystems are widespread and often substantial. Strong associations between the ecological integrity of inland waters and agriculture have been demonstrated (Allan et al.1997). Agricultural land use practices include clearing, planting of crops and pastures, irrigation and livestock grazing. These practices may contribute to the degradation of aquatic ecosystems through resultant changes to riparian vegetation, habitat quality, water quality and flow regimes (Allan and Flecker 1993).

A substantial amount of agricultural activity occurs on floodplains (Allan and Flecker 1993). As outlined above, floodplains provide important habitat and food resources for many native freshwater fish species during times of inundation, therefore degradation of floodplains may have direct impacts on fish. The impact of floodplain grazing and cropping on the success of emergence of invertebrates aestivating in the soil (which become food resources for fish during flooding) is largely unknown (Boulton and Lloyd 1992).

Land and water degradation have occurred widely in Australia, and particularly in the Murray-Darling Basin. Many tributaries have been changed from narrow, clear-water streams with deep holes to wide, shallow, muddy tracts (Cadwallader and Lawrence 1990). Much of this change has resulted from development of agriculture which is clearly a major factor contributing to the degradation of freshwater ecosystems and is hence an important threat to freshwater fish resources in Australia.

Mining in rivers (i.e. for sand and gravel) or catchments can also have serious impacts on freshwater ecosystems. Sand and gravel mining can cause habitat degradation in rivers through increases in turbidity and sedimentation, and alteration of channel morphology (Lake and Marchant 1990; McNee 1990; Wasson et al. 1996). Other forms of mining can cause substantial pollution in freshwater ecosystems. Mining is addressed in the section on 'Pollution, Water quality and Water temperature'.

Riparian vegetation degradation.

Riparian vegetation and its role in freshwater ecosystems

Riparian vegetation is that growing in the riparian zone – the land immediately adjacent to a stream or water body which is involved in the direct interaction between terrestrial and aquatic ecosystems. This zone extends outward to the limits of flooding and upward into the canopy of streamside vegetation (Gregory et al. 1991).

Riparian vegetation is an integral part of the aquatic ecosystem as it influences many aspects of the freshwater environment that determine habitat availability and quality (Bunn 1993; Hancock et al. 1996; Jackson 1997). Riparian vegetation has three main influences on stream ecology. Firstly, it has a geomorphic influence as the vegetation stabilises river banks and protects them from erosion (Arthington et al. 1992; Campbell 1993; Cummins 1993; Cullen and Lake 1995). Secondly, riparian vegetation has a strong influence on the energy sources and cycles in aquatic ecosystems. Vegetation in the riparian zone acts as a filter for runoff from the catchment, reducing the quantity of sediment, nutrients and chemicals being transported into rivers (Gregory et al. 1991; Cummins 1993; Hancock et al. 1996). Riparian vegetation further influences nutrient levels in streams through the input of leaf litter and other organic debris. This material is also an important food source for detritivorous fish and invertebrates (Campbell and Doeg 1989; Lake and Marchant 1990; Gippel et al. 1992; Cullen and Lake 1995; Hancock et al. 1996). It also influences primary production through shading which affects light levels and stream temperatures (Allan and Flecker 1993; Arthington et al. 1992; Cullen and Lake 1995; Gregory et al. 1991; Campbell 1993; Cummins 1993; Wilson et al. 1996).

Lastly, as discussed earlier, riparian vegetation provides important instream habitat for fish and other aquatic organisms. These include undercut banks, submerged roots and large woody debris (Gregory et al. 1991; Arthington et al. 1992; Campbell 1993; Cummins 1993; Wager and Jackson 1993; Cullen and Lake 1995; Horwitz et al. 1998). In addition, riparian vegetation becomes spawning and/or nursery habitat during times of inundation (Campbell and Doeg 1989). Riparian vegetation also serves as habitat for terrestrial fauna, some of which (e.g. insects) fall into streams and provide food for predatory fish (Cadwallader et al. 1980; Pen and Potter 1991; Arthington et al. 1992; Cullen and Lake 1995).

Threats to riparian vegetation

Several factors have contributed to the degradation of riparian vegetation. For example, clearing, forestry activities, urbanisation, cropping, grazing by stock and feral animals, salinisation, drowning caused by the creation of impoundments, burning, damage associated with the recreational use of rivers, loss of natural flooding and drying cycles and invasion by introduced plant species (Walker 1992; Humphries 1994; Hancock et al. 1996; Jackson 1997). In the worst cases, these activities result in riparian vegetation being either completely lost or converted to communities of introduced species.

Effects of riparian vegetation degradation on fish

Effects of clearing

The most serious, direct impact of the clearing of riparian vegetation is the removal of instream fish habitat; the effects of such habitat loss have been discussed earlier. However, clearing may have substantial indirect impacts on freshwater ecosystems.

Clearing of riparian vegetation leads to the degradation of fish habitat as it can cause: the loss of littoral habitat and undercut banks, increased bank erosion (sedimentation) and nutrient input, decreased input of leaf litter and large woody debris, reduced shading of the river, the shallowing and widening of the river channel, and loss of deep pools (Campbell and Doeg 1989; Delong and Brusven 1991; Cullen and Lake 1995; Jackson 1997; Horwitz et al. 1998). Fish can be affected by these processes through the loss of spawning and refugia sites as well as through changes to food resources because of resultant impacts on aquatic flora and invertebrates (Campbell and Doeg 1989; Cullen and Lake 1995; Jackson 1997).

Loss of riparian vegetation may lead to changes in water quality and productivity in streams (Bunn 1993; Cullen and Lake 1995; Wasson et al. 1996). Excess runoff and increased flows may result from the clearing of riparian vegetation and consequently sediment and nutrient loads in streams may increase (Campbell and Doeg 1989; Delong and Brusven 1991; Horwitz et al. 1998). Sedimentation and nutrient enrichment can have serious effects on aquatic systems and fish – these are addressed in later sections of this review.

Reduced shading may lead to increased primary production. This is because of the increased availability of light and warmer stream temperatures (Gregory et al. 1991). In the short term, this may result in an increase in fish production through increased food resources and greater visibility associated with higher light levels in streams (Gregory et al. 1991). However, in the long term, reduced riparian vegetation cover may cause excessive algal and aquatic weed growth, which may alter stream ecology and lead to degradation of habitat for fish (Gregory et al. 1991).

There is some evidence that the clearing of riparian vegetation has contributed to the decline of native freshwater fish species. For example, in WA, a number of galaxid species (*Galaxias munda, G.nigrostriata* and *Lepidogalaxias salamandroides*) have disappeared in streams where extensive riparian vegetation has been cleared for agricultural purposes (Horwitz et al. 1998).

Effects of introduced plant species

Introduced plants can have serious impacts on riparian vegetation. In contrast to the problems generated by clearing, the growth of introduced plants, especially weeds, may be more prolific than that of the endemic species they have replaced. This may lead to reduced nutrient levels in streams and increased shading (Abramovitz 1996). In this way introduced plants can affect stream productivity. In addition, the replacement of endemic species with introduced species may lead to bank instability, as some species (e.g. introduced grasses) do not have sufficient root strength to maintain undercut banks (Wilson et al. 1996).

Riparian zones are prone to weed invasion (Humphries 1994). Various weed species have become established in Australian catchments including willows (*Salix spp.*) and blackberries (*Rubus spp.*) (Cullen and Lake 1995). Willows have substantially degraded riparian zones in some areas by smothering native vegetation (Walker 1993; Jackson 1997). River red gum (*Eucalyptus camaldulensis*) forests along the Murray River in South Australia have been displaced by willows (Walker 1992). The rapid root growth of willows can alter streambanks and the river channel which may lead to the simplification of instream habitat (Mussared 1997).

In addition, introduced plants contribute different types of organic material (e.g. leaf litter, bark) at different times of the year from native species (Gregory et al. 1991; Campbell 1993). Organic material in streams is decomposed by heterotrophic microorganisms, consumed or fragmented by macroinvertebrates, physically abraded into smaller particles, or leached and released as dissolved organic matter (Gregory et al. 1991). Introduced plant material may have a different composition and may require a much greater time for complete decomposition compared to material from native flora (Gregory et al. 1991).

This is the case with willow leaves which have thick, waxy cuticles (Gregory et al. 1991). Hence, there may be excessive organic debris in streams with high inputs of introduced plant material, this may constitute habitat degradation. Furthermore, introduced plant material may be less palatable than native material and therefore introduced riparian vegetation may affect the food resources of fish and invertebrates (Gregory et al. 1991; Campbell 1993).

The timing of the input of leaf litter into streams is also important. In Australia the peak input is generally in summer (for eucalypts), although input occurs throughout the year (Campbell 1993). Conversely, the peak input for many introduced plants (e.g. willows) occurs in autumn (Campbell 1993). Therefore, changes to the timing of detritus input is another way in which introduced plants may affect the food resources of fish and invertebrates (Campbell and Doeg 1989; Horwitz et al. 1998).

Wetland degradation.

Wetlands and their role in freshwater ecosystems

Wetlands are depressions in the land covered either permanently or temporarily with fresh, brackish or saline water. Wet meadows, marshes, ponds, lakes, billabongs and swamps are all forms of wetlands (Jackson 1997). Wetlands may be classified by particular features including hydrological regime (i.e. by the frequency/duration of filling/drying), dominant vegetation or fauna present, soil type or geomorphic origin (Pressey 1990).

Wetlands have significant ecological value. They play an important role in carbon reduction and cycling, nutrient assimilation, geochemical cycling and sediment stabilisation, as well as providing important habitat for fish and other fauna (Russell and Hales 1996). In contrast to most Australian streams, wetlands are usually autochthonous and have very high biomass production relative to water volume (Boon et al. 1990). Consequently, wetlands contribute large amounts of organic matter to freshwater ecosystems and provide a rich source of food (e.g. algae, plankton and macroinvertebrates) for freshwater fish (Boon et al. 1990; McComb and Lake 1990).

Threats to wetlands

The extent and condition of Australia's wetlands have deteriorated greatly since European settlement. Wetlands have been degraded as a result of land use activities such as agriculture and by changes to hydrological regimes from river regulation. Recreation and tourism, which may involve boating, fishing and camping, may also cause wetland degradation and the displacement of wetland wildlife (Pressey 1990). In addition, some wetlands are mined for diatomaceous earth and peat (Wasson et al. 1996).

These activities have adversely affected wetlands through grazing and trampling by livestock, introduced plants (e.g. floating water hyacinth, *Salvinia molesta*, Canadian pond weed) and animals (e.g. water buffalo, pigs, carp), increased salinity and sedimentation, nutrient enrichment, and pollution (Arthington et al. 1983; Pressey 1990; Usback and James 1993). Altered flow regimes as a result of river regulation have caused some wetlands to dry up and other low-lying wetlands to be permanently connected to rivers. These changes represent degradation for most wetlands as this disrupts the natural cycle of drying and refilling to which flora and fauna are adapted (Pressey 1990).

Effects of wetland degradation on fish

Wetlands are important habitat for some fish species. Thus, wetland degradation may be considered a specific form of habitat degradation and, therefore, represent a serious threat to the sustainability of some freshwater fish species. Interference with the hydrological regimes of wetlands will cause loss of habitat in cases when wetlands dry out completely. Conversely, permanent flooding of wetlands may reduce overall biological productivity, thereby reducing food resources for fish and other organisms (e.g waterfowl) (Pressey 1990). Fish may be affected if wetlands become degraded through changes in aquatic and

riparian vegetation, changes in sediment transport and deposition, erosion, nutrient enrichment, pollution, and changes in zooplankton abundance and littoral invertebrate communities (Bren 1992; Timms 1992; Jackson 1997).

One form of wetland degradation in particular, the proliferation of introduced aquatic and riparian weeds, has been identified as a potentially serious problem for fish (Jackson 1997). These weeds can smother wetlands affecting flows and trapping sediments (Pressey 1990). High weed densities may also impede the ability of fish to locate prey (invertebrates) (Closs 1990). There is evidence that this type of degradation has had an impact on fish populations. For example, the distribution and abundance of some fish species have been affected by the introduced pasture species para grass, which has invaded many shallow waters in the Johnstone River catchment, Queensland (Arthington et al. 1983).

Sedimentation.

What is sedimentation?

Sediment is defined as solid material, both mineral and organic, that is in suspension, is being transported, has been moved from its site of origin by water, air or ice and has come to rest on the land, or has settled from suspension (SoEAC 1996).

There are four different types of sediment in freshwater ecosystems. Suspended sediment refers to particles in the water column, deposited sediment is material lying (static) on the stream or lake bed, bed-load sediment is the transient material on the stream bed, and hyporheic sediment refers to particles within the matrix of the stream bed or substratum (Doeg and Koehn 1990; Metzeling et al. 1995).

Causes of sedimentation

Sediments have a wide range of sources including erosion, agricultural activities, road works, construction sites, mining, logging, sewage effluent and the desilting of weirs (Beschta 1978; Richardson 1985; Davey et al. 1987; Campbell and Doeg 1989; Cadwallader and Lawrence 1990; Koehn and O'Connor 1990; Lake and Marchant 1990; Walker 1992; Wager and Jackson 1993; Doeg and Koehn 1994; Sweeting 1994; Metzeling et al. 1995; Wasson et al. 1996; Allan et al. 1997). In undisturbed catchments only small amounts of sediment are generally input into streams (Metzeling et al. 1995).

Agricultural activities, including the clearing, overgrazing of land and bank erosion (from stock access to streams), may lead to substantially increased runoff and sedimentation. Such activities are a major cause of sedimentation. Sediment loads are generally found to be elevated in areas where there is extensive agriculture (Allan et al. 1997; CSIRO 1992).

Effects of sedimentation on fish

Sediment is regarded as the single worst pollutant in streams (Cadwallader and Lawrence 1990; Arthington et al. 1992). Sedimentation affects channel morphology and bed structure, increases turbidity and reduces light availability, which in turn lowers rates of primary production in streams (Arthington et al. 1992; Lake and Marchant 1990; Doeg and Koehn 1994; Petts 1994; Cullen and Lake 1995; Metzeling et al. 1995; Jackson 1997).

Sedimentation affects all forms of aquatic life as most species are unable to escape by migration (Metzeling et al. 1995). Sedimentation has been implicated in the reduced growth and loss of macrophytes and algae in many Australian river systems (Cullen and Lake 1995; Metzeling et al. 1995). Changes in macroinvertebrate communities have been attributed to sedimentation including lower species diversity, reduced biomass and changes in species composition (Chessman et al. 1987, Doeg et al. 1987, Marchant 1989; Campbell and Doeg 1989; Growns and Davis 1994).

In Australian inland waters, sedimentation has also been identified as a major cause of loss of fish habitat and breeding areas (Cadwallader 1978; Metzeling et al. 1995; Jackson 1997). Fish are also affected by sedimentation indirectly through its impacts on food

resources, namely invertebrates. The decline in abundance and range of a number of native freshwater fish species (e.g. Australian bass, freshwater blackfish and Macquarie perch) has been attributed to sedimentation (Koehn and O'Connor 1990).

Aquatic fauna are affected by the amount of sediment, the length of time exposed to the sediment, and the frequency of sedimentation events (Newcombe and MacDonald 1991). The adverse effects of sedimentation also depend on the type of sediment and often more than one form may be involved, thereby making it difficult to attribute impacts to a particular type of sediment (Metzeling et al. 1995). The effects of different types of sediment are discussed below.

Suspended sediments

Suspended sediment can have extreme effects on stream biota. High levels of suspended sediments can be lethal to fish (Koehn and O'Connor 1990). They have been shown to cause stress, altered behaviour, displacement, reduced feeding, reduced growth and survival, and increased incidence of disease (Lloyd 1987; Campbell and Doeg 1989; Wager and Jackson 1993; Metzeling et al. 1995; Jackson 1997). The fine particles in suspended sediment may coat or clog the gills of fish, causing asphyxiation, as well as smothering eggs and spawning sites (Doeg and Koehn 1990; Koehn and O'Connor 1990; Arthington et al. 1992; Metzeling et al. 1995). The feeding ability of fish may be reduced when suspended sediment levels are high as their ability to visually locate prey may be impaired (Campbell and Doeg 1989). Suspended sediment may have similar effects on invertebrates, especially filter feeding organisms, hence fish would also be affected indirectly through impacts on their food resources (Doeg et al. 1987; Doeg and Koehn 1990).

Deposited and bed-load sediment

Deposited sediment and bed-load sediment have similar effects on freshwater ecosystems. These forms of sedimentation may represent a more serious threat to stream biota than suspended sediment (Campbell and Doeg 1989). The effects of deposited sediment can also be persistent (Alexander and Hansen 1986; Berkman and Rabeni 1987; Doeg et al. 1987).

The most direct impact of deposited and bed-load sediment on stream ecology is the filling of spaces among coarse substrata, filling deep holes, and overall blanketing of the stream bottom. This reduces or destroys fish and invertebrate habitat. The filling of deep holes removes important refuge habitat, while sediment deposition on the stream bed may adversely affect the spawning success of fish species which lay their eggs on or amongst boulders or logs. Furthermore, the smothering of detritus may reduce the availability of food resources for fish and invertebrates.

Deposited sediment has been implicated in the decline of both native freshwater fish and invertebrate populations (Cadwallader 1981; Cullen and Lake 1995; Wager and Jackson 1993). For example, the only healthy-sized populations of Macquarie perch are now found in upland areas where there is minimal sedimentation and where both deep pool and riffle habitat still exist (Wager and Jackson 1993). Similarly, little or no spawning success of freshwater blackfish has been recorded in areas where there are substantial amounts of deposited sediment (e.g. spawning sites covered by 1m or more of sediment) (Doeg and Koehn 1994).

Both bed-load and deposited sediment may also have abrasive effects on the stream bed during high flows. This may dislodge fish eggs and contribute to invertebrate drift (Campbell and Doeg 1989; Cadwallader and Lawrence 1990; Arthington et al. 1992). Invertebrate drift is the downstream movement of substantial numbers of stream-dwelling organisms (Allan 1995).

Hyporheic sediment

Deposited sediment may easily be flushed from stream beds, however major floods are probably necessary to flush out fine sediment trapped within the stream bed (Campbell

and Doeg 1989; Horwitz et al. 1998). Consequently, hyporheic sediment may be even more persistent and detrimental than deposited and bed-load sediment.

Both fish and invertebrates use the hyporheic zone. Some fish deposit eggs in the substratum (e.g. Macquarie perch). Invertebrates may live deep in the substratum or use this area as refugia during times of stress or as part of daily or seasonal vertical migrations (Doeg and Koehn 1990). Hyporheic sediment can fill the interstitial space in substratum leaving it largely homogenous (Doeg and Koehn 1990; Metzeling et al. 1995; Jackson 1997). This sediment may smother fish eggs, reducing spawning success, and invertebrates using the hyporheic zone (Hogg and Norris 1991; Lloyd et al. 1991; Newcombe and McDonald 1991; Arthington et al. 1992; Metzeling et al. 1995). Therefore, increased hyporheic sedimentation can lead to severe habitat degradation for both fish and invertebrates. Benthic flora may also be affected by sedimentation and as these organisms are food resources for fish, this may represent an additional, indirect impact on fish (Arthington et al. 1992; Metzeling et al. 1995).

Hyporheic sediment may also lower dissolved oxygen levels and raise intra-gravel temperatures. As these conditions can persist even after sediment has been flushed out, this represents an additional threat to the survival of fish eggs and juveniles (Platts et al. 1989; Doeg and Koehn 1990; Jackson 1997).

River modification.

River modification, river improvement or river engineering are general terms encompassing activities aimed at controlling erosion, flood mitigation, improving discharge capacity of waterways (drainage capacity) and removing obstacles to river traffic (Cadwallader and Lawrence 1990). Such activities include the removal of fallen timber and other debris (desnagging), removal of trees likely to fall into the river (clearing of riparian vegetation), bank stabilisation, channelisation and channel straightening (Cadwallader and Lawrence 1990; Cullen and Lake 1995; Bayley 1991). The main impacts of river modification on fish are reduced habitat availability and habitat degradation.

Desnagging represents a serious form of habitat degradation. As discussed earlier, snags are important instream habitat features for fish in lowland streams. In addition, snags, debris dams, log jams and leaf packs serve to retain organic matter and nutrients which would otherwise be flushed from the system before being utilised by biota (Lake 1994). Hence, the removal of snags can have a direct impact on fish and invertebrates through the reduction of habitat availability, but can also affect stream ecology more generally by reducing the amount of allochthonous material retained in the system.

Channelisation can also cause habitat degradation. Channelisation generally causes loss of habitat and reduction in habitat diversity (e.g. loss of pool–riffle sequences, snags and fringing vegetation) which in turn leads to reduction in abundance and diversity of aquatic biota (Hortle and Lake 1983; Lake 1994). Reductions in fish species richness, total fish biomass and fish densities have been recorded in 'improved' channelised sites compared with those which have not been modified and remain unchannelised (Hortle and Lake 1983).

Other river modification activities associated with river regulation are discussed in the section on 'Reduced environmental flows'.

Forestry/Logging.

The headwaters of most Australian rivers occur in forests. Logging occurs in a number of these areas.

Forestry practices can have profound effects on ecology and hydrology of rivers. Overall, logging alters physicochemical conditions, hydrological regimes and may lead to a shift towards autotrophy and changes in relative proportions of species in aquatic faunal assemblages (Horwitz et al. 1998). Streamflows are likely to be affected by forestry

activities as land clearing increases runoff. In extreme cases, forest removal may cause catastrophic flooding downstream (Campbell and Doeg 1989; Allan and Flecker 1993).

Logging may also degrade the quality of water in streams. Nutrient inputs may be increased following timber harvest as dissolved nutrients leached from organic debris into the soil are transported into streams. In addition, extra nutrients adsorbed onto inorganic particulate material or contained within organic particulate material maybe washed into streams by overland flows (Campbell and Doeg 1989; Horwitz et al. 1998). Overall, significant increases in dissolved nutrients have been reported for streams in logged catchments (Campbell and Doeg 1989; Horwitz et al. 1998). As with agriculture, forestry practices contribute to pollution through the use of pesticides and fertilizers. Pollution from forestry chemicals has been shown to cause disturbance and mortality of stream invertebrates and fish (Barton and Davies 1993, Davies et al. 1994). Furthermore, dissolved oxygen levels in the streams of logged areas may be significantly reduced through the decomposition of large amounts of logging debris (Campbell and Doeg 1989).

Logging may also affect stream ecology in ways similar to those associated with the degradation of riparian vegetation (i.e. the clearing of vegetation and invasion of introduced plant species). In particular, the replacement of native forests with exotic plantation species may cause problems through the input of different plant material into streams at different times of the year (Campbell and Doeg 1989; Horwitz et al. 1998). Light and temperatures changes in streams resulting from the clearing of riparian vegetation may cause higher periphyton and filamentous algae production in forested areas (Campbell and Doeg 1989). Changes to riparian vegetation from forestry practices are likely to have long term biological implications for the streams in these areas.

Perhaps the most serious short term effect of logging is increased sedimentation. The increase in sediment accession to streams following and during logging is well documented (Campbell and Doeg 1989; Wasson et al. 1996; Horwitz et al. 1998). Along with runoff, a major source of increased sediment appears to be from roads and land slips.

Lastly, fires which are used for forest management may affect stream ecology and hence fish. Fires can destroy riparian vegetation and lead to increases in the levels of inorganic sediment, nutrients and organic material input into streams (Campbell and Doeg 1989; Horwitz et al. 1998).

Pollution, water quality and water temperature.

Water quality is fundamental to the integrity of aquatic ecosystems and hence for the sustainability of freshwater fish. Indeed, poor water quality and pollution have long been recognised as phenomena that affect species diversity and richness in streams and other water bodies (Buckney 1995). Water quality generally refers to a variety of characteristics including pH, temperature, turbidity, colour, and nutrient, ion, metal and bacteria/algal concentrations. Pollution is defined as "...the direct or indirect alteration of the physical, thermal, biological or radioactive properties of any part of the environment in such a way as to create a hazard or potential hazard to the health, safety or welfare of any living species..." (pA-30, SoEAC 1996). Following this definition, water pollution is the deterioration in water quality as a result of changes to the physical, chemical and/or biological conditions and is usually associated with the inputs of pollutants.

Although salinity has been identified as a distinct threat to freshwater ecosystems, it can also be regarded as a form of pollution, and hence it is discussed in this section. Sediment is sometimes regarded as a pollutant, however, as discussed earlier, sedimentation generally causes habitat degradation and was, therefore, discussed in the previous section.

This section examines the issues of pollution and water quality and the effects on fish in three subsections: 'pollution and water quality' (general forms of pollution or changes to water quality excluding salinity and changes to water temperature), 'salinity' and 'water temperature' (i.e. thermal pollution).

Pollution and water quality.

Pollutants include things such as petrochemicals, pesticides, heavy metals, sewage effluent, and nutrients (including fertilisers) (McNee 1990; Buckney 1995; Wasson et al. 1996; Mussared 1997). They arise from many sources including agricultural, industrial and urban practices.

Agricultural activity causes pollution in aquatic ecosystems through the use of pesticides, fertilisers and the production of solid material (e.g. sediment from soil erosion and manure) (Norris 1991; Horwitz et al. 1998). Runoff from agricultural areas often contains high levels of pollutants, nutrients, sediments, is more saline, and has depleted dissolved oxygen levels (Cullen and Lake 1995; Abramovitz 1996). Agricultural pollutants can enter waterways from runoff after rainfall, via irrigation runoff and groundwater inflow, and from spray drift (i.e. for pesticides) (Jackson 1997). In particular, the cotton industry uses up to 40 different chemicals which too often find their way into aquatic ecosystems (Jackson 1997). Furthermore, fertilisers can cause soil acidification which may, in turn, lead to the acidification of waterways (Wasson et al. 1996).

Industrial activity may cause pollution through the production of various substances including organic chemicals, metals and solid material which may enter waterways directly, through waste output into rivers/lakes, or indirectly via runoff or leaching from waste dumps (Buckney 1995). Mining can introduce both new chemicals and increase levels of existing chemicals in aquatic ecosystems. Pollution generated from mining activity includes: dissolved metals (released through bacterial oxidation of sulfide minerals); mercury (from gold mining); acidification (from sulphuric acid produced by the oxidation of pyrites in the spoils of open-cut and coal mines); alkalisation and soluble salts (from bauxite mining); and ammonia, which is highly toxic to fish (from gravel extraction and sand mining processes) (Wasson et al. 1996; Horwitz et al. 1998).

Urban areas contribute pollutants to waterways similar to those from agricultural, industrial and mining activities. They also produce petrochemicals and treated sewage (Buckney 1995; Jackson 1997). Another pollutant is lead from hunters' lead shot, which has been recorded in large quantities in South Australian and Northern Territory waters (Lund et al. 1991; Whitehead and Tschirner 1991).

Acidification of aquatic ecosystems can also occur from the draining of naturally occurring acid sulfate soils (Sammut et al. 1996; White et al. 1997).

Dams affect water quality characteristics in freshwater ecosystems. They trap sediment and nutrients which may lead to eutrophication and algal blooms, particularly in summer (Thomson 1994; Cullen and Lake 1995). Water both in dams and upstream of the dams has lower dissolved oxygen levels, warmer temperatures, greater amounts of organic material and increased sediment loads. This may cause changes in the substrata and primary production which may, in turn, affect habitat availability and quality for fish and invertebrates (Arthington et al. 1992; Davies et al. 1992; Horwitz et al. 1998). Consequently, species composition and production of aquatic faunal communities may be affected (Arthington et al. 1992; Davies et al. 1992; Horwitz et al. 1998). Downstream water quality may also be affected by water released from dams as this water may be cooler, more acidic, more saline, low in dissolved oxygen, and/or rich in sulfide, manganese, iron, ammonia and other toxicants (CSIRO 1992; Cullen and Lake 1995; Sweeting 1994). There is evidence that such releases can have serious impacts on fish. For example, massive fish kills (mainly golden perch) have been attributed to the high levels of eucalyptus oil, ash and copper sulphate (used for algal control) in water released from Lake Hume, in the Murray-Darling Basin (Cadwallader and Lawrence 1990). Downstream water quality may be further affected because dams prevent the transport of sediment and organic materials to downstream reaches (Bayley and Li 1992). This may lead to changes in stream ecosystem function, with an overall shift from heterotrophy to autotrophy (Marchant 1989; Davies et al. 1992).

Effects of pollution on freshwater fish.

Pollutants rarely occur singly. Interactions between pollutants, as well as between pollutants and other factors (e.g. river regulation), make isolating the effects of single pollutants difficult (Buckney 1995). It is also difficult to generalise about the effects of pollution on aquatic ecosystems because species differ in susceptibilities to various substances/conditions (Barmuta 1990). In the most severe cases, pollutants may cause fish kills. They can also build up in the tissues of fish where they may lead to reductions in growth, changes in behaviour or changes in metabolic activity (McNee 1990; Wager and Jackson 1993; Jackson 1997). Pollution can affect fish indirectly through effects on habitat (e.g. riparian vegetation and macrophytes) (Barmuta 1990), and/or food availability through impacts on the macroinvertebrate community (Koehn and O'Connor 1990). Overall, pollution is likely to cause local reductions in species richness through the selective removal of susceptible species and increases in the relative abundance of tolerant ones (Barmuta 1990; Buckney 1995). The main forms of pollution in freshwater ecosystems can be broadly classified as 'toxicant' pollution (heavy metals, pesticides and other poisons); 'eutrophication and dissolved oxygen' pollution (nutrient enrichment and altered levels of dissolved oxygen); and 'acidification' pollution. The effects of each of these types of pollution on freshwater fish are discussed below.

Toxicant pollution.

Toxicants can have both lethal and sublethal effects on fish. Metals such as mercury, lead, cadmium and zinc may accumulate in biota to levels toxic to organisms. Toxicity levels of six heavy metals for five Australian freshwater fish species are given by Bacher and O'Brien (1988). Mercury is highly toxic to biota and known to accumulate in the food chain (Jackson 1997).

The concentration of toxic metals in the spoil and mill tailings dumps of mines are usually high enough to cause considerable biotic change. In general, lower diversity and abundance of macroinvertebrate taxa has been recorded downstream of mining sites. This has been attributed to metal contamination. Although pollution from mining has not had an impact on aquatic ecosystems on a national scale, it has had a major local effect on several rivers (Wasson et al. 1996). For example, heavy metal pollution of the Molonglo River caused by collapse and leaching of mine waste at Captains Flat near the ACT, has reduced invertebrate species richness and abundance, and led to the absence of fish for 40km downstream (Norris 1986). Despite decontamination and rehabilitation efforts in this area, pollution persisted for more than 20 years (CSIRO 1992).

Pesticides are an increasing problem and may have chronic effects on biota even at low concentrations (Schultz and Liess 1995). Pesticides may remain in sediment and therefore accumulate in biota and the environment causing long term problems (Jackson 1997). Pyrethroid insecticides may lead to massive short-term increases in invertebrate drift (Davies and Cook 1993). This may also lead to significant long-term impacts on stream ecology through the resultant changes in invertebrate community structure (Jackson 1997). Endosulfan, the main pesticide chemical used in the cotton industry, is extremely toxic to fish (Rayment and Simpson 1993; Napier et al. 1998). A number of fish kills have been recorded in cotton growing areas (Cullen and Lake 1995). For example, fish kills have been recorded in QLD and NSW streams adjacent to cotton fields. These have been attributed to pesticide contamination from runoff (Arthington et al. 1992). Cadmium (from fertilisers) has also been found in fish tissues (Horwitz et al. 1998). Furthermore, herbicides used in the control of aquatic plants (e.g. acrylaldehyde) have routinely caused large scale fish kills in irrigation channels (Mackay and Shafron 1989).

Sublethal impacts of toxicants include effects on metabolism and behaviour; retarded life cycles and deformities; these may all lead to reduced feeding or spawning ability (Koehn and O'Connor 1990; Bruton 1995, Nowak 1991; Barmuta 1990).

Eutrophication and dissolved oxygen pollution.

Eutrophication is defined as the enrichment of a water body with nutrients leading to increased primary production (Wager and Jackson 1993). Eutrophication is well documented as contributing to cyanobacterial algal blooms in many inland waters (Cullen and Lake 1995). A bloom is defined as any concentration of algae sufficient to impair water or habitat quality (McComb and Davis 1993). Further impacts of eutrophication include the toxins released from cyanobacteria, the smothering of substrates and filling of water bodies by filamentous algae, and deoxygenation caused by the decay of algae (McComb and Davis 1993).

Eutrophication may affect the fish and invertebrate communities and their habitats both directly – through increased algal growth, and indirectly – through oxygen depletion. The toxicity of cyanobacteria to native fish and invertebrates is largely unknown (Johnston et al. 1994). Reduced macroinvertebrate species richness has been attributed to eutrophication in some areas where sensitive species (e.g. plecopterans, trichopterans, ephermeropterans) may be reduced to very low numbers or become absent and tolerant species (e.g. chironomids) may become prevalent (Horwitz et al. 1998).

Altered levels of dissolved oxygen or other gases are changes to water quality that may be regarded as pollution. Oxygen depletion may occur as a result of eutrophication, raised water temperatures (e.g. because of reduced riparian vegetation cover), large inputs of organic material (which consumes oxygen during decomposition), and increased water salinity (see 'Salinity' section for more information) (Jackson 1997). Organisms vary in tolerance to reductions in dissolved oxygen, but levels below tolerance will kill biota (Jackson 1997). Furthermore, areas of low dissolved oxygen will be unavailable as habitat (Jackson 1997). On the other hand, very high levels of dissolved oxygen and/or other gases may also be lethal to fish (Jackson 1997). For example, a large fish kill has been recorded as a result of the release of water supersaturated with oxygen and other gases from a hydroelectric power station dam on the Pieman River, Tasmania (TDEP 1990).

Acidification.

Increases in acidity can affect at least the respiration of fish, their susceptibility to disease and the survival of eggs and juveniles (QFMA 1996). Increased acidity can also impact riparian vegetation and lead to reduced macroinvertebrate species richness (Jackson 1997). Leachate from acid sulfate soils may also lead to fish kills (Sammut et al. 1993; 1996).

Salinity.

What is salinity and how is it caused?

Salinity is a measure of the concentration of salts in solution and is often expressed as total dissolved solids (TDS). Salts include chlorides and sulfates of sodium, calcium, magnesium and potassium which are present in the water as dissociated ions (Close 1990a).

In Australia, large rivers naturally have widely fluctuating salinity levels. During times of low flow (summer) it is common for highly saline groundwater to enter rivers (Cullen and Lake 1995). In the last century salinity levels have increased substantially in some Australian freshwater ecosystems. These increased salinity levels have two main causes. The first is dryland salinity which is brought about through the clearing of deep-rooted native vegetation and the replacement of such trees with shallow-rooted crops and pasture. The second is large-scale irrigation (irrigation salinity). Both result in the greater infiltration of surface water and the gradual filling of aquifers. This raises the level of the water table, bringing with it accumulated salts thereby leading to increased salinisation of soils and waterways (Close 1990a; Hart et al. 1990; Lake and Marchant 1990; McNee 1990; Metzeling et al.1995; Wasson et al. 1996; Horwitz et al. 1998).

The effects of salinity on freshwater ecosystems

Salinity may have several adverse effects on freshwater ecosystems. The most direct impact occurs when salinity levels are high enough to be lethal or harmful to aquatic organisms. Hart et al. (1991) produced an extensive review of the salt sensitivity of aquatic flora and fauna in Australia. Adverse biological effects are likely in Australian freshwater ecosystems when salinity levels are at or above $1000mgL^{-1}$, however sensitivity to salinity varies between groups of organisms (Hart et al. 1990; 1991).

Algae, macrophtyes, riparian vegetation and macroinvertebrates have been found to be the most salt sensitive biological communities. Algae and macrophytes show adverse effects, such as reduced growth rates and mortality, above salinity levels of $1000mgL^{-1}$ (Hart et al. 1991; James and Hart 1993). Most common riparian plants (e.g. *Eucalyptus spp., Casuarina spp., Melaleuca spp.*) are salt tolerant up to approximately $2000mgL^{-1}$, however sublethal effects are likely at lower salinities (Hart et al. 1990; 1991; Halse and Jensen 1993; Metzeling 1993). Furthermore, salinity effects on riparian vegetation are likely to be the most serious in areas where waterlogging also occurs as salinity appears to interfere with the ability to cope with waterlogging (Hart et al. 1990). The salinity tolerance of freshwater invertebrates varies widely between species, but generally these organisms cannot tolerate salinities higher than 9000 mgL^{-1} (Hart et al. 1991). Most invertebrates experience significant deleterious effects in physiology, biochemistry and behaviour at far lower salt concentrations and adverse effects are apparent for some species at salinities as low as 1000 mgL-1 (Hart et al. 1991).Fish have generally been found to be less sensitive to salt, however salinity tolerance again varies substantially between species. The adults of most Australian freshwater fish species can tolerate salinity levels up to or greater than 10000 mgL^{-1} (Hart et al. 1991). However, eggs are less tolerant than adults, and larvae are more sensitive than both eggs and adults (Hart et al. 1991). High levels of salinity may affect fish through a decrease in reproductive success and a reduction in the growth rate of larvae and juveniles (Metzeling et al. 1995). When salt levels are excessively high, fish are likely to die as they are unable to osmoregulate their internal fluids (Hart et al. 1991; Metzeling et al. 1995). Some species are more salt sensitive than others with freshwater blackfish and silver perch being among the most sensitive Australian freshwater fish (Hart et al. 1991; Guo et al. 1993; Metzeling et al. 1995).

Although salinity does not have serious direct impacts on fish at low levels, the indirect effects may be substantial. The effects of salinity on aquatic plants and macroinvertebrate communities may represent significant changes to fish habitat and/or food resources (Hart et al. 1991). Another way in which salinity may affect fish habitat is through stable salinity stratification which occurs at salinity levels well below those toxic to fish (McGuckin 1991). In this phenomenon, salinity affects levels of dissolved oxygen, with deoxygenated water becoming trapped in deep saline pools (Effler et al. 1997). This may represent a reduction in habitat availability as fish will no longer be able to inhabit such pools (Cadwallader and Lawrence 1990; Jackson 1997).

Thus, salinity has the potential to substantially alter freshwater ecosystems. Relatively low levels are likely to cause changes to the aquatic plant and macroinvertebrate communities, which will in turn impact on fish. Changes in salinity levels may affect the distribution of freshwater fish in Australian river systems. Sensitive species may become more restricted as higher salinity becomes more widespread, and estuarine fish may move further inland (Horwitz et al. 1998). There would be an overall loss in biodiversity if salinity was to increase to unacceptable levels, as salt sensitive species would be replaced by salt tolerant species and rare species may be lost altogether (Metzeling et al. 1995).

Water temperature (thermal pollution).

Water temperature is an important factor affecting geographic distribution, growth rate and survival of fish and other aquatic organisms (Barthalow 1989; Holmes and Regier 1990). Water temperature is thought to influence migration patterns, egg maturation, incubation success, inter- and intra-specific competitive ability and resistance to parasites,

disease and pollutants (Armour 1991; LeBlanc et al. 1997). Significant changes to water temperatures have occurred in Australian freshwater ecosystems since European settlement, largely because of broad scale river regulation activities. Similarly urbanisation has also affected water temperatures through changes to riparian vegetation and flow regime, and geomorphological alteration of rivers (LeBlanc et al. 1997).

The most serious changes to water temperature occur as a result of the release of water from impoundments. Water is generally released from the base (hypolimnion) of a dam. This water is colder than the water in the river, thus there is a reduction in water temperature which can be measured at least 67km and possibly more than 300km downstream of a dam (Walker et al. 1978; Harris 1997). The reduction in water temperature brought about by these releases can affect the fish and invertebrate populations downstream of the impoundment in a number of ways including reductions in growth rate and swimming performance, and inhibition of feeding, maturation and spawning (Harris 1984a; Cadwallader and Lawrence 1990; Koehn and O'Connor 1990; Lake and Marchant 1990; Shafron et al. 1990; Wager and Jackson 1993; Gore 1994; Cullen and Lake 1995; Kingsford 1995; LeBlanc et al. 1997). Cold water releases made during summer, when streams flows are usually low and temperatures warm, may be particularly deleterious to native fish as many species rely on water temperature as a cue for spawning (Koehn and O'Connor 1990). Changed water temperatures may also affect fish indirectly through impacts on food resources such as algae and macroinvertebrates (Gore 1994; Jackson 1997). Cooler stream conditions may favour introduced species such as salmonids (Lake 1980; Kingsford 1995), and have been recognised as a major cause of local extinctions of golden perch and freshwater catfish (*Tandanus tandanus*) (Walker 1985).

Although cooler water temperatures are regarded as the more serious problem, warmer temperatures may also pose a threat to freshwater fish. Stream temperatures may increase if riparian vegetation has been cleared and shading reduced. This may impact fish populations if temperatures rise to lethal levels (Koehn and O'Connor 1990).

Freshwater fish are unlikely to be driven to extinction through pollution, salinity or changes to water temperatures alone. However , for species with highly restricted ranges already threatened by habitat degradation, these additional factors may represent a serious problem (Allan and Flecker 1993). As with habitat degradation, pollution is likely to eventually lead to changes in the community structure of riverine ecosystems with tolerant and/or introduced species becoming more prevalent (Buckney 1995). Furthermore, the time frame over which pollution persists is likely to be an important factor in the determination of the ultimate size of such threats to fish production. Deterioration of water quality over the long term may be as serious as a direct toxic kill as it may mean reduced suitability of environmental conditions which may make fish more susceptible to predation and disease, as well as reducing reproductive success (Koehn and O'Connor 1990).

Reduced environmental flows.

As noted in Chapter 1, both rainfall and runoff in Australia are relatively low. Consequently, relatively few large rivers and freshwater lakes occur here (SoEAC 1996). Furthermore, rainfall, runoff and stream flow are highly variable both between and within years. Thus, floods, droughts and low flows are features of the natural flow regime (Cullen and Lake 1995; Crabb 1997).

The natural flow regime has a profound influence on aquatic ecosystems, especially rivers and floodplains, and the ecological importance of natural flow regimes is now well recognised. This issue has recently been reviewed by Poff et al. (1997). In particular, flow regime effects channel morphology, sediment movement, substrate composition, organic detritus transport and the development of aquatic and riparian vegetation (Arthington et

al. 1992; Poff and Allan 1995; Poff et al. 1997; Richter et al. 1997; Puckridge et al. 1998). Aquatic organisms, including native freshwater fish, have evolved with these flow regimes and are well suited to the natural conditions as they have developed morphological, physiological, behavioural and life history traits to enable them to persist in these unpredictable environments (Wager and Jackson 1993; Lake 1994). Therefore, given the ecological significance of natural flow regimes, changes to these conditions may represent a serious threat to freshwater fish and aquatic ecosystems in general.

Since European settlement, the natural flow regimes of many of Australia's inland waters have been altered substantially because of a nation-wide program of water storage and river regulation to provide water for human consumption, agricultural purposes including irrigation, industry and electricity generation (Davies et al. 1992; Kingsford 1995; Crabb 1997). Agriculture, in particular, has placed very large demands on Australia's water resources.

River regulation involves impoundments (lakes, dams), irrigation schemes, water abstraction, drainage, stream diversion, dredging and canalisation, flood control measures (e.g. levee banks), weirs and locks, and interbasin transfers (IBTs). These activities have changed Australian rivers through reductions in flow volume, frequency of small and medium flood flows, duration of floods and variability of flow, and have also altered the seasonality of flow (Walker 1992; Walker et al. 1992; Maheshwari et al. 1995; Mussared 1997). Some of the most substantial changes have occurred in the Murray-Darling Basin. Annual flows in the lower Murray have been greatly reduced in volume, with outflow at the Murray Mouth now only 36% of the natural outflow (Walker and Thoms 1993; Maheshwari et al. 1995). The seasonality of flows in the upper and middle Murray has also been changed, with the naturally high flows which occur during the wet season being stored in impoundments and released for use during the dry (Walker 1985; Cadwallader and Lawrence 1990; Close 1990b; McNee 1990; Walker and Thoms 1993; Cullen and Lake 1995; Kingsford 1995; Maheshwari et al. 1995; Wasson et al. 1996; Mussared 1997). The seasonality of flows in the lower Murray remains unchanged because of the number of tributaries flowing into the main channel downstream of the major impoundments which add to the winter/spring flows, and the extraction of water for irrigation which decrease the summer/autumn flows (Walker and Thoms 1993; Maheshwari et al. 1995). Flows in the Murray River are more stable under regulated conditions than under natural conditions. Medium sized floods are mostly retained in impoundments, while large floods still move down the river (Maheshwari et al. 1995).

The need for the allocation of water for environmental requirements (environmental flows) in regulated rivers is becoming increasingly important (Lake 1994; Wasson et al. 1996). Environmental flows may not only benefit fish, but may also be useful in the restoration of degraded rivers, floodplains and wetlands, and in the protection of biological diversity in freshwater ecosystems overall (Petts 1996).

Effects of changes to the natural flow regime on freshwater ecosystems

Natural flow regimes have been altered in many Australian river systems primarily through river regulation. River regulation has had significant impacts on aquatic ecosystems and it has been recognised as a significant threat to freshwater fish (Bruton 1995, Allan and Flecker 1993, Wager and Jackson 1993).

In Australia, river regulation has been linked to declines in populations of crayfish, mussels, snails and fish (Cadwallader and Lawrence 1990; Geddes 1990; Walker et al. 1992; Gehrke et al. 1995). Reduced abundance and species richness in invertebrate communities have been recorded downstream of dams (Cadwallader and Lawrence 1990; Cullen and Lake 1995; Horwitz et al. 1998). River regulation is thought to have contributed to the local extinctions of more than 15 species of freshwater snail (Walker et al. 1995). There is also evidence that river regulation has had serious impacts on freshwater fish fauna. Major differences in the relative abundance of endemic and exotic

fish have been recorded between regulated and unregulated rivers, with exotic species (particularly carp, *Cyprinus carpio*) dominating regulated systems in the Murray and Murrumbidgee Rivers (Gehrke et al. 1995; Gehrke 1997b; Harris and Gehrke 1997). River regulation may also have a range of other impacts on freshwater ecosystems, as discussed in a later section.

In addition, it has been suggested that global climate change may be altering the natural flow regime.

Reduced frequency and extent of flooding.

Changes to the frequency and extent of flooding, and to water levels within rivers have had significant impacts on freshwater ecosystems. Floods are important 'reset' mechanisms for maintaining normal community structure and ecological processes in river systems. Flooding is essential for the successful recruitment of many native freshwater fish species as it serves as a cue for spawning (e.g. golden perch and silver perch), while floodplains provide habitat and feeding grounds for juvenile fish (e.g. Murray cod and freshwater catfish) (Cadwallader and Lawrence 1990; Koehn and O'Connor 1990; Walker 1992; Walker and Thoms 1993). Other species, such as the western carp gudgeon (*Hypseleotris klunzingeri*) and crimson spotted rainbowfish (*Melanontaenia splendida fluviatilis*), do not rely on floods to spawn but spawn more intensely when flooding occurs (Walker 1992; Walker and Thoms 1993). Periodic flooding is also required for the regeneration of river red gum forests (Bren 1988; Bayley 1991). Junk et al. (1989) summarised these relationships using a 'flood-pulse concept' which recognises periodic flooding (disturbance) as the principle force responsible for the existence, productivity and interactions of biota in these ecosystems.

Flood mitigation disrupts the ecological processes occurring in river-floodplain ecosystems (Boulton and Lloyd 1992; Cadwallader and Lawrence 1990; Cullen and lake 1995; Davies et al. 1994). The most significant impact of reduced flooding on fish populations is a reduction in spawning and, hence, recruitment. Mitigation of peak flood levels reduces the area of floodplain available to fish (Cadwallader and Lawrence 1990; Allan and Flecker 1993; Kingsford 1995; Horwitz et al. 1998). Alienating floodplains or reducing flood frequency is likely to reduce invertebrate productivity and hence riverine fish biomass (Boulton and Lloyd 1992). There is strong evidence that the productivity of river fisheries is significantly improved when fish have access to floodplains (Junk and Welcomme 1990).

It is clear that the reduced extent and frequency of flooding has contributed to the decline of native freshwater fish species in Australian river systems. For example, river regulation in the Murray-Darling Basin has limited the incidence of all but the largest floods. This has contributed to the decline of Murray cod and other species over the last 30 to 40 years (Rowland 1989; Thomson 1994). Another indirect effect of flood mitigation is a change in the composition of vegetation associations, and establishment and persistence of introduced plant species in areas of low flood frequency (Bren 1988). The effects of introduced plant species are discussed under 'Habitat degradation – Riparian vegetation degradation'.

The mitigation of smaller floods has also impacted aquatic ecosystems. The interception of small to medium floods reduces the frequency of peak flows which stimulate migratory fish species to move upstream to spawn (Cadwallader and Lawrence 1990). In addition, mitigation of the smaller floods which normally recharge soils and aquifers may cause the water table to be lowered and summer base flows to be reduced (Allan and Flecker 1993). Reductions in flow volume and flood frequency have reduced the flushing effects of flood flows which are beneficial after periods of low flow when sedimentation and salinity may have increased and water quality decreased (Koehn and O'Connor 1990; Walker and Thoms 1993). This has led to increases in salinity and in the incidence of algal blooms in the Murray River (Bell et al. 1996). The effects of sedimentation, salinity and poor water quality have been addressed in earlier sections.

Altered river levels and flow velocity.

Periodic high and low flows are important in structuring invertebrate and fish communities (Lake 1994; Puckridge et al. 1998). River regulation has generally decreased the amplitude of river rises and falls and prolonged periods of flow stability (Walker et al. 1995). In areas influenced by major dams, downstream river levels have been reduced and made more constant by controlled releases of flood flows, while upstream river levels are held at higher, more static levels (Cadwallader and Lawrence 1990; Thomson 1994; Cullen and Lake 1995; Walker et al. 1995; Puckridge et al. 1998).

Altered river levels have had various impacts on freshwater ecosystems. In some areas, riparian corridors have contracted and there have been shifts in plant species composition in response to reduced water availability (Allan and Flecker 1993). Similarly, reduced flows have reduced the availability of water for the recharge of wetlands. Consequently, some of these wetlands are no longer viable (Cullen and Lake 1995). Conversely, permanent flooding of some floodplains and wetlands has led to the drowning of riparian vegetation (Klimas 1988; Close 1990b; Kingsford 1995). Altered river levels may also lead to changes in water quality and sediment transport. This generally represents habitat degradation for fish and other freshwater organisms.

The rate of fall of flow levels is another aspect of the natural flow regime that has been affected by river regulation. Fluctuations in flow level may be more rapid in regulated rivers as compared with unregulated rivers (Cadwallader and Lawrence 1990). In particular, releases from dams can result in very rapid lowering of water levels within the dam. Fish may be adversely affected by this sudden lowering. It may be especially deleterious to fish that spawn in shallow water. The sudden lowering of water levels results in the rapid loss of aquatic habitat which may lead to the stranding of eggs or larvae (Cadwallader and Lawrence 1990; Lloyd et al. 1994). Some freshwater fish species, for example freshwater blackfish, require water levels to remain high, covering their eggs for several weeks, for the successful completion of their life cycle (Koehn and O'Connor 1990). Such species may be particularly susceptible to a rapid lowering of water levels. Rapid falls in water levels may also affect littoral and riparian vegetation (Bishop and Bell 1978).

Lastly, river regulation has changed the cross-sectional area of streams, and thus flow velocity. For a given flow volume, flow velocity will be faster in narrow channels and slower in broader channels (Close 1990b). Changes to flow velocity may have adverse effects on freshwater fish through impacts on swimming ability (Gore 1994). This, in turn, may affect migration and spawning success (Gore 1994).

Altered seasonality of flows

Changes to the seasonality of flows may have significant impacts on freshwater ecosystems. In some areas flow regimes have been altered so that downstream areas are deprived of spring flushing flows resulting from snow melt. Flushing flows benefit stream productivity by inducing the upwelling of nutrient rich water and other water chemistry changes associated with the increased acidity from decomposition of vegetation and mobilisation of naturally occurring mercury (Allan and Flecker 1993).

The timing of periods of high flow is extremely important for many Australian freshwater fish. For many fish species the ideal breeding time is spring/summer when the physical requirements for breeding are met (Lloyd et al. 1991). In some areas, this is also the time when flows are naturally at their highest. Indeed, many species migrate or spawn in response to high flows (Koehn and O'Connor 1990; Wager and Jackson 1993). For example, Australian bass require seasonal high flows for their migration downstream to estuarine spawning grounds (Harris 1986), while rising water levels during spring are thought to be a trigger for the spawning of silver perch (Koehn and O'Connor 1990). In regulated river systems flows may not remain high enough for sufficient periods of time, or may not be high enough at critical times to stimulate spawning and/or migration. Floods outside these critical times are of little use to breeding native fish. The absence of

high flows at critical times may therefore have a substantial impact on spawning success, recruitment and hence freshwater fish populations. Furthermore, large releases of dam water at the wrong time of year may also affect spawning success and the survival of eggs or fry. The lowering of water levels may leave eggs stranded, or releases of relatively cold water may interfere with spawning cues. Altered seasonality of flows has had a substantial impact on some species of Australian freshwater fish. In particular, decreased spring flows contributed to the decline of Murray cod and other species over at least 30 to 40 years (Rowland 1989).

Effects of reduced flow variability.

Hydrological variability is an important feature of the natural flow regime, to which Australian freshwater fish and other organisms are adapted (Lake 1994; Wager and Jackson 1993). One of the most significant changes river regulation has had in freshwater ecosystems is a reduction in flow variability (Close 1990b; Lake 1994; Cullen and Lake 1995; Crabb 1997). As outlined above, river regulation has resulted in flows being more predictable and less variable.

Reduced variability in flows may have substantial impacts on freshwater ecosystems. Importantly, reduced variability may cause changes in freshwater fish communities. Endemic species with flexible and opportunistic life histories may be replaced by others adapted for seasonally stable, low-flow environments, such as the introduced species carp, mosquitofish (*Gambusia holbrooki*) and salmonids (Walker et al. 1995; Gehrke et al. 1995). Overall, increased predictability in freshwater environments may lead to reduced biological diversity (Gehrke et al. 1995). The effects of changes to flow variability on freshwater ecology have recently been reviewed by Puckridge et al. (1998).

Effects of global climate change on flows

The impacts of global climate change on aquatic ecosystems are difficult to predict. However, it is likely that the seasonality, variability, intensity and quantity of rainfall will be affected; hence changes in runoff and flows would be expected.

Recent predictions of changes in rainfall patterns in Australia indicate decreases in winter rainfall over most of mainland Australia and increases generally over Tasmania (CIG 1996). For summer, predictions suggest little change in the east and south-west of the continent and reductions over the rest of the country (CIG 1996). The associated hydrological predictions indicate that runoff, flows and flooding may increase in some areas, at certain times, but decrease in others (CIG 1996). Increased summer flows may reduce summer irrigation demands, and increase fish production through increases in flooding, but may lead to higher sediment and pollutant loads as a result of increased runoff (Close 1988; Burchmore 1990; Richardson and Pollard 1990; CIG 1996).Lower flows would result in reduced dilution of pollutants and, hence, poorer water quality, as well as reduced habitat availability for fish and other organisms. These conditions would increase the levels of stress placed on aquatic biota (Burchmore 1990; Richardson and Pollard 1990).

In addition to affecting flows and water quality, global warming may also increase water temperatures. Such a change is likely to have implications for freshwater ecosystems.

A substantial and increasing amount of research on the effects of global climate change on freshwater ecosystems has been undertaken over the past decade. Unfortunately most of this research has been carried out in North America and Europe, therefore less information is available for Australia. Furthermore, a number of studies have attempted to model the impacts of global climate change on freshwater fish (e.g. DeStasio et al. 1996; McDonald et al. 1996; Rahel et al. 1996; Wood and McDonald 1997). Worldwide, the general predictions for freshwater fish are changes in community composition, habitat loss and reductions in species distributions (Eaton and Scheller 1996; Wood and McDonald 1997). For species which exist in areas where water temperatures are already at or near thermal tolerances, warming may lead to heat death (Allan and Flecker 1993;

Wood and McDonald 1997). Warmer water temperatures may lead to changes in the distribution of freshwater fish as species may move into new areas as conditions become favourable (e.g. tropical species may move into once temperate areas), or conversely, species may be lost from areas as conditions become unfavourable (e.g. temperate/alpine species may no longer persist) (Allan and Flecker 1993; Rahel et al. 1996; Wood and McDonald 1997).

Some specific predictions of the possible effects of global climate change on freshwater fish in NSW are given by Burchmore (1990) and Faragher (1990). More comprehensive, worldwide information is provided in Wood and McDonald (1997).

Other impacts of river regulation.

River regulation involves, among other things, the construction of dams and weirs. While large dams generally pose the greatest threat to river systems, smaller structures (e.g. low level weirs) are also an issue as there may be many present in an ecosystem (Thoms and Walker 1993; Walker et al. 1995). Freshwater fish may be affected by river regulation through changes to channel characteristics, habitat availability, water quality, sedimentation and barriers to migration (discussed in the following section) (Allan and Flecker 1993; Crabb 1997; Jackson 1997). In addition, dams destroy lotic habitat and create lentic habitat which may favour introduced fish species such as carp (Walker 1985; Allan and Flecker 1993; Jackson 1997). These changes have been linked to declines in the populations of a number of endemic fish species.

Dams affect water quality characteristics in freshwater ecosystems as discussed earlier under 'Pollution, Water quality and Water temperature'.

Changes in hydrostatic pressure may occur as water is pumped out of dams. This may affect fish by causing changes in nitrogen levels (similar to 'the bends') which, in turn, causes haemorrhaging in the circulatory system and bleeding from the gills and fins (Sweeting 1994).

Furthermore, the infrastructure associated with dams may have direct impacts on fish. For example, there are records of fish mortalities among fish migrating downstream caused by generating turbines, spillways and outlet valves (Harris 1984a).

Dams may also be centres for the transmission of disease among fish (Bayley and Li 1992).

Barriers to migration.

Many native Australian freshwater fish species migrate extensively throughout their life (Reynolds 1983; Mallen-Cooper 1989). Fish undergo migrations not only for spawning and feeding, but also for recolonisation and habitat selection (Koehn and O'Connor 1990). All 66 freshwater fish species endemic to southeastern Australia undergo some migration and 40% make large scale movements which are essential for the completion of their life histories (Mallen-Cooper and Harris 1990). Some migrate between freshwater and the sea, termed diadromous migration (Harris 1984a). Four specific diadromous migration types are recognised: anadromous, catadromous, amphidromous and potamodromous. Readers are referred to Harris (1984a) for further information regarding these types.

Barriers to migration have been identified as a serious threat to freshwater fish in Australia and population declines in some species have been partially attributed to such barriers (Cadwallader and Lawrence 1990; Allan and Flecker 1993; Wager and Jackson 1993; Lake 1994; Jackson 1997). Natural features, namely waterfalls, may prevent fish migration unless other features, such as long rapids or cascades, are present (Pusey and Kennard 1996). However, large, man-made structures currently represent the most serious barriers to fish passage (Cullen and Lake 1995; Jackson 1997).

Effects of barriers to migration on fish

Dams are a major physical barrier to fish passage, restricting both upstream and downstream spawning migrations and the dispersal of fish (Walker 1985; Cadwallader and Lawrence 1990; Lake and Marchant 1990; Cambray 1991; Allan and Flecker 1993). Barriers to migration may be affecting a number of Australian freshwater fish species which migrate upstream to spawn, including Macquarie perch, golden perch and silver perch. Also affected are many of the species found in coastal streams which migrate to estuaries or the sea and return to fresh water at some stage of their life cycle (e.g. Australian bass) (Cadwallader and Lawrence 1990; Koehn and O'Connor 1990; Wager and Jackson 1993). Indeed, populations of golden perch and silver perch in some upstream areas have declined, primarily because of lack of recruitment of adults from downstream where weirs block migration (Cadwallader and Lawrence 1990). Smaller structures, such as low level weirs and road culverts, may also hinder fish movements although these are less likely to cause major problems (Cadwallader and Lawrence 1990; Horwitz 1994). Movements of diadromous species may be affected by structures built at river mouths, such as the barrages at the mouth of the Murray River (Cadwallader and Lawrence 1990).

In addition to acting as physical barriers, the changes in water quality associated with impoundments (e.g. reduced water temperatures and changes in dissolved oxygen levels) may create more subtle barriers to fish migration (Harris 1984b). Similarly, artificial structures commonly alter flows. Uniform channels offer no shelter from high flow velocities and this may hinder fish passage for some species (Koehn and O'Connor 1990).

By restricting movement, barriers reduce the amount of habitat available to fish (Jackson 1997). It has been estimated that up to half of the habitat of potential use to migratory fish in the coastal drainages of southeastern Australia has been affected by the construction of physical barriers to fish passage (Harris 1984a). Obstructions may concentrate populations into smaller river reaches or pools and therefore may increase the potential for disease, starvation, and predation (Pethebridge et al. 1998). Dams may also lead to a reduction in genetic diversity by isolating fish populations (Cambray 1991; Sheridan 1995; Wasson et al. 1996). Changes in water quality may affect fish by reducing swimming performance and altering migration behaviour (Harris 1984b).

Fishways

Although dams and other structures may be affecting fish movements, there are ways in which their effects as barriers may be mitigated. One such strategy is to construct fish ladders or fishways around dams. Fishways are structures that channel water between different elevations and permit fish passage past obstacles (Harris 1984b). Other strategies to facilitate fish passage may be to remove unnecessary structures (e.g. redundant weirs) and to reduce the amount of time when weirs or lock gates block movement (i.e. increase the frequency and duration of weir removal/opening of lock gates), especially during times of known fish migration (Cadwallader and Lawrence 1990).

There is some evidence to suggest that these sorts of measures are helping to mitigate the effects of physical barriers on fish migration. For example, fish have been recorded utilising fish ladders at Euston, NSW (Cadwallader and Lawrence 1990). However, very few fishways or fish ladders have been constructed in Australia's regulated river systems and there is also strong evidence that many such structures are not working. Harris (1984a; 1984b) surveyed the coastal streams of southeastern Australia and for the 316 dams, weirs and causeways recorded, only 29 fishways were present and 23 of these failed to provide conditions suitable for fish passage. A similar situation exists throughout the Murray-Darling Basin (Mallen-Cooper 1989).

Introduced species.

The introduction of exotic aquatic species, particularly fish, has been identified as a major threat to the sustainability of freshwater fisheries resources, not only in Australia but

worldwide (Wager and Jackson 1993; Bruton 1995; Abramovitz 1996; Arthington and McKenzie 1997). In Australia a variety of exotic species have been introduced and there have also been translocations of Australian native species to areas outside their natural range. That such translocations may pose equally serious problems is often less appreciated (Allan and Flecker 1993).

The issue of introduced species in Australian freshwater ecosystems, including their effects on native fish, is reviewed in this section. The review is primarily focussed on the effects of introduced fish species, with brief notes on introduced invertebrates. Introduced plant species were discussed earlier under 'Habitat degradation – Riparian vegetation degradation'. One exotic species in particular, carp, is recognised as a major problem and will therefore be discussed separately. Introduced fish species have also been reviewed by Fletcher (1986) and Arthington and McKenzie (1997).

In Australia, at least 24 species of exotic fish have been recorded in inland waters, 18 of these are thought to have established self-sustaining populations in the wild (Fletcher 1986; Allen 1989; Arthington 1991; Arthington and McKenzie 1997). A further 26 indigenous species are thought to have been translocated (Bruton 1995; Arthington and McKenzie 1997).

A number of exotic invertebrates have also been introduced into Australian waters, e.g. aquarium snails *Lymnacea columella* and *Physa acuta* (Horwitz et al. 1998). The impact of introduced invertebrates on native aquatic fauna is not well documented (Horwitz et al. 1998) and is thought to be a less serious issue than that of introduced fish, hence it is not discussed further.

Introductions occur for various reasons. Some have occurred deliberately, with species introduced as sporting fish, e.g. salmonids, and others as biological controls, e.g. for the control of mosquitoes (Allan and Flecker 1993; Arthington and McKenzie 1997). In other cases, fish have entered natural systems accidentally through escape from aquariums or ornamental ponds, e.g. oriental weatherloach (*Misgurnus anguillicaudatus*) and tilapia (*Orechromis mossambicus*) (Cadwallader and Lawrence 1990; Arthington and McKenzie 1997). Introductions also may have occurred as a result of interbasin water transfers (Walker 1985; Allan and Flecker 1993).

There is a moderate amount of literature available regarding the adverse effects of introduced fish on endemic fish species. Unfortunately there is little strong evidence of these effects with most information being anecdotal and fragmented (Cadwallader and Lawrence 1990; Horwitz et al. 1998). Nevertheless, it is recognised that introduced fish may affect endemic species directly and indirectly through a variety of mechanisms.

The most direct, and usually lethal, impact of introduced fish on natives is predation. Mosquitofish, redfin perch (*Perca fluviatilis*), salmonids and oriental weatherloach are known to prey on the eggs, juveniles or even adults of some native species (e.g. galaxiids) (Koehn and O'Connor 1990; Lintermans et al. 1990; Ault and White 1994; Cullen and Lake 1995; Horwitz et al. 1998).

Introduced species may impact the diversity and abundance of native fish through competition. Exploitation competition may occur if native and introduced species utilise similar, limited resources such as food items or spawning sites (Abramovitz 1996). Introduced fish have been implicated in the local extinction and altered community structure of macroinvertebrates which are major food resources for native fish (Bruton 1995; Horwitz et al. 1998). More specifically, dietary overlap has been observed between Murray cod, golden perch and redfin perch; freshwater blackfish and brown trout (*Salmo trutta*); and between Macquarie perch and rainbow trout (*Oncorhynchus mykiss*) (Cadwallader 1978; Koehn and O'Connor 1990). However, in a more recent review Crowl et al. (1992) reported there was insufficient data available to make unambiguous generalisations regarding the impact of trout on native fish.

Introduced fish may also affect native species through interference competition whereby exclusion from habitat is achieved through aggressive territorial behaviour (Abramovitz 1996; Horwitz et al. 1998). For example, mosquitofish are known to aggressively attack other fish by nipping their fins (Koehn and O'Connor 1990; Bayley and Li 1992; Arthington and McKenzie 1997).

Native fish populations may be affected by introduced fish through hybridisation (Wager and Jackson 1993; Bruton 1995; Horwitz et al. 1998). Although as all exotic species present in Australia are members of different families from the native species, hybridisation in unlikely (Fletcher 1986). However, the genetic characteristics of populations of endemic species may be affected by translocated species (Horwitz et al. 1998).

Another way in which introduced species may impact on native fish is the alteration of habitat and water quality which can represent habitat degradation for native species (Horwitz et al. 1998; Arthington and McKenzie 1997).

Lastly, introduced species may bring new parasites and diseases which could potentially threaten native species (Cadwallader and Lawrence 1990; Arthington 1991; Abramovitz 1996; Horwitz et al. 1998; Arthington and McKenzie 1997). It is not clear exactly how such parasites and diseases may impact native fish but they could potentially have sublethal effects such as reduced health or spawning ability (Koehn and O'Connor 1990; Bayley and Li 1992). Parasites can have more varied and indirect impacts on communities than predators. It is possible that the abundance and distribution of native fish species, while appearing to be governed by physical factors such as habitat availability/quality, may actually be controlled by the susceptibility in a subset of the population to a parasite (Bayley and Li 1992). In Australia, there are cases of parasites and diseases originating from exotic fish being present in native species. For example, the introduced fish louse (*Argulus spp.*), anchor worm (*Lernaea cyprinacea*) and Asian fish tapeworm (*Bothriocephalus acheilognathi*) have been found in several native fish species (Arthington 1991; Dove et al. 1997; Dove and Fletcher, Submitted). Furthermore, some native species e.g. Macquarie perch, silver perch, mountain galaxias (*Galaxias olidus*) and Murray cod have been found to be susceptible to the epizootic haemotopoietic necrosis (EHN) virus found in redfin perch (Langdon and Humphrey 1987; Cadwallader and Lawrence 1990). The EHN virus has also thought to have been responsible for major declines in populations of Macquarie perch in the ACT (Lintermans 1991).

Carp.

On a global scale, carp were probably one of the earliest fish to be introduced into new areas. They are recognised as a significant problem in Australian freshwater ecosystems (Allan and Flecker 1993; Arthington and McKenzie 1997). Consequently, much attention has been directed to investigating the ecological impacts and prospects for the control of carp. Recently a number of detailed reports have been produced on these issues (e.g. King 1995; Roberts and Ebner 1997; Roberts and Tilzey 1997; BRS In Prep.).

Carp were introduced into Australia late last century, however their rapid increase in abundance and expansion of range did not occur until about 1964 (Shearer and Mulley 1978; Arthington and McKenzie 1997). Carp are now found in every state except the Northern Territory (Arthington and McKenzie 1997) and are the most abundant fish in the Murray region (Harris and Gehrke 1997).

There are a number of reasons carp have become so prevalent in Australian waters. Carp adapt quickly to different habitats and are able to tolerate a wide range of environmental conditions including relatively poor water quality (Gehrke et al. 1995; Roberts and Ebner 1997). They can survive water temperatures ranging from 4°C to 35°C, can quickly adapt to extremely low levels of dissolved oxygen and appear to be unaffected by high levels of sediment (Brown 1996; Roberts and Ebner 1997). Carp do not generally undertake long-distance migrations and are therefore local stocks not adversely affected by dams or other obstacles (Roberts and Ebner 1997). Carp have few predators in Australian waters; birds

and some fish (e.g Murray cod and golden perch) prey on carp, however only small fish are usually taken (Brown 1996).

Carp are not known to prey on native fish but they may compete with certain species. In some areas the diet of carp is similar to that of various native fish including Australian smelt (*Retropinna semoni*), bony bream (*Nematalosa erebi*), freshwater catfish, flathead galaxias (*Galaxias rostratus*), silver perch and western carp gudgeon (Cadwallader 1978; Cadwallader and Lawrence 1990; Arthington and McKenzie 1997). Carp are also known to use spawning sites similar to those of some native species, e.g. crimson-spotted rainbowfish and western carp gudgeon (Fletcher 1986; Koehn and O'Connor 1990; Brown 1996). Carp may also spread disease and parasites and are known to carry anchor worm (Brown 1996; Dove et al. 1997; Dove and Fletcher Submitted).

Potentially the greatest threat posed by carp to native fish is the alteration of aquatic environments. Recent research has shown that carp can reduce aquatic plant cover by uprooting plants during feeding (Roberts 1993; Roberts et al. 1995). Carp are also believed to resuspend sediments and excrete nutrients which may contribute to cyanobacterial blooms (Gehrke and Harris 1994; Wasson et al. 1996; King et al. 1997). Despite there being no general consensus on the ecological impact of carp, they are suspected of causing habitat degradation which may contribute to the decline of certain native species (Cullen and Lake 1995; Arthington and McKenzie 1997).

Carp are, therefore, recognised as a major threat to native fish and to the integrity of freshwater systems. Furthermore, despite increased research efforts into the effects of and control prospects of this species, no single approach nor a coordinated strategy for the management of carp has yet been established.

The above discussion has highlighted the ways in which introduced fish species may represent a threat to Australian freshwater fisheries resources. Introduced fish have been implicated in the decline of nine endangered, eight vulnerable and five rare or uncommon native species (Wager and Jackson 1993). However, it is not possible to state that introduced species are the main threat to native fish as other factors are involved. In particular, habitat degradation has occurred in many of the areas in which introduced fish are prevalent, e.g. high carp densities in much of the Murray-Darling Basin (Gehrke et al. 1995; Driver et al. 1997). Some introduced fish are known to tolerate a wider range of environmental conditions than native species (Cadwallader and Lawrence 1990; Allan and Flecker 1993) and introduced species are generally more likely to be successful in disturbed habitats (Harris 1995). For example, in waters which have high levels of sedimentation, and consequently a muddy substrate, oriental weatherloach may persist as they prefer this substratum for burrowing, however such conditions may not suitable for native species (Cadwallader and Lawrence 1990). In many cases it is impossible to establish whether habitat degradation has caused the decline of native fish populations thus enabling introduced species to become dominant, or whether the introduced species themselves are to blame. There is no doubt that introduced fish species represent a real and significant threat to the sustainability of Australian freshwater fisheries resources, however a number of factors are operating.

Fishing.

Overexploitation of freshwater fish by commercial, subsistence or recreational fishers can alter abundance and diversity of fish (Abramovitz 1996). In most industrialised countries, natural freshwater fisheries have already collapsed from the cumulative pressures of overfishing and other assaults, as a result, most fish now consumed are from aquaculture and marine sources (Abramovitz 1996).

There are commercial fisheries for freshwater species in all Australian States except the Australian Capital Territory; freshwater fishing is also a major recreational industry in Australia (McNee 1990; Kailola et al. 1993; Jackson 1997). Many freshwater fish species,

including a number of exotic species, are targeted by commercial and recreational fishers. Catch data and a list of the targeted species for each State are given in Chapter 11.

Effects of overfishing in Australian freshwater ecosystems

Although overfishing is not thought to be the primary cause of current declines in Australian freshwater fish populations, fishing does, nevertheless, impact the ecology of aquatic ecosystems (Cadwallader and Lawrence 1990; McNee 1990; Wager and Jackson 1993; Cullen and Lake 1995).

Fishing may have an obvious impact on target species, as well as indirect effects on the composition of aquatic communities through the removal of individuals and biomass from the local ecosystem (Horwitz et al. 1998). As the numbers of the target species are reduced, fishing efforts may be intensified or directed toward other species. The result may be a decline in the populations of some fish species and/or in the biodiversity of species (Abramovitz 1996).

Fishing has also led to the presence of exotic and translocated species, not just in Australian waters, but throughout the world (Radonski et al. 1984; Abramovitz 1996; Arthington and McKenzie 1997). Such introductions have occurred deliberately, as part of fish stocking operations, and accidentally (see 'Introduced species' above for further information). Fish released from farms may bring new diseases, additional competition and possibly smaller, less fit fish which may weaken the genetic base of wild fish through interbreeding (Abramovitz 1996).

Recreational fishing activity may have indirect impacts on aquatic ecosystems such as habitat degradation from trampling of wetland or riparian areas (Jackson 1997).

In Australia, there is limited information on the impact that fishing is having on native freshwater fish and invertebrate populations. For example, in the Murray-Darling Basin, there is information regarding yabby (*Cherax destructor*) and Murray River crayfish (*Euastacus armatus*) populations which suggests that overfishing has contributed to the decline of these species in some areas (Koehn and O'Connor 1990). In Tasmania, overfishing and habitat degradation have had a very damaging impact on populations of the giant freshwater crayfish (*Astacopsis gouldi*), the largest freshwater arthropod in the world (Cullen and Lake 1995). Commercial catch data from New South Wales, South Australia and Victoria indicate declines in abundance of Murray cod, golden perch, silver perch, and freshwater catfish (Pollard et al. 1980) but the cause(s) of these declines cannot be defined.

It is possible that the impact of overfishing may be obscured by natural fluctuations in population size. Where populations have declined to very low numbers and the distribution has become patchy, a species may be highly vulnerable to excessive exploitation (Cadwallader and Lawrence 1990; Abramovitz 1996). In short, fishing alone is not likely to drive freshwater fish populations to extinction. However, when combined with other stresses such as habitat destruction, pollution and flow changes, overfishing may represent a significant threat to fish production.

Chapter 3. Surveys undertaken.

Three 'surveys' were carried out as part of this project:

- a nationwide survey of the objectives and priorities of organisations involved with freshwater;
- workshops with the project's steering committee; and
- interviews with State representatives (freshwater fisheries researchers and managers).

The information gathered in these three surveys was collated and is presented in the following chapters, each of which describes the methods used to prepare the information presented.

All three surveys were subjective: an unavoidable result of the type of information required for this project. This subjectivity leads to difficulties in comparing results from different organisations/States as the responses from those surveyed are likely to involve subtle differences in meaning. The problem of such subjectivity is discussed further in the following chapters.

Nationwide survey of organisations involved with freshwater.

A total of 77 organisations around the country were contacted, 63 responded; the organisations contacted are given in Appendix 3. These organisations were selected from all States and Territories, including the Australian Capital Territory, and were all involved with freshwater in some way; for example university research groups, environment protection agencies, cooperative research centres, government departments (state and federal), commercial fishing bodies, recreational fishing bodies, Aboriginal groups, parks and wildlife agencies, museums, water managers, fisheries agencies and hydro electricity generators.

In all cases those within each organisation working with fresh or inland waters were asked what they considered to be the major threats affecting freshwater ecosystems. If no direct answer was available they were requested to provide a list of projects involving freshwater that their organisation was undertaking at the time. The question related to freshwater ecosystems rather than the freshwater fisheries resource as many of the organisations surveyed were not directly involved with fisheries. It was assumed that all threats affecting the freshwater ecosystem would affect the fisheries resources at some stage, either directly or indirectly; for example through a cascade of impacts moving through the food web. Printed material was requested in all cases. The results of this national survey were tabulated and are presented in Appendix 3. The threats identified were ranked according to the number of organisations which raised each issue. These results provided the initial listing of threatening processes used in deliberations by the Steering Committee.

It is realised that this survey was not exhaustive, many other organisations could have been contacted. However, after assessing the information obtained from those contacted it was concluded that contacting further organisations would be most unlikely to identify any new threats of high priority. An adequate number were contacted nationally to allow the identification and ranking of threats nationwide to the sustainability of Australia's freshwater fisheries resources. The survey also gave representative coverage of organisations throughout Australia.

Workshops with the Steering Committee.

A Steering Committee was an integral part of this project. Members were selected in consultation with FRDC to include a representative from each State who was also a

representative of a major organisation involved with freshwater. The Steering Committee consisted of:

Mr Rod Coombs, commercial fisherman, South Australia;

Dr Jane Doolan, Natural Resources and Environment, Victoria;

Mr Wayne Fulton, Inland Fisheries Commission, Tasmania;

Dr Peter Jackson, Department of Primary Industries, Queensland;

Dr Klaus Koop, Environment Protection Authority, New South Wales;

Dr Noel Morrissy, Fisheries Department, Western Australia;

Associate Professor Stephan Schnierer, College of Indigenous Australian People, Southern Cross University, New South Wales;

Mr Trevor Simmonds, recreational fisherman, Northern Territory;

Dr Karyn Davis, Project leader, University of Canberra;

Professor Robert Kearney, Principal investigator, University of Canberra.

A set of questions, aimed to determine the causes of threats, the organisations monitoring and/or managing threats, strategies that have been used to address the threats, the major data requirements and likely management actions, was designed for the top ten threats identified by the national survey (actually 14 threats, as five were tied for 10th position). These questions are listed in Appendix 1 and were discussed at the Steering Committee workshops. References were requested for strategies that had been used to address the threats. The results of this workshop were tabulated and are presented in Appendices 4, 8, 11, 15 and 19.

Interview with State representatives.

FRDC contacted each State agency responsible for fisheries; these agencies were asked to nominate a key person within the organisation responsible for freshwater fisheries management and another for research. Once nominations were received these people were contacted and arrangements made to meet with them in person; in a few cases only telephone interviews were possible. As a result of these meetings input from a freshwater fisheries manager and researcher from each of New South Wales, Northern Territory, Queensland, South Australia and Victoria was obtained. Both Tasmania and Western Australia nominated a single representative for both management and research. It was decided not to include the Australian Capital Territory as a separate State as it is geographically encapsulated in New South Wales and to include it separately would give undue weight to one geographical region. Further, as both the Principal Investigator and the CRC for Freshwater Ecology are based in the Australian Capital Territory it was considered that major issues peculiar to the Australian Capital Territory could be identified.

The questions asked at these interviews can be seen in Appendix 2. The first question determined the five threats affecting the sustainability of freshwater fisheries in each State; these threats were selected from a list of the threats discussed at the Steering Committee workshop. If other threats were a major problem in a particular State these were added. The remaining questions related to each of the five highest priority threats identified and aimed to determine the state of the knowledge, the causes, the monitors, the managers, strategies that have been used to address the threat, information required, possible funding agencies and management actions likely to result from the acquisition of the knowledge. Primarily because of time constraints discussion was limited to the five threats raised by each fisheries manager or researcher. The results from the fisheries managers and researchers were combined for each State and can be found in Appendices 5, 6, 9, 12, 16 and 20.

When interpreting the results presented in this report, it must be remembered that they are largely the product of expert opinion. Personal concerns and experience will always bias expert opinions. This has been reduced as much as possible by requesting scientific literature to support responses, interviewing two experts from each State and having a Steering Committee composed of experts from a wide range of organisations and States. Nonetheless bias still exists.

Chapter 4. Major threats to the sustainability of freshwater fisheries resources.

Introduction.

This chapter satisfies an objective of the project: 'to identify the major threats to the sustainability of freshwater fisheries resources in each State and Territory'. The major threats to sustainability, as identified by the three surveys (Chapter 3), are presented.

It should be noted that while threats are discussed individually throughout this report, this has been done somewhat arbitrarily and is for convenience only. As stated by Wager and Jackson (1993) 'The [threatening] processes are inexorably linked, and rarely is one factor alone responsible for the decline of a species'.

Methods and Results.

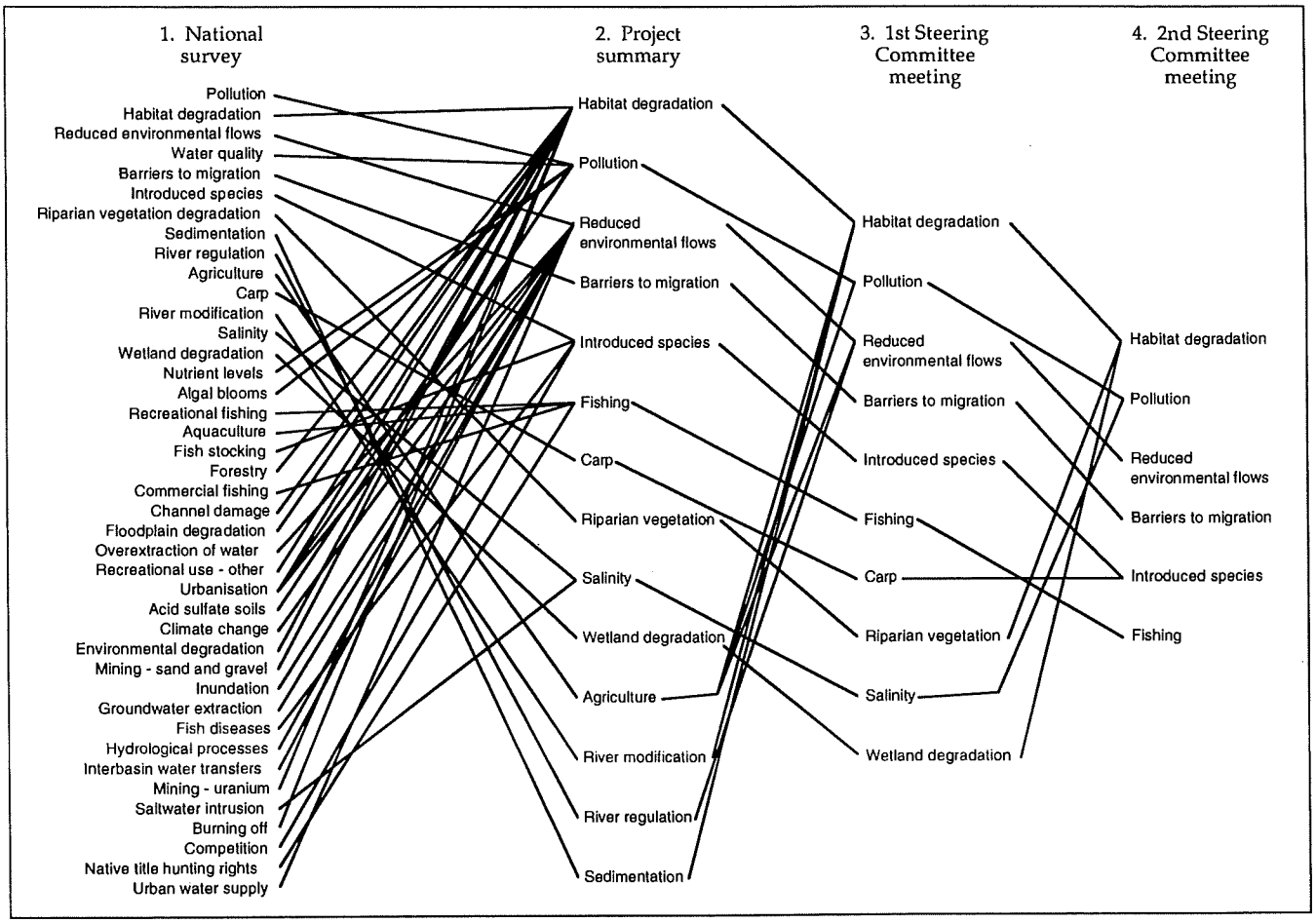
The information presented in this chapter was compiled using the three surveys discussed in Chapter 3; results from each survey were tabulated separately (Appendix 3, Figure 1 and Appendix 4). It should be noted that the only independent listing of threats was obtained from the national survey. Listings from the Steering Committee and State representatives had the benefit of previous surveys when identifying threats.

A total of 41 threats to the sustainability of Australia's freshwater fisheries was obtained from the national survey (Appendix 3). Also shown in Appendix 3 are the organisations contacted in each State, the threats that each organisation identified and the references used to identify those threats; threats are grouped by State. A summary showing the percentage of respondents per threat for each State, the percentage of respondents per threat from all States combined, the ranking of each threat as a result of this survey and the total number of threats identified in each State is included with Appendix 3.

Threat mergers.

Figure 1 shows how the 41 threats identified in the national survey (column 1) were merged to obtain the overall 6 major threats identified in this study (column 4 of Figure 1). A list of the major threats identified in the national survey, with the addition of fishing was given to the Steering Committee for discussion at the first meeting (column 2 of Figure 1). This list of threats was obtained by taking the top 10 threats identified in the national survey, actually 14 as five were tied for tenth position, and merging water quality with pollution. These were further reduced to 10 threats by the Steering Committee (column 3 of Figure 1). The results from the interviews with the State representatives were supplied to the Steering Committee for discussion at the second workshop. As a result of this meeting the threats were further condensed to obtain the six major threats to freshwater fisheries in Australia (column 4 of Figure 1). These six threats were prioritised during the meeting. The mergers of the threats were performed in order to determine the overall priority threats to the sustainability of Australia's freshwater fisheries resources.

Figure 1. Threat mergers resulting from Steering Committee input.



The five threats identified by the freshwater fisheries researcher and manager from each State are presented in Appendix 4. These threats have been ranked five to one, with the threat scored five being of the most concern. These scores were totalled across all representatives to provide an overall ranking. When examining these results it should be remembered that each State representative was asked to identify the five major threats in their State. The threats presented in Appendix 4 are not intended as a complete listing of all threats in a particular State, they are simply those identified as the five major threats by the State representatives.

Non-weighted results.

An overall ranking of the major threats to sustainability was obtained by adding the number of organisations which raised each issue in the national survey to the number of State representatives who raised each issue during the State interviews; another point was added to each of the threats given priority by the Steering Committee. These scores were then graphed to show the number of times each issue was identified as a major threat to sustainability. When several threats were combined, for example introduced species and carp, each participant in the surveys was given a single point for the combined issue even if they had identified both threats separately. These results are presented in Table 1.

Weighted results.

A maximum overall score of 100 was assigned to each issue. This score was divided into three equal parts to give a maximum score of 33.3 for each issue raised by the national survey, the State representatives and to each of the threats discussed by the Steering Committee. A maximum of 3.6 points per issue was assigned to each State in the national survey which is the maximum number of points per issue (33.3) divided by the number of States surveyed (nine including Commonwealth organisations). The threats identified by the Steering Committee each received the maximum allocation of 33.3 points. Each State

involved in the State surveys was allocated a maximum of 4.7 points, that is the maximum of 33.3 points for each issue divided by the number of States involved (seven). The weighted points for each issue obtained from these three surveys were totalled to give an overall weighted score for each of the threats discussed (Table 1). A graph showing the overall weighted score for each State for each of the threats, excluding the Steering Committee results, was produced (Figure 2). When several threats were combined into a single issue, for example pollution, water quality and water temperature, each participant in the three surveys was treated as though they had identified the combined issue even if they had identified both threats separately.

Table 1. Major threats to the sustainability of Australia's freshwater fisheries resources (based on the National survey, interviews with State representatives and input from the Steering Committee).

Threat	Commonwealth	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	Total	Rank
	Non-weighted results										
Pollution/Water quality	12	2	9	3	8	4	5	5	2	50	1
Habitat degradation	9	1	5	1	7	4	4	8	2	41	2
Reduced environmental flows	9	1	8	0	8	2	5	5	1	39	3
Barriers to migration	8	0	8	3	6	3	4	5	1	38	4
Introduced species	7	1	5	4	6	4	5	0	3	35	5
Fishing	7	1	2	2	4	4	4	3	2	29	6
Riparian vegetation degradation	7	0	4	0	5	0	3	5	0	24	7
Carp	4	0	7	0	2	2	3	5	0	23	8
Sedimentation	7	1	5	2	3	0	1	2	1	22	9
River regulation	7	0	4	0	4	1	1	3	1	21	10
Salinity	10	0	3	1	1	1	0	1	3	20	11
Wetland degradation	8	0	3	2	3	0	1	2	1	20	11
Agriculture	5	1	4	1	4	0	1	1	1	18	13
River modification	6	0	3	0	2	0	3	4	0	18	13
	Weighted results										
Habitat degradation	35.2	1.8	5.8	0.7	6.8	6.2	6.9	7.9	5.6	76.9	1
Pollution/Water quality	35.9	3.7	7.3	2.2	5.2	6.2	7.6	4.5	1.8	74.3	2
Reduced environmental flows	35.2	1.8	6.9	0.0	7.2	3.1	7.6	6.3	4.7	72.8	3
Barriers to migration	34.9	0.0	6.9	5.4	6.3	3.8	2.9	6.3	4.7	71.4	4
Introduced species	34.7	1.8	1.8	6.2	6.3	6.2	7.6	0.0	6.5	71.3	5
Fishing	34.7	1.8	0.7	4.7	3.6	4.6	2.9	3.4	5.6	62.1	6
Carp	34.0	0.0	6.5	0.0	0.8	1.5	6.2	4.5	0.0	53.5	7
Riparian vegetation degradation	34.7	0.0	1.5	0.0	2.0	0.0	2.2	4.5	0.0	44.9	8
Salinity	35.4	0.0	1.1	2.4	0.4	0.7	0.0	0.5	2.8	43.3	9
Wetland degradation	34.9	0.0	1.1	3.1	1.2	0.0	0.7	1.0	0.9	43.0	10
Sedimentation	1.6	1.8	1.8	1.5	1.2	0.0	0.7	1.0	0.9	10.7	11
Agriculture	1.1	1.8	1.5	0.7	1.6	0.0	0.7	0.5	0.9	9.0	12
River regulation	1.6	0.0	1.5	0.0	1.6	0.7	0.7	1.6	0.9	8.7	13
River modification	1.4	0.0	1.1	0.0	0.8	0.0	2.2	2.1	0.0	7.6	14

Discussion.

The major threats to freshwater fisheries in Australia were prioritised in three ways: using the non-weighted ranking (Table 1), the weighted ranking (Table 1) and the ranking given by the Steering Committee after its second meeting (Figure 1). It was found that while the weighting of the threats did not alter the prioritisation of the threats, it did imply an analytical rigour which was not justified as both the identification of the threats and the method used for weighting the scores were subjective. For this reason, the ordering of the threats, as discussed in the remainder of the report, is based on the prioritisation of the

Steering Committee. We acknowledge that such a prioritisation is difficult and subjective. As stated by Lake (1994) in relation to freshwater ecosystems 'to draw up a list of research priorities is hazardous as such a judgement is not only coloured by personal enthusiasms and incomplete knowledge, but also requires good powers to prophesise the rate of scientific knowledge gathering and development of severe environmental problems'. However the issue of prioritisation does not change the overall six major threats. They were identified as the major threats in all three surveys (Table 2).

The results show that the six major threats to the sustainability of freshwater fisheries resources around Australia are:

- habitat degradation;
- pollution/water quality/water temperature;
- reduced environmental flows;
- barriers to migration;
- introduced species; and
- fishing.

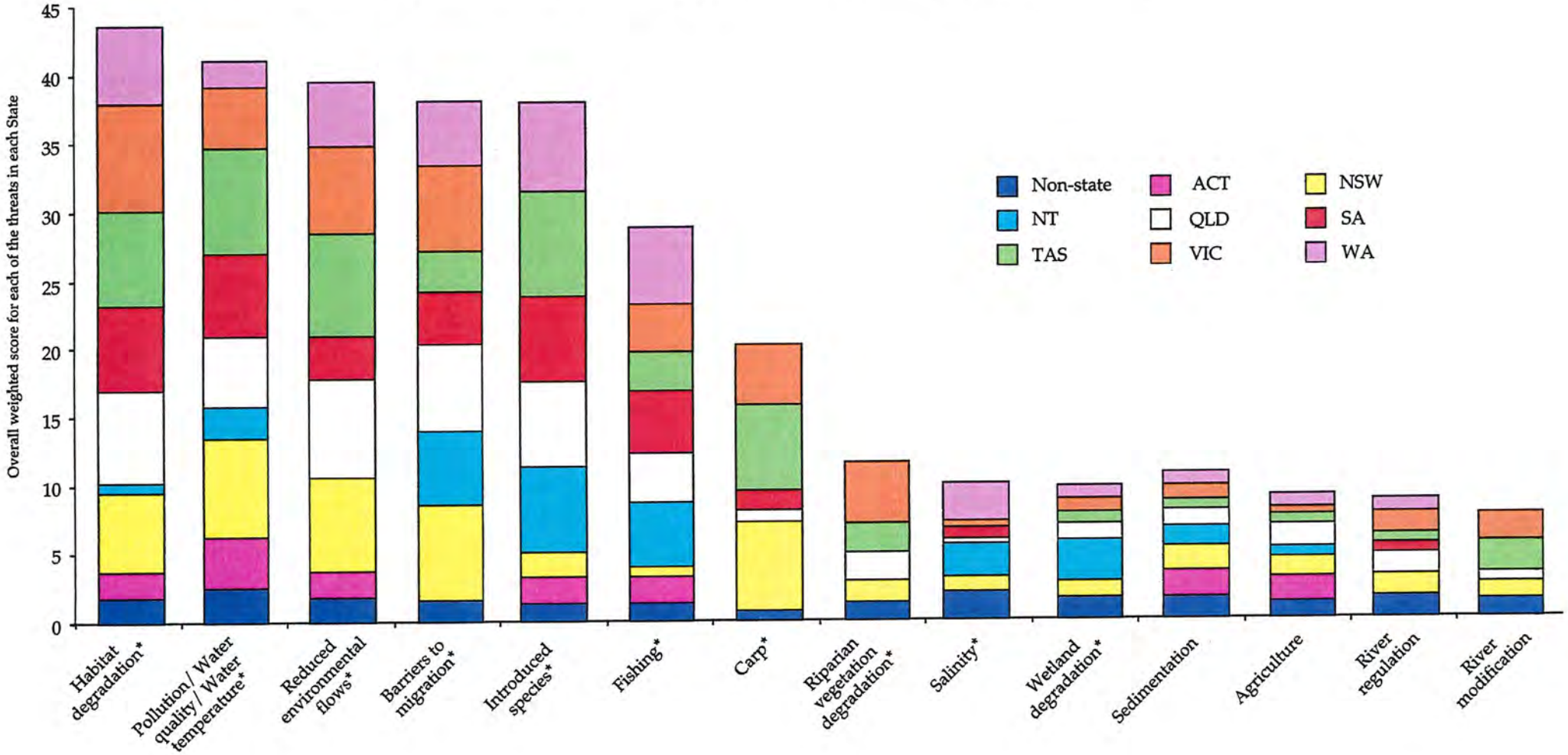
A description of these threats can be found in Chapter 2. If more than these six threats were examined we would essentially be examining the opinions of individual States, as the discussions with State representatives were limited to five threats in each State.

Figure 1 shows that all of the threats identified in the national survey were covered to some extent by the six major threats. Some were covered by more than one threat; for example some aspects of both agriculture and urbanisation were covered by habitat degradation, others by pollution and still others by reduced environmental flows. Many of the threats which were merged were specific examples of more general threats. For example, carp are a specific case of an introduced species, nutrient levels of pollution, and degradation of wetlands, riparian vegetation and floodplains are all specific examples of habitat degradation. Some of the threats identified were actually secondary effects of other threats. For example, algal blooms are a secondary effect of an increase in nutrient levels, while an increase in nutrient levels is, in turn, a secondary effect of threats such as agriculture and urbanisation. It was realised that by merging the individual threats identified in the surveys into the six overall major threats some information would be lost and that the resulting mergers may not entirely reflect the intentions of the respondents who listed the individual threats. As the major concern was to identify the overall priority threats to the sustainability of Australia's freshwater fisheries resources and this was concluded to be of minor concern. Also, as Figure 1 shows which threats have been merged, the relationship of components to final priorities can be traced.

A major problem with the surveys performed (Chapter 3) is the level of subjectivity involved. This has led to issues with the naming of the major threats, for example water quality and pollution have been merged for the determination of the six major threats (Table 1) but remain separate in the national survey (Appendix 3), while threats such as river regulation and reduced environmental flows remain separate. The subjectivity involved can lead to subtle differences in opinion which can easily be misinterpreted during data analysis. For this reason there has been little combination of threats within the results from the national survey. Some combination has been performed during the assembly of the summary tables, however such combinations have been identified where possible to reduce confusion.

Another problem encountered was that the threats identified by the Steering Committee and the State representatives were not independently derived. The Steering Committee was provided with a list of threats obtained from the national survey, while the list provided to the State representatives was obtained from the Steering Committee. Thus the threats identified in these surveys are not free from suggestion. Because of this,

Figure 2. Major threats to the sustainability of Australia's freshwater fisheries resources (based on the National survey and interviews with State representatives, excluding input from the Steering Committee) - weighted results.



* These threats were discussed by the Steering Committee, therefore the weighted score for these threats is actually 33.3 points higher than that shown in the graph.

threats may have been identified, or ranked more highly, than they would have if no suggestions were made. The results obtained from the national survey (Appendix 3) are the only results arising from this study which are wholly independent. No indication of possible threats was provided to the organisations surveyed.

When examining the results obtained from the State representatives (Appendix 4) it can be seen that there is concurrence regarding the major threats between the fisheries researchers and managers within each State. This confirms that the threats raised are major issues within each State and not just the opinion of an individual.

When comparing the results from the three surveys (Table 2), it is seen that the six major threats are the same in all three cases. The difference between the surveys lies in the ordering of the threats. Some of these differences may have arisen because of the type of respondents involved in the three surveys. Both the national survey and the Steering Committee involved non-fisheries agencies, while the State representatives were limited to freshwater fisheries managers and researchers. The commonality in results from the three surveys strongly suggests that these six threats are indeed dominant throughout Australia.

Table 2. The six major threats identified, in the order in which they are ranked, by each of the three surveys*.

National	Steering Committee	State representatives
Pollution	Habitat degradation	Reduced environmental flows
Habitat degradation	Pollution	Habitat degradation
Reduced environmental flows	Reduced environmental flows	Barriers to migration
Barriers to migration	Barriers to migration	Fishing
Introduced species	Introduced species	Pollution
Fishing	Fishing	Introduced species

*Taken from Appendix 3, Figure 1, Appendix 4

State versus Commonwealth issues.

It can be seen that the threats presented in Table 1 and Figure 2 are all of significance to several States. Of the six major threats all nine groups (States plus Commonwealth based organisations) considered pollution/water quality/water temperature, habitat degradation and fishing to be major threats, while eight of the nine groups identified reduced environmental flows, barriers to migration and introduced species. Of the remaining threats identified in Table 1 and Figure 2, sedimentation and agriculture are identified by eight of the nine groups. All other threats were identified by five to seven groups. None of these threats was raised by a single State.

Threats within the R&D funding charter of FRDC.

FRDC has two basic research programs (presented in Table 3) (FRDC 1996):

- resources sustainability and
- ecosystems protection.

Table 3. Research programs of FRDC (FRDC 1996).

	Program 1 – Resources Sustainability	Program 2 – Ecosystems Protection
Scope:	This program generally relates to the fish, although some research will include the relationship between the fish and the rest of the ecosystem (as covered by Program 2).	This program generally relates to where the fish live, although some research will include the fish themselves (as covered by Program 1).
Goal:	To develop Australia's wild fish resources in a sustainable manner.	To protect the Australian ecosystems upon which fisheries and aquaculture depend.
The FRDC will work towards achieving this goal by investing in the following key areas:	RESOURCES STATUS – R&D that will increase the knowledge of wild fish resources for sustainable management, including: general biology and genetics, fish behaviour, stock definition, interaction between fish stocks, and resource assessment techniques.	ECOSYSTEMS STATUS – R&D that will increase knowledge for the protection of the ecosystems, including: inter-relationships between fish and their environments; impacts of fishing, aquaculture and other marine and land use; bio-diversity; fish health; and impacts of exotic organisms.
	FISHERIES MANAGEMENT IMPROVEMENT – R&D that will develop and evaluate sustainable fisheries management, including: developing systematic approaches to ESD; developing sustainability indicators; assessing fishing effort and changes in effort; regulating access to resources; and analysing institutional, legal, policy or economic factors.	ECOSYSTEMS MAINTENANCE AND IMPROVEMENT – R&D that will maintain and improve ecosystems, including: protecting, restoring and enhancing habitat; reducing bycatch and impacts on other non-target flora and fauna; and enhancing wild fish resources.
		ECOSYSTEMS MANAGEMENT IMPROVEMENT – R&D that will help to develop and evaluate ecosystems management, including: developing systematic approaches to ESD, determining impacts on ecosystems, and regulating access to ecosystems.

Given the key areas for FRDC R&D investment listed in Table 3, it can be seen that all of the 14 threats presented in Table 1 fall into FRDC investment areas; this is presented in greater detail in Table 4.

Table 4. Key investment areas of FRDC under which the major threats identified in this study are covered.

Issue	Research Program/Investment Area* (FRDC 1996)
Habitat degradation	Program 2/Ecosystems maintenance and improvement
Pollution/water quality/water temperature	Program 2/Ecosystems maintenance and improvement
Reduced environmental flows	Program 2/Ecosystems maintenance and improvement
Barriers to migration	Program 2/Ecosystems maintenance and improvement
Introduced species	Program 2/Ecosystems status
Fishing	Program 1/Resources status Program 1/Fisheries management improvement Program 2/Ecosystems status
Carp	Program 2/Ecosystems status
Riparian vegetation degradation	Program 2/Ecosystems maintenance and improvement
Salinity	Program 2/Ecosystems maintenance and improvement
Wetland degradation	Program 2/Ecosystems maintenance and improvement
Sedimentation	Program 2/Ecosystems maintenance and improvement
Agriculture	Program 2/Ecosystems maintenance and improvement
River regulation	Program 2/Ecosystems maintenance and improvement
River modification	Program 2/Ecosystems maintenance and improvement

* As identified in Table 3.

Comparison with issues identified in other Australian studies.

Several other studies have examined issues affecting either the freshwater ecosystem (SoEAC 1996; EPA NSW 1997c) or freshwater fisheries (McNee 1990; Commonwealth of Australia 1991; Wager and Jackson 1993). While all of these studies are informative, they are of limited use to managers as the threats identified are broad and therefore difficult to address. The issues identified in these studies are presented in Table 5. The majority of issues listed in Table 5 were also identified in this study (Table 1, Appendix 3).

Table 5. Issues affecting freshwater ecosystems and/or fisheries which have been identified in other Australian studies.

	Freshwater ecosystem		Freshwater fisheries		
Issues	SoEAC 1996	EPA NSW 1997c	McNee 1990	Commonwealth of Australia 1991	Wager and Jackson 1993
Agriculture	X			X	
Aquaculture				X	
Barriers to migration			X	X	X
Boating		X			
Clearing				X	
Climate change				X	
Competition for resource				X	
Continuous inundation			X		X
Erosion			X		X
Excess nutrients	X	X	X	X	X
Exposure of acid sulfate soils		X			
Farm dams	X				
Floodplain degradation			X	X	
Forestry	X		X	X	X
Habitat degradation	X	X	X	X	X
Inappropriate stocking			X		X
Inter-basin transfers		X			
Introduced species	X		X	X	X
Irrigation	X	X		X	
Lack of interpretation of existing data	X				
Lack of monitoring/data	X			X	
Lack of national data compilations	X				
Loss of genetic diversity				X	X
Loss of riparian vegetation	X	X	X	X	X
Mining	X		X	X	X
Over allocation of ground and surface water	X				
Overfishing			X	X	X
Overgrazing					X
Pollution	X	X	X	X	X
Reduced environmental flows	X	X	X		
River modification			X	X	X
River regulation	X	X	X	X	X
Run-off		X	X	X	
Salinity – dryland and irrigation	X	X		X	
Sedimentation	X	X	X	X	X
Turbidity		X		X	
Urbanisation				X	
Waterweeds	X				
Wetland degradation	X			X	X

Comparison with issues affecting freshwater fish worldwide.

Worldwide threats to freshwater fish include the vast number of large dams and smaller barriers on waterways, levees disconnecting the rivers from floodplains, agricultural pollution, industrial pollution, and agricultural runoff (Tuxill and Bright 1998). Habitat degradation is reportedly causing the decline of at least 60% of all threatened freshwater fish species, while introduced species are pressuring approximately 34% of endangered freshwater fish species worldwide (Tuxill and Bright 1998). Many freshwater fish species are also highly exploited through commercial fishing (Tuxill and Bright 1998). Table 6 shows that the six major threats identified in this study are far from unique to Australia.

Table 6. Principal threats to freshwater fish identified worldwide (Abramovitz 1996).

Area	Principal threats*
Amazon River	Habitat degradation, overharvest
Asia	Habitat degradation, competition for water, overharvest
North America	Habitat degradation, introduced species
Mexico (arid lands)	Competition for water, pollution
Europe	Habitat degradation, pollution
South Africa	Habitat degradation, pollution, competition for water
Lake Victoria	Introduced species
Costa Rica	Habitat degradation
Iran	Habitat degradation, competition for water
Australia	Habitat degradation, competition for water

* Habitat degradation includes barriers to migration

Comparison with issues affecting other sectors in Australia.

An attempt was made to compare the major threats identified in this study with those identified in other sectors within Australia. Similar threats were noted in other sectors: agriculture, land resources, biodiversity, estuaries and the sea. However, due to differences in the objectives of the documentation from these sectors (NSW Agriculture 1997, 1998; DLWC 1997a; SoEAC 1996) detailed comparisons were not possible.

Cappo et al. (1998) recently determined the major threats to coastal and marine fisheries habitat to be (listed in order of priority):

- natural dynamics and environmental variability;
- change to drainage and habitat alteration (includes barriers to movement, reduced environmental flows and habitat disturbance);
- nutrient and contaminant inputs;
- effects of harvesting on biodiversity and ecosystems; and
- introduced and translocated pests and diseases.

Aside from the ordering of these threats, the major difference between these results and the six major threats identified in the present study is the inclusion of natural dynamics and environmental variability. Indeed, natural dynamics and environmental variability appear to have been included in the study of Cappo et al. (1998) through a need to better understand such variability in order to better address the other major issues identified (see Chapter 8).

Conclusions.

- It was determined that the major threats to the sustainability of Australia's freshwater fisheries are:
    - habitat degradation;

  - pollution/water quality/water temperature;
  - reduced environmental flows;
  - barriers to migration;
  - introduced species; and
  - fishing.
- These threats were found to be of nationwide, as opposed to just statewide, significance.
- All fall within the R&D funding charter of FRDC to at least some extent.
- All of the major threats were also identified as threats to the freshwater ecosystem or to freshwater fisheries in other Australian studies.
- The major threats identified in this study are closely aligned with the major threats to freshwater fish worldwide.

Chapter 5. State of knowledge of the major threats.

Introduction.

In this chapter we provide an overview of the status of knowledge of the major threats. A comparison of the state of knowledge between States is also presented.

Methods and Results.

The information presented in this chapter was compiled using the interviews with State representatives discussed in Chapter 3; the results from representatives were combined within each State. Each representative was asked the question 'What is known about this issue in your State?' for each of the five threats raised (Appendix 2). References relating to the knowledge identified were also requested. The responses of the State representatives, together with references for many of the items discussed, can be found in Appendix 5.

A summary table showing the state of knowledge for the six major threats, listed State by State, was compiled from the individual State tables. (Appendix 6) This table allows comparisons to be made between the States regarding the level of knowledge for the six major threats. The summary results are limited to the six major threats to allow comparisons to be made between States.

As there is a great deal of overlap between introduced species and carp, the information relating to these two threats has been combined both in this chapter and in those which follow.

Discussion.

When the knowledge of the six major threats (Appendix 6) is examined it can be seen that there are many differences between States. However, when this knowledge is examined as a whole the larger picture of the nationwide state of knowledge for these threats becomes apparent (reviewed in Chapter 2).

Habitat degradation is an expansive problem covering many smaller issues. There is little knowledge of the impacts and extent of habitat degradation as a whole, but there is a great deal of knowledge for some for the specific problems. Some of these specific problems are covered in the other threats presented in Appendix 6.

Pollution is another broad problem covering a number of issues, for example sewage, industrial waste, thermal pollution, excess nutrients and pesticides. There is considerable knowledge for some specific pollution problems, for example nutrients, pesticides, agricultural chemicals and acid sulfate soils; however, the knowledge is reasonably fragmented and the effect of combinations of the pollutants appears not to be understood.

Reduced environmental flows are identified as a major threat. While it is recognised that there is insufficient water flowing downstream in many regulated rivers, the amount of water required for environmental sustainability is not yet known. The difficulty of differentiating between environmental sustainability and pristine is acknowledged. It is also apparent that there is little quantitative information available on the effects of altering the flows in rivers.

The location of major barriers to fish migration in most of the States is known. It is also known that the major impact of barriers is to prevent both upstream and downstream movement. It is apparent that in some States there is monitoring of fishways after they are completed, however this is not the case in all States and fisheries managers and researchers involved stated this to be a major omission.

There is considerable knowledge relating to introduced fish species, including identification of the individual species present, the distribution of those fish and the impacts that they are likely to cause.

Fishing was identified as an issue by fisheries managers and/or researchers in five of the seven States involved in this survey and was discussed in four of these States. It became apparent that there is inadequate knowledge of the status of native fish stocks in most States, the exceptions were New South Wales, Northern Territory and Western Australia. This is discussed further in Chapter 10.

Conclusions.

- There is a great deal of knowledge available regarding some aspects of the major threats.
- Available knowledge is far from comprehensive and is not adequate for efficient management.
- The amount of knowledge available varies between States.
- Knowledge available in one State is generally useful in other States but is not always accessible by other States.

Chapter 6. Primary causes of the major threats.

Introduction.

The major factors causing each of the key threats are presented in this chapter. This satisfies an objective of the project: 'to identify the primary causes for the most significant threats in each State and Territory'.

Methods and Results.

The information presented here was compiled using the Steering Committee workshop and the interviews with the State representatives discussed in Chapter 3. The Steering Committee discussed the question 'What are the causes [of the major threats]?' for each of the threats examined (Appendix 1). Results are presented in Appendix 7. The State representatives were asked a similar question regarding the five threats raised (Appendix 2). The results from the State representatives were combined within each State and can be found in Appendix 8.

A summary table showing the primary causes for the six major threats, listed State by State, was compiled from these tables (Appendix 9). The summary results are limited to the six major threats to allow comparisons between States.

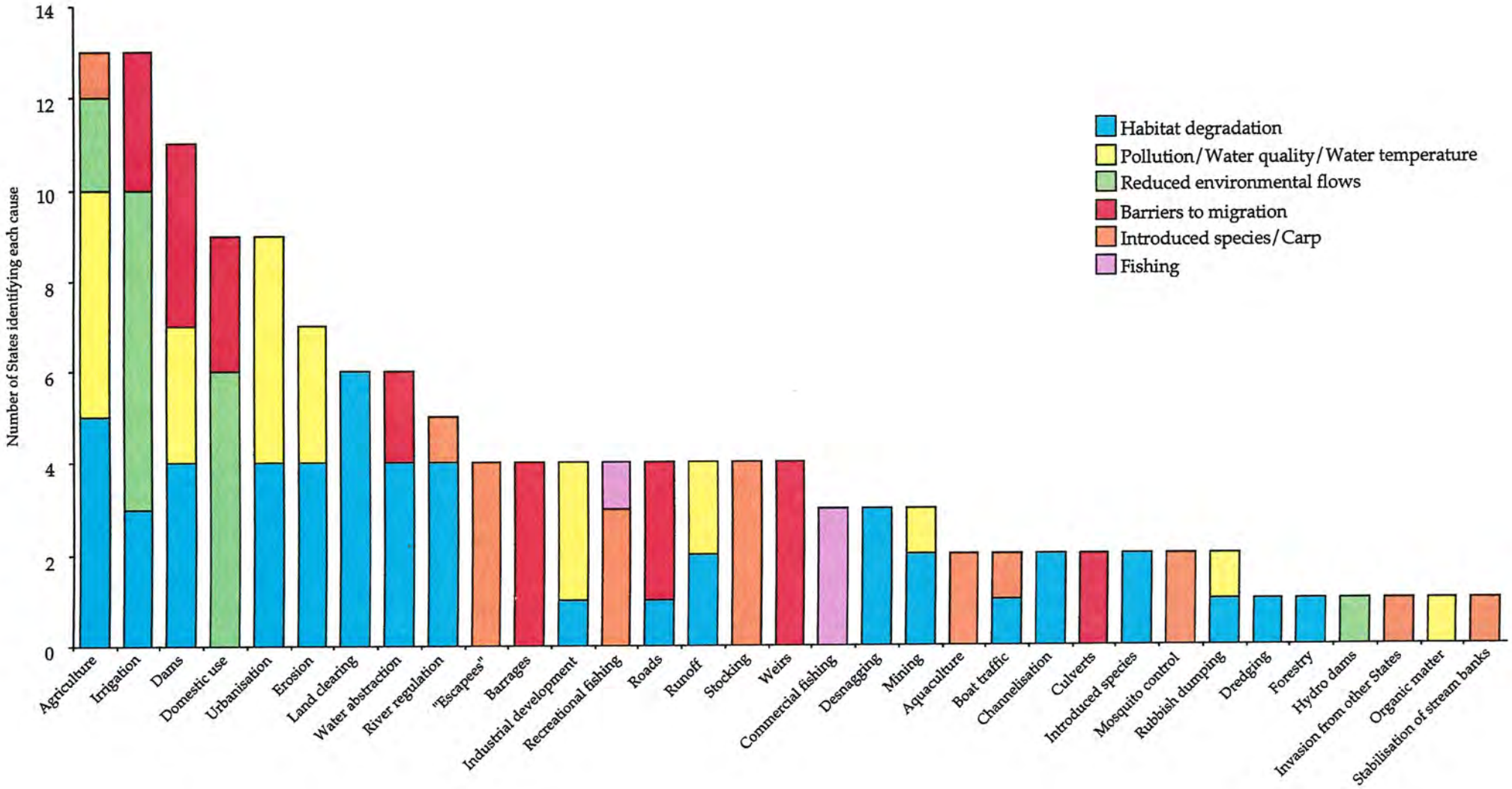
The information presented in the summary table (Appendix 9) was used to prepare a graph showing the number of times a cause was identified for each of the six major threats by assigning a single point to each issue raised by each of the researchers and managers from each State and by the Steering Committee. When a State had only a single researcher/manager two points were assigned to each issue discussed. The number of points for each cause of each of the six major threats were totalled and graphed as a stacked column chart (Figure 3).

Discussion.

It can be seen from Figure 3 that no single cause is responsible for any of the major threats identified. Several of the causes were identified as being partially responsible for two major threats, while two of the causes were identified as being partially responsible for three of the major threats. The causes identified by the most individuals (10 or more) were irrigation use (partially responsible for barriers to migration, reduced environmental flows and habitat degradation), domestic use (causing barriers to migration and reduced environmental flows), agriculture (causing reduced environmental flows, pollution and habitat degradation), dams (causing barriers to migration and habitat degradation) and stock (causing pollution and habitat degradation). The major causes of fishing problems were identified as commercial and recreational fishing and a lack of information on the sustainability of fish stocks (Appendix 9 and Figure 3).

It can be seen that most causes were identified in more than one State (Appendix 8). This implies that these causes are more than just a State-by-State problem, in many cases they are nationwide concerns.

Figure 3. Primary causes of the six major threats (based on interviews with State representatives and input from the Steering Committee).



Causes identified in other Australian studies of the freshwater ecosystem or fisheries.

Several other studies have discussed causes of major threats to freshwater ecosystem. Results from four major studies are presented in Table 7.

Table 7. Causes identified in other Australian studies which relate to the six major threats identified in this study.

Causes	Habitat degradation	Pollution	Reduced environmental flows	Barriers to migration	Introduced species	Fishing
Acid sulfate soil exposure		4				
Agriculture	1,3,4	1,2,4	2,3			
Algal blooms	3,4					
Aquaculture		3			3	
Aquarium trade					1,2,3	
Boating	4	4				
Channelisation	1,3,4					
Clearing	4	4				
Commercial fishing						1,2,4
Dams	1,3,4			3		
Demand for water			1,2,4			
Desnagging	1,3,4					
Domestic use			2,3			
Dredging	1					
Erosion	1,3,4	1,3,4				
Flood mitigation	1,4					
Forestry	1,3,4	1,2,3,4				
Heavy metals		1				
Inappropriate stocking					1,2	
Industry		1,3,4				
Introduced species	3,4	4				
Irrigation			3	2		
Loss of riparian vegetation	1,2,3,4	1,2,4				
Mining	1,2	1,3,4				
Nutrients	3	1,2,3,4				
Organic matter		4				
Over allocation			3,4			
Pest control					2	
Pesticides		1,3,4				
Pollution	3,4					
Recreational fishing					2,3	1,2,4
River regulation	2,3,4	3	1,2	1,2,3,4		
Run-off		1,2,4				
Salinity	3,4	1,2				
Sediment	2	1				
Sewage		3,4				
Stock		2,3				
Stormwater		1,2				
Thermal pollution	3	1,2,3,4				
Urbanisation	3	1,3,4				
Water abstraction	1			3		
Weir pool formation	1,2,3,4					
Weirs				3,4		

1 = McNee 1990, 2 = Wager and Jackson 1993, 3 = SoEAC 1996, 4 = EPA NSW 1997c

A great deal of overlap is seen when the causes identified in other Australian studies (Table 7) are compared with those identified in this study (Appendix 9 and Figure 3). Additional causes of habitat degradation were algal blooms and flood mitigation works. Other causes of pollution were forestry, urbanisation, aquaculture, loss of riparian vegetation, clearing, boating, erosion, introduced species and salinity. Reduced environmental flows had fewer additional causes: over allocation, demand for water and river regulation. River regulation was also identified as a cause of barriers to migration. It should be noted that many of these additional causes are very similar to those listed in the present study.

Conclusions.

- Several causes were identified for each of the major threats.
- Several of these causes were implicated in more than one of the major threats.
- The most commonly identified causes were irrigation use, domestic use, agriculture, dams and stock.
- Most causes were identified in more than one State; in many cases they are nationwide concerns.
- Causes identified were consistent with those found in previous, though less comprehensive, studies of Australia's freshwater ecosystems.

Chapter 7. Monitors and managers of the major threats.

Introduction.

The agencies most responsible for the management of each of the major threats presented in Chapter 4 are identified in this chapter, as are the agencies involved in the monitoring of these threats.

Methods and Results.

The information used in this chapter was compiled from the Steering Committee workshop and the survey of the State representatives discussed in Chapter 3. The Steering Committee discussed the questions 'Who monitors [the problem]?' and 'Who decides on management policy?' (Appendix 1) for the threats examined. Results are presented in Appendix 10. The State representatives were asked similar questions for the five threats raised (Appendix 2). The results from the State representatives were combined within each State and are tabulated in Appendix 11.

A summary table showing the agencies involved in the monitoring and management of the six major threats, listed by State, was compiled from the individual tables (Appendix 12). An overall summary showing the types of agencies involved in the monitoring and management of the six major threats was also compiled (Appendix 13). Summary tables are limited to the six major threats to allow comparisons between States.

Graphs showing the number of threats monitored and managed by each of the agency types were prepared from the overall summary table (Figure 4 and Figure 5).

Discussion.

When examining the agencies identified as being involved in the monitoring and management of the six major threats it should be kept in mind that although State agencies manage many of the problems, the specific agency involved may vary from State to State. For example natural resource agencies were identified as being involved in the management of four of the six major threats (Appendix 13 and Figure 5), in Victoria this agency is called Natural Resources and Environment, in New South Wales it is the Department of Land and Water Conservation.

Figure 4 shows that two agencies were identified as monitoring four of the six major threats, these were university groups and natural resource agencies. Fisheries agencies, water management authorities, EPAs, local government and parks and wildlife agencies were identified as being involved in the monitoring of three of the six major threats. The remaining ten agencies were identified as monitoring one or two of the six major threats. Fisheries agencies were the only agencies identified as being involved in the monitoring of fishing.

Agencies involved in the management of these threats are shown in Figure 5. It can be seen that two agencies (natural resource agencies and water management authorities) were identified as having a role in the management of four of the six major threats. Four agencies had a role in managing three of the six major threats (MDBC, parks and wildlife agencies, fisheries agencies and State Government). The remaining nine agencies were identified as having a role in the management of one or two of the six major threats. Fisheries agencies and State Governments were the only groups identified as being involved in the management of fishing.

The number of agencies involved in the monitoring and management of each of the six major threats is summarised in Table 8. This table shows that no agency has absolute control over the management of any one threat, with the exception of fishing, and then secondary impacts confound the relationship. The monitoring of the threats is even more

fragmented. Thus, it is likely that data collection is not designed to give a nationwide perspective of the threat, and that the data being collected are not used to their full extent.

Table 8. Number of agencies identified in this study as being involved in the monitoring and management of each of the six major threats.

Threat	Number of monitoring agencies identified	Number of managing agencies identified
Habitat degradation	11	7
Pollution	5	3
Reduced environmental flows	4	5
Barriers to migration	7	9
Introduced species	9	6
Fishing	1	2

Conclusions.

- With the exception of fishing, no single type of agency was identified as having sole responsibility for the monitoring and management of any of the major threats.
- Such fragmentation of both monitoring and management leads to ineffective data collection, monitoring and management of the major threats, both within and between States.

Figure 4. Agencies involved in the monitoring of the six major threats (based on interviews with the State representatives and input from the Steering Committee).

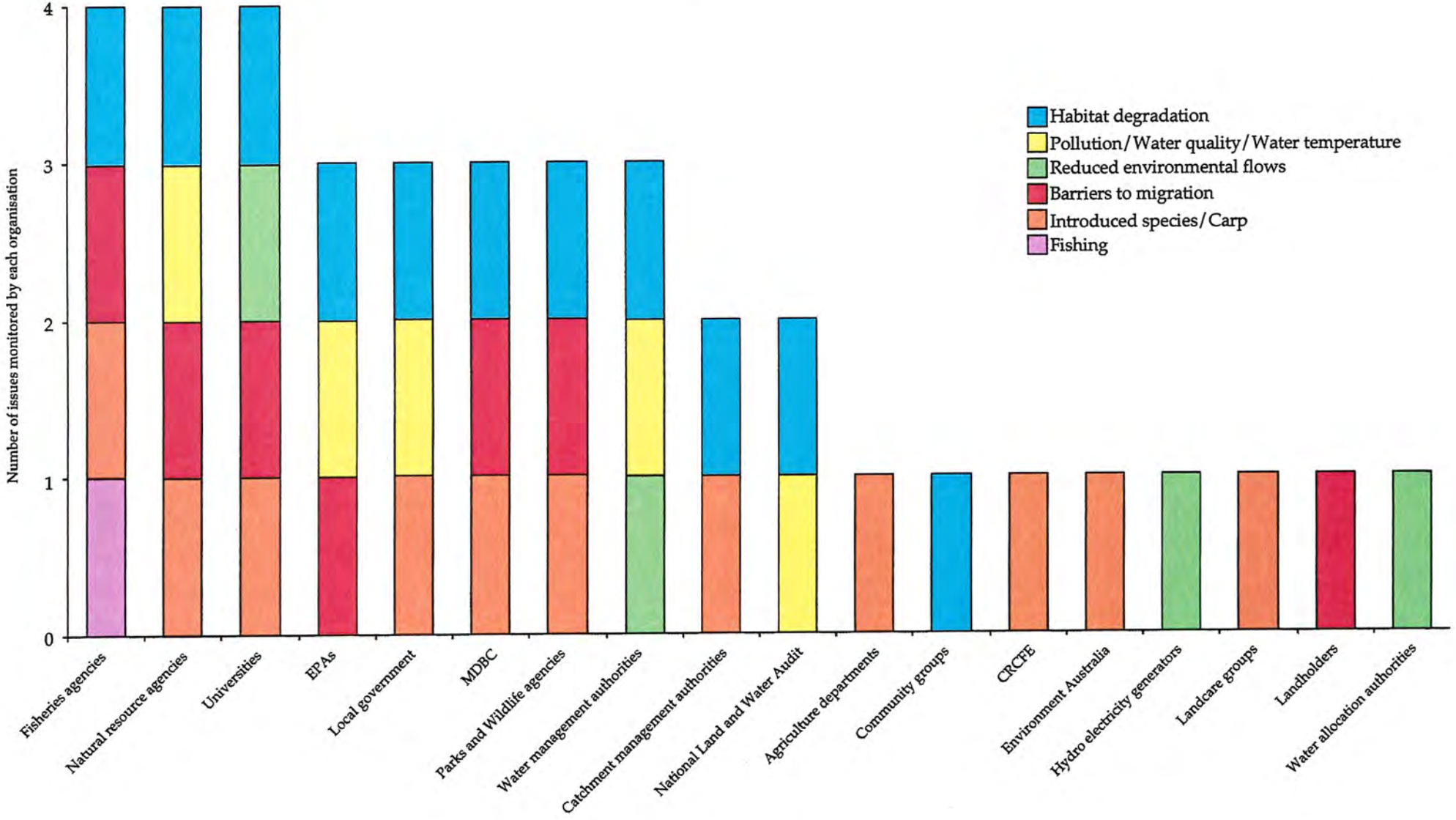
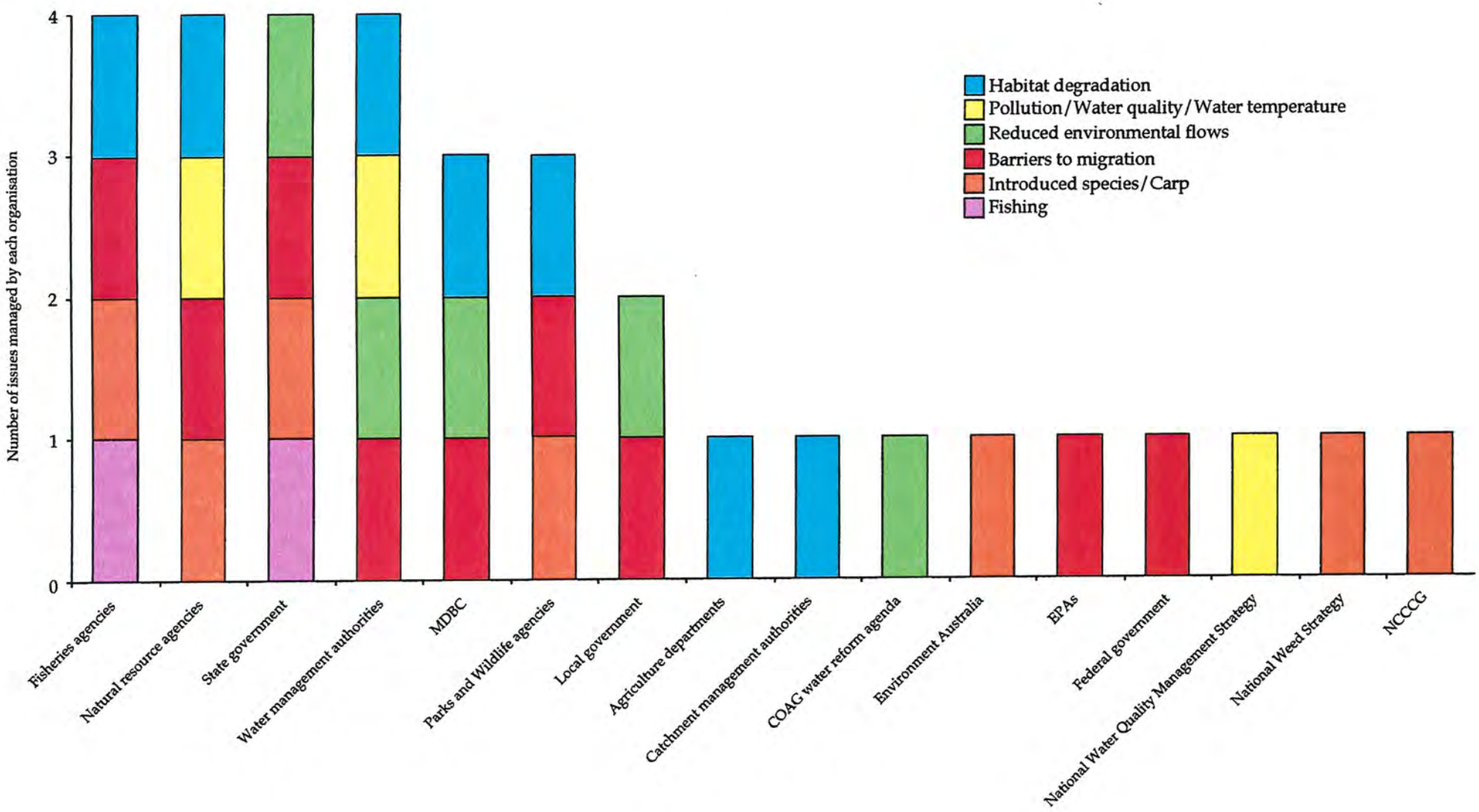


Figure 5. Agencies involved in the management of the six major threats (based on interviews with the State representatives and input from the Steering Committee).



Chapter 8. Knowledge required to address the major threats.

Introduction.

In this chapter an objective of the project is satisfied: 'to assess which threats could be approached by a national or State by State cooperative strategy for research'. Research and monitoring programs which would facilitate management are proposed for each of the six major threats discussed in Chapter 4. Desired directions for future management are also suggested.

Methods and Results.

The information used in this chapter was compiled from the Steering Committee workshop and the survey of the State representatives discussed in Chapter 3. The Steering Committee discussed the questions 'What are the major data needs for each issue?' and 'What management actions are likely to arise from the acquisition of this knowledge?' for each of the threats examined (Appendix 1). Results are presented in Appendix 14. The State representatives were asked similar questions relating to the five threats raised (Appendix 2). The results from the State representatives were combined within each State and are tabulated in Appendix 15.

Summary tables showing the knowledge required to address the six major threats and management actions likely to result from the acquisition of this knowledge were compiled from the individual State tables. One table examines the threats State by State (Appendix 16), the other examines each threat as a whole (Appendix 17). The summary tables are limited to the six major threats to allow comparisons between States.

The knowledge requirements presented in Appendix 17 have been ranked in decreasing order of priority by the Steering Committee using a weighted individual voting system. Under this voting system each threat was examined separately. Each member of the Steering Committee was allocated a number of votes for each threat. This number was determined by dividing the total number of knowledge requirements for a particular threat by two. Thus, if there were seven requirements for a threat each member was permitted four votes for that threat. The number of votes for each requirement was then totalled and the requirements ranked accordingly.

The possible management actions identified in Appendix 17 are not intended to be prescriptive, rather they are an indication of desirable actions arising from the acquisition of the knowledge requirements identified.

Discussion.

Appendix 17 shows that much knowledge is required to overcome the major threats. Acquisition of all (or any) of this knowledge would facilitate the management of Australia's freshwater fisheries resource. None of the knowledge requirements identified is specific to a single State; all could be approached by a an inter-State, or possibly Commonwealth, research strategy. Although the knowledge requirements were not identified as requirements in all States, the Steering Committee determined that they are best approached on a cooperative basis.

While it has been shown that all of the six major threats are of interest to all States, it must be noted that research priorities can be allocated between States based on the relative importance of different fish species in each State and by the relative importance of various aspects of the major threats. For example barramundi (*Lates calcarifer*) are clearly an important species in the Northern Territory, Queensland and Western Australia but are not at all a concern in Tasmania; introduced plant species are the major concern with regard to introduced species in the Northern Territory while carp are the major concern in New South Wales.

The knowledge requirements identified in Appendix 17 are listed in decreasing order of priority as determined by the Steering Committee. These rankings are subjective. The ranking does not imply that projects involved with the lowest priority requirements, or information not listed, should not be considered for funding. These listings are simply intended as a guide to the type of information required for each of the major threats. Also, the ranking of the requirements does not necessarily reflect the importance of factors contributing to the threats.

When the knowledge requirements (Appendix 17) are examined common themes can be found between the major threats. The use of fisheries species as indicators was identified in habitat degradation, reduced environmental flows and pollution; biological and habitat information were identified in habitat degradation, reduced environmental flows and barriers to migration; understanding of the ecosystem in habitat degradation and reduced environmental flows; the extent of the problem in habitat degradation, reduced environmental flows (with respect to private dams) and pollution; and finally information on restoration /rehabilitation /control methods was identified in habitat degradation, reduced environmental flows, pollution, barriers to migration and introduced species.

Knowledge requirements identified in other Australian studies.

Knowledge requirements identified in other studies of freshwater which relate to the six major threats are shown in Table 9. It can be seen that there is a great deal of overlap between the requirements identified in this study (Appendix 17) and those from other the studies; for example under reduced environmental flows both 'determine environmental flows required' and 'understanding natural flow regimes' were identified in this study, as were 'significance and value of fisheries to local communities and indigenous people' and 'stock assessment' listed under fishing. Table 9 also lists four general knowledge requirements, these are all mentioned in Appendix 17 under one or more of the major threats.

Cappo et al. (1998) identified several major knowledge gaps relating to coastal and marine fisheries habitat; these are presented below, together with an indication of the major threats identified in this study for which similar requirements were noted (taken from Appendix 17):

- knowledge of habitat processes/dynamics (identified in the present study under habitat degradation and reduced environmental flows);
- habitat inventories and monitoring (identified under habitat degradation in the present study);
- integration of fisheries and habitat data, including knowledge of fisheries-habitat links (raised under habitat degradation in the present study);
- knowledge of life histories (identified in habitat degradation, reduced environmental flows and barriers to migration in the present study);
- develop and maintain inventories of threatening structures and processes (in the present study this was raised under habitat degradation, pollution, reduced environmental flows and barriers to migration);
- effects and transmission of introduced species and pests (identified under introduced species in the present study);
- develop suitable indicators of fishery and ecosystem health (identified in the present study under habitat degradation); and
- monitor the effectiveness of management actions (raised under habitat degradation, pollution, reduced environmental flows and barriers to migration).

Table 9. Knowledge requirements discussed in other Australian freshwater studies which relate to the six major threats identified in this study.

Threat	Requirements	CoA 1991	Wager and Jackson 1993	Lake 1994	DIST 1996	Freshwater Fisheries MAC 1996	SoEAC 1996	EPA NSW 1997c
Habitat degradation	Develop habitat rehabilitation measures					X		
	Identify and protect critical freshwater habitat	X				X		
Pollution	Background values of pollutants in sediments and biota							X
	Effects of pollutants				X			X
	Links between pesticide application and concentration in waterways							X
	Low cost methods for detection of pollutants				X			
	Methods for control of urban and rural diffuse sources of pollution						X	
	Trends in concentrations in sediments				X			X
Reduced environmental flows	Determine environmental flows required			X		X		
	Effect of flow variability			X				
	Extent, condition and threats to use of water as a guide to its allocation				X			
	Relationship between flows, ecology and maintenance of river health							X
	Understanding natural flow regimes and hydrological processes				X			X
Barriers	Identify critical barriers to fish movement and design fish passage for those barriers	X	X			X		
Introduced species	Extent, status, importance and effects of intro species	X	X	X		X		X
Fishing	Data on fishing effort and profitability (required to set sustainable fishing limits)	X						
	Impact of fishing activities on stocks, habitats, non-target species		X					X
	Recreational fishing data					X		X
	Significance and value of fisheries to local communities and indigenous people					X		
	Stock assessment	X						
General	Determine effectiveness of management/rehabilitation measures					X		X
	Distribution of biota (required to achieve reliable monitoring)			X		X		
	Impact of threatening processes on fish and habitat							X
	Species specific biological and ecological research on species important to fisheries	X	X			X		
	Understanding of the ecosystem and interactions within it	X					X	

CoA = Commonwealth of Australia

The major knowledge gaps identified by Cappo et al. (1998) presented above are all relevant to the present study, as are the remainder of the knowledge gaps identified in that study (not presented here).

Requirements for an understanding of the ecology of running waters.

An understanding of the ecosystem was listed as a requirement for several of the major threats identified (Appendix 17). In a study of knowledge requirements for understanding the ecology of running water in Australia, Lake (1994) identified the following requirements:

- long-term ecological research;
- protocols for rigorous surveys, experimentation and environmental monitoring and assessment;
- ecology of floodplain rivers;
- trophic structure;
- ecological role(s) of natural disturbance on streams, rivers and their floodplains;
- nutrient dynamics;
- patterns and maintenance of biotic diversity;
- ecological impacts of introduced biota;
- patterns and levels of biotic production in rivers;
- assessment of the nature and strengths of biotic interactions;
- the role of riparian vegetation in in-stream ecological processes; and
- stream classification

These requirements are not listed in Table 9 as they are much broader than freshwater fisheries and the major threats identified; they are necessary to improve our understanding of the ecology of freshwater ecosystems as a whole, including of course, fisheries processes.

Use of fish as indicators.

The use of fish as indicators of the success of management measures or as an indicator of river health was considered for three of the major threats identified (Appendix 17). The reasons for using fish in both the assessment and monitoring of various actions and effects are several:

- fish are found at all trophic levels and eat food from aquatic and terrestrial sources providing an overall view of the catchment area and an integrated view of the ecological processes occurring in the waterways (Harris 1995);
- assessment and monitoring programs using fish can be performed relatively rapidly and inexpensively (Harris 1995);
- as fish live for a relatively long time they can be used over a wide temporal scale and because they are mobile they can be used over wide spatial scales. The use of indicators that reflect changes over scales similar to those of the major threats results in effective assessment of the condition of affected waterways (Harris 1995). On the other hand larval and juvenile fish can be valuable indicators of short-term events;
- it is relatively easy to identify fish (Harris 1995);
- fish are sensitive to most forms of human disturbance (Harris 1995);

- fish allow evaluation of acute toxicity effects through missing species and of stress effects through decreases in growth or reproductive success (Harris 1995);
- fish are mainly affected by macro-environmental issues whereas macroinvertebrates and algae are affected by both micro- and macro-environmental issues (Harris 1995);
- the public has a well established affinity with fish and their wellbeing, thereby engendering public support for measures to protect them and community group support for monitoring and management.

Harris (1995) goes on to say that for fish to be used in ecological assessments data collection must be standardised and the effort used to produce each catch must be known. Confounding effects, such as improvements in gear which increases the catch and changes in social values which lead to a change in catch and exploitation of fish populations, also need to be identified and quantified (Harris 1995).

Stock assessment.

Both the State representatives and the members of the Steering Committee were questioned regarding the use of data from commercial, recreational and indigenous fishing in stock assessments (Appendix 1 and Appendix 2). All questioned stated that these data should definitely be used in stock assessments. In many cases commercial fishing data are the only data available with which to manage the fishery, although most individuals questioned considered that the collection of such data needed improvement for it to be truly useful.

Stock assessments require information on the stock structure, stock size, productivity and catch history, which should include information on by-catch and dumping (Commonwealth of Australia 1991). Productivity estimates require knowledge of biological parameters, for example recruitment, growth and natural mortality (Commonwealth of Australia 1991). Other information required for ecologically sustainable and economically efficient harvests includes environmental data showing how species react to natural and anthropogenic changes in their environment, the importance and position of each species in the food web and the interdependence of each species. Also required are economic data such as fishing effort, profitability and valuation of the environmental resource (Commonwealth of Australia 1991).

Commercial fishing.

The Steering Committee concluded that cooperation between commercial fishers and scientists would better enable collection of data suitable for an assessment of the resource. If commercial fishing was used to assess the resource the main problem would be coverage of the waterways, for example in New South Wales none of the coastal rivers and only 5% of the inland rivers are fished commercially for freshwater species. Thus, commercial fishing would be indicative of the state of the rivers only in some areas. When interviewing the State representatives the only State which assessed that the data already being collected were sufficient for the management of the fisheries was Western Australia, where there are relatively few freshwater fisheries.

Recreational fishing.

Data from recreational fisheries was considered to be of use in a few localised areas, but was seen to have little cross-regional significance at the present time. Tournaments and special events need to be well designed to enable the collection of data valuable for resource monitoring. It appears that there are few current sources of recreational fishing data that would be useful in an assessment of the fisheries resource. Nonetheless recreational fisheries have the potential to provide extremely valuable monitoring information if target fisheries are well designed and appropriately sampled.

Indigenous fishing.
It was found that there was a lack of data relating to the indigenous freshwater fishery. Indeed, in many areas there is no recognition that there is such a fishery. Indigenous knowledge would be useful in the management of the freshwater fisheries resource and could be incorporated into management plans along with scientific knowledge.

Conclusions.

- Knowledge required to overcome the major threats was identified.
- It was determined that all of the knowledge requirements identified were best approached on a cooperative basis.
- Priority can be allocated between States based on individual fish species important in a particular State and the relative importance of aspects of the major threats in each State.
- Several knowledge requirements were identified as necessary for more than one of the major threats.
- Similar knowledge requirements have been identified in other Australian studies of the freshwater ecosystem, freshwater fisheries and marine and coastal fisheries habitat.
- A separate study (Lake 1994) has identified the knowledge required for an understanding of the ecology of freshwater ecosystems and Lake's requirements should be considered together with those identified in this study, particularly when addressing issues directly relating to freshwater ecology.
- There is good reason to use fish as indicators of the health of both the fisheries and the rivers.
- Stock assessment needs to be improved in most States. There is generally insufficient data collected from the commercial, recreational and indigenous fishing sectors.
- There is little recognition of the existence of an indigenous freshwater fishery.
- There is great potential for increased use of community groups (e.g. Landcare and River Care) and angling groups in the monitoring of the health of fish populations and therefore river health.

Chapter 9. Strategies that have addressed the major threats.

Introduction.

In this chapter we present strategies that have addressed, or are addressing, the six major threats and examine the likelihood of success from transporting these strategies to other States.

Methods and Results.

This information was compiled from the Steering Committee workshop and the interviews with State representatives discussed in Chapter 3. The Steering Committee discussed the request 'List up to five strategies which have worked to overcome a specific problem' for each of the threats examined (Appendix 1). Results are presented in Appendix 18. The State representatives were asked a similar question relating to the five threats raised (Appendix 2). The results from the State representatives were combined within each State and are tabulated in Appendix 19. References discussing the strategies identified were requested from both the Steering Committee members and the fisheries managers and researchers and are listed in Appendix 18 and Appendix 19. It should be noted that a large amount of the material presented in these tables is not referenced, much of the material was taken solely from the Steering Committee workshop and the interviews with the State representatives.

A summary table showing the strategies that have addressed, or are addressing, the six major threats, listed State by State, was compiled from these individual tables (Appendix 20). The summary results are limited to the six major threats to allow comparisons between States.

Discussion.

It can be seen from Appendix 20 that there are several strategies that have worked, or that appear to be working, for each of the six major threats.

It was found when requesting references, both published and unpublished, regarding these strategies that many strategies had never been written up in any form. This was often due to a lack of funding, a lack of time or a lack of staff continuity. The lack of written material poses problems when attempting to examine the strategies used in more detail and when determining the degree of monitoring performed both before and after implementation of the strategy. This makes it difficult to quantify the success of the strategy.

Strategies which are transportable to other States.

Strategies that have been tried in more than one State are shown in Table 10, which was compiled from Appendix 20 and Appendix 18. As these strategies have been used in more than one State, it has already been shown that they are transportable.

All other strategies shown in Appendix 20 are likely to succeed if transported to other States and would therefore benefit from a State-by-State cooperative approach, as would those listed in Table 10.

Table 10. Strategies which have been used in more than one State to address each of the six major threats.

Threat	Strategy	States in which this has been tried	Completed/ Underway*
Habitat degradation	Rehabilitation/restoration projects	NSW	C/U
		QLD	U
		TAS	C
		VIC	C/U
	Fencing/replanting of riparian zones	NSW	C/U
		SA	C/U
		WA	C/U
	Reserves and national parks	QLD	C/U
		WA	C/U
Pollution	Multi-level offtakes on dams	NSW	C
		VIC	C
	Changes in farming practices / improved land management	NSW	C/U
		QLD	C/U
Reduced environmental flows	Assessing effects of environmental releases	NSW	U
		TAS	U
		VIC	U
Barriers to migration	Building of appropriate fishways	NSW	C/U
		QLD	C/U
		VIC	C/U
	Documentation of barriers in the Murray-Darling Basin and elsewhere	NSW	C/U
		QLD	C
		VIC	C
	Removal of unnecessary barriers	NSW	C/U
		VIC	C/U
Introduced species	Legislation preventing introductions	Federal	C
	Legislation against translocations	QLD	C
		WA	C
	Rotenone to eradicate spot infestations	QLD	C
		SA	C
		TAS	C
		WA	C
Fishing	Stock assessment	NT	C/U
		SA	U

C = Completed, U = Underway, C/U = some completed, others underway

Strategies identified in other Australian studies.

Strategies have also been identified in 'Australia: State of the Environment 1996' (SoEAC 1996) and 'New South Wales State of the Environment' (EPA NSW 1997c). These include Federal and State legislation involving all of the major threats, integrated catchment management, for example the Murray–Darling Basin Initiative, long-term monitoring of environmental flow releases and pollution/water quality levels, water industry reform/restructuring (SoEAC 1996; EPA NSW 1997c), and education regarding pollution and habitat degradation (EPA NSW 1997c). These strategies are all being used in more than one State and are therefore transportable to other States.

Conclusions.

- Several strategies which have addressed, or are addressing, the major threats were identified.

- All strategies identified are likely to be transportable to other States and would therefore benefit from a State-by-State cooperative approach.
- Strategies have been identified in other Australian studies. Many of these are also transportable to other States.

Chapter 10. Status.

National.

State of knowledge.

The most recent report of the state of knowledge of freshwater fish in Australia was that included in the report of the Working Group on Ecologically Sustainable Development (Commonwealth of Australia 1991). This report examined the state of knowledge of the species, species groups and stocks for which the State fisheries agencies are responsible. An assessment of this knowledge relating to management and ecologically sustainable development for freshwater species is summarised in Table 11 and given in more detail in Table 12. From these tables it can be seen that there is generally inadequate information for the management of the majority of freshwater fish species throughout Australia.

Table 11. Summary of the status of knowledge of key Australian freshwater fish species, species groups and stocks (from Table 12).

	No. listed in one or more States*
Total no. of species	20
Overfished	4
Fully fished	9
Underfished	7
Uncertain	9
Good/adequate information for management	8
Incomplete/inadequate information for management	16
Good/adequate for information ESD	5
Incomplete/inadequate information for ESD	17
Total no. of alien species	5
Total no. of indigenous species	15
Good/adequate information for management – alien species	5
Good/adequate information for management – indigenous species	3
Good/adequate information for ESD - alien species	4
Good/adequate information for ESD – indigenous species	1

* As some species are listed in different categories for different States the total from each section may not equal the total number of species.

Targeted species.

The species targeted by commercial and recreational fishers in each State are shown in Table 13. This table is not intended as a complete listing of all species caught by recreational and commercial fishers in each state, rather it is intended to convey the major species targeted. Catch data for each State, where available, is presented in the sections which follow.

Table 12. Status of knowledge of Australian freshwater fish species, species groups and stocks (Commonwealth of Australia 1991).

Species	Status	Status of knowledge for		Status	Status of knowledge for		Status	Status of knowledge for	
		Management	ESD		Management	ESD		Management	ESD
	NSW			SA			VIC		
Australian bass	Overfished	Incomplete	Incomplete				Uncertain	Inadequate	Inadequate
Murray cod	Overfished	Incomplete	Incomplete	Overfished	Incomplete	Inadequate	Fully fished	Adequate	Inadequate
Rainbow trout	Fully fished	Adequate	Adequate				Fully fished	Good	Adequate
Carp	Underfished	Incomplete	Incomplete	Underfished	Incomplete	Inadequate	Underfished	Good	Adequate
Long finned eel	Underfished	Inadequate	Inadequate						
Short finned eel	Underfished	Inadequate	Inadequate						
Redfin perch	Underfished	Inadequate	Inadequate	Uncertain	Incomplete	Inadequate	Underfished	Adequate	Incomplete
Freshwater catfish	Uncertain	Incomplete	Incomplete	Overfished	Inadequate	Inadequate			
Golden perch	Uncertain	Incomplete	Inadequate				Fully fished	Incomplete	Inadequate
Brown trout	Uncertain	Adequate	Adequate				Fully fished	Good	Adequate
Bony bream				Underfished	Inadequate	Inadequate			
Yabbie				Underfished	Incomplete	Inadequate	Uncertain	Incomplete	Incomplete
Quinnat salmon							Fully fished	Good	Adequate
Estuarine perch							Uncertain	Inadequate	Inadequate
Crayfish (*Euastacus* spp.)							Fully fished	Incomplete	Inadequate
Macquarie perch							Fully fished	Incomplete	Inadequate
	NT			QLD			WA		
Barramundi	Fully fished	Adequate	Adequate	Fully fished	Adequate	Incomplete	Fully fished	Incomplete	Incomplete
Marron							Fully fished	Good	Incomplete
	TAS								
Lobster (*Astacopis goldi*)	Overfished	Inadequate	Inadequate						
Salmonids	Underfished	Adequate	Adequate						
Blackfish	Uncertain	Inadequate	Inadequate						
Freshwater eel	Uncertain	Inadequate	Inadequate						

Threatened species.

Some of the freshwater fish species targeted by recreational and commercial fishers (Table 13) are found on the Australian Society for Fish Biology listing of threatened species (not shown here, published annually in the Society newsletter). This includes the Mary River cod which is endangered and fished for by recreational anglers in Queensland, however this species is also subject to stocking. Silver perch are listed as potentially threatened, but is a recreational target in both New South Wales and Victoria and is commercially fished in South Australia. Macquarie perch is classified as indeterminate and is on the list of commercial fish species for South Australia and is a recreational target in Victoria. Finally, saratoga is categorised as restricted, but is stocked in Queensland and is subject to recreational fishing.

Table 13. Main species targeted by recreational and commercial fishers in each state.

Common name #	Scientific name	ACT*	NSW*	NT*	QLD*	SA*	TAS*	VIC*	WA*
Barramundi	*Lates calcarifer*			R,C	R,C				R,C
Bass, Australian	*Macquaria novemaculeata*		R,S		R,S				
Blackfish, river	*Gadopsis marmoratus*		R				R		
Bream, bony	*Nematalosa erebi*			R		C			
Carp	*Cyprinus carpio*	R	R,C		R	R,C		R,C	
Catfish, eel-tailed	*Tandanus tandanus*		R		R	R			
Catfish, fork-tailed	*Arius spp.*			R					
Catfish, Lake Argyle	*Arius midgleyi*								C
Cobbler, freshwater	*Tandanus bostocki*								R
Cod, Mary River	*Maccullochella peelii mariensis*				R,S				
Cod, Murray	*Maccullochella peelii peelii*	R	R,C		R,S	R,C		R,C	
Cod, sleepy	*Oxyeleotris lineolatus*			R	R,S				
Crayfish, freshwater	*Astacopsis goldi*						R		
Crayfish, Marron	*Cherax tenuimanus*								R
Crayfish, Murray	*Euastacus armatus*		R						
Crayfish, redclaw	*Cherax quadricarinatus*			R	R				
Crayfish, Yabby	*Cherax destructor*		R,C			R,C		R,C	
Eel, long-finned	*Anguilla reinhardtii*		R,C		C		C	C	
Eel, short-finned	*Anguilla australis*		R,C		C		C	C	
Garfish, snub-nosed	*Arrhamphus sclerolepis*								
Grunter, Barcoo	*Scortum barcoo*								
Grunter, black striped	*Amniataba percoides*			R					
Grunter, sooty	*Hephaestus fuliginosus*			R	R,S				
Herring, freshwater	*Potamalosa richmondia*		R			R			
Mangrove jack	*Lutjanus argentimaculatus*			R	R				
Mullet, freshwater	*Myxus petardi*		R			R			
Mullet, sea	*Mugil cephalus*			R					
Perch, estuary	*Macquaria colonorum*		R			R			
Perch, golden	*Macquaria ambigua*	R	R,C,S		R,S	R,C		R,C	
Perch, jungle	*Kuhlia rupestris*				R				
Perch, Macquarie	*Macquaria australasica*							R	
Perch, redfin	*Perca fluviatilis*	R	R			C		R,C	R
Perch, silver	*Bidyanus bidyanus*		R		R,S	R		R	
Perch, spangled	*Leiopotherapon unicolor*			R	R				
Roach	*Rutilus rutilus*							R	
Salmon, Atlantic	*Salmo salar*		R,S						
Salmon, chinook	*Oncorhynchus tshawytscha*							R	
Saratoga	*Scleropages leichardti*				R,S				
Saratoga, gulf	*Scleropages jardinii*			R					
Tarpon	*Megalops cyprinoides*			R					
Tench	*Tinca tinca*							R	
Trout, brook	*Salvelinus fontinalis*	R	R,S			R,S	R		
Trout, brown	*Salmo trutta*	R	R			R	R	R	R
Trout, rainbow	*Oncorhynchus mykiss*	R	R			R	R	R	R

* R = recreational fishing, C = commercial fishing, S = species is stocked (data from NSW and QLD only)
Data from Kailola et al. (1993), McNee (1990), Wildlife Research and Monitoring Environment ACT, NSW Fisheries, Walters et al. (1997), NT DPIF, NT Amateur Fisherman's Association, Freshwater Fisheries MAC

(1996), QFMA (1997), SA DPI, Davies and Hussey (1996), Fisheries Victoria, Barnham (1997), Recfish West, WAFIC, Fisheries Dept of WA.

Knowledge required.

The State representatives involved in freshwater fisheries management were asked several questions relating to the state of the fisheries (Appendix 2). The results of the questions relating to information required and possible funding agencies have been tabulated and presented in Table 14. The information obtained from the other questions is presented in the following sections.

The information requirements presented in Table 14 fall into four basic groups:

- collection of data relating to the impacts of various threats to fisheries;
- impact of fishing on the resource;
- resource assessment – including different stocks of a single species and
- collection of biological data.

Of these four groups all except the impact of fishing were listed in the requirements given in Chapter 8.

Table 14. Information suggested by State representatives as required to improve our knowledge of Australian freshwater fisheries and suggestions of possible funding agencies.

State	Information required	Possible funding sources*
NSW	Environmental data (e.g. environmental flows, water quality) Information on the recreational fishery Effects of fishing (both commercial and recreational)	State government agencies Recreational licence fees
NT	Development of ecosystem management models as opposed to stock management models Information on the status and distribution of different stocks of the same species	International organisations (development of mgmt tools) State Government FRDC
QLD	Basic biological data – don't have life history data for many species Information on the status and distribution of different stocks of the same species	University groups QDPI NHT FRDC
SA	Resource assessment (underway) Impact of recreational fishing on the freshwater fisheries resource	State Government
TAS	Resource assessment (for both commercial and recreational species) Factors influencing recruitment, production, maximum size (differs from water body to water body) – mainly for recreational species	FRDC
VIC	–	–
WA	None identified	–

*Funding sources do not necessarily correspond to the adjacent information requirement

As mentioned in Chapter 1 the information required to ensure that fishing limits are compatible with ecological sustainability includes biological data (e.g. information on stock structure and size, productivity of the resource and catch history), environmental data (e.g. the reaction of species to natural and anthropogenic changes in their environment, the importance and position of a species in the food web and the interdependence of species) and economic data (fishing effort, profitability and valuations of the environmental resource) (Commonwealth of Australia 1991).

Australian Capital Territory.

There is no commercial fishery in the Australian Capital Territory.

The main species targeted by recreational fishers are Murray cod, trout, golden perch, redfin perch and carp. There are no data available on catch rates or participation rates; creel surveys are not performed and there is no recreational licence system.

New South Wales.

Analysis of historical commercial freshwater catch data (1947/48-1995/96) has been performed (Reid et al. 1997). There are currently 40 commercial freshwater fishers in New South Wales, as compared with 280 in 1973/74, with most of the commercial fishing occurring on the lower Murray River (Reid et al. 1997). Table 15 shows the catch figures for the 1975/76 to 1983/84, and 1992/93 to 1995/96 years. Effort data are also available but are not discussed here.

When carp catch figures are examined, it is seen that the catch has declined markedly since the 1970's, however since 1982/83 it has been relatively stable. The golden perch catch over the last 30 years has been reasonably stable (Reid et al. 1997). Peaks in golden perch production are seen to occur after good flood years (Reid et al. 1997). The 1995/96 catch of Murray cod was the largest since 1981/82, however this catch has been relatively stable over the last 20 years. The yabby catch is seen to vary greatly from year to year. The redfin perch catch shows a gradual decline over the years. Catches of both silver perch and freshwater catfish have declined markedly, the landing of these species has been voluntarily banned by commercial fishers since 1993 (Reid et al. 1997).

Table 15. Commercial catch figures for freshwater species taken in New South Wales waters from 1975/76 to 1983/84 and 1992/93 to 1995/96.

Species	Annual Production (tonnes)*												
	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84	1992/93	1993/94	1994/95	1995/96
Carp	280.4	445.4	547.6	237.7	369.7	217.9	246.6	132.0	218.2	164.6	180.4	148.1	141.1
Golden perch	292.7	241.8	204.5	165.3	116.0	98.4	155.5	105.9	78.4	159.8	173.3	105.4	91.1
Murray cod	19.6	16.6	18.5	20.5	13.3	21.3	29.7	11.5	25.1	7.7	12.4	6.8	25.9
Yabbies	33.5	31.0	9.6	17.6	10.3	8.0	14.9	2.3	44.5	64.9	124.0	73.2	37.3
Redfin perch	37.7	19.9	15.0	4.6	9.5	5.6	3.4	8.4	5.3	2.8	2.6	3.7	4.1
Silver perch	4.5	4.2	4.7	3.0	6.2	6.4	7.4	8.2	5.2	0.4	0.4	0.5	0.3
Eel-tailed catfish	13.1	14.8	9.0	15.4	25.9	11.2	9.9	4.4	2.6	0.1	0.0	0.0	0.0

*Data from Reid et al. (1997).

There is little information available regarding the recreational freshwater fishery. The main species targeted are silver perch, golden perch, Murray cod, eel-tailed catfish, short and long finned eels, Australian bass, estuary perch, Murray crayfish, rainbow trout, brook trout, brown trout, Atlantic salmon, redfin perch and carp.

The recent New South Wales Rivers Survey (Harris and Gehrke 1997) has provided information on native species and alien species in New South Wales waters. This report showed that less fish (both total abundance and species diversity) were found in the Murray region compared to other New South Wales regions sampled. It also showed that the main inland recreational and commercial species in the Murray region (Murray cod, eel-tailed catfish, silver perch and golden perch) appear to be declining. It was found that 62% of native fish species in New South Wales have shown a decrease in either range or abundance, or have restricted distributions; making these species particularly susceptible to environmental disturbance (Schiller et al. 1997). Alien fish species (brown trout, rainbow trout, redfin perch, gambusia (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and carp) accounted for 18.4% of all fish caught during the survey. The highest proportion of alien species was found in the Murray region (57.5%) compared to 25.1% for the Darling region, 9.1% for the South Coast region and 8.7% for the North Coast region (Faragher and Lintermans 1997).

A list of the information required to improve the knowledge of the freshwater fishery in New South Wales and possible funding agencies for this work is given in Table 14.

Northern Territory.

There is a great deal of information available regarding the main commercial and recreational 'freshwater' species, barramundi, in the Northern Territory (see Fallu 1997b; Walters et al 1997).

There are currently 28 commercial fishers licensed to take barramundi (Fallu 1997b). In the late 1970s catch/effort figures began to decline which lead to changes in the management of the fishery. Since this time barramundi catches have risen and now appear relatively stable (Table 16). Effort data are also available, but are not discussed here.

Table 16. Commercial catch figures for barramundi taken in Northern Territory waters from 1972 to 1996.

Annual catch (tonne)*													
1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
382	431	656	432	-	1054	820	745	532	764	856	607	632	592
1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	-	-	-
438	482	508	599	454	433	389	466	447	502	542	-	-	-

*Data from (Fallu 1997b).

Estimates indicate that the barramundi populations in the Mary and Kakadu Rivers are under-exploited by commercial fishers (less than 3% of the stocks are taken by commercial fishers annually); while the populations in the Daly, McArthur, and Roper Rivers are exploited commercially at the maximum sustainable level (10-20% taken annually by commercial fishers) (Walters et al 1997).

Each year an estimated 5-10% of the Mary River juvenile barramundi stock is taken by recreational anglers, recreational catch estimates are not available for other Northern Territory rivers (Walters et al. 1997). In a survey of recreational fishing in the Northern Territory it was estimated that a total of 103,431 barramundi were taken over a 17 month period from 1994-1996, other species targeted by recreational fishers were taken in much smaller numbers (Coleman 1998).

It is known that there is also an indigenous fishery for barramundi, however the level of utilisation is unknown (Fallu 1997b).

A fishery for aquarium species exists in the Northern Territory. This targets a large number of freshwater species which are taken in reasonably small numbers (<10 – 13,581 individuals) with an average of <1300 individuals over all species taken (Fallu 1997a).

A list of the information required to improve the knowledge of the freshwater fishery in Northern Territory and possible funding agencies for this work is given in Table 14.

Queensland.

The only commercial freshwater fishery currently operating in Queensland is the eel fishery. No landing data are available for this fishery, however it is known that there are about 60 licensed eel fishers (Freshwater Fisheries MAC 1996).

A telephone survey of recreational fishers in Queensland found that 28.8% of those surveyed had taken part in freshwater angling in the year October 1995 - September 1996 (QFMA, 1997). Data regarding the number of fish caught was also collected. The main species targeted are presented in Table 13.

Stocking has led to the establishment of fisheries in several impoundments. These fisheries rely on an ongoing program of stocking (QDPI 1998).

Legislation is in place regarding indigenous fishing (Freshwater Fisheries MAC 1996), but there is no published information on the size of this fishery.

A list of the information required to improve the knowledge of the freshwater fishery in Queensland, and possible funding agencies for this work is given in Table 14.

South Australia.

There are two main freshwater fisheries in South Australia. The first is the River fishery which is based on the Murray River; the second is the Lakes and Coorong fishery which is based on Lake Alexandrina, Lake Albert and the Coorong. Together they form the Inland Waters Fishery. There are currently no stock assessment data available for this fishery. A subjective assessment of the status of fish stocks in the Lakes and Coorong fishery has been made (IFMC 1998). Of the freshwater species taken in this fishery the status of bony bream and golden perch is thought to be 'sustainable', yabbies 'unknown', while carp are listed as 'exotic' (IFMC 1998). Sustainable implies that the 'stock is currently maintained on a long term basis taking into account natural fluctuations in environmental parameters', unknown that 'there is a lack of information, a realistic assessment is not possible' and 'exotic' that the 'stock is introduced and is being actively minimised to reduce abundance' (IFMC 1998). SARDI is currently carrying out a stock assessment for both the River and Lakes and Coorong fisheries (Miller, S., PIRSA, pers. comm., 1998). This should allow more accurate estimates of the status of fish stocks to be made.

Catch data from the Inland Waters fishery is shown in Table 17. These figures show that the carp catch has increased markedly over the last 20 years, however it has been relatively stable over the last three years. The bony bream and golden perch catches have also increased markedly over the last 20 years, with a slight decline over the last three years. The Murray cod catch has been very unstable.

Table 17. Commercial catch figures for the Inland Fishery (River fishery and Lakes and Coorong fishery) of South Australia from 1976/77 to 1983/84, 1986/87 to 1987/88 and 1994/95 to 1996/97.

Species	Annual catch (tonnes)												
	1976 /77*	1977 /78*	1978 /79*	1979 /80*	1980 /81*	1981 /82*	1982 /83*	1983 /84*	1986 /87*	1987 /88*	1994 /95^	1995 /96^	1996 /97^
Carp	122.8	64.9	95.9	56.1	23.9	127.6	44.8	102.2	48.0	19.0	904.0	876.0	911.0
Bony bream	22.0	30.4	31.4	55.3	16.1	42.3	42.4	18.7	17.0	12.0	888.0	752.0	734.0
Golden perch	122.7	78.3	116.5	53.2	29.0	100.9	36.8	96.6	43.0	29.0	286.0	293.0	235.0
Murray cod	3.5	4.1	10.9	8.1	9.7	18.4	6.0	8.0	7.0	5.0	1.0	3.0	6.0
Others	0.7	0.2	1.0	0.3	0.6	0.3	0.7	0.1	-	-	802.0	792.0	766.0

* Data from McNee (1990)
^ Data from South Australian Research and Development Institute

There are no data available for the recreational fishery.

A list of the information required to improve the knowledge of the freshwater fishery in South Australia and possible funding agencies for this work is given in Table 14.

Tasmania.

The only commercial freshwater fishery currently operating in Tasmania is the eel fishery. The history of this fishery is well understood, however there is no information available regarding the size of the resource. Based on historical data it is inferred that the fishery is sustainable at current levels (Fulton, W., IFC, pers. comm., 1998).

The recreational fishery in Tasmania brings about $30 million into the State each year from out-of-State fishers. The main species targeted are brown trout, rainbow trout, brook trout and some Atlantic salmon. It is recognised that the fishery is sustainable at current levels (Fulton, W., IFC, pers. comm., 1998)

No catch data are available for either the commercial or recreational fisheries.

A list of the information required to improve the knowledge of the freshwater fishery in Tasmania and possible funding agencies for this work is given in Table 14.

Victoria.

The main commercial freshwater fishery in Victoria is the eel fishery; there are currently 18 licensed commercial eel fishers (MAFRI 1997). There are also six fishers licensed for the Inland fishery (MAFRI 1997), the species targeted here are listed in Table 13. A catch and effort database is maintained by MAFRI for the Victorian Fisheries Division of Natural Resources and Environment. Commercial catch figures from 1992/93 to 1996/97 for carp and short-finned eel are shown in Table 18. The data show that catches for both eels and carp have been relatively unstable over this period.

Table 18. Commercial catch figures for carp and short-finned eel taken in Victorian waters from 1992/93 to 1996/97.

Species	Annual catch (tonnes)*				
	1992/93	1993/94	1994/95	1995/96	1996/97
Carp	469	415	372	437	556
Eel, short-finned	324	342	245	208	184

* Data from MAFRI 1997.

A 1996 survey of recreational fishing in Victoria showed that 37% of anglers fished only in freshwater rivers and lakes. Of these 49% targeted trout, 38% redfin perch, 17% Murray cod, 16% golden perch, 7% carp, 2% Macquarie perch, 1.5% chinook salmon, 1% eels, and 1% yabbies (Barnham 1997).

There is a large stocking program in Victoria which supplies lake fisheries with both natives and trout, and river fisheries with trout. The trout fisheries are a mixture of self-sustaining and stocked populations (Brown, P., MAFRI, pers. comm., 1998). Creel surveys are regularly performed on a few stocked reservoirs (Brown, P., MAFRI, pers. comm., 1998). Annual fisheries assessments are also performed on several reservoirs to determine the level of stocking required (e.g. Brown and Douglas 1998a; Brown and Vallis 1998).

Western Australia.

There are two commercial freshwater fisheries in Western Australia, both are centred on the Kimberley region; one for Lake Argyle catfish and the other for barramundi. These fisheries are well monitored. Status reports are produced yearly for both fisheries by the Fisheries Department of Western Australia. These reports cover catch/effort, stock assessment, exploitation status and breeding stock levels. According to the 1996-1997 report (Fisheries Department of WA 1997c) the Lake Argyle catfish fishery is unsustainable at current levels, while the barramundi fishery is fully-exploited but sustainable. Catch figures for both fisheries are presented in Table 19.

The two main recreational freshwater fisheries are the marron fishery and the angling fishery for trout, redfin perch and freshwater cobbler. Both of these fisheries are licensed, with a separate licence required for each. Information on these fisheries is also presented in the status reports produced by the Fisheries Department of Western Australia. According to the 1996-97 report (Fisheries Department of WA 1997c), marron stocks in rivers are improving while stocks in dams are below optimal levels; no stock assessment details are given for the angling fishery.

Table 19. Commercial catch figures for Lake Argyle catfish and barramundi taken in Western Australian waters from 1976/77 to 1995/96.

Species	Annual catch (tonne)*									
	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86
Lake Argyle catfish	–	–	–	19.6	5.6	5.7	25.6	40.3	25.3	76.8
Barramundi	22.9	35.3	32.7	24.2	30.8	27.9	60.7	54.3	60.0	44.4
	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96
Lake Argyle catfish	67.1	106.4	133.1	112.1	122.2	119.7	100.0	99.0	117.7	128.9
Barramundi	58.6	68.9	44.9	56.0	61.3	59.2	45.8	39.6	39.3	45.6

* Data from Fisheries Department of WA (1997c).

Conclusions.

From the preceding discussions it is seen that few States have adequate data describing the sustainability of their freshwater fisheries resources. The information required includes resource status, biological, environmental and economic data.

Chapter 11. Strategy for coordinating and funding new research.

Introduction.

This chapter satisfies an objective of the project: 'to propose a strategy for coordinating and funding new research relevant to ensuring the sustainability of Australia's freshwater fisheries resources'. Potential cooperating and possible funding agencies are identified as are strategies for cooperative support among those funding agencies.

Methods and Results.

The information used in this chapter was compiled from interviews with the State representatives discussed in Chapter 3. The State representatives were asked 'Which organisations should be approached for funding?' for each of the five threats identified in each State (Appendix 2). The results from the State representatives were combined within each State and are presented in Appendix 15.

Table 20 summarises the possible funding agencies identified in Appendix 15. Funding agencies have not been separated by knowledge requirement or threats, but are simply presented as a list. This list is not exhaustive. It is provided to give an indication of the organisations to which fisheries managers and researchers apply for the funding of projects involved with the six major threats. This list has been produced solely from information provided by the freshwater fisheries researchers and managers interviewed.

Table 20. Possible funding sources for projects involved with the six major threats (based on interviews with the State representatives).

Possible funding sources
Agriculture departments
Catchment management authorities
Commonwealth Government
CRCFE
Environment Australia
EPAs
Fisheries agencies
FRDC
Industries impacting fisheries e.g. power stations, cotton growers, mining
Landcare
Local Government
LWRRDC
MDBC
National Carp Taskforce
Natural resource agencies
NCCCG
NHT
PhD student on scholarship or ARC grant
State Government
Vertebrate Biocontrol CRC
Water management agencies
Water users

Agencies involved in the monitoring and management of the six major threats were identified in Appendix 13 (Chapter 7). These agencies are also those with the potential to cooperate in strategies for addressing each of the major threats.

Inherent in the design of this project is a commitment for the Principal Investigator to work with FRDC to develop and pursue a strategy for coordinating support for research relevant to ensuring the sustainability of Australia's freshwater fisheries resources. The first stage in this process is the completion of this report on issues affecting that sustainability. Secondly is the need to obtain endorsement of the principle findings by FRDC and acceptance that there is merit in pursuing a coordinated approach to supporting key research areas. Thirdly is the adoption of an appropriate strategy. As stages two and three follow completion and acceptance of this report only a tentative proposal for a strategy can be given at this time. This strategy is outlined under the Discussion to this Chapter.

Discussion.

The available data plus input from the Steering Committee suggest that projects with a well-designed monitoring component should be given priority by funding agencies. The need for monitoring of management actions was stressed for several of the major threats (Appendix 17). Also worthy of consideration are future studies that take advantage of data already collected by agencies but not currently being fully utilised; for example data collected by water management authorities which would be relevant to fisheries resource assessments.

The Steering Committee concluded that FRDC could benefit by concentrating on projects which shed light on general principles as opposed to specifics. Projects which are very specific should only be considered if they are applicable to many geographic areas or if they can be used as an example for future work; that is they are truly of national significance. Agencies such as local Government bodies or land and water management authorities may have a role in carrying out area specific projects. However, coordination of any projects undertaken is required to reduce duplication of effort and to ensure that these projects are of national significance.

In reducing the 41 threats identified in the national survey to a prioritised list of the six major threats (Figure 1), the inter-relationships between component threats are emphasised. This provides research and funding agencies with a mechanism of cross-referencing current and potential projects and relating them to the six primary threats. It therefore represents a framework for a nationally coordinated grid of six programs (the six key threats) with multiple projects.

It must also be stressed that the knowledge requirements identified for each of the six major threats are relevant to the 41 component threats identified in the national survey. For example the knowledge requirements for pollution (major threat number 2) are relevant for the components water quality, nutrient levels, algal blooms, urbanisation and acid sulfate soils (see Appendix 17). This identification of commonality of knowledge requirements and therefore broad relevance of subsequent research is a major output from this analysis. It allows funding agencies to gain national perspective on research projects, ongoing or proposed, on any of the 41 component threats. It should greatly facilitate the development of a national strategy for coordinating and supporting future freshwater fisheries research in Australia.

In light of the comments it is suggested that FRDC develop a strategy for allocating primary funding responsibilities between the numerous agencies which support the pursuit of knowledge on freshwater management and ecosystem conservation. For example, FRDC may be the major contributor to projects examining the effects of pollution on species important to freshwater fisheries. Other more appropriate agencies could be the major contributor to projects such as those examining the source of pollution, its retention in sediments, or its effects on other freshwater flora and fauna.

In order to develop this strategy the FRDC has agreed to hold a public launch of the project results in May and encouraged participants to attend a workshop immediately following the launch.

Chapter 12. Conclusions.

Project objectives.

Project objectives were to:

- identify the major threats to sustainability of freshwater fisheries resources in each State and Territory (Chapter 4);
- identify probable primary causes for the most significant threats in each State and Territory (Chapter 6);
- assess which threats could be approached by a national or State by State cooperative strategy for research (Chapter 8); and
- propose a strategy for coordinating and funding new research relevant to ensuring the sustainability of Australia's freshwater fisheries resources (Chapter 11).

Project outcomes.

It is realised that the national survey performed in this study was not exhaustive; many other organisations could have been contacted. However, it was concluded that it was most unlikely that new threats of high priority would be identified by contacting further organisations. Those contacted were more than adequate to allow the identification and ranking of nationwide threats to the sustainability of Australia's freshwater fisheries resources. The survey also gave representative coverage of organisations throughout Australia.

It was determined that the major threats to the sustainability of Australia's freshwater fisheries are:

- habitat degradation;
- pollution/water quality/water temperature;
- reduced environmental flows;
- barriers to migration;
- introduced species; and
- fishing.

All were found to be of nationwide significance and to fall within the R&D funding charter of FRDC to at least some extent.

Several causes were identified for each of the major threats, with many being implicated in more than one threat. Several of the causes were determined to be of concern nationwide.

With the exception of fishing, both the monitoring and management of the major threats were found to be fragmented. Such fragmentation leads to ineffective data collection and management of the major threats.

Knowledge required to address the major threats was identified. All of the requirements are best approached on a cooperative basis with inter-State, and possibly national, coordination an advantage.

Several strategies which have addressed, or are addressing, the major threats were identified. All are likely to be transportable to other States and would benefit from a State-by-State cooperative approach.

Few States currently have data relating to the sustainability of their fisheries resources. Necessary information includes biological data (e.g. information on stock structure and

size, productivity of the resource and catch history), environmental data (e.g. the reaction of species to natural and anthropogenic changes in their environment, the importance and position of a species in the food web and the interdependence of species) and economic data (fishing effort, profitability and valuations of the environmental resource) (Commonwealth of Australia 1991). Further stock assessment data from the commercial, recreational and indigenous sectors is required to improve the management of freshwater fisheries. There also needs to be greater recognition of the existence of indigenous freshwater fisheries.

In general, there needs to be more emphasis on communicating the outcomes of research to managers, and more documentation of the response from managers. This means that the research/ management/ policy interface must be improved.

Benefits.

Beneficiaries.

In the original application the beneficiaries of this project were identified as:

- commercial and recreational fishing industries;
- freshwater fisheries managers;
- natural resource management agencies;
- Aboriginal community leaders;
- local government agencies; and
- research funding agencies with an interest in fisheries, water conservation and management.

Completion of the project has not changed this list of beneficiaries.

Benefits.

By providing annotated listings of the problems encountered in each State and Territory, and of relevant research and management already undertaken or proposed, the project will benefit all of the above groups by:

- identifying major issues;
- demonstrating inter-relationships between fisheries issues and those of other water use and management interests;
- highlighting key sources of information (data and knowledge) relevant to specific problems;
- identifying knowledge gaps;
- suggesting future approaches;
- promoting cooperation between groups with similar problems or responsibilities;
- preventing overlap or duplication; and
- facilitating the best use of Australia's research resources.

These benefits were identified in the original project application. They have not changed on completion of the project.

Further development.

As discussed in Chapter 11 the Principal Investigator will work with the FRDC Executive to promote a coordinated strategy to support pursuit of the knowledge requirements identified in this study.

Intellectual property.

Methods and outcomes of this project will be published in the scientific literature.

There is no information in this report of a confidential or commercially sensitive nature.

Staff.

Professor Robert Kearney, Principal investigator.

Dr Karyn Davis, Project leader.

Kerry Beggs, Technical assistant.

Acknowledgments.

The authors gratefully acknowledge the members of the Steering Committee; Rod Coombs, Jane Doolan, Wayne Fulton, Peter Jackson, Klaus Koop, Noel Morrissy, Stephan Schnierer, Trevor Simmonds. Sincere thanks also to the State representatives from the following agencies: NSW Fisheries, Department of Primary Industries and Fisheries – Northern Territory, Queensland Fisheries Management Authority, Queensland Department of Primary Industries, South Australian Research and Development Institute, Primary Industries and Resources South Australia, Inland Fisheries Commission – Tasmania, Natural Resources and Environment – Victoria, Marine and Freshwater Resources Institute – Victoria and Fisheries Department of Western Australia. Individual State representatives are not named due to a desire to protect the confidentiality of their input. Thank you also to members of those organisations who responded to the national survey and to those who supplied documentation where requested.

Abbreviations and definitions.

ACIAR	Australian Centre for International Agricultural Research
ACT	Australian Capital Territory
AGPS	Australian Government Publishing Service
ANU	Australian National University
ANZECC	Australian and New Zealand Environment and Conservation Council
AQIS	Australian Quarantine and Inspection Service
ARC	Australian Research Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CALM	Conservation and Land Management
CCISR	Centre for Catchment and In-Stream Research, Griffith University
CEO	Chief Executive Officer
CIG	Climate Impact Group
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CRCCH	Cooperative Research Centre for Catchment Hydrology
CRCFE	Cooperative Research Centre for Freshwater Ecology
CRCSLM	Cooperative Research Centre for Soil and Land Management
CRCWMPC	Cooperative Research Centre for Waste Management and Pollution Control
CRCWQT	Cooperative Research Centre for Water Quality and Treatment
CRES	Centre for Resource and Environmental Studies, Australian National University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEHAA	Department of Environment, Heritage and Aboriginal Affairs
DELM	Department of Environment and Land Management
DIST	Department of Industry, Science and Tourism
DLPE	Department of Lands, Planning and Environment
DLWC	Department of Land and Water Conservation
DNR	Department of Natural Resources
DPI	Department of Primary Industries
DPIF	Department of Primary Industry and Fisheries
EPA	Environment Protection Authority
ERISS	Environmental Research Institute of the Supervising Scientist
ESD	Ecologically Sustainable Development
FRAB	Fisheries Research Advisory Board
FRDC	Fisheries Research and Development Corporation

IFC	Inland Fisheries Commission
IFMC	Inland Fisheries Management Committee
IMEF	Integrated Monitoring of Environmental Flows
ISNAR	International Service for National Agricultural Research
LWRRDC	Land and Water Resources Research and Development Corporation
MAC	Management Advisory Committee
MAFRI	Marine and Freshwater Resources Institute
MDB	Murray-Darling Basin
MDBC	Murray-Darling Basin Commission
NCCCG	National Carp Control Coordinating Group
NHT	Natural Heritage Trust
NPWS	National Parks and Wildlife Service
NRE	Natural Resources and Environment
NRMS	Natural Resources Management Strategy
NS ESD	National Strategy for Ecologically Sustainable Development
NSW	New South Wales
NT	Northern Territory
PIRSA	Primary Industry and Resources South Australia
QCFO	Queensland Commercial Fishermen's Association
QDPI	Queensland Department of Primary Industries
QFMA	Queensland Fisheries Management Authority
QLD	Queensland
QMDBCC	Queensland Murray-Darling Basin Coordinating Committee
R&D	Research and Development
RIRDC	Rural Industries Research and Development Corporation
SA	South Australia
SAFIC	South Australian Fishing Industry Council
SARDI	South Australian Research and Development Institute
SCA	Standing Committee on Agriculture
SoEAC	State of the Environment Advisory Council
TAS	Tasmania
TDEP	Tasmanian Department of Environment and Planning
UNE	University of New England
VBCRC	Vertebrate Biocontrol Cooperative Research Centre
VIC	Victoria
WA	Western Australia
WAFIC	Western Australian Fishing Industry Council
WRAP	Water Resource Allocation and Planning

WWF	Worldwide Fund for Nature

State	refers to States and Territories unless otherwise specified.

The following definitions were taken from Harris (1995) and Arthington and McKenzie (1997):

Alien	an exotic species which is now established.
Endemic	a species occurring within a natural range or localised area.
Established	an introduced species which has formed a self-maintaining population.
Exotic	a species not naturally found in or established in Australian waters.
Indigenous	a species originating and occurring naturally in Australia (native).
Introduced	a species (exotic or translocated) brought in or established.
Translocated	a species moved to new areas within its natural range or outside of its natural range, displaced.

References.

Abramovitz, J.N. 1996, *Imperiled waters, impoverished future: The decline of freshwater ecosystems*, Worldwatch Paper 128, Worldwatch Institute, Washington D.C.

Alexander, G.R. and Hansen, E.A. 1986, 'Sand bed load in a brook trout stream', *North American Journal of Fisheries Management*, 6: 365–372.

Allan, J.D. 1995, *Stream Ecology. Structure and function of running waters*, Chapman and Hall, London.

Allan, J.D. and Flecker, A.S. 1993, 'Biodiversity conservation in running waters', *Bioscience*, 43: 32–43.

Allan, J.D., Erickson, D.L. and Fay, J. 1997, 'The influence of catchment land use on stream integrity across multiple spatial scales', *Freshwater Biology*, 37: 49–161.

Allen, G.R. 1989, *Freshwater fishes of Australia*, TFH Publications, New Jersey.

Allen, J. and Lovett, S. 1997, *Impediments to managing environmental water provisions*, Bureau of Resource Sciences, Canberra.

Armour, C. 1991, 'Guidance for evaluating and recommending temperature regimes to protect fish', *U.S. Fish and Wildlife Service Biological Report*, 90(22), Instream Flow Information Paper 27.

Arthington, A.H. 1991, 'Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia', *Canadian Journal of Fisheries and Aquatic Science*, 48: 33–43.

Arthington, A.H. 1998, 'Rapid procedure for practical in–stream flow assessments, Final report 1998', LWRRDC Project GRU–18, Centre for Catchment and In–Stream Research, Griffith University, Brisbane.

Arthington, A.H. and McKenzie, F. 1997, *Review of impacts of displaced/introduced fauna associated with inland waters*, Australia: State of the Environment Technical Paper Series (Inland Waters), Department of the Environment, Canberra.

Arthington, A.H. and Zalucki, J.M. 1998, *Water for the environment: recent approaches to assessing and providing environmental flows*, Australian Water and Wastewater Association, Brisbane.

Arthington, A.H., Bycroft, B.M. and Conrick, D.L. 1992, *Environmental study: Barker–Barambah Creek, Volume 1: Executive Summary*, Water Resources Commission, Department of Primary Industries, Queensland and Centre for Catchment and In–stream Research, Griffith University.

Arthington, A.H., Milton, D A. and McKay, R.J. 1983, 'Effects of urban development and habitat alterations on the distribution and abundance of native and exotic freshwater fish in the Brisbane region, Queensland', *Australian Journal of Ecology*, 8: 87–101.

Ault, T.R. and White, W.G. 1994, 'Effects of habitat structure and the presence of brown trout on the population density of Galaxias truttaceus in Tasmania, Australia', *Transaction of the American Fisheries Society*, 123: 939–949.

Australian Water and Wastewater Association. 1994, *Proceedings of the environmental flows seminar*, Canberra 25–26 August 1994, Australian Water and Wastewater Association Incorporated, Sydney.

Bacher, G.J. and O'Brien, T.A. 1988, *The sensitivity of Australian freshwater organisms to heavy metals*, Scientific Report Series no 88/018, Victorian Environmental Protection Agency, Melbourne.

Baker, R. 1990, 'The impact of tourism on the Aboriginal community of the Borroloola area of the Northern Territory', paper presented to the Institute of Australian Geographers 24th Conference, Armidale 24 September 1990.

Barmuta, L.A. 1990, 'Ecology of aquatic invertebrates and the effects of toxic agents on aquatic systems', *Wetlands, their conservation, ecology, function, restoration and management*, Proceedings of the Applied Ecology and Conservation Seminar Series, Wildlife Reserves, La Trobe University, Oct–Dec 1989, pp25–29.

Barnham, C. 1997, *A report on the 1996 tracking survey on fishing in Victoria*, Fisheries Victoria, Natural Resources and Environment, Melbourne.

Barthalow, J.M. 1989, 'Stream temperature investigations: field and analytical methods', *U.S. Fish and Wildlife Service Biological Report*, 89(17) Instream Flow Paper 13.

Barton, J.L. and Davis, P.E. 1993, 'Buffer strips and streamwater contamination by atrazine and pyrethroids aerially applied to *Eucalyptus nitens* plantations', *Australian Forestry*, 56: 201–210.

Bayley, P.B. 1991, 'The flood pulse advantage and the restoration of river–floodplain systems', *Regulated rivers: Research and management*, 6:75–86.

Bayley, P.B. and Li, H.W. 1992, 'Riverine fishes', *The Rivers Handbook Volume 1*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp251–281.

Bell, J., Cullen, P., Blackmore, D., Simpson, C., Davis, R., Price, P., Walker, R. and Forsyth, D. 1996, *Managing Australia's Inland Waters*, A paper prepared for the Prime Minister's Science and Engineering Council, Department of Industry, Science and Tourism, Commonwealth of Australia.

Bennett, P. 1997, 'Towards a State Fishway Program', *Second national fishway technical workshop proceedings*, June 1997 Rockhampton, eds A.P. Berghuis, P.E. Long and I.G. Stuart, Fisheries Group, Department of Primary Industries, Queensland, pp9–18.

Berghuis, A.P., Long, P.E. and Stuart, I.G. 1997, *Second national fishway technical workshop proceedings*, June 1997 Rockhampton, Fisheries Group, Department of Primary Industries, Queensland.

Berkman, H.E. and Rabeni, C.F. 1987, 'Effect of siltation on stream fish communities', *Environmental Biology of Fishes*, 18: 285–294.

Betschta, R.L. 1978, 'Long–term patterns of sediment production following road construction and logging in the Oregon Coast Range', *Water Resources Research*, 14: 1011–1016.

Bevitt, R., Erskine, W., Gillespie, G., Harris, J., Lake, P.S., Miners, B. and Varley I. 1998, *Expert panel environmental flow assessment of various rivers affected by the Snowy Mountains Scheme*, Report to the NSW Department of Land and Water Conservation.

Billyard, R. n.d., *Fishcare – Our Freshwater Rivers and Streams*, Fishnote DF/33, NSW Fisheries.

Bishop, K.A. and Bell, J.D. 1978, 'Observations on the fish fauna below Tallowa Dam, Shoalhaven River, New South Wales, during river flow stoppages', *Australian Journal of Marine and Freshwater Research*, 29: 543–549.

Boon, P., Frankenberg, J., Hillman, T., Oliver, R. and Shiel, R. 1990, 'Billabongs', *The Murray*, eds N. Mackay and D. Eastburn, Murray-Darling Basin Commission, Canberra, pp183-198.

Boulton, A.J. and Lloyd, L.N. 1992, 'Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia', *Regulated rivers: Research and management*, 7: 137–151.

Bren, L.J. 1988, 'Effects of river regulation on flooding of a riparian red gum forest on the river Murray, Australia', *Regulated rivers: Research and management*, 2: 65–77.

Bren, L.J. 1992, 'Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia', *Australian Journal of Ecology*, 17: 395–408.

Brooks, A. 1994, 'River Channel Change', *The Rivers Handbook Volume 2*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp55-75.

Brown, P. 1996, 'Carp in Australia', *Fishfacts*, 4, NSW Fisheries.

Brown, P. and Douglas, J. 1998a, *Lake Cullulleraine fisheries assessment January 1998*, MAFRI Freshwater Division Fish Survey 98/5, Freshwater Division, Fisheries Program, Marine and Freshwater Resources Institute, Snobs Creek, Victoria.

Brown, P. and Douglas, J. 1998b, *Evaluation of operational river management works and aquatic habitat restoration in the mid–Broken River catchment, Progress report – January 1998*, Freshwater Division, Fisheries Program, Marine and Freshwater Resources Institute, Snobs Creek, Victoria.

Brown, P. and Vallis, S. 1998, *Toolondo Reservoir fisheries assessment March 1998*, MAFRI Freshwater Division Fish Survey 98/9, Freshwater Division, Fisheries Program, Marine and Freshwater Resources Institute, Snobs Creek, Victoria.

Brown, P., McKinnon, L. and Strongman, R. 1997a, *A preliminary assessment of fish passage at Rice's Weir fishway, November 1997*, MAFRI Freshwater Division Fish Survey 97/15, Freshwater Division, Fisheries Program, Marine and Freshwater Resources Institute, Snobs Creek, Victoria.

Brown, P., McKinnon, L., Gasior, R. and Douglas, J. 1997b, *Broken Creek Pre–fishway assessment, March–April 1997*, MAFRI Freshwater Division Fish Survey 97/9, Freshwater Division, Fisheries Program, Marine and Freshwater Resources Institute, Snobs Creek, Victoria.

BRS, In preparation, *Managing the impacts of carp*, Bureau of Resource Sciences, Australia.

Bruton, M.N. 1995, 'Have fishes had their chips? The dilemma of threatened fishes', *Environmental Biology of Fishes*, 43: 1–27.

Buchhorn, R. 1997, *Boobera Lagoon: a focus for reconciliation*, Catholic Social Justice Series No. 30, Australian Catholic Social Justice Council.

Buckney, R.T. 1995, 'Water pollution, biodiversity and the effectiveness of water quality criteria', *Conserving biodiversity: threats and solutions*, eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen, Surrey Beatty and Sons, pp137-143.

Bunbury, E. 1987, *The effects of gauging station control structures on native fish migration in freshwater streams of south west Australia*, Bulletin No. 282, Environmental Protection Authority Perth, Western Australia.

Bunn, S., Morrish, B. and Fairweather, L. 1997 (Draft), 'The Cooper's Creek Institute for Arid Zone Wetland and River Research'.

Bunn, S.E. 1993, 'Riparian–stream linkages: research needs for the protection of in–stream values', *Australian Biologist*, 6: 46–51.

Burchmore, J.J. 1990, 'Implications of the greenhouse effect for native freshwater fishes in New South Wales', *Wetlands (Australia)*, 10: 30–32.

Cadwallader, P. 1978, 'Some causes of the decline in range and abundance of native fish in the Murray–Darling River system', *Proceedings of the Royal Society of Victoria*, 90: 211–224.

Cadwallader, P. 1981, 'Past and present distributions and translocations of Macquarie Perch *Macquaria australasica* (Pisces: Perchichthyidae), with particular reference to Victoria', *Proceedings of the Royal Society of Victoria*, 93: 23–30.

Cadwallader, P. and Lawrence, B. 1990, 'Fish', *The Murray*, eds N. Mackay and D. Eastburn, Murray–Darling Basin Commission, Canberra, pp316–335.

Cadwallader, P.L., Eden, A.K. and Hook, R.A. 1980, 'Role of streamside vegetation as a food source for *Galaxias olidus* Gunther (Pisces: Galaxiidae)', *Australian Journal of Marine and Freshwater Research*, 31: 257–262.

Cambray, J.A. 1991, 'The effects on fish spawning and management implications of impoundment water releases in an intermittent South African river', *Regulated rivers: Research and management*, 6: 39–52.

Campbell, I.C. 1993, 'Riparian stream linkages: an Australian perspective on in–stream issues', *Ecology and management of riparian zones in Australia*, Occasional Paper no. 05/93, eds S.E. Bunn, B.J. Pusey and P. Price, LWRRDC, pp21-30.

Campbell, I.C. and Doeg, T.J. 1989, 'Impact of timber harvesting and production on streams: a review', *Australian Journal of Marine and Freshwater Research*, 40: 519–539.

Cappo, M., Alongi, D.M., Williams, D.McB. and Duke, N. 1998, *A review and synthesis of Australian fisheries habitat research, major threats, issues and gaps in knowledge of coastal and marine fisheries habitats – Volume 1: A prospectus of opportunities for the FRDC "Ecosystem Protection Program"*, Final report to FRDC, project no. 95/055, Australian Institute of Marine Science.

CARE. 1994, 'Irrigation Management Planning – the 1994 Irrigation Management Field Day and Workshop Program', CARE Murray–Darling Basin South Australia.

Carter, D. 1997, *State of the rivers Lockyer Creek and major tributaries – An ecological and physical assessment of the condition of streams in the Lockyer Creek catchment*, Department of Natural Resources Queensland.

Caughley, A. 1990, 'Victorian native fish – distribution and conservation with particular reference to non–riverine habitats', *Wetlands, their conservation, ecology, function, restoration and management*, Proceedings of the Applied Ecology and Conservation Seminar Series, Wildlife Reserves, La Trobe University Oct–Dec 1989, pp87–88.

CCISR. 1997, *Summary of CCISR*, http://www.gu.edu.au/research.

Chessman, B. and Jones, H. 1998, *Integrated Monitoring of Environmental Flows scoping report*, Department of Land and Water Conservation, New South Wales.

Chessman, B.C., Robinson, D.P. and Hortle, K.G. 1987, 'Changes in the riffle macroinvertebrate fauna of the Tanji River, southeastern Australia, during construction of Blue Rock Dam', *Regulated rivers: Research and management*, 1: 317–329.

CIG 1996. *Climate change Scenarios for the Australian Region*, Climate Impact Group, CSIRO Division of Atmospheric Research, Melbourne.

Close, A. 1988, 'Potential impact of greenhouse effect on the water resources of the River Murray', *Greenhouse: planning for climate change*, ed G.I. Pearman, CSIRO, Australia, pp312–323

Close, A. 1990a, 'River salinity', *The Murray*, eds N. Mackay and D. Eastburn, Murray-Darling Basin Commission, Canberra, pp126–144.

Close, A. 1990b, 'The impact of man on the natural flow regime', *The Murray*, eds N. Mackay and D. Eastburn, Murray-Darling Basin Commission, Canberra, pp60–74.

Closs, G. 1990, 'Ecology of fish and their role in wetlands', *Wetlands, their conservation, ecology, function, restoration and management*, Proceedings of the Applied Ecology and

Conservation Seminar Series, Wildlife Reserves, La Trobe University Oct–Dec 1989, pp89–95.

Cod Radiotracking Project. 1995, 'Snag management', *Codwatch Newsletter*, 8, Conservation and Natural Resources, Victoria.

Coleman, A.P.M. 1998, *Fishcount: a survey of recreational fishing in the Northern Territory, Summary*, Fishery Report No. 41, Department of Primary Industry and Fisheries.

Commonwealth of Australia. 1991, Ecologically Sustainable Development Working Groups, Final Report – Fisheries, AGPS, Canberra.

Cotterell, E. 1998, *Fish passage in streams: fisheries guidelines for design of stream crossings*, Fish Habitat Guideline FHG 001, Fisheries Group, Department of Primary Industries, Brisbane.

Coughanowr, C. 1997, *State of the Derwent Estuary: A review of environmental quality data to 1997*, Supervising Scientist Report 129, Supervising Scientist, Canberra.

Crabb, P. 1997, *Impacts of anthropogenic activities, water use and consumption on water resources and flooding*, Australia: State of the Environment Technical Paper Series (Inland Waters), Department of the Environment, Canberra.

CRCCH . 1997, *Annual report 1996–1997*, CRC for Catchment Hydrology.

CRCFE. 1997, *Annual report 1996–1997*, CRC for Freshwater Ecology.

CRCFE. 1998a, *Annual report 1997–98*, CRC for Freshwater Ecology.

CRCFE. 1998b, *Flow related ecosystem processes – The research portfolio: Theme 1, 5th Year Review, Stage 1*, CRC for Freshwater Ecology.

CRCFE. c. 1998, *Environmental flows for the Campaspe River*, CRC for Freshwater Ecology, Canberra and Goulburn–Murray Water, Victoria.

CRCSLM. 1997, *Annual report 1996–97 Volume 1*, CRC for Soil and Land Management.

CRCWMPC. 1997, *Annual report 1996/97*, CRC for Waste Management and Pollution Control.

CRCWQT. 1997, *1996/97 Annual report*, CRC for Water Quality and Treatment.

CRES. 1996, *Annual report 1996*, http://cres.anu.edu.au/ar96, Centre for Resource and Environmental Studies, Australian National University.

Crowl, T.A., Townsend, C.R. and McIntosh, A.R. 1992, 'The impact of introduced brown and rainbow trout on indigenous fish: the case of Australasia', *Reviews in Fish Biology and Fisheries*, 2: 217–241.

CSIRO. 1992, *Towards healthy rivers*, Consultancy report No. 92/44, CSIRO Division of Water Resources.

CSIRO. 1997, *CSIRO Strategic Research Plan 1997–98 to 1999–2000*, CSIRO Publishing, Melbourne.

Cullen, P. 1997, *Improving Ecological Knowledge in the Northern Parts of the Murray–Darling Basin*, Issues paper 7 October 1997, CRC for Freshwater Ecology.

Cullen, P. and Lake, P.S. 1995, 'Water resources and biodiversity: past: present and future problems and solutions', *Conserving biodiversity: threats and solutions*, eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen, Surrey Beatty and Sons, pp115–125.

Cummins, K.W. 1993, 'Ecology of riparian zones', *Ecology and management of riparian zones in Australia*, Occasional Paper no. 05/93, eds S.E. Bunn, B.J. Pusey and P. Price, LWRRDC, pp5-19.

Davey, G.W., Doeg, T.J. and Blyth, J.D. 1987, 'Changes in benthic sediment in the Thomson River, southeastern Australia, during construction of the Thomson Dam', *Regulated rivers: Research and management*, 1: 71–84.

Davies, B.R., Thoms, M.C. and Meador, M. 1992, 'An assessment of the ecological impacts of inter–basin water transfers, and their threats to river basin integrity and conservation', *Aquatic conservation: Marine and freshwater ecosystems*, 2: 325–349.

Davies, B.R., Thoms, M.C., Walker, K.F., O'Keeffe, J.H. and Gore, J.A. 1994, 'Dryland rivers: their ecology, conservation and management', *The Rivers Handbook Volume 2*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp484-511.

Davies, P. and Hussey, F. 1996, *A strategic review of inland fishery management, Tasmania*, Final report to the Minister for Inland Fisheries, 158pp.

Davies, P., Mitchell, N. and Barmuta, L. 1996, *Mount Lyell Remediation – The impact of historical mining operations at Mount Lyell on the water quality and biological health of the King and Queen River catchments, western Tasmania*, Supervising Scientist Report 118, Supervising Scientist, Canberra.

Davies, P.E. and Cook, L.S.J. 1993, 'Catastrophic macroinvertebrate drift and sublethal effects on brown trout, *Salmo trutta*, caused by cypermethrin spraying on a Tasmanian stream', *Aquatic toxicology*, 27: 201–224.

Davies, P.E. and McDowall, R.M. 1996, 'Family Salmonidae – Salmons, trouts and char', *Freshwater fishes of south-eastern Australia*, ed R.M. McDowall, Reed Books, Australia, pp 81-91.

Delbridge, A., Bernard, J.R.L., Blair, D., Peters, P. and Butler, S. 1991, *The Macquarie Dictionary*, 2nd edition, The Macquarie Library Pty Ltd.

Delong, M.D. and Brusven, M.A. 1991, 'Classification and spatial mapping of riparian habitat with application toward management of streams impacted by nonpoint source pollution', *Environmental Management*, 15: 565–571.

Department of Conservation and Natural Resources. 1995, *The bulk entitlement conversion process*, Bulk Water Entitlements Report Series, Report No. 2, Goulburn/Broken Bulk Entitlement Forum and Water Bureau, Department of Conservation and Natural Resources Victoria.

Department of Lands. 1987, *Boobera Lagoon Discussion Paper*, 25 pages, The Crown Lands Office, Department of Lands.

Department of the Environment, Sport and Territories. 1997, *Annual report 1996–97*, Department of the Environment, Sport and Territories.

DeStasio Jr., B. T., Hill, D. K., Kleinhans, J. M., Nibbelink, N. P. and Magnuson, J. J. 1996, 'Potential effects of global climate change on small north-temperate lakes: physics, fish and plankton', *Limnology and Oceanography*, 41: 1136–1149.

Digman, R. 1998, 'Creation of lagoons or wetlands in a tropical agricultural setting', pp171–176 in *Wetlands in a dryland: Understanding for management*, eds W.D. Williams, Environment Australia, Canberra.

DIST. 1996, *Managing Australia's Inland Waters, A paper prepared for the Prime Minister's Science and Engineering Council*, Department of Industry, Science and Tourism, Commonwealth of Australia.

DLWC. 1996, *Technical services directorate weir inventory project annual report, June 1996*, Department of Land and Water Conservation.

DLWC. 1997a, *Annual Report 1996/97*, Department of Land and Water Conservation, New South Wales.

DLWC. 1997b, *NSW Water reform fact sheets 1–19*, Department of Land and Water Conservation, New South Wales.

DLWC. 1997c, *Securing our water future*, Department of Land and Water Conservation, Sydney.

DLWC. 1997d, *NSW Weirs policy*, Department of Land and Water Conservation, Sydney.

DLWC. 1998a, *Stressed rivers assessment report – NSW State Summary*, Department of Land and Water Conservation, Sydney.

DLWC. 1998b, *Water sharing in New South Wales – access and use, A discussion paper*, Department of Land and Water Conservation, Sydney.

DLWC. 1998c, *Aquifer risk assessment report*, Department of Land and Water Conservation, Sydney.

DLWC. 1998d, *Hunter environmental flow rules for 1998/99*, Department of Land and Water Conservation, Sydney.

DLWC. c. 1997, *RIVERCARE*, Department of Land and Water Conservation, Sydney.

Doeg, T.J. and Koehn, J.D. 1990, *A review of Australian studies on the effects of forestry practices on aquatic values*, Silvicultural Systems Project Technical Report No. 5, Department of Conservation and Environment Victoria, Fisheries Division.

Doeg, T.J. and Koehn, J.D. 1994, 'Effects of draining and desilting a small weir on downstream fish and macroinvertebrates', *Regulated Rivers: Research and Management*, 9: 263–277.

Doeg, T.J., Davey, G.W. and Blyth, J.D. 1987, 'Response of the aquatic macroinvertebrate communities to dam construction on the Thompson River, southeastern Australia', *Regulated rivers: Research and management*, 1: 195–209.

Dove, A.D.M. and Ernst, I. In press, 'Concurrent invaders – four exotic species of Monogenea now established on exotic freshwater fishes in Australia', *International Journal of Parasitology*, In press.

Dove, A.D.M. and Fletcher, A.S. Submitted for publication, 'The distribution of the introduced tapeworm *Bothriocephalus acheilognathi* (Cestoda: Pseudophyllidea) in Australian freshwater fishes', *Australian Journal of Zoology*.

Dove, A.D.M., Cribb, T.H., Mockler, S.P. and Lintermans, M. 1997, 'The Asian fish tapeworm, *Bothriocephalus acheilognathi*, in Australian freshwater fishes', *Marine and Freshwater Research*, 48: 181–183.

DPIF. 1997, *Technical Annual Report 1996/97*, Department of Primary Industry and Fisheries, NT.

Driver, P.D., Harris, J.H., Norris, R.H. and Closs, G.P. 1997, 'The role of the natural environment and human impacts in determining biomass densities of common carp in New South Wales rivers', *Fish and Rivers in Stress – The NSW Rivers Survey*, eds J.H. Harris and P.C. Gehrke, NSW Fisheries Office of Conservation and Cooperative Research Centre for Freshwater Ecology, pp225–250.

Eaton, J. G. and Scheller, R. M. 1996, Effects of climate warming on fish thermal habitat in streams of the United States', *Limnology and Oceanography*, 41: 1109–1115.

Effler, S.W., Doerr, S.M. and Owens, E.M. 1997, 'Effect of reduced salinity input on river stratification and dissolved oxygen', *Water, air and soil pollution*, 95: 45–58.

Engineering and Water Supply Department. c. 1983, *Noora Drainage Disposal Scheme*, Engineering and Water Supply Department, South Australia.

Environment Australia. 1997, *National Strategy for the Conservation of Australia's Biological Diversity*, http://www.environment.gov.au/portfolio/esd/biodiv/strategy.

EPA NSW, DLWC, NSW Agriculture, NSW Fisheries, NPWS. 1997, *Proposed interim environmental objectives for NSW waters*, Environment Protection Authority, NSW.

EPA NSW. 1997a, *Proposed Interim Environmental Objectives for NSW Waters: Inland Rivers*, Environment Protection Authority, NSW.

EPA NSW. 1997b, *Annual report 96–97*, Environment Protection Authority, NSW.

EPA NSW. 1997c, *New South Wales State of the Environment 1997*, Environment Protection Authority, NSW.

EPA VIC. 1995, *Protecting Water Quality in the Yarra Catchment*, Environment Protection Authority, VIC.

EPA VIC. 1997, *Corporate Plan 1997–2000*, Environment Protection Authority, VIC.

ERISS. 1997, *Annual report 1996–1997*, Supervising Scientist, Canberra.

Everett, R.A. and Ruiz, G.M. 1993, 'Coarse woody debris as a refuge from predation in aquatic communities – an experimental analysis', *Oecologia*, 93: 475–486.

Fallu, R. 1997a, *Aquarium fish status report 1996*, Department of Primary Industry and Fisheries, Northern Territory.

Fallu, R. 1997b, *Barramundi status report 1996*, Department of Primary Industry and Fisheries, Northern Territory.

Faragher, R.A. 1990, 'Implications of the greenhouse effect for trout habitats and fisheries in New South Wales', *Wetlands (Australia)*, 10: 33–34.

Faragher, R.A. and Lintermans, M. 1997, 'Alien fish species from the New South Wales Rivers Survey', *Fish and Rivers in Stress – The NSW Rivers Survey*, eds J.H. Harris and P.C. Gehrke, NSW Fisheries Office of Conservation and CRC for Freshwater Ecology, pp201–223.

Fisheries Department of WA. 1996, *Annual Report 1995–1996*, Fisheries Department of Western Australia.

Fisheries Department of WA. 1997a, *Annual report 1996–97*, Fisheries Department of Western Australia.

Fisheries Department of WA. 1997b, *Strategic plan 1997–2002*, Fisheries Department of Western Australia.

Fisheries Department of WA. 1997c, *State of the Fisheries Report*, Fisheries Department of Western Australia.

Fisheries Victoria. 1996, *Victorian Fisheries Research Plan 1995/96 to 1999/00*, Department of Natural Resources and Environment, Melbourne.

Fitzpatrick, C.R. and Bennett, P.A. 1994, 'Environmental flows – Jumping the implementation hurdle', *Environmental Flows Seminar Proceeding*, Canberra, 25–26 August 1994, Australian Water and Wastewater Association Incorporated, Sydney, pp103–110.

Fletcher, A.R. 1986 'Effects of introduced fish in Australia', *Limnology in Australia*, eds P. DeDeckker and W.D. Williams, CSIRO Australia, pp231-238.

FRDC. 1996, *Investing for Tomorrow's Catch – The FRDC's Research and Development Plan, 1996 to 2001*, Fisheries Research and Development Corporation, Canberra.

FRDC. 1997, *Fisheries Research and Development Corporation Annual Report, 1996–1997*, Fisheries Research and Development Corporation, Canberra.

Freshwater Fisheries MAC. 1996, *Queensland freshwater fisheries*, Discussion Paper No. 4, Queensland Fisheries Management Authority.

Geddes, M.C. 1990, 'Crayfish', *The Murray*, eds N. Mackay and D. Eastburn, Murray-Darling Basin Commission, Canberra, pp302-307.

Gehrke, P.C. 1997a, 'Species richness and composition of freshwater fish communities in New South Wales rivers', *Fish and Rivers in Stress – The NSW Rivers Survey*, eds J.H. Harris and P.C. Gehrke, NSW Fisheries Office of Conservation and CRC for Freshwater Ecology, pp103–132.

Gehrke, P.C. 1997b, 'Differences in composition and structure of fish communities associated with flow regulation in New South Wales rivers', *Fish and Rivers in Stress – The NSW Rivers Survey*, eds J.H. Harris and P.C. Gehrke, NSW Fisheries Office of Conservation and CRC for Freshwater Ecology, pp169–200.

Gehrke, P.C. and Harris, J.H. 1994, 'The role of fish in cyanobacterial blooms in Australia', *Australian Journal of Marine and Freshwater Research*, 45: 905–915.

Gehrke, P.C., Brown, P., Schiller, C.B., Moffatt, D.B. and Bruce, A.B. 1995, 'River regulation and fish communities in the Murray–Darling River system, Australia', *Regulated Rivers: Research and Management*, 11: 363–375.

Gippel, C.J., Finlayson, B.L. and McNeill, I.C. 1996, 'Distribution and hydraulic significance of large woody debris in a lowland Australian river', *Hydrobiologia*, 318: 179–194.

Gippel, C.J., O'Neill, I.C. and Finlayson, B.L. 1992, *The hydraulic basis of snag management*, Centre for Environmental Applied Hydrology, Department of Civil and Agricultural Engineering and Department of Geography, University of Melbourne.

Gore, J.A. 1994, 'Hydrological change', *The Rivers Handbook Volume 2*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp33–54

Gregory, S.V., Swanson, F.J., McKee, W.A. and Cummins, K.W. 1991, 'An ecosystem perspective of riparian zones', *Bioscience*, 41: 540–551.

Griffin, R. and de Lestang, P. 1998, *Fish kills in the Mary River*, Fishnote No. 26, Department of Primary Industry and Fisheries, Northern Territory.

Griffin, R.K. 1995a, 'Barramundi and the Mary River wetlands – impacts of habitat change', *Making multiple land use work, Proceedings of the Wetlands Workshop 6–7 December 1994*, eds P. Jonauskas, Department of Lands, Planning and the Environment, Darwin, Northern Territory, p45–48.

Griffin, R.K. 1995b, 'Wetland habitats and barramundi', *Wetland research in the wet–dry tropics of Australia, Workshop 22–24 March, Jabiru Northern Territory*, eds C.M. Finlayson, Supervising Scientist Report 101, Land and Water Resources Research and Development Corporation and Supervising Scientist, Canberra, pp64–68.

Griffin, R.K. 1995c, *Identification and mapping of barramundi nursery swamp habitat in the Chambers Bay/Finke Bay area*, Report to Fisheries Research and Development Corporation for project T94/144, Department of Primary Industry and Fisheries, Northern Territory.

Growns, I.O. and Davis, J.A. 1994, 'The effects of forestry activities (clearfelling) on stream macroinvertebrate fauna in south–west Australia', *Australian Journal of Marine and Freshwater Research*, 45: 963–975.

Guo, R., Mather, P. and Capra, M.F. 1993, 'Effect of salinity on the development of silver perch (*Bidyanus bidyanus*) eggs and larvae', *Comparative Biochemistry and Physiology*, 104A: 531–535.

Hall, D.N. 1989, *Preliminary assessment of the daily flows required to maintain habitat for fish assemblages in the LaTrobe, Thomson, Mitchell and Snowy Rivers, Gippsland*, Technical Report Series No. 85, Department of Conservation, Forests and Lands, Victoria.

Halse, S.A. 1998, 'Wetland R&D requirements in Western Australia', *Wetlands in a dry land: Understanding for management*, eds W.D. Williams, Environment Australia, Canberra.

Halse, S.A. and Jensen, A. 1993, 'Riparian zone management in WA and SA: policy and practice', *Ecology and management of riparian zones in Australia*, Occasional Paper no. 05/93, eds S.E. Bunn, B.J. Pusey and P. Price, LWRRDC, pp143–156.

Hancock, C.N., Ladd, P.G. and Froend, R.H. 1996, 'Biodiversity and management of riparian vegetation in Western Australia', *Forest Ecology and Management*, 85: 239–250.

Harden Jones, F.R. 1994, *Fisheries Ecologically Sustainable Development: Terms and concepts*, Institute of Antarctic and Southern Ocean Studies, University of Tasmania, Hobart.

Harmon, M.E., Franklin, J.F., Swanson, F.J, Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack, K. and Cummins, K.W. 1986, 'Ecology of coarse woody debris in temperate streams', *Advances in Ecological Research*, 15: 133–302.

Harris, J.H. 1984a, 'Impoundment of coastal drainages of south–eastern Australia, and a review of its relevance to fish migrations', *Australian Zoologist*, 21: 235–250.

Harris, J.H. 1984b, 'A survey of fishways in streams of coastal south–eastern Australia', *Australian Zoologist*, 21: 219–233.

Harris, J.H. 1986, 'Reproduction of the Australian bass, *Macquaria novemaculeata* (Perciformes: Perchichthyidae) in the Sydney Basin', *Australian Journal of Marine and Freshwater Research*, 36: 235–246.

Harris, J.H. 1995, 'Carp: the prospects for control', *Water*, May/June, 25–28.

Harris, J.H. 1995, 'The use of fish in ecological assessments', *Australian Journal of Ecology*, 20: 65–80.

Harris, J.H. 1997, 'Environmental rehabilitation and carp control', *Controlling carp – exploring the options for Australia, Proceedings of a workshop 22–25 October 1996, Albury*, eds J. Roberts and R. Tilzey, CSIRO Land and Water, pp21–36.

Harris, J.H. and Gehrke, P.C. 1997, *Fish and Rivers in Stress – The NSW Rivers Survey*, NSW Fisheries Office of Conservation and the CRC for Freshwater Ecology.

Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C. and Swadling, K. 1990, 'Effects of salinity on river, stream, and wetland ecosystems in Victoria, Australia', *Water Research*, 24:1103–1117.

Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C. and Swadling, K. 1991, 'A review of the salt sensitivity of the Australian freshwater biota', *Hydrobiologica*, 210: 105–144.

Hogan, A. 1998, *Culvert and drain design tips for fish*, Freshwater Fisheries and Aquaculture Centre, DPI Walkamin, Queensland.

Hogan, A. and Graham, P. 1994a, *Herbert River floodplain fish distributions and fish habitat*, Interim Report to the Consultants, Herbert River Sugar Industry Infrastructure Package, Freshwater Fisheries and Aquaculture Centre, DPI Walkamin, Queensland.

Hogan, A. and Graham, P. 1994b, *Tully–Murray floodplain fish distributions and fish habitat*, Report to the Consultants, Tully–Murray Sugar Industry Infrastructure Package, Freshwater Fisheries and Aquaculture Centre, DPI Walkamin, Queensland.

Hogan, A., Graham, P. and Vallance, T. 1997, *Re–design of the Clare Weir fishway: identification of fish movement*, Preliminary Report to the Manager, Regional Infrastructure Development, Department of Natural Resources, Townsville, Freshwater Fisheries and Aquaculture Centre, DPI Walkamin, Queensland.

Hogan, A.E, Graham, P.G. and Malcolm, H. 1995a, *Tully–Murray floodplain water management scheme impact assessment study (Phase 2)*, Technical Brief No. 5 – Fish Habitat, Freshwater Fisheries and Aquaculture Centre, DPI Walkamin, Queensland.

Hogan, A.E., Graham, P.G. and Malcolm, H. 1995b, *Tully–Murray Floodplain Water Management Scheme Impact Assessment Study*, Technical Brief No 5 – Fish Habitat, Tully–Murray Sugar Industry Infrastructure Package, DPI, Walkamin, Queensland.

Hogg, I.D. and Norris, R.H. 1991, 'Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river', *Australian Journal of Marine and Freshwater Research*, 42: 507–518.

Holmes, J.A. and Regier, H.A. 1990, 'Influence of temperature changes on aquatic ecosystems: an interpretation of empirical data', *Transactions of the American Fish Society*, 119: 374–389.

Hortle, K.G. and Lake, P.S. 1983, 'Fish of the channelized and unchannelized sections of the Bunyip River, Victoria', *Australian Journal of Marine and Freshwater Research*, 34: 441–450.

Horwitz, P. 1994, 'Distribution and conservation status of the Tasmanian giant freshwater lobster *Astocopsis gouldi* (Decapoda: Parastacidae)', *Biological Conservation*, 69: 199–206.

Horwitz, P., Jasinska, E.J., Fairhurst, E. and Davis, J.A. 1998, *A review of knowledge on the effect of key disturbances on aquatic invertebrates and fish in the south–west forest region of Western Australia*, Report prepared for Environment Australia (Environment Forest Taskforce) and Western Australian Department of Conservation and Land Management.

Humphries, S. 1994, 'Weeds – insidious threats to biological diversity', *Biolinks*, 7: 8–10.

Hunter, H.M., Eyles, A.G. and Rayment, G.E. 1996, *Downstream effects of landuse*, Proceedings of a National Conference on Downstream Effects of Landuse, held in Rockhampton, Queensland, Australia, from 26 to 28 April 1995, Department of Natural Resources, Brisbane, Queensland.

IFC. 1995, *Inland Fisheries Commission Newsletter*, Vol 24, Inland Fisheries Commission, Tasmania.

IFC. 1996, 'On the rise', *Inland Fisheries Commission Newsletter*, Vol 25, Inland Fisheries Commission, Tasmania.

IFC. 1997, 'On the rise', *Inland Fisheries Commission Newsletter*, Vol 26, Inland Fisheries Commission, Tasmania.

IFMC. 1998 (Draft), *Management plan for the Lakes and Coorong fishery of South Australia*, Primary Industries and Resources South Australia.

Ingeme, Y. 1996 (Draft), *Glenelg River Catchment environmental flows technical report – A report on the environmental values and case for environmental water for the Glenelg River Catchment*, Department of Natural Resources and Environment, Victoria.

Jackson, J. 1997, *State of habitat availability and quality in inland waters*, Australia: State of the Environment Technical Paper Series (Inland Waters), Department of the Environment, Canberra.

James, K.R. and Hart, B.T. 1993, 'Effect of salinity on four freshwater macrophytes', *Australian Journal of Marine and Freshwater Research*, 44: 769–777.

Johnson, G. 1996, *Barramundi status report 1995*, Department of Primary Industry and Fisheries, Northern Territory.

Johnston, N.A.L., Campagna, V.S., Hawkins, P.R. and Banens, R.J. 1994, 'Response of the eastern rainbowfish (*Melanotaenia duboulayi*) to toxic *Microcystis aeroruginosa*', *Australian Journal of Marine and Freshwater Research*, 45: 917–923.

Junk, W.J. and Welcomme, R.L. 1990, 'Floodplains', *Wetlands and Shallow Continental Water Bodies*, ed B.C. Patten, SPB Academic Publishing, The Hague, The Netherlands.

Junk, W.J., Bayley, P.B and Sparks, R.E. 1989, 'The flood–pulse concept in river–floodplain systems', Proceedings International Large Rivers Symposium (LARS), ed D.P. Dodge, *Canadian Special Publications in Fisheries and Aquatic Science*, 106:110–127.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. and Grieve, C. 1993, *Australian fisheries resources*, Bureau of Resource Sciences, Department of Primary Industries and Energy and the Fisheries Research and Development Corporation, Canberra, Australia.

Kennedy, L. 1996, 'Exercising native title hunting rights: Dershaw v Sutton', *Aboriginal Law Bulletin*, 3: 31–32.

King, A. 1995, *The effects of carp on aquatic ecosystems – A literature review*, Report prepared for the Environment Protection Authority NSW, Murray region; November 1995, Charles Sturt University and EPA NSW.

King, A.J., Robertson, A.I. and Healey, M.R. 1997, 'Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs, I. Impacts on water–column properties', *Marine and Freshwater Research*, 48: 435–443.

Kingsford, R.T. 1995, 'Ecological effects of river management in New South Wales', *Conserving biodiversity: threats and solutions*, eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen, Surrey Beatty and Sons, pp144–161.

Klimas, C.V. 1988, 'River regulation effects on floodplain hydrology and ecology', *The Ecology and management of Wetlands, Vol 1, Ecology of Wetlands*, eds D.D. Hook, W.H. McKee Jr, H.K. Smith, J. Gregory, V.G. Burrell Jr, M.R. DeVoe, R.E. Sojka, S. Gilbert, R. Banks, L.H. Stolzy, C. Brooks, T.D. Matthews, and T.H. Shear, Croom and Helm, Sydney, pp40-49.

Koehn, J., Doeg, T., Harrington, D. and Milledge, G. 1996, 'Dartmouth Dam: Effects on the downstream aquatic fauna', *Riverine Environment Research Forum Proceedings, October 1995, Attwood, Victoria*, eds R.J. Banens and R. Lehane, Murray–Darling Basin Commission, pp49–56.

Koehn, J.D. and O'Connor, W.G. 1990, *Biological information for management of native freshwater fish in Victoria*, Freshwater Fish Management Branch, Department of Conservation and Environment, Melbourne, Victorian Government Publishing Office.

Koori Mail. 1995a, 'Kakadu waters "poisoned": Owners', 22 March 1995, p5.

Koori Mail. 1995b, 'Groups consulted on riverine management', 31 May 1995, p37.

Koori Mail. 1996a, 'Winning artists mourn Murray', 10 April 1996, p3.

Koori Mail. 1996b, 'Rivercare efforts recognised', 20 November 1996, p20.

Ladson, A., Doolan, J., White, L., Metzeling, L. and Robinson, D. 1996, 'Index of stream condition as a tool to aid management of rivers', *23rd Hydrology and Water Resources Symposium, 21–24 May 1996, Hobart, Tasmania*, Institution of Engineers, Australia, pp325–332.

Ladson, A., White, L. and Doolan, J. 1997, 'Trialing the index of stream condition in Victoria, Australia', *24th Hydrology and Water Resources Symposium, 25–27 November 1997, Auckland, New Zealand*, Institution of Engineers, Australia, pp109–114.

Lake, P.S. 1980, 'Conservation', *An ecological basis for water resource management*, ed W.D. Williams, Australian National University Press: Canberra, pp163-173.

Lake, P.S. 1994, *Understanding the ecology of Australian running waters: An assessment of current endeavours and of future priorities*, LWRRDC Occasional Paper Series No. 13/94, Land and Water Resources Research and Development Corporation.

Lake, P.S. and Marchant, R. 1990, 'Australian upland streams: ecological degradation and possible restoration', *Proceedings of the Ecological Society of Australia*, 16: 79–91.

Land Conservation Council. 1991, *Rivers and streams special investigation – Final recommendations*, Lands Conservation Council, Melbourne.

Langdon, J.S. and Humphrey, J.D. 1987, 'Epizootic haematopoietic necrosis, a new viral disease in redfin perch, *Perca fluviatilis* L., in Australia', *Journal of Fish Diseases*, 10: 289–297.

LeBlanc, R.T., Brown, R.D. and Fitzgibbon, J.E. 1997, 'Modelling the effects of land use change on the water temperature in unregulated urban streams', *Journal of Environmental Management*, 49: 445–469.

Lintermans, M. 1991, 'The decline of indigenous fish in the Canberra region: The impacts of introduced species', *Bogong*, 12: 18–22.

Lintermans, M., Rutzou, T. and Kukolic, K. 1990, 'Introduced fish of the Canberra region', *Introduced and translocated fish and their ecological effects*, Bureau of Rural Resources Proceedings no. 8,Australian Government Publishing Service, Canberra, pp50-60.

Lloyd, L.N. 1987, 'Turbidity as a water quality standard for salmonid habitats in Alaska', *North American Journal of Fisheries Management*, 6: 34–45.

Lloyd, L.N., Atkins, N., Boon, P., Jacobs, T. and Roberts, J. 1994, 'Natural processes within Murray–Darling floodplain wetlands', *Murray–Darling Basin floodplain wetlands management: Proceedings of the floodplain wetlands management workshop, Albury, NSW, 20–22 October 1992*, eds A.J. Sharley and C.A. Huggan, Murray–Darling Basin Commission, Canberra, pp6-23.

Lloyd, L.N., Puckridge, J.T. and Walker, K.F. 1991, 'The significance of fish populations in the Murray–Darling system and their requirements for survival', *Conservation and Management of the River Murray: Making Conservation Count*, eds T. Dendy and M. Coombe, Department of Environment and Planning, Adelaide, South Australia.

Lund, M., Davis, J. and Murray, F. 1991, 'The fate of lead from duck shooting and road run–off in three Western Australian wetlands', *Australian Journal of Marine and Freshwater Research*, 42: 139–149.

LWRRDC. 1997, *Annual report 1996–97*, Land and Water Resources Research and Development Corporation, Canberra.

Mackay, N. and Eastburn, D. 1990, *The Murray*, Murray–Darling Basin Commission.

Mackay, N. and Shafron, M. 1989, 'Water quality', *Proceedings of the workshop on native fish management, 1988*, Murray-Darling Basin Commission, Canberra, pp111-125.

MAFRI. 1997, *Victorian Fisheries catch and effort information bulletin 1997*, Natural Resources and Environment, Victoria.

Maheshwari, B.L., Walker, K.F. and McMahon, T.A. 1995, 'Effects of regulation on the flow regime of the River Murray, Australia', *Regulated Rivers: Research and Management*, 10: 15–38.

Mallen–Cooper, M. 1989, 'Fish passage in the Murray–Darling Basin', *Proceedings of the workshop on native fish management, 1988*, Murray-Darling Basin Commission, Canberra, pp123-136.

Mallen–Cooper, M. and Harris, J. 1990, 'Fishways in mainland south–eastern Australia', *Proceedings of the International Symposium on Fishways '90, Japan*, pp221–229.

Marchant, R. 1989, 'Changes in the benthic invertebrate communities of the Thomson River, southeastern Australia, after dam construction', *Regulated rivers: Research and management*, 4: 71–89.

McComb, A.J. and Davis, J.A. 1993, 'Eutrophic waters of southwestern Australia', *Journal of Fertilizer Research*, 36:105–114.

McComb, A.J. and Lake, P.S. 1990, *Australian Wetlands*, Angus and Robertson, Australia.

McDonald, M. E., Hershey, A. E. and Miller, M. C. 1996, 'Global warming impacts on lake trout in arctic lakes', *Limnology and Oceanography*, 41: 1102–1108.

McGuckin, J.T. 1991, *Environmental considerations of salinity in the Goulburn River downstream of Shepparton*, Technical Report Series no. 133, Arthur Rylah Institute for Environmental Research, Department of Conservation and Environment, Victoria.

McKay, R.J. 1984, 'Introductions of exotic fishes in Australia', *Distribution, Biology and Management of Exotic Fishes*, eds W.R. Courtenay Jr, J.R. Stauffer Jr, Johns Hopkins University Press, London, pp177–199.

McNee, A. 1990, *The status of Australian streams and rivers (with reference to the status of recreational fish species)*, Australian Recreational and Sport Fishing Confederation, Canberra.

MDBC. 1994, *Waikerie Salt Interception Scheme*, Murray–Darling Basin Commission and Engineering and Water Supply Department, South Australia.

MDBC. 1997, *Annual report 1996–97*, Murray–Darling Basin Commission.

MDBC. c. 1992, *Woolpunda Salt Interception Scheme*, Murray–Darling Basin Commission and Engineering and Water Supply Department, South Australia.

Metzeling, L. 1993, 'Benthic macroinvertebrate community structure in streams of different salinities', *Australian Journal of Marine and Freshwater Research*, 44: 335–351.

Metzeling, L., Doeg, T. and O'Connor, W. 1995, 'The impact of salinization and sedimentation on aquatic biota', *Conserving biodiversity: threats and solutions*, eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen, Surrey Beatty and Sons, pp126-136.

Mitchell, B., Rutherfurd, I., Constable, A., Stagnitti, F. and Merrick, C. 1996, *An ecological and environmental flow study of the Glenelg River from Casterton to Rocklands Reservoir*, Prepared for the Department of Natural Resources and Environment, Aquatic Resource Utilization and Management Research Group, Deakin University, Warrnambool.

Mitchell, P. 1990, *The environmental condition of Victorian streams*, Department of Water Resources Victoria, Melbourne.

Moller, G. 1996, *State of the rivers Herbert River and major tributaries – An ecological and physical assessment of the condition of streams in the Herbert River catchment*, Department of Natural Resources Queensland.

Morgan, D.L., Gill, H.S. and Potter, I.C. 1998, *Distribution, identification and biology of freshwater fishes in south–western Australia*, Records of the Western Australian Museum Supplement No. 56, Western Australian Museum.

Morrissy, N. 1983, *Potential fisheries of the Ord in the short, medium and long terms*, Report No. 59, Department of Fisheries and Wildlife Western Australia, Perth.

Morrissy, N.M. and Cassells, G. 1992, *Spread of the introduced yabbie* Cherax albidus *Clark, 1936 in Western Australia*, Fisheries Research Report No. 92, Fisheries Department Western Australia.

Murray-Darling Association. 1995, *National carp summit proceedings, Renmark, South Australia, 6–7 October, 1995*, Murray-Darling Association Inc.

Mussared, D. 1997, *Living on floodplains*, CRC for Freshwater Ecology and Murray–Darling Basin Commission.

Nannestad, C. 1994, *Proceedings of the forum on European carp, Wagga Wagga, NSW, 20 June 1994*, Murrumbidgee Catchment Management Committee.

Napier, G.M., Fairweather, P.G. and Scott, A.C. 1998, 'Records of fish kills in inland waters of NSW and Queensland in relation to cotton pesticides', *Wetlands (Australia)*, 17: 60–71.

Nathan, R.J., McMahon, T.A. and Finlayson, B.L. 1988, 'The impact of the greenhouse effect on catchment hydrology and storage–yield relationships in both winter and summer rainfall zones', *Greenhouse: Planning for climate change*, ed G.I. Pearman, CSIRO Australia, pp273-295.

National Landcare Program. 1997, *National Landcare Program – Report on operations of the land and water elements 1994–95 & 1995–96 financial years*, Department of Primary Industries and Energy, Canberra.

Newcombe, C.P. and MacDonald, D.D. 1991, 'Effects of suspended sediments on aquatic ecosystems', *North American Journal of Fisheries Management*,11,72–82.

Norris, R.H. 1986, 'Mine waste pollution of the Molonglo River, New South Wales and the Australian Capital Territory: Effectiveness of remedial works at Captains Flat mining area', *Australian Journal of Marine and Freshwater Research*, 37: 147–157.

Norris, R.H. 1991, 'Agriculture and modified temperate environments', *Australian Biology*, 4: 220–227.

Northern Territory of Australia. 1998, *Integrated catchment management plan – Mary River*, Northern Territory Government.

Nowak, B. 1991, 'Toxicity of organic chemicals', *Modelling the fate of chemicals in the environment*, ed I.D. Moore, Australian National University Centre for Resource and Environmental Studies and Department of the Arts, Sport, Environment, Tourism and Territories, pp128–134.

NPWS. 1996, *Corporate Plan 1995–96 to 1997–98*, NSW National Parks and Wildlife Service.

NRE. 1997, *Victoria's environmental flow program – A key component of integrated river management*, Department of Natural Resources and Environment, Victoria.

NS ESD. 1992, *National Strategy for Ecologically Sustainable Developmen*t, AGPS, Canberra.

NSW Agriculture. 1997, *NSW Agriculture Corporate Plan 1997–2000*, NSW Agriculture.

NSW Agriculture. 1998, *Strategic Plan for Sustainable Agriculture – Sydney Region*, NSW Agriculture.

NSW Fisheries. 1996, *Review of research programs NSW Fisheries September/October 1996*, NSW Fisheries.

NSW Fisheries. 1997, *Annual report 1996/97*, NSW Fisheries.

NSW Fisheries. 1998, *Policy and guidelines: Aquatic habitat management and fish conservation*, eds A.K. Smith and D.A. Pollard, NSW Fisheries.

O'Brien, M. 1998a, *Guide to the Flora and Fauna Guarantee Regulations 1991*, Flora and Fauna Guarantee Information Paper No. 2, Flora and Fauna Program, Department of Natural Resources and Environment, Victoria.

O'Brien, M. 1998b, *Guidelines for nominating items for listing, Flora and Fauna Program*, Department of Natural Resources and Environment, Victoria.

O'Connor, N.A. 1992, 'Quantification of submerged wood in a lowland Australian stream system', *Freshwater Biology*, 27: 387–395.

Olsen, G. and Skitmore, E. 1991, *State of the rivers of the south west drainage division*, Western Australian Water Resources Council Publication No. 2/91, Western Australian Water Resources Council, Perth.

Overman, T. 1996 (Draft), *Wimmera River environmental flows technical report – A report on the environmental values and case for environmental water for the Wimmera River system*, Department of Natural Resources and Environment, Victoria.

Parliament of NSW. 1992, *The NSW State Rivers and Estuaries Policy*, NSW Government.

Parliament of Victoria. 1988, *Gazette Special*, No. S13, Friday 26 February, 1988, Parliament of Victoria.

Parliament of Victoria. 1998a, *Fisheries Act 1995*, Act No. 92/1995, Version No. 011, Incorporating amendments as at 1 July 1998, Parliament of Victoria.

Parliament of Victoria. 1998b, *Flora and Fauna Guarantee Act 1988*, Act No. 47/1988, Version No. 023, Incorporating amendments as at 1 July 1998, Parliament of Victoria.

Pen, L. 1997, 'The management and protection of wetlands', *A Systematic Overview of Environmental Values of the Wetlands, Rivers and Estuaries of the Busselton–Walpole Region*, Water Resource Allocation and Planning Report Series Report No WRAP 7, Water and Rivers Commission, Perth, pp105–117.

Pen, L.J. and Potter, I.C. 1991, 'Biology of the western minnow, *Galaxias occidentalis* Olgiby (Telestei: Galaxiidae), in a south–western Australian river. 2. Size and age composition, growth and diet', *Hydrobiologia*, 211: 89–100.

Pethebridge, R., Lugg, A. and Harris, J. 1998, *Obstructions to fish passage in New South Wales South Coast streams*, New South Wales Fisheries Final Report Series No. 4, Cooperative Research Centre for Freshwater Ecology and NSW Fisheries.

Petts, G.E. 1994, 'Rivers: dynamic components of catchment ecosystems', *The Rivers Handbook Volume 2*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp3-22.

Petts, G.E. 1996, 'Water allocation to protect river ecosystems', *Regulated rivers: Research and management*, 12: 353–365.

Pierce, B.E. 1988, 'Improving the status of our River Murray fishes – A discussion paper on the potential of cooperative management', *Proceedings of the Workshop on Native Fish Management, Canberra 16–17 June 1988*, Murray–Darling Basin Commission, pp7–17.

Pierce, B.E. 1996, 'River rabbits', *Southern Fisheries*, Winter: 28–33.

Pierce, B.E. 1997a, 'The Fish Factory', *Southern Fisheries*, Autumn: 6–11.

Pierce, B.E. 1997b, '"Fair go" for endangered eight', *Southern Fisheries*, Autumn: 12–13.

Platts, W.S., Torquemada, R.J., McHenry, M.L. and Graham, C.K. 1989, 'Changes in salmon spawning and rearing habitat from increased delivery of fine sediment to the South Fork Salmon River, Idaho', *Transactions of the American Fish Society* 118: 274–283.

Poff, N.L. and Allan, J.D. 1995, 'Functional organization of stream fish assemblages in relation to hydrological variability', *Ecology*, 76: 606–627.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. 1997, 'The natural flow regime', *Bioscience*, 47(11): 769–784.

Pollard, D.A. and Hannan, J.C. 1994, 'The ecological effects of structural flood mitigation works on fish habitats and fish communities in the lower Clarence River System of South–Eastern Australia', *Estuaries*, 17: 427–461.

Pollard, D.A., Llewellyn, L.C and Tilzey, R.D.J. 1980, 'Management of freshwater fish and fisheries', *An ecological basis for water management*, ed W.D. Williams, Australian National University Press, pp227-270.

Presser, J. 1996, *A draft plan for structural adjustment in the South Australian river fishery*, South Australian Fisheries Management Series Paper No. 17, Primary Industries South Australia.

Pressey, B. 1990, 'Wetlands', *The Murray*, eds N. Mackay and D. Eastburn, Murray-Darling Basin Commission, Canberra, pp166-181.

Puckridge, J.T., Sheldon, T., Walker, K.F. and Boulton, A. 1998, 'Flow variability and the ecology of large rivers', *Marine and Freshwater Research*, 49: 55–72.

Pusey, B.J. and Kennard, M.J. 1996, 'Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the wet tropics region of northern Queensland', *Marine and Freshwater Research*, 47: 563–573.

Pusey, B.J., Arthington, A.H. and Read, M.G. 1995, 'Species richness and spatial variation in fish assemblage structure in two rivers of the Wet tropics of northern Queensland, Australia', *Environmental Biology of Fishes*, 42: 181–199.

QDPI. 1998 (Draft), *Fisheries Group Strategy for Freshwater Fisheries in Queensland*, Department of Primary Industries.

QFMA,1996,,Queensland Freshwater Fisheries Discussion Paper, No. 4,128pp.

QFMA. 1997, *Recreational Fishing Information System Newsletter*, June 1997, Queensland Fisheries Management Authority.

QMDBCC. 1997, *Summary of a workshop on the Proposal to Establish a Freshwater Ecology Research Centre in the Northern Murray–Darling Basin, Queensland*, Queensland Murray–Darling Basin Coordinating Committee.

Radonski, G.C., Prosser, N.S., Martin, R.G. and Stroud, R.H. 1984, 'Exotic fishes and sport fishing', *Distribution, biology and management of exotic fishes*, eds W.R. Courtenay Jr. and J.R. Stauffer Jr., John Hopkins University Press, Baltimore, Maryland, pp313-321.

Rahel, F. J, Keleher, C. J. and Anderson, J. L. 1996, 'Potential habitat loss and popultion fragmentation for cold water in the North Platte drainage of the Rocky Mountains: response to climate warming', *Limnology and Oceanography*, 41: 1116–1123.

Rayment, G.E. and Simpson, B.W. 1993, 'Pesticide audit for the Condamine–Balonne–Culgoa catchment', *Water quality management in the Condamine–Balonne–Culgoa catchment*, ed S.J. Kenway, Condamine–Balonne Water Committee, Dalby, Queensland, pp99–166.

Reid, D.D.; Harris, J.H. and Chapman, D.J. 1997, *NSW Inland commercial fishery data analysis*, FRDC Project No. 94/027, Fisheries Research and Development Corporation, NSW Fisheries and the Cooperative Research Centre for Freshwater Ecology.

Reynolds, L.F. 1983, 'Migration patterns of five fish species in the Murray–Darling River system', *Australian Journal of Marine and Freshwater Research*, 34: 857–871.

Richardson, B.A. 1985, 'The impact of forest road construction on the benthic invertebrate and fish fauna of a coastal stream in southern New South Wales', *Bulletin of the Australian Society for Limnology*, 10: 65–87.

Richardson, B.A. and Pollard, D.A. 1990, Summary of potential greenhouse effects on fish habitats and fisheries resources in New South Wales', *Wetlands (Australia)*, 10: 48–51.

Richter, B.D., Baumgartner, J.V., Wigington, R. and Braun, D.P. 1997, 'How much water does a river need?', *Freshwater Biology*, 37: 231–249.

River Murray Water Resources Committee. 1995, *River Murray regional water resource management plan – Border to the barrages and beyond*, River Murray Water Resources Committee, South Australia.

Roberts, J. and Ebner, B. 1997, *An overview of carp*, Cyprinus carpio *L., in Australia*, (2 volumes), Final report on NRMS project R5058, An advisory document to the Murray–Darling Basin Commission, CSIRO Land and Water, Griffith.

Roberts, J. and Tilzey, R. 1997, *Controlling carp – exploring the options for Australia*, CSIRO Land and Water.

Roberts, J., Chick, A., Oswald, L and Thompson, P. 1995, 'Effect of carp, *Cyprinus carpio* L., and exotic benthivorous fish, on aquatic plants and water quality in experimental ponds', *Marine and Freshwater Research*, 46: 1171–1180.

Roberts, J.R. 1993, *Carp and the demise of aquatic plants in rivers and wetlands of south–western New South Wales*, Written presentation, Conference and Symposium of the Ecological Society of Australia, Canberra.

Robertson, A.I., Healey, M.R. and King, A.J. 1997, 'Experimental manipulations of the biomass of introduced carp (Cyprinus carpio) in billabongs, II. Impacts on benthic properties and processes', *Marine and Freshwater Research*, 48: 445–454.

Robertson, A.I., King, A.J., Healey, M.R., Robertson, D.J., Helliwell, S. 1995, *The impact of carp on billabongs*, A report prepared for the Environment Protection Authority, NSW; Riverina region; December 1995, Charles Sturt University and EPA NSW.

Rowland, S.J. 1989, 'Aspects of the history and fishery of the Murray cod, *Maccullochella peeli* (Mitchell) (Perchichthyidae)', *Proceedings of the Linnean Society of New South Wales*, 11: 201–213.

Rozas, L.P. and Odum, W.E. 1988, 'Occupation of submerged vegetation by fishes: testing the roles of food and refuge', *Oecologia*, 77:101–106.

Russell, D.J. 1991, 'Fish movements through a fishway on a tidal barrage in sub–tropical Queensland', *Proceedings of the Royal Society of Queensland*, 101:109–118.

Russell, D.J. and Hales, P.W. 1996, 'Major fisheries resource habitat issues in the Johnstone River Catchment', *Downstream effects of land use*, eds H.M. Hunter, A.G. Eykes and G.E. Rayment, Department of Natural Resources, Queensland, pp353–357

Russell, D.J. and Hales, P.W. 1997, *Fish resources and stream habitat of the Liverpool, Maria and Hull catchments*, Department of Primary Industries, Northern Fisheries Centre, Cairns.

Russell, D.J., Hales, P.W. and Helmke, S.A. 1996, *Fish resources and stream habitat of the Moresby River catchment*, Department of Primary Industries, Northern Fisheries Centre, Cairns, Queensland.

Sammut, J. and Lines–Kelly, R. 1997, *An introduction to acid sulfate soils*, Department of the Environment, Sport and Territories, Canberra.

Sammut, J., Callinan, R.B. and Fraser, G.C. 1993, 'The impact of acidified water on freshwater and estuarine fish populations in acid sulphate soil environments', *Proceedings of the National Conference on Acid Sulphate Soils, June 24–25 1993,*

Coolangatta, Queensland, Australia, ed R. Bush, NSW Agriculture, Wollongbar Agricultural Institute: Wollongbar, NSW, pp26–40.

Sammut, J., White, I. and Melville, M.D. 1996, 'Acidification of an estuarine tributary in eastern Australia due to drainage of acid sulfate soils', *Marine and Freshwater Research*, 47: 669–684.

Sanger, A. 1996, 'Redfin perch', *On the rise*, Inland Fisheries Commission Newsletter, 25(2), Inland Fisheries Commission, Tasmania, pp6–7.

Sanger, A.C. and Fulton, W. 1991, *Conservation of endangered species of Tasmanian freshwater fish*, Final report WWF Project P100, Inland Fisheries Occasional Report 91–01, Inland Fisheries Commission, Tasmania.

SARDI. 1996, *SARDI Aquatic sciences research report*, South Australian Research and Development Institute.

Savino, J.F. and Stein, R.A. 1989, 'Behaviour of fish predators and their prey: habitat choice between open water and dense vegetation', *Environmental Biology of Fishes*, 24: 287–293.

Schiller, C.B., Bruce, A.M. and Gehrke, P.C. 1997, 'Distribution and abundance of native fish in New South Wales rivers', *Fish and Rivers in Stress – The NSW Rivers Survey*, eds J.H. Harris and P.C. Gehrke, NSW Fisheries Office of Conservation and CRC for Freshwater Ecology, pp71–102.

Schultz, R. and Liess, M. 1995 'Chronic effects of low insecticide concentrations in freshwater caddisfly larvae', *Hydrobiologia*, 299:103–113.

Sedgwick, I. 1995, 'RIVERCARE – Community groups looking after our river', *RIVERWISE – Advisory notes for rural landholders from the Department of Land and Water Conservation*, AGDEX 580, Department of Land and Water Conservation, Sydney.

Shafron, M., Croome, R. and Rolls, J. 1990, 'Water quality', *The Murray*, eds N. Mackay and D. Eastburn, Murray–Darling Basin Commission: Canberra, pp146–165.

Sharley, T. and Huggan, C. 1995, *Chowilla resource management plan*, Final report March 1995, Murray–Darling Basin Commission, Canberra.

Shearer, K.D. and Mulley, J.C. 1978, 'The introduction and distribution of the Carp, *Cyprinus carpio* Linnaeus, in Australia', *Australian Journal of Marine and Freshwater Research*, 29: 551–563.

Sheridan, A.K. 1995, 'The genetic impact of human activities on wild fish populations', *Reviews in Fisheries Science*, 3: 91–108.

Snowy River Expert Panel. 1996a, *Expert panel environmental flow assessment of the Snowy River below Jindabyne Dam*, Report for the Snowy Genoa Catchment Management Committee.

Snowy River Expert Panel. 1996b, *Expert panel environmental flow assessment of the upper Murrumbidgee River*, Report for the NSW Environment Protection Authority.

SoEAC. 1996, *Australia: State of the Environment 1996*, State of the Environment Advisory Council, Department of the Environment, Sport and Territories, CSIRO Publishing, Melbourne.

South Australia FRAB. 1998, *South Australian Fisheries and Aquaculture Five Year Research and Development Strategy, June 1998*, South Australia Fisheries Research Advisory Board.

South Australian River Murray Wetlands Management Committee. c. 1994, Wetlands and Floodplain Management Workshop Program, River Murray Water Resources Committee, South Australia.

Southern Fishermen's Association, Baker, D. and Pierce, B. 1998, *Wild fisheries with a future*, Environmental management plan of the Southern Fishermen's Association, Southern Fishermen's Association Inc, South Australia and South Australian Research and Development Institute.

Storey, A. and Beesley, L. 1998, *Limnology of the Fitzroy River, Western Australia: A technical workshop*, Proceedings of a workshop held on 18th February 1998, at Edith Cowan University, Claremont Campus, Claremont, Western Australia, Australian Society for Limnology Inc.

Stuart, I.G. 1997, *Assessment of a modified vertical–slot fishway, Fitzroy River, Queensland*, Department of Primary Industries, Queensland.

Sustainable Land and Water Resources Management Committee. 1996, *National principles for the provision of water for ecosystems*, ARMCANZ and ANZECC.

Sweeting, R.A. 1994, 'River Pollution', *The Rivers Handbook Volume 2*, eds P. Calow and G.E. Petts, Blackwell Scientific Publications, pp23–32.

Swirepik, J. 1998, Physical disturbance of *Potamogeton tricarinatus* and sediment by carp (*Cyprinus carpio*) in experimental ponds, M. App. Sc. Thesis, Cooperative Research Centre for Freshwater Ecology and Applied Ecology Research Group, University of Canberra.

Sydney Water Corporation. 1996, *Sydney Water Annual Environment Report 1996*, Sydney Water Corporation.

TDEP. 1990, *Pieman river fish kill incident March 1990*, A report to the minister for Environment and Planning prepared by the State Government Task Force, Tasmania.

The Chambers Dictionary. 1993, Chambers Harrap Publishers Ltd.

Thomson, C. 1994, *The impact of river regulation on the natural flows of the Murray–Darling Basin*, MDBC Technical Report 92/5.3.

Timms, B.V. 1992, 'The conservation status of athalassic lakes in New South Wales, Australia', *Hydrobiologia*, 243/244: 435–444.

Tuxill, J. and Bright, C. 1998, 'Losing strands in the web of life', *State of the World 1998*, eds L. Starke, Worldwatch Institute, Washington D.C., pp41–58.

Usback, S. and James, R. 1993, *A directory of important wetlands in Australia*, Australian Nature Conservation Agency, Canberra.

Wager, R. and Jackson, P. 1993, *The action plan for freshwater fishes*, Australian Nature Conservation Agency, Canberra.

Walker, K.F. 1985, 'A review of the ecological effects of river regulation in Australia', *Hydrobiologia*, 125: 111–129.

Walker, K.F. 1992, 'The River Murray, Australia: A semiarid lowland river', *The Rivers Handbook Volume 1*, eds P. Calow and G.E. Petts, Blackwell Science, pp472–492.

Walker, K.F. 1993, 'Issues in riparian ecology of large rivers', *Ecology and management of riparian zones in Australia*, Occasional Paper no. 05/93, eds S.E. Bunn, B.J. Pusey and P. Price, LWRRDC, pp21–30.

Walker, K.F. and Thoms, M.C. 1993, 'Environmental effects of flow regulation on the lower River Murray, Australia', *Regulated rivers: Research and management*, 8: 103–119.

Walker, K.F., Hillman, T.J. and Williams, W.D. 1978, 'The effects of impoundments on rivers: an Australian case study', *Verhandlungen des internationalen vereinigung fuer theoretique und augewandte limnologie*, 20: 1695–1701.

Walker, K.F., Sheldon, F. and Puckridge, J.T. 1995, 'A perspective on dryland river ecosystems', *Regulated rivers: Research and management*, 11: 85–104.

Walker, K.F., Thoms, M.C. and Sheldon, F. 1992, 'Effects of weirs on the littoral environment of the River Murray, South Australia', *River Conservation and Management*, eds P.J. Boon, P. Calow and G.E. Petts, John Wiley and Sons Ltd, pp271–292.

Walters, C., Buckworth, R., Gribble, N., Griffin, R., Johnson, G., Loneragan, N. and Ramm, D. 1997, 'Status and management options for the barramundi fishery', *Towards the sustainable use of Northern Territory Fishery Resources: Review workshops led by Carl J. Walters*, Final report to the Fisheries Research and Development Corporation on project 96/158, Fishery Report 39, eds D.C. Ramm, Northern Territory Department of Primary Industry and Fisheries, pp25–31.

Wasson, B., Banens, B., Davies, P., Maher, W., Robinson, S., Volker, R., Tait, D. and Watson–Brown, S. 1996, 'Inland Waters', *Australia: State of the Environment 1996*, State of the Environment Advisory Council, Department of the Environment, Sport and Territories, CSIRO Publishing, Melbourne, pp7.1–7.55.

Water and Rivers Commission. 1997, *The state of the northern rivers*, Publication No. WRAP 10, Water and Rivers Commission, Perth.

Waterwatch. 1997, *Snapshot 97*, Waterwatch.

Webb, A.C. 1994, *Ecological aspects of the Mozambique mouthbrooder*, Oreochromis mossambicus, *and other introduced cichlids in North Queensland*, MSc thesis, Department of Ecology, James Cook University, Townsville.

Welcomme, R.L. 1995, 'Relationships between fisheries and the integrity of river systems', *Regulated rivers: Research and management*, 11: 121–136.

Western Australian Water Resources Council. 1992, *The state of the rivers of the south west*, Western Australian Water Resources Council Publication No. WRC 2/92, Western Australian Water Resources Council, Perth.

White, I. and Melville, M.D., Sammut, J., van Oploo, P., Wilson, B.P. and Yang, X. 1996, *Acid sulfate soils – facing the challenges*, Earth Foundation Australia, Monograph 1. Earth Foundation Australia, Sydney.

White, I., Melville, M.D., Wilson, B.P. and Sammut, J. 1997, 'Reducing acidic discharges from coastal wetlands in eastern Australia', *Wetlands Ecology and Management*, 5: 55–72.

Whitehead, P.J. and Tschirner, K. 1991, 'Lead shot ingestion and lead poisoning of magpie geese *Annseranus semipalmata* foraging in a northern Australian hunting reserve', *Biological Conservation*, 58: 99–118.

Wilson, C., Argent, R., Bunn, S.E., Davies, P.M., Harisine, P. and Rutherfurd, I. 1996, 'Toward an integrated model of the effects of riparian revegetation on stream values in large catchments', *Downstream effects of land use*, eds H.M. Hunter, A.G. Eykes and G.E. Rayment, Department of Natural Resources, Queensland, pp205–212.

Wimmera and Glenelg Environmental Flows Intercatchment Advisory Group. 1996 (Draft), *Flow sharing arrangements of environmental water allocations from savings of pipelining portions of the Wimmera Mallee Stock and Domestic Supply System – 1996/97*, Report prepared for The Minister of Agriculture and Natural Resources and The Minister for Conservation and Land Management, Wimmera and Glenelg Environmental Flows Intercatchment Advisory Group.

Wood, C. M. and McDonald, D. G. 1997, *Global warming : implications for freshwater and marine fish*, Cambridge University Press, Cambridge.

Woodford, J. 1995, 'Dam water "destroying" native fish', *Sydney Morning Herald*, Wednesday July 19 1995, p2.

Woodroffe, C.D. and Mulrennan, M.E. 1993, *Geomorphology of the lower Mary River plains, Northern Territory*, North Australia Research Unit, Australian National University, Darwin.

Appendices.

Appendix 1. Questions discussed at the Steering Committee workshop regarding the major threats identified in the National survey.

- What are the causes?
- Who monitors it?
- Who funds data collection?
- Who decides on management policy?
- Who implements the management policy (funds)?
- List up to five strategies which have worked to overcome a specific problem.
- Where and when was each strategy implemented?
- How do we know the strategy worked?
- Is the strategy likely to work in other regions?
- What are the major data needs for each issue?
- Relative costing of each dataset (<$1,000; $1,000–10,000; $10,000–$100,000; $100,000–1,000,000;l >$1,000,000).
- Can each of these requirements for data be met cost effectively?
- What management actions are likely to arise from the acquisition of this knowledge?

Appendix 2. Questions used in the interviews with the State representatives.

- What are the five major issues affecting the sustainability of freshwater fisheries in your State?

The following questions were asked for each of the five major issues identified in 1) above.

- What is known about this issue in your State?
- Do you know of any reports that I can use to follow–up on this issue?
- What are the main causes of this issue in your State?
- Who monitors this issue in your State?
- Who decides on management policy for this issue in your State?
- What strategies do you know of that have partially or totally solved this problem in your State?
- Do you know of any reports that I can use to follow–up on this strategy?
- In what areas is more information required before beginning to solve the problem of this issue in your State?
- Which organisations should be approached for funding?
- What management actions would be likely to result from the acquisition of this information?

Appendix 3. Threats to freshwater ecosystems identified in the National survey and organisations contacted.

(Percentage of respondents from each State in the national survey identifying each of the threats to freshwater ecosystems. Other tables present the threats identified in each State by each of the organisations surveyed.)

Threat	Commonwealth % (n*=16)	ACT % (n*=2)	NSW % (n*=10)	NT % (n*=5)	QLD % (n*=9)	SA % (n*=5)	TAS % (n*=5)	VIC % (n*=7)	WA % (n*=4)	Overall % (n*=63)	Ranking
Pollution	63	100	50	40	44	20	60	57	50	52	1
Habitat degradation	50	50	30	20	56	40	60	86	25	48	2
Reduced environmental flows	50	50	60		67	20	80	43		46	3
Water quality	56		60	20	56	40	60	14	25	44	4
Barriers to migration	44		60	20	44	40	80	43		43	5
Introduced species	38	50	50	40	44	40	80		50	41	6
Riparian vegetation degradation	38		40		56		60	57		35	7
Sedimentation	44	50	50	40	33		20	29	25	35	7
River regulation	44		40		44	20	20	43	25	33	9
Agriculture	31	50	40	20	44		20	14	25	29	10
Carp	19		50		22	40	40	57		29	10
River modification	38		30		22		60	57		29	10
Salinity	56		30		11	20		14	75	29	10
Wetland degradation	44		30	20	33		20	29	25	29	10
Nutrient levels	50	50	30		22	20	20	14		27	15
Algal blooms	38		40		44				25	24	16
Recreational fishing	19	50	10		22	40	40	14	25	21	17
Aquaculture	13		10		11	20	40	43	25	17	18
Fish stocking	19	50	10		22	20		43		17	18
Forestry	13		30		22		20	29		16	20
Commercial fishing	19		10		11	20	40	14		14	21
Channel damage	19		20				40	14		13	22
Floodplain degradation	25		20		22					13	22
Overextraction of water	25				22		40			13	22
Recreational use - other	6		20	40	22					11	25
Urbanisation	6		20		22				25	10	26
Acid sulfate soils	13	50	10		11					8	27
Climate change	13	50	10	20						8	27
Environmental degradation			10	20		20		14	25	8	27
Mining - sand and gravel	6		30		11					8	27
Inundation	19		20							8	27
Groundwater extraction	19				11					6	32
Fish diseases	13				11					5	33
Hydrological processes					22					3	34
Interbasin water transfers					22					3	34
Mining - uranium				40						3	34
Saltwater intrusion				40						3	34
Burning off				20						2	38
Competition	6									2	38
Native title hunting rights									25	2	38
Urban water supply	6									2	38
Total no. threats identified	34	11	30	14	31	15	20	21	15	41	41

* 'n' is the number of respondents from each State

State	Commonwealth																		
Issue	Australia State of Environment 1996 (1)	CRC Freshwater Ecology (2-4)	CRC Catchment Hydrology (5)	CRC Soil and Land Management (6)	CRCWMPC (7)	CRC Water Quality and Treatment (8)	CSIRO Land & Water Sector (9)	CSIRO Biodiversity Sector (9)	Dept Industry, Science & Tourism (10)	Environment Australia (11, 12)	Freshwater Fishermen's Assembly (13)	FRDC (14)	LWRRDC (15, 16)	MDBC (17)	Recfish Australia (18)	Waterwatch (19)	Total	% of organisations identifying each issue (n = 16)	Rank
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o	o	o		o		o		o	o			o	o	o		10	63	1
Salinity	o	o	o	o			o		o	o			o	o			9	56	2
Water quality	o	o					o		o	o	o		o	o		o	9	56	2
Reduced environmental flows	o	o							o	o	o		o	o	o		8	50	4
Habitat (assessment, disturbance)/Catchment management	o	o					o		o	o		o	o	o			8	50	4
Nutrient levels	o	o	o				o		o	o			o	o			8	50	4
Barriers to migration, fishways and spillways	o	o							o	o			o	o	o		7	44	7
River regulation	o	o							o	o			o	o	o		7	44	7
Sedimentation / Erosion/Turbidity	o	o	o				o			o			o	o			7	44	7
Wetlands (degradation, drainage, ecology)	o	o							o	o			o	o	o		7	44	7
Algal blooms / Eutrophication	o	o							o				o	o	o		6	38	11
Introduced species (inc. plants)	o	o						o				o	o	o			6	38	11
Rehabilitation (environmental, habitat, floodplain, wetland, river)		o	o							o		o	o	o			6	38	11
Riparian vegetation (inc. aquatic vege) - degradation		o	o						o	o			o	o			6	38	11
River modification (inc. desnagging)	o	o								o	o		o	o			6	38	11
Agriculture (inc. overgrazing, farm dams) - effects		o					o		o				o	o			5	31	16
Biodiversity		o						o		o		o		o			5	31	16
Increasing knowledge of aquatic ecosystem (inc. fish, fauna, flora)		o							o	o		o		o			5	31	16
Floodplains (alienation & ecology)	o	o							o	o							4	25	19
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)		o					o						o			o	4	25	19
Overextraction of water	o	o							o	o							4	25	19
Carp		o									o				o		3	19	22
Channel damage		o	o										o				3	19	22
Commercial fishing		o								o		o					3	19	22
Fish stocking											o	o		o			3	19	22
Groundwater extraction							o			o			o				3	19	22
Recreational fishing		o								o				o			3	19	22
Threatened species	o									o				o			3	19	22
Inundation									o	o				o			3	19	22
Acid sulfate soils				o											o		2	13	30
Aquaculture										o		o					2	13	30
Climate change / Global warming / Greenhouse effect		o								o							2	13	30
Fish diseases		o										o					2	13	30
Forestry			o										o				2	13	30
Genetic integrity of stocks	o									o							2	13	30
Competition														o			1	6	36
Mining - sand and gravel	o																1	6	36
Recreational use - other		o															1	6	36
Recruitment													o				1	6	36
Urbanisation		o															1	6	36
Urban water supply						o											1	6	36

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

1 SoEAC 1996
2 CRCFE 1997
3 Mussared 1997
4 Harris & Gehrke 1997
5 CRCCH 1997
6 CRCSLM 1997
7 CRCWMPC 1997
8 CRCWQT 1997
9 CSIRO 1997
10 DIST 1996
11 Environment Australia 1997
12 Department of Environment, Sport and Territories 1997
13 Pers. comm. Jeff Tancred 1997
14 FRDC 1997
15 LWRRDC 1997
16 Lake 1994
17 MDBC 1997
18 Pers. comm. John Harrison 1997
19 Waterwatch 1997

Other organisations contacted: Murray-Darling Basin Association

Pers. comm. = Personal communication

State	ACT				
Issue	ANU (CRES) (20)	Environment ACT (21, 22)	Total	% of organisations identifying each issue (n = 2)	Rank
Pollution (inc. pesticides, stormwater, runoff, wastewater, therma	o	o	2	100	1
Acid sulfate soils	o		1	50	2
Agriculture (inc. overgrazing, farm dams) - effects	o		1	50	2
Habitat (assessment, disturbance)/Catchment management	o		1	50	2
Climate change / Global warming / Greenhouse effect	o		1	50	2
Reduced environmental flows		o	1	50	2
Fish stocking		o	1	50	2
Introduced species (inc. plants)		o	1	50	2
Nutrient levels	o		1	50	2
Recreational fishing		o	1	50	2
Sedimentation / Erosion/Turbidity	o		1	50	2
Threatened species		o	1	50	2

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:
20 CRES 1996
21 Pers. comm. Brian Wilkinson 1997
22 Pers. comm. Mark Lintermans 1997

Pers. comm. = Personal communication

Other organisations contacted: ACT Electricity and Water

State	NSW												
Issue	Australian Museum (23)	DLWC (24)	Commercial fishermen (25)	EPA (26, 27)	NSW Fisheries (28-30)	NSW State Government (31)	NPWS (32, 33)	UNE (34)	Aboriginal Issues (35-39)	Sydney Water (40)	Total	% of organisations identifying each issue (n = 10)	Rank
Barriers to migration, fishways and spillways		o	o	o	o	o				o	6	60	1
Reduced environmental flows	o	o	o	o		o				o	6	60	1
Water quality		o		o	o	o		o		o	6	60	1
Carp	o		o	o	o				o		5	50	4
Introduced species (inc. plants)	o			o	o	o		o			5	50	4
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)				o	o	o			o	o	5	50	4
Sedimentation / Erosion/Turbidity				o	o	o		o	o		5	50	4
Agriculture (inc. overgrazing, farm dams) - effects				o	o	o			o		4	40	8
Algal blooms / Eutrophication				o	o	o				o	4	40	8
Riparian vegetation (inc. aquatic vege) - degradation				o		o		o	o		4	40	8
River regulation				o	o	o				o	4	40	8
Forestry				o	o	o					3	30	12
Habitat (assessment, disturbance)/Catchment management				o	o	o					3	30	12
Mining - sand and gravel				o	o	o					3	30	12
Nutrient levels				o		o				o	3	30	12
River modification (inc. desnagging)				o	o	o					3	30	12
Salinity		o		o		o					3	30	12
Wetlands (degradation, drainage, ecology)				o		o	o				3	30	12
Biodiversity				o		o					2	20	19
Channel damage				o		o					2	20	19
Floodplains (alienation & ecology)				o		o					2	20	19
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)				o	o						2	20	19
Recreational use - other						o			o		2	20	19
Urbanisation				o		o					2	20	19
Inundation		o				o					2	20	19
Acid sulfate soils				o							1	10	26
Aquaculture				o							1	10	26
Climate change / Global warming / Greenhouse effect				o							1	10	26
Commercial fishing					o						1	10	26
Environmental degradation									o		1	10	26
Fish stocking					o						1	10	26
Increasing knowledge of aquatic ecosystem (inc. fish, fauna, flora)					o						1	10	26
Protection of rivers							o				1	10	26
Recreational fishing					o						1	10	26
Recruitment					o						1	10	26
Threatened species					o						1	10	26

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

23 Pers. comm. John Paxton 1997
24 DLWC 1997a
25 Pers. comm. Howie Davidson 1997
26 EPA NSW 1997a
27 EPA NSW 1997b
28 NSW Fisheries 1996
29 NSW Fisheries 1997
30 Billyard n.d.
31 Parliament of NSW 1992
32 NPWS 1996
33 Pers. comm. Richard Kingsford 1997
34 Pers. comm. Andrew Boulton 1998
35 Department of Lands 1987
36 Buchhorn 1997
37 Koori Mail 1995b
38 Koori Mail 1996a
39 Koori Mail 1996b
40 Sydney Water Corporation 1996

n.d. = not dated

Other organisations contacted: Institute of Freshwater Anglers, NSW

Pers. comm. = Personal communication

State	NT							
Issue	Dept Primary Industries & Fisheries (41)	ERISS (42)	Amateur Fishermen's Association (43)	Aboriginal issues (44, 45)	Museum & Art Gallery (46)	Total	% of organisations identifying each issue (n = 5)	Rank
Introduced species (inc. plants)		o	o			2	40	1
Mining - uranium		o		o		2	40	1
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)	o	o				2	40	1
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)		o		o		2	40	1
Recreational use - other			o	o		2	40	1
Saltwater intrusion	o		o			2	40	1
Sedimentation / Erosion/Turbidity		o	o			2	40	1
Agriculture (inc. overgrazing, farm dams) - effects			o			1	20	8
Barriers to migration, fishways and spillways	o					1	20	8
Burning off			o			1	20	8
Climate change / Global warming / Greenhouse effect		o				1	20	8
Environmental degradation				o		1	20	8
Habitat (assessment, disturbance)/Catchment management	o					1	20	8
Recruitment	o					1	20	8
Rehabilitation (environmental, habitat, floodplain, wetland, river)		o				1	20	8
Water quality			o			1	20	8
Wetlands (degradation, drainage, ecology)		o				1	20	8
Which species is where?					o	1	20	8

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

41 DPIF 1997
42 ERISS 1997
43 Pers. comm. Trevor Simmonds 1997
44 Baker 1990
45 Koori Mail 1995a
46 Pers. comm. Helen Larson 1997

Other organisations contacted:
Northern Territory Fishing Industry Council
Department of Environment, NT

Pers. comm. = Personal communication

State	QLD											
Issue	CCISR, Griffith University (47)	QCFO (48)	Dept of Environment (49)	Australian centre for tropical freshwater research, James Cook Uni (50)	Dept Natural Resources (51)	QDPI (Nth Qld and Inland) (52, 53)	QFMA (54)	Proposed Coper's Creek Institute (55)	Proposed Northern Murray-Darling Research Institute (56, 57)	Total	% of organisations identifying each issue (n = 9)	Rank
Reduced environmental flows	o			o		o	o	o	o	6	67	1
Habitat (assessment, disturbance)/Catchment management	o			o		o	o		o	5	56	2
Increasing knowledge of aquatic ecosystem (inc. fish, fauna, flora)	o					o	o	o	o	5	56	2
Riparian vegetation (inc. aquatic vege) - degradation	o			o		o	o		o	5	56	2
Water quality			o	o		o	o		o	5	56	2
Agriculture (inc. overgrazing, farm dams) - effects				o		o	o	o		4	44	6
Algal blooms / Eutrophication					o	o	o		o	4	44	6
Barriers to migration, fishways and spillways		o		o		o	o			4	44	6
Introduced species (inc. plants)		o		o			o		o	4	44	6
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o						o	o	o	4	44	6
River regulation		o					o	o	o	4	44	6
Sedimentation / Erosion/Turbidity						o	o		o	3	33	12
Wetlands (degradation, drainage, ecology)				o		o	o			3	33	12
Carp						o	o			2	22	14
Fish stocking						o	o			2	22	14
Floodplains (alienation & ecology)				o					o	2	22	14
Forestry				o			o			2	22	14
Genetic integrity of stocks						o	o			2	22	14
Hydrological processes								o	o	2	22	14
Interbasin water transfers				o			o			2	22	14
Nutrient levels							o		o	2	22	14
Overextraction of water						o	o			2	22	14
Recreational fishing						o	o			2	22	14
Recreational use - other				o		o				2	22	14
River modification (inc. desnagging)						o	o			2	22	14
Urbanisation				o		o				2	22	14
Acid sulfate soils							o			1	11	27
Aquaculture							o			1	11	27
Biodiversity				o						1	11	27
Commercial fishing							o			1	11	27
Fish diseases							o			1	11	27
Groundwater extraction									o	1	11	27
Mining - sand and gravel							o			1	11	27
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)					o					1	11	27
Rehabilitation (environmental, habitat, floodplain, wetland, river)				o						1	11	27
Salinity							o			1	11	27
Which species is where?							o			1	11	27

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

47 CCISR 1997
48 Pers. comm. Daryl McPhee 1997
49 Pers. comm. Andrew Moss 1997
50 Pers. comm. Richard Pearson 1997
51 Pers. comm. Satish Choy 1997
52 Pers. comm. Alf Hogan 1997
53 Pers. comm. Alex Hamlyn 1997
54 Freshwater Fisheries MAC 1996
55 Bunn et al. 1997
56 Cullen 1997
57 QMDBCC 1997

Other organisations contacted: Sunfish, QLD

Pers. comm. = Personal communication

State	SA							
Issue	EPA (58)	SA Recreational fishing advisory council (59)	SAFIC (60)	University of Adelaide (61)	SARDI (62)	Total	% of organisations identifying each issue (n = 5)	Rank
Barriers to migration, fishways and spillways		o			o	2	40	1
Carp			o		o	2	40	1
Habitat (assessment, disturbance)/Catchment management		o		o		2	40	1
Introduced species (inc. plants)	o			o		2	40	1
Recreational fishing				o	o	2	40	1
Water quality	o	o				2	40	1
Aquaculture	o					1	20	7
Commercial fishing				o		1	20	7
Environmental degradation		o				1	20	7
Reduced environmental flows			o			1	20	7
Fish stocking					o	1	20	7
Increasing knowledge of aquatic ecosystem (inc. fish, fauna, flora)					o	1	20	7
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)	o					1	20	7
Nutrient levels	o					1	20	7
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o					1	20	7
River regulation				o		1	20	7
Salinity					o	1	20	7
Threatened species					o	1	20	7

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

58 Pers. comm. Peter Goonan 1997
59 Pers. comm. Henry Jones 1997
60 Pers. comm. John Winwood 1997
61 Pers. comm. Keith Walker 1997
62 SARDI 1996

Pers. comm. = Personal communication

State	TAS							
Issue	DPIF (63-65)	Parks & Wildlife (66)	IFC (67, 68)	Hydro-Electric Corporation (69)	University of Tasmania (70)	Total	% of organisations identifying each issue (n = 5)	Rank
Barriers to migration, fishways and spillways	o		o	o	o	4	80	1
Reduced environmental flows	o		o	o	o	4	80	1
Introduced species (inc. plants)	o	o	o		o	4	80	1
Habitat (assessment, disturbance)/Catchment management	o	o	o			3	60	4
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o		o		o	3	60	4
Riparian vegetation (inc. aquatic vege) - degradation	o	o	o			3	60	4
River modification (inc. desnagging)	o	o	o			3	60	4
Threatened species	o		o	o		3	60	4
Water quality	o		o	o		3	60	4
Aquaculture	o		o			2	40	10
Carp	o		o			2	40	10
Channel damage			o	o		2	40	10
Commercial fishing	o		o			2	40	10
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)	o			o		2	40	10
Overextraction of water	o				o	2	40	10
Recreational fishing	o		o			2	40	10
Agriculture (inc. overgrazing, farm dams) - effects			o			1	20	17
Forestry			o			1	20	17
Nutrient levels			o			1	20	17
Protection of rivers	o					1	20	17
River regulation			o			1	20	17
Sedimentation / Erosion/Turbidity			o			1	20	17
Wetlands (degradation, drainage, ecology)			o			1	20	17

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

63 Pers. comm. Martin Read 1998
64 Pers. comm. Mark Nelson 1998
65 Pers. comm. Chris Bobbies 1998
66 Pers. comm. Mike Askey-Doran 1997
67 Pers. comm. David Crook 1997
68 Davies and Hussey 1996
69 Pers. comm. Helen Locher 1997
70 Pers. comm. Rob White 1997

Other organisations contacted:
Environment Tasmania
Tasmanian Fishing Industry Council
Freshwater Anglers Council of Tasmania

Pers. comm. = Personal communication

State	VIC									
Issue	EPA (71-73)	Native fish Australia (74)	Aboriginal Issues (75)	Fisheries Victoria (76)	Recreational fishing (77)	Australian Trout Federation (78)	MAFRI (79)	Total	% of organisations identifying each issue (n = 7)	Rank
Habitat (assessment, disturbance)/Catchment management	o	o		o	o	o	o	6	86	1
Carp		o	o		o		o	4	57	2
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o	o	o		o			4	57	2
Riparian vegetation (inc. aquatic vege) - degradation	o	o			o		o	4	57	2
River modification (inc. desnagging)			o	o		o	o	4	57	2
Aquaculture				o	o		o	3	43	6
Barriers to migration, fishways and spillways		o	o				o	3	43	6
Reduced environmental flows				o	o	o		3	43	6
Fish stocking				o	o		o	3	43	6
Monitoring of freshwater ecosystems (inc. fish, macroinvertebrates)	o			o			o	3	43	6
River regulation	o		o				o	3	43	6
Forestry						o	o	2	29	12
Genetic integrity of stocks				o			o	2	29	12
Rehabilitation (environmental, habitat, floodplain, wetland, river)				o			o	2	29	12
Sedimentation / Erosion/Turbidity	o	o						2	29	12
Threatened species					o		o	2	29	12
Wetlands (degradation, drainage, ecology)			o		o			2	29	12
Agriculture (inc. overgrazing, farm dams) - effects						o		1	14	18
Biodiversity	o							1	14	18
Channel damage	o							1	14	18
Commercial fishing					o			1	14	18
Environmental degradation					o			1	14	18
Increasing knowledge of aquatic ecosystem (inc. fish, fauna, flora)	o							1	14	18
Nutrient levels	o							1	14	18
Recreational fishing					o			1	14	18
Salinity							o	1	14	18
Water quality	o							1	14	18

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

71 EPA VIC 1995
72 EPA VIC 1997
73 Parliament of Victoria 1988
74 Pers. comm. Graeme Creed 1997
75 Pers. comm. Colin Walker Yorta Yorta Land Council,1998
76 Fisheries Victoria 1996
77 Barnham 1997
78 Pers. comm. Jim Allen 1997
79 Pers. comm. Garth Newman 1997

Other organisations contacted:
Victorian Fishing Industry Federation
Deakin University, VIC
Monash University, VIC

Pers. comm. = Personal communication

State	WA						
Issue	Recfish West (80)	Fisheries Dept of WA (81, 82)	Aboriginal issues (83)	CALM (84, 85)	Total	% of organisations identifying each issue (n = 4)	Rank
Salinity	o	o		o	3	75	1
Introduced species (inc. plants)		o		o	2	50	2
Pollution (inc. pesticides, stormwater, runoff, wastewater, thermal)	o			o	2	50	2
Agriculture (inc. overgrazing, farm dams) - effects	o				1	25	4
Algal blooms / Eutrophication		o			1	25	4
Aquaculture		o			1	25	4
Environmental degradation		o			1	25	4
Genetic integrity of stocks		o			1	25	4
Habitat (assessment, disturbance)/Catchment management		o			1	25	4
Native title hunting rights			o		1	25	4
Recreational fishing		o			1	25	4
River regulation	o				1	25	4
Sedimentation / Erosion/Turbidity	o				1	25	4
Urbanisation		o			1	25	4
Water quality				o	1	25	4
Wetlands (degradation, drainage, ecology)				o	1	25	4
Which species is where?				o	1	25	4

Table includes threats to the freshwater ecosystem and projects involving freshwater.

References:

80 Pers. comm. Ian Stagles 1997
81 Fisheries Department of Western Australia 1996
82 Pers. comm. Craig Lawrence 1997
83 Kennedy 1996
84 Halse 1998
85 Pers. comm. Stuart Halse 1997

Other organisations contacted:
Murdoch University, WA
Water and Rivers Commission, WA

Pers. comm. = Personal communication

Appendix 4. Major threats to the sustainability of freshwater fisheries resources in each State (based on interviews with the State representatives).

Threat	NSW		NT		QLD		SA		TAS*		VIC		WA*		Total
	A	B	A	B	A	B	A†	B	A	B	A	B	A	B	
Reduced environmental flows	5	3			4	5		5	4	4	5	5	4	4	48
Habitat degradation	3	2			5	3	4	4	5	5	4	2	5	5	47
Barriers to migration	4	5	2	5	3	4		2			3	4	3	3	38
Fishing			4	3		2	5					3	1	1	19
Pollution	2	1			2		3	3	2	2	1				16
Introduced species			3	1	1	1	2	1	1	1			2	2	15
Carp	1	4							3	3		1			12
Lack of information			5												5
Natural fish kills				4											4
Riparian vegetation degradation											2				2
Wetland degradation				2											2
Salinity			1												1

A, B = Manager or Researcher

* Both Tasmania and Western Australia identified the same person as the research and management representative, their results have been duplicated to give columns A and B.

† Considered there to be only 4 highest priority threats.

5 = threat of most concern, 1 = fifth most important threat.

Both NSW representatives combined water quality and pollution.

One NSW representative grouped wetland degradation, riparian vegetation with habitat degradation, while both grouped sedimentation with habitat degradation.

Both QLD representatives grouped riparian vegetation with habitat degradation, while one also grouped wetland degradation with habitat degradation.

One QLD representative grouped pollution, salinity and sedimentation with water quality.

One QLD representative grouped carp with introduced species.

One SA representative grouped barriers to migration, carp and water quality with habitat degradation.

One VIC representative grouped riparian vegetation, sedimentation (major problems), pollution, salinity, water quality and wetland degradation (all minor problems) with habitat degradation and call it Catchment management.

Appendix 5. State of knowledge for the major threats identfied in each State (based on interviews with the State representatives).

Not all of the material discussed in the tables below is referenced, much is from the interviews.

NSW

	Barriers to migration	Carp	Reduced environmental flows	Habitat degradation	Pollution/Water quality
Knowledge	There is an inventory of all weirs in NSW	There is a lot of information on carp	River regulation has had a profound effect on the river ecosystem and biodiversity	There are a number of detailed responses to degradation, but the overall significance in the decline of fish populations and communities is poorly understood and is likely to remain so because it is hard to quantify	The knowledge is very fragmented
	There are about 5000 artificial tidal barriers and 4000 artificial barriers in rivers	Dominant in fish communities in inland rivers at all sites below 500m			Acid sulfate soil drainage is a major problem in coastal systems
	Barriers to migration have been a major factor in the decline of freshwater fish	Associated with parasites and diseases of other fish	We know that current flow levels are unsatisfactory, not yet sure of the flows required		Nutrient loading is a problem in many streams
		Impact aquatic macrophytes			Large proportions of rivers are affected by cold water pollution
	All fish require free passage in streams, some undertake major migrations	Responsible for bioturbation	There is some knowledge of the flow requirements of the major commercial and recreational species	Much is common sense, eg a decrease in wetlands results in a decrease in nursery habitat, feeding areas, energy input, & refuges leads to an increase in mortality and a decrease in population size	Pesticide residues are distributed in association with intensive agriculture, the significance of these pesticides is not well known
		Decrease water quality			
	There are about 22 effective new fishways, many of which have been assessed, and about 45 old ineffective fishways	It is known that they have a significant impact, but the significance of the interaction with native fauna is poorly understood			
	There is a great deal of information relating to the main fish species and for certain barriers	It is known that we could control them, but we are not able to apply these methods for various reasons eg spring viraemia, commercial exploitation		Habitat degradation is extremely widespread and diffuse	
		Cause enormous community concern			
References	DLWC 1996	Nannestad 1994	CRCFE 1998b	MacKay and Eastburn 1990	Walker et al. 1978
	CRCFE 1998a, b	King 1995	Gehrke 1997b		Woodford 1995
	Pethebridge et al. 1998 and therein	Murray-Darling Assoc. 1995	Australian Water and Wastewater Association 1994	SoEAC 1996	Sammut et al. 1996, 1997
		Robertson et al. 1995		EPA NSW 1997c	White et al. 1996, 1997
		Dove et al. 1997	DLWC 1998a	Gehrke 1997b	EPA NSW 1997c
		Driver et al. 1997			Harris 1997
		Gehrke 1997a			
		King et al. 1997			
		Roberts and Ebner 1997			
		Roberts and Tilzey 1997			
		Robertson et al. 1997			
		Swirepik 1998			
		Dove and Ernst In press			
		Dove and Fletcher Submitted			

NT

	Barriers to migration	Fishing	Information gathering	Introduced species	Natural fish kills
Knowledge	Most freshwater fish in the NT are catadromous, if there are no permanent areas of freshwater available they can live at sea all the time	Sustainable levels for the harvest of barramundi have been determined, this hasn't been done for other species as no others are targeted	Not discussed	All current problems are plant related, introduced fish species are a potential problem with carp and tilapia being the major threats	The basic mechanisms of this problem are understood; it is not human induced, it is a natural process
	Some barriers on the Mary River are passable others are not	A survey of recreational fishing was recently completed		Fish living under salvinia infestations are limited and in poor condition	At the beginning of the wet season stratification of waters can occur; when the stratified waters turnover there is a decrease in oxygen levels which can kill a large number of fish
	The barriers on the Mary River provide areas for use as ponded pastures	Barramundi account for about 98% of the inland recreational fishery			
	There are few barriers in the NT, the main ones are on the Mary River to prevent saltwater intrusion	Commercial fishing is very stable, barramundi stocks have recovered from over exploitation in the 1970s; this is shown in the catch/effort statistics for the last 7-8 years, however the commercial catch is decreasing as pressure from recreational groups increases		Very little is known about the problem	
	The 3 high wall dams in the NT do not prevent access to permanent areas of freshwater, they are all on temporary streams providing Darwin with drinking water				
References	Woodroffe and Mulrennan 1993	Johnson 1996	-	Nothing published	Griffin and Lestang 1998
		Fallu 1997b			
		Walters et al. 1997			
		Coleman 1998			

	Salinity	Wetland degradation
Knowledge	This is only a problem on the Mary River and is related to the problem of barriers to migration. The barriers were built to prevent saltwater intrusion.	The main problems arise from the saltwater intrusion in the Mary River and from introduced pastures
		Saltwater intrusion is resulting in an increase in saltwater wetlands and a decrease in freshwater wetlands.
		Possible impacts on barramundi populations through saltwater degradation
References	Woodroffe and Mulrennan 1993	Woodroffe and Mulrennan 1993
		Griffin 1995a, b, c

QLD

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge	Barriers on coastal streams impede migrations eg bass, barramundi	CCISR has examined flows on small streams	Commercial fishing is a potential problem based on understanding from NSW and VIC	There have been several studies on habitat degradation	They take bait meant for other species making them a nuisance for recreational fishers
	Many QLD fish are diadromous	In large rivers the impact of decreased flows is poorly understood	By-catch could be a problem	A strategy for the management of fish habitat is being developed by QDPI	Introduced fish replace natives
	Fish need to disperse as well as migrate		Commercial fishing conflicts with recreational fishing		There is the possibility of disease transfer
	There is some retrofitting of fishways to existing barriers	Much information has been gained from environmental impact statements prepared during the building of large dams	Native fish populations decline with commercial fishing	Weirs result in a change from flowing habitat to pool habitat	It is known which species are present
	QDPI Fisheries can require that a fishway be built		QFMA consider all applications for new commercial fisheries	Other fish require riffles for spawning	Can prey on natives or compete for resources
	QDPI have programs monitoring fishways once they are built, this data is used by the designers to improve the design of fishways	There is little information on the impacts that flow changes have had on fish outside the Murray-Darling Basin	Fish stocking in impoundments is mainly done for recreational purposes, it creates a fishery where there wasn't one	A review of barriers in the Murray-Darling Basin has been performed, this has enabled the identification of priority barriers	There is only circumstantial evidence that tilapia are a problem. It is known that there aren't many natives in areas
	It is known that many species need to migrate to spawn, if there is a barrier blocking their passage they can't complete the migration		Some stocking is done in conjunction with habitat restoration for the recovery of threatened species eg Mary River cod	It is known that Mary River cod like good in-stream and riparian cover	CCISR have determined that tropical aquarium species are a problem for some natives
				Wetlands in the Tully and Murray have been examined	Often occur in degraded waters, are they a symptom or a cause?
	Barriers increase predation; fish accumulate downstream of the barrier		There is currently a commercial fishery for eels, eel catches have declined	Golden perch require a long stretch of flowing water for successful spawning	Tilapia can use saltwater to move between freshwater systems
	Priority barriers have been identified in a review of the barriers in the Murray-Darling Basin		QFMA have proposed introducing a commercial non-sustainable fishery for carp as a control method	Lungfish have specific habitat requirements for spawning - 10-20cm of macrophyte growth, 15-40cm of water	Fisheries can be created in areas in which they did not previously exist eg impoundments
					Can modify the environment
					Translocation is an issue
References	Russell 1991	Berghuis et al. 1997	-	Hogan and Graham 1994a, b	Webb 1994
	Berghuis et al. 1997 and therein	Crabb 1997		Hogan et al. 1995a, b	Russell et al. 1996
	Hogan et al. 1997	Arthington 1998		Freshwater Fisheries MAC 1996	Arthington and McKenzie 1997
	Stuart 1997	Arthington and Zalucki 1998		Hunter et al. 1996	
	Cotterell 1998			Moller 1996	
	Hogan 1998			Russell et al. 1996	
				Carter 1997	
				Crabb 1997	
				Jackson 1997	
				Russell and Hales 1997	
				QDPI 1998	

QLD (continued)

	Pollution/Water quality
Knowledge	Department of Environment have a strategy for dealing with fish kills
	It is recognised that many pesticides and fertilisers have an impact on fish
	Acid sulfate soils are a problem
References	Hunter et al. 1996
	Crabb 1997
	Jackson 1997

SA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge	This is well researched for the Murray-Darling	There is no longer any surface water in many places in the Adelaide Hills	The public perception is that the commercial river fishery isn't sustainable, this arises from a lack of understanding and affects the ability of PIRSA to manage the fishery	Weir pools in the lower Murray have resulted in backwater rather than flowing habitat	Redfin are the main problem, they compete with native fish for habitat and other resources
		When there are over-bank flows in the Murray-Darling there is good recruitment of the major fish species, these flows are not controlled by SA		There is a great deal of knowledge relating to environmental changes that have occurred over the last 100 years, however it isn't possible to quantify which of these have been the most important	
		Commercial catches reflect flows; ie to catch fish emulate conditions prior to regulation		Carp have an impact on habitat	
				Barrages inhibit the movement of fish	
References	No reports written	Sharley and Huggan 1995	Presser 1996	Pierce 1988, 1997a, b	McKay 1984
			South Australian FRAB 1998		Pierce 1996

	Pollution/Water quality
Knowledge	SA Water monitors the quality of water coming into SA
	PIRSA may have some information relating to inputs, potential problem areas and likely point sources; other agencies may know more about pollution
	A SARDI study of disease dynamics and water quality has shown that when the water coming across the border is of low quality, there is an increase in disease amongst fish caught
References	–

VIC

	Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Knowledge	In the last ten years it has been realised that barriers are a major threat to freshwater fish	Not discussed	There is little information on the impact of changes to the flow regime	There are catch and effort databases for the commercial fisheries	There have been expert panel assessments of the Snowy and Murray Rivers
	A great deal of money has been spent building fishways		Many streamflow studies have been performed	There are creel surveys on the number of fish removed from the salmonid fishery, little is known about the native fisheries	Lakes and dams have received little attention
	It is accepted that fish passage must be provided at barriers		A study of the Campaspe River downstream of Lake Eppalock will provide baseline information on the ecosystem, this will allow before and after comparisons to be made when changes to the flow regime are implemented		Threatening processes can be listed under the Flora and Fauna Guarantee Act, there are many relating to freshwater eg sedimentation, toxic inputs, snag removal, flow alteration, riparian vegetation, barriers
	There is a great deal of knowledge relating to small fish which are only involved in the fishery resource as part of the food chain				
	The State Fishway Program is prioritising barriers and building fishways as required		Environmental releases have been made from Thomson and Dartmouth Dams		The way in which the catchments have changed over time can be measured and correlated with evidence that fisheries have declined over similar time scales
	There is little evaluation of the effectiveness of fishways once they are built.		Environment is being included as a water user in the conversion to bulk water entitlements		
	All barriers in Victoria are documented		Relationship between flow decreases and decline in native fish populations is not perfect		Little is really known
References	Doeg and Koehn 1994	–	Hall 1989	Barnham 1997	Mitchell 1990
	Koehn et al. 1996		Fitzpatrick and Bennett 1994	MAFRI 1997	Land Conservation Council 1991
	Bennett 1997		Department of Conservation and Natural Resources 1995		Doeg and Koehn 1994
			Ingeme 1996		Snowy River Expert Panel 1996a, b
			Koehn et al. 1996		
			Overman 1996		Bevitt et al. 1998
			Snowy River Expert Panel 1996a, b		
			Sustainable Land and Water Resources Management Committee 1996		
			Wimmera & Glenelg Environmental Flows Intercatchment Advisory Group 1996		
			Allen and Lovett 1997		
			NRE 1997		
			Bevitt et al. 1998		
			CRCFE c. 1998		

VIC (continued)

	Riparian vegetation degradation	Water temperature
Knowledge	Riparian vegetation holds the stream bank together, prevents things falling into the stream, provides terrestrial food input, shading etc	In many places the water temperatures critical for the spawning of native fish are no longer reached, in these areas native fish are being replaced by trout eg below Eildon, Hume and Dartmouth Dams
	The percentage of bank with an intact riparian zone is known, most is in poor condition or is not fenced	In the upper reaches of most rivers there are dams with low level outlets
References	Mitchell 1990	Koehn et al. 1996

TAS

	Carp	Reduced environmental flows	Habitat degradation	Introduced species	Pollution
Knowledge	It is known where they are and that they are a potential problem	There is no environmental flow legislation and, with the exception of releases to satisfy old riparian demands, no agreements in place	There is spot evidence and anecdotal claims relating to habitat degradation, not an overall picture	It is known which species are present	There is a fair body of knowledge on industrial, urban and agricultural pollution sources
	As yet they haven't caused any problems in Lakes Crescent and Sorell; their numbers have been reduced and they are spawning only once per year, they take longer to reach spawning size than they do on the mainland			The problems they do and probably could cause are known	There is no overall survey of the sources, many are in the Derwent River
		Most major rivers have a dam, some streams have no flow	Habitat degradation is advancing in many areas	The extent of their current distribution is known	There are continuing pollution problems from old mines
		The magnitude of the problem has not been examined	Not much is really known		Most industrial sources have been addressed; urban and agricultural sources haven't yet
References	IFC 1995, 1996, 1997	Don't know of any	There are no specific reports	IFC 1996	Coughanowr 1997

WA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge	Barriers prevent the upstream movement of barramundi and other species in the north	Don't know of any reviews specific to WA, the problem has been mentioned in eastern Australia for many years	Not discussed	It is extensive especially in the southwest where wetlands are being drained and filled	Introduced species impact natives through disease, competition etc
	In the southwest roads, bridges, culverts, gauging weirs and private dams block the movement of small native fish	People in WA are aware of the problem		There is no baseline to which changes can be compared	Translocation is an issue
		No attention is paid to the problem of private dams. They cover an enormous area, some are very large in size, they decrease the amount of water flowing downstream, increase the amount of evaporation, can stop downstream flow when water is pumped from them, and can lead to an increase in water temperature downstream if the overflow flows over a shallow lip			Gambusia, redfin, koi carp, goldfish, tilapia and trout are present in WA
References	Morrissy 1983		–	Olsen & Skitmore 1991	Morrissy and Cassells 1992
	Bunbury 1987			Western Australian Water Resources Council 1992	Morgan et al. 1998
	Storey and Beesley 1998			Pen 1997	
				Water and Rivers Commission 1997	
				Horwitz et al. 1998	
				Morgan et al. 1998	

Appendix 6. State of knowledge for the overall six major threats (based on interviews with the State representatives).

Habitat degradation

NSW	NT	QLD	SA	TAS	VIC	WA
Habitat degradation is extremely widespread and diffuse	Not raised as a major issue for this State	Weirs result in a change from flowing habitat to pool habitat	Barrages inhibit the movement of fish	Habitat degradation is advancing in many areas	Lakes and dams have received little attention	There is no baseline to which changes can be compared
There are a number of detailed responses to degradation, but the sense of the overall significance in the decline of fish populations and communities is poorly understood and is likely to remain so because it is hard to quantify		A review of barriers in the Murray-Darling Basin has been performed, this has enabled the identification of priority barriers	There is a great deal of knowledge relating to environmental changes that have occurred over the last 100 years, however it isn't possible to quantify which of these have been the most important	There is spot evidence and anecdotal claims relating to habitat degradation, there is no overall picture	Threatening processes can be listed under the Flora and Fauna Guarantee Act, there are many relating to freshwater eg sedimentation, toxic inputs, snag removal, flow alteration, temperature alterations, riparian vegetation, barriers	Habitat degradation is extensive especially in the southwest where wetlands are being drained and filled
		A strategy for the management of fish habitat is being developed by QDPI				
Much of what is known is common sense, for example a decrease in wetlands results in a decrease in nursery habitat, feeding areas, energy input, and refuges which leads to an increase in mortality and a decrease in population size		Wetlands on the Tully and Murray Rivers have been examined	Weir pools in the lower Murray have resulted in backwater rather than flowing habitat			
		Some native species have specific habitat requirements			The way in which the catchments have changed over time can be measured and correlated with evidence that fisheries have declined over similar time scales	
		There have been several studies on habitat degradation	Carp have an impact on habitat		There have been expert panel assessments of the Snowy and Murray Rivers	

Pollution/Water Quality/Water temperature

NSW	NT	QLD	SA	TAS	VIC	WA
The knowledge is very fragmented	Not raised as a major issue for this State	Acid sulfate soils are a problem	SA Water monitors the quality of water coming into SA	There is no overall survey of the sources, many are in the Derwent River	In the upper reaches of most rivers there are dams with low level outlets	Not raised as a major issue for this State
Acid sulfate soil drainage is a major problem in coastal systems		It is recognised that many pesticides and fertilisers have an impact on fish				
Pesticide residues are distributed in association with intensive agriculture; the significance of these pesticides is not well known		Department of Environment have a strategy for dealing with fish kills	PIRSA may have some information relating to inputs, potential problem areas and likely point sources; other agencies may know more about pollution	There are several sources of pollution on which there is a fair body of knowledge: industrial, urban and agricultural	In many places the water temperatures critical for the spawning of native fish are no longer reached, in these areas native fish are being replaced by trout	
Large proportions of many rivers are affected by cold water pollution from stratified irrigation dams, this impacts the spawning and migration triggers of native fish				Most industrial sources have been addressed, urban and agricultural sources haven't been as yet		
Nutrient loading is a problem in many streams			A SARDI study of disease dynamics and water quality has shown that when the water coming across the border is of low quality there is an increase in disease amongst fish caught	There are continuing pollution problems from old mines		
There is a great deal of knowledge relating to algal blooms, pesticides, nutrients and agricultural chemicals						

Reduced environmental flows

NSW	NT	QLD	SA	TAS	VIC	WA
River regulation has had a profound effect on the river ecosystem and biodiversity	Not raised as a major issue for this State	Much information has been gained from environmental impact statements prepared during the building of large dams	There is no longer any surface water in many places in the Adelaide Hills	The magnitude of the problem has not been examined	In the process of converting to bulk water entitlements the environment is being included as a water user	No attention is paid to the problem of private dams in the southwest. It is known that they cover an enormous area, some are very large in size, they decrease the amount of water flowing downstream, increase the amount of evaporation, can stop downstream flow when water is pumped from them, and can lead to an increase in water temperature downstream if the overflow flows over a shallow lip
We know that current flow levels are unsatisfactory, as yet we are not sure of the flows required		There is little information on the impacts that flow changes have had on fish outside the Murray-Darling Basin	When there are over-bank flows in the Murray-Darling there is good recruitment of the major fish species, these flows are not controlled by SA	There is no environmental flow legislation and, with the exception of releases to satisfy old riparian demands, no agreements in place	A study of the Campaspe River downstream of Lake Eppalock will provide baseline information on the ecosystem, this will allow before and after comparisons to be made when changes to the flow regime are implemented	
There is some knowledge of the flow requirements of the major commercial and recreational species		In large rivers the impact of decreased flows is poorly understood	Commercial catches reflect flows; it is known that to catch fish the conditions prior to regulation must be emulated	Most major rivers have a dam, some streams have no flow	Environmental releases have been made from Thomson and Dartmouth Dams	
		CCISR has examined flows on small streams			Many streamflow studies have been performed	People in WA are aware of the problem
					The cause and effect relationship of flow decreases and declines in native fish populations is less than perfect	Don't know of any reviews specific to WA, the problem has been mentioned in eastern Australia for many years
					There is little information on the impact of changes to the flow regime	

Barriers to migration

NSW	NT	QLD	SA	TAS	VIC	WA
There are about 5000 artificial tidal barriers and 4000 artificial barriers in rivers	The 3 high wall dams in the NT do not prevent access to permanent areas of freshwater	Priority barriers have been identified in a review of the barriers in the Murray-Darling Basin	This is well researched for the Murray-Darling	Not raised as a major issue for this State	In the last ten years it has been realised that barriers are a major threat to freshwater fish	Barriers prevent the upstream movement of barramundi and other species in the north
All fish require free passage in streams, some undertake major migrations	There are few barriers in the NT, the main ones are on the Mary River	Barriers on coastal streams impede migrations of diadromous fish eg bass, barramundi			The State Fishway Program is prioritising barriers and building fishways as required	In the southwest roads, bridges, culverts, gauging weirs and private dams block the movement of small native fish
There are about 22 effective new fishways, many of which have been assessed, and about 45 old ineffective fishways	Some of the barriers on the Mary River, designed to prevent saltwater intrusion, are passable others are not	It is known that many species need to migrate to spawn, if there is a barrier blocking their passage they can't complete the migration			There is a great deal of knowledge relating to small fish which are only involved in the fishery resource as part of the food chain	
There is a great deal of information relating to the main fish species and for certain barriers	Most freshwater fish in the NT are catadromous; if there are no permanent areas of freshwater available they can live at sea all the time	QDPI have programs monitoring fishways once they are built, this data is used by the designers to improve the design of fishways			All barriers in Victoria are documented	
Barriers to migration have been a major factor in the declines of freshwater fish		Barriers increase predation; large numbers of fish accumulate at the barrier			There is little evaluation of the effectiveness of fishways once they are built	
There is an inventory of all weirs in NSW	The barriers on the Mary River provide areas for use as ponded pastures	Fish need to disperse as well as migrate			A great deal of money has been spent building fishways.	
		There is some retrofitting of fishways to existing barriers				
		QDPI Fisheries can require that a fishway be built on a new barrier			It is accepted that fish passage must be provided at barriers	

Introduced species/Carp*

NSW	NT	QLD	SA	TAS	VIC	WA
There is a great deal of information on carp	All current problems are plant related	Translocation is an issue	Redfin are the main problem; they compete with native fish for habitat and other resources	It is known which species are present	Not discussed	Translocation is an issue
Carp cause enormous community concern	Fish living under salvinia infestations are limited and in poor condition	Introduced fish replace natives		The problems they do, and probably could cause, are known		Introduced species impact natives through disease, competition etc
Carp have an impact on aquatic macrophytes		There is the possibility of disease transfer				
Carp decrease water quality	Carp and tilapia are the main potential problem fish	Introduced species can modify the environment		The extent of their current distribution is known		Gambusia, redfin, koi carp, goldfish, tilapia and trout are present in WA
Carp are associated with parasites and diseases of other fish		They can prey on natives and compete with them for food and space				
Carp are dominant in fish communities in inland rivers at all sites below 500m		They take bait meant for other species making them a nuisance for recreational fishers				
Carp are responsible for bioturbation		Aquarium species are a problem				
It is known that carp have a significant impact, but the significance of the interaction with native fauna is poorly understood		Fisheries can be created in areas in which they did not previously exist				
		Tilapia can use saltwater to move between freshwater systems				
It is known that we could control carp but we are not able to apply these methods for various reasons eg spring viraemia, commercial exploitation		It is known which species are present				
		Introduced species often occur in degraded waters				
		There is only circumstantial evidence that tilapia are a problem				

*Introduced species and carp have been combined for the purposes of this table.

Fishing

NSW	NT	QLD	SA	TAS	VIC	WA
Not raised as a major issue for this State	A recreational fishing survey was recently completed	Commercial fishing is a potential problem based on understanding from NSW and VIC	The public perception is that the commercial river fishery isn't sustainable, this arises from a lack of understanding and affects the ability of PIRSA to manage the fishery	Not raised as a major issue for this State	There are catch and effort databases for the commercial fisheries	Not discussed
	Barramundi account for about 98% of the inland recreational fishery	Native fish populations decline with commercial fishing			There are creel surveys on the number of fish removed from the salmonid fishery, little is known about the native fisheries	
	Sustainable levels for the harvest of barramundi have been determined, this hasn't been done for other species as no others are targeted	Fish stocking in impoundments is mainly for recreational purposes, it creates a fishery where there wasn't one previously				
		Commercial fishing conflicts with recreational fishing				
	Commercial fishing is very stable, barramundi stocks have recovered from over exploitation in the 1970s; this is shown in the catch/effort statistics for the last 7-8 years, however the commercial catch is decreasing as pressure from recreational groups increases	By-catch could be a problem				
		There is currently a commercial fishery for eels, eel catches have declined				
		Some stocking is done in conjunction with habitat restoration for the recovery of threatened species eg Mary River cod				
		QFMA have proposed introducing a commercial non-sustainable fishery for carp as a control method				
		QFMA consider all applications for new commercial fisheries				

Appendix 7. Primary causes of the major threats (based on input from the Steering Committee).

Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Dams	Introductions	Lack of water	Not discussed	Boat traffic
Demand for water	"Escapees"	Water storage		Dredging
Pasture pondage		Water control		Desnagging
On-stream farm dams		Water abstraction		Channelisation
Salt water mitigation weirs		Diversion		Irrigation
Road crossings		Storage releases		Bank and bed erosion
				Water regulation
				Rubbish dumping
				Mining - sand and gravel
				See other issues for more

Introduced species	Pollution/Water quality	Riparian vegetation degradation	Salinity	Wetland degradation
Pet dumping	Stormwater	Clearing	Irrigation practices	Overstocking
Relocation	Sewage	Grazing	Clearing of deep-rooted, salt-tolerant, native vegetation	Cropping
Stocking	Dryland runoff	Cropping		Pasture pondage
Flooding of farm dams	Stock grazing on banks	Lack of fencing	Reduction in river flow rates	Clearing
"Improved" pastures	Pesticides	Bank erosion	Saltwater intrusion	Lowering of the water table
Stabilisation of stream banks with willows	Rubbish dumping	Introduced pests eg pigs, willow, blackberry	Impoundment	Dams
	Heavy metals		Evaporation	River regulation
	Nutrients			Levee banks
	Sediment			Water diversion
	Organic matter			Drainage
	Thermal stratification of dams			Feral animals
	Phosphorous in sediments			Recreational use
	Decrease in oxygen levels			Fire
	Re-use of water as it flows downstream			

Appendix 8. Primary causes of the major threats identified in each State (based on interviews with the State representatives).

NSW

Barriers to migration	Carp	Reduced environmental flows	Habitat degradation	Pollution/Water quality
Dams	Reduction in native fish communities	Agricultural practices	Agriculture - irrigation	Agriculture
River regulation - irrigation, domestic supply		Alteration of inundation patterns	Catchment erosion	Drainage and disturbance of coastal acid sulfate soils
	Habitat disturbance	Barriers in streams	Streambank clearing and grazing	
Road crossings	Introductions	Alteration of flow distributions	Herbicides	Eutrophication - caused by sedimentation and nutrients from municipal sources and agricultural fertilisers
Weirs	River degradation	Alteration of flow volumes	Human influence	
	River regulation	Alteration of the disturbance regime of the ecosystem	Overclearing	
		Alteration of the water quality, especially thermal pollution	Removal of water	Large stratified storages with bottom release valves
			Sedimentation - agriculture	
		Inappropriate farming techniques for the driest inhabited continent	Snag removal - boat traffic	
			Weir pool formation - irrigation, domestic supply	
		River regulation		

NT

Barriers to migration	Fishing	Information gathering	Introduced species	Natural fish kills
Culverts (local significance)	Commercial fishing	Not discussed	Escaped ornamental - salvinia	Stratification followed by turnover of oxygen poor water
Prevention of saltwater intrusion	Recreational fishing		Spread by boat traffic - salvinia	
			Potential problem - fish	

Salinity	Wetland degradation
Saltwater intrusion	Coastal development
	Introduced pastures
	Saltwater intrusion

QLD

Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Barrages - saltwater intrusion	Development	Potential problem	Agriculture	Aquaculture
Culverts	Irrigation demands		Changes in water flow due to water abstraction	Contaminated hatchery stocks - potential source
Dams and weirs - irrigation and domestic supply			Damming	Deliberate introductions for fishing and mosquito control
Gauging weirs			Illegal harvesting of water	Dumping of aquarium fish
Road crossings			Land clearing	Escape from aquaria
			Localised loss of riparian vegetation	Inappropriate stocking of farm dams and other water bodies
			Urbanisation	Invasion from other states
				Use of live bait

Pollution/Water quality
Aerial spraying
Agricultural chemicals and sprays
Exposure of acid sulfate soils
Farm animals
Feedlots
Industrial waste
Sedimentation - mainly agriculture

SA

Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Barrages	Alternative water use	Lack of information about commercial fishing	Barrages - constant water levels	Recreation
Weirs			Carp	
		Lack of reports on sustainability	Changes to seasonality of flows	
		Lack of stock assessment data	Clearing of trees	
			Farm dams	
			Nutrients	
			Pollution	
			Stock use	
			Water abstraction	

Pollution/Water quality
Sewage, pesticides etc. flowing downstream from other States

VIC

Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Large weirs and dams	Not discussed	Domestic supply dams	Overfishing of natives in river fisheries	Agricultural development
Water abstraction		Irrigation supply dams		Barriers
Water storage		Water usage - agricultural		Changes from pre-European state
				Clearing of vegetation
				Flow alterations
				Removal of riparian vegetation
				Sedimentation
				Snag removal
				Temperature alterations
				Toxic inputs
				Urban development

Riparian vegetation degradation	Water temperature
Grazing - prevents regrowth	Dams with low level outlets
Land clearing	
Removal of vegetation	
Timber harvesting (upland areas)	

TAS

Carp	Reduced environmental flows	Habitat degradation	Introduced species	Pollution/Water quality
Introduction	Abstraction for irrigation	Forestry	Deliberate introductions	Agriculture - spray runoff, stock access to streams
	Hydro dams	Farming practices - clearing riparian vegetation, farming up to stream banks		Industry
		Some industrial problems		Mining
		Urbanisation		Urban - sewage treatment

WA

Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Domestic supply dams	Domestic supply dams	Not discussed	Agriculture	Aquaculture
Irrigation supply dams	Irrigation supply dams		Cattle	Aquarium trade
			Clearing	Hobbyists
			Dams	Mosquito control
			Development	Sportfish
			Erosion and sedimentation	Tourism
			Eutrophication	
			Flow regulation	
			Introduced species	
			Mining	
			Pastoral land use	
			Pollution	
			Population pressure	
			Roads and tracks	
			Salinity	
			Training and diversion	

Appendix 9. Primary causes of the overall six major threats (based on interviews with State representatives and input from the Steering Committee).

Steering Comm. = Steering Committee

Habitat degradation

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Boat traffic	Erosion	Not raised as a major issue for this State	River regulation	River regulation	Land clearing	Agriculture	Urbanisation
Dredging	Land clearing		Water abstraction	Water abstraction	Agriculture	Land clearing	Irrigation
Desnagging	Agriculture		Land clearing	Dams	Industry	Urbanisation	Runoff
Channelisation	Water abstraction		Agriculture	Land clearing	Forestry	Erosion	Dams
Irrigation	Irrigation		Urbanisation	Runoff	Urbanisation	Desnagging	Agriculture
Erosion	Desnagging		Dams	Agriculture		River regulation	Land clearing
Water abstraction	Dams			Introduced species		Dams	Introduced species
Rubbish dumping							Mining
Mining							Roads
							Erosion
							Channelisation
							River regulation

Pollution/Water quality/Water temperature

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Urbanisation	Agriculture	Not raised as a major issue for this State	Agriculture	Urbanisation	Industry	Dams	Not raised as a major issue for this State
Runoff	Urbanisation		Urbanisation	Agriculture	Mining		
Agriculture	Dams		Industry		Urbanisation		
Rubbish dumping	Erosion		Erosion		Agriculture		
Industry	Runoff						
Erosion							
Organic matter							
Dams							

Reduced environmental flows

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Irrigation	Irrigation	Not raised as a major issue for this State	Domestic use	Domestic use	Hydro dams	Irrigation	Irrigation
Domestic use	Domestic use		Irrigation	Irrigation	Irrigation	Domestic use	Domestic use
	Agriculture					Agriculture	

Barriers to migration

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Dams	Irrigation	Barrages	Dams	Weirs	Not raised as a major issue for this State	Weirs	Irrigation
Water abstraction	Domestic use	Culverts	Weirs	Barrages		Dams	Domestic use
Barrages	Dams		Domestic use			Water abstraction	
Roads	Weirs		Irrigation				
	Roads		Barrages				
			Culverts				
			Roads				

Introduced species/Carp*

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Stocking	River regulation	Boat traffic	Aquaculture	Recreational fishing	Stocking	Not discussed	Mosquito control
Escapees	Stocking	Escapees	Escapees				Recreational fishing
Stabilisation of stream banks			Invasion from other States				Aquaculture
Agriculture			Stocking				Escapees
			Recreational fishing				
			Mosquito control				

*Introduced species and carp have been combined for the purposes of this table.

Fishing

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Not discussed	Not raised as a major issue for this State	Recreational fishing	Potential problem	Commercial fishing	Not raised as a major issue for this State	Commercial fishing	Not discussed
		Commercial fishing					

Appendix 10. Monitors and managers of the major threats (based on input from the Steering Committee).

	Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Who monitors the problem	Fisheries agencies	Fisheries agencies	Water management agencies	Not discussed	Catchment management authorities
	Natural resource agencies	MDBC	Water allocation authorities		Fisheries agencies
					Water management agencies
					National Land and Water Audit
Who decides on management policy	All levels of government	Fisheries agencies	COAG water reform agenda	Not discussed	Catchment management authorities
	Rural water agencies	NCCCG	State agencies		Natural Resource Agencies
	Landholders				There is a lack of national consistency, and little actual HABITAT monitoring or management
	Natural resource agencies				
	Fisheries agencies				
	MDBC				

	Introduced species	Pollution/Water quality	Riparian vegetation degradation	Salinity	Wetland degradation
Who monitors the problem?	Fisheries agencies	Local government authorities	Wildlife authorities	State government agencies	Wildlife agencies
	Catchment management authorities	EPA	Catchment management authorities	MDBC	Natural resource agencies
	Local government	Water managers	Local government	Rural water agencies	Conservation groups
	Landcare groups	National Land and Water	Landcare groups	Waterwatch	Sporting groups
	Agriculture departments			Landcare groups	Landcare groups
	Environment Australia			Agriculture departments	School groups
				Industry	Local action planning groups
Who decides on management policy?	State government authorities	National Water Quality Management Strategy	Natural resource agencies	MDBC	Local government
	Environment Australia		Catchment management authorities	State government	Natural resource agencies
	National Weed Strategy			Catchment management authorities	Landowners
			Wildlife agencies		Pastoral leases

Appendix 11. Monitors and managers of the major threats identified in each State (based on interviews with the State representatives).

* Representative not sure about the involvement of this organisation in the particular issue

NSW

	Barriers to migration	Carp	Reduced environmental flows	Habitat degradation	Pollution/Water quality
Who monitors the problem?	State Fishways Program (DLWC, NSW Fisheries, MDBC)	CRCFE	DLWC	DLWC	DLWC
		NSW Fisheries	Policy and technical committee responsible to Water CEOs	EPA	EPA
	Weir Review Program (DLWC, NSW Fisheries, MDBC)	NSW Rivers Survey		MDBC	No one is monitoring changes that take place over time
		University groups	Water CEOs	Piecemeal monitoring only	State Water Monitoring Committee
				Soil conservation agency	
				Streamwatch	Streamwatch
Who decides on management policy?	Water CEOs (DLWC, NSW Fisheries, EPA, NSW Agriculture, NPWS)	NSW Fisheries*	River Management Committees make recommendations on details	DLWC (rivers and foreshore legislation, management of riverbeds)	EPA
	Weir Review Program		Water CEOs	MDBC (desnagging)	State Water Monitoring Committee (responsible to Water CEOs)
				NPWS* (macrophytes)	
				NSW Agriculture (sedimentation)	
				NSW Fisheries	Water CEOs

NT

	Barriers to migration	Fishing	Information gathering	Introduced species	Natural fish kills
Who monitors the problem?	DLPE	DPIF	Not discussed	DPIF	DPIF respond to the kills
	DPIF			Kakadu park management	
	Landholders			Parks and Wildlife Commission	
Who decides on management policy?	Fish Passage Coordination Group (Department of Transport and Works, DLPE, DPIF)	DPIF advises the Minister after consulting with stakeholders	Not discussed	DPIF	DPIF developed a response plan
	Mary River Taskforce	State Government		Kakadu park management	
	Mary River Working Group (DLPE, Parks and Wildlife Commission)			Parks and Wildlife Commission	

	Salinity	Wetland degradation
Who monitors the problem?	DPIF	DPIF
Who decides on management policy?	Fish Passage Coordination Group (Department of Transport and Works, DLPE, DPIF)	Mary River Taskforce
		Mary River Working Group (DLPE, Parks and Wildlife Commission)

QLD

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Who monitors the problem?	QDPI	CCISR	Potential problem	DNR	DNR
		DNR		QDPI	QDPI
		James Cook University		QFMA	QFMA
					University groups
Who decides on management policy?	Fisheries Act	DNR	Potential problem	Department of Environment	QDPI Fisheries (translocation policy)
	QDPI	Local councils		DNR	
		QDPI Fisheries can advise DNR		QDPI	QFMA
				QDPI Forestry (riparian vegetation)	

	Pollution/Water quality
Who monitors the problem?	Department of Environment
	Industry groups eg cotton growers
Who decides on management policy?	Department of Environment

SA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Who monitors the problem?	SA Water lock masters	SA Water	No one	DEHAA*	SARDI
	SARDI			SARDI	
Who decides on management policy?	No one	MDBC - flows coming over the border	IFMC	DEHAA*	PIRSA
		SA Water			

	Pollution/Water quality
Who monitors the problem?	EPA
	PIRSA Fisheries (fish kills)
	SA Water
Who decides on management policy?	EPA
	MDBC
	SA Water - no control over what comes over the border

TAS

	Carp	Reduced environmental flows	Habitat degradation	Introduced species	Pollution
Who monitors the problem?	IFC	DELM	No one specifically, there is some monitoring of particular attributes	IFC	DELM
		Hydro-Electric Corporation	DELM		Local government
		DPIF Water Resources	IFC		Water Resources Division of DPIF
			Local government		
			Parks and Wildlife		There is no broad approach
Who decides on management policy?	Carp Working Group (IFC, Parks and Wildlife, DELM, DPIF Water Resources)	DPIF Water Resources	DELM (various aspects)	IFC	DELM
	IFC		No one as a whole		Local government
					DPIF Water Resources

VIC

	Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Who monitors the problem?	No one	Not discussed	Lots of people doing little bits	MAFRI, Snobs Creek	Catchment Management Authorities*
			MAFRI, Flora and Fauna Group		
			MAFRI, Snobs Creek		
			NRE Water Bureau check that flows are released		
Who decides on management policy?	State Fishway Program, NRE	Not discussed	MDBC	Fisheries Victoria	Catchment Management Authorities
	Water Act		Regional water managers		
			Water Bureau with input from NRE Fisheries and Flora and Fauna Divisions		Flora and Fauna Guarantee Act does some things
			Politicians		Nothing overall

	Riparian vegetation degradation	Water temperature
Who monitors the problem?	No one	No one
Who decides on management policy?	Code of Forest Practice	Don't know
	Native Vegetation Retention Act	
	NRE	

WA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Who monitors the problem?	CALM	No one	Not discussed	Murdoch University	Fisheries
	EPA			Water and Rivers Commission	Murdoch University
	Fisheries WA				
	University groups				
	Water and Rivers Commission				
Who decides on management policy?	CALM	Water and Rivers Commission	Not discussed	Agriculture WA	AQIS (national)
	Community - through public submissions on large dams			CALM	Fisheries WA
	EPA			Water and Rivers Commission	Wildlife Protection Act (national)
	Fisheries WA				
	Water and Rivers Commission				

Appendix 12. Monitors and managers of the overall six major threats (based on interviews with the State representatives and input from the Steering Committee).

Steering Comm. = Steering Committee

* Representative not sure about the involvement of this organisation in the particular issue

Habitat degradation

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Catchment management authorities	Only piecemeal monitoring	Not raised as a major issue for this State	QDPI	SARDI	Local government	Catchment management authorities*	Water and Rivers Commission
		MDBC		QFMA	DEHAA*	Department of Environment and		Murdoch University
	Fisheries agencies	DLWC		DNR (invertebrates and habitat)		Parks and Wildlife	No one	
	Water management agencies	Soil conservation agency						
	National Land and Water Audit	EPA				IFC		
		Streamwatch				No one specifically		
Who decides on management policy?	Catchment management authorities	MDBC	Not raised as a major issue for this State	Department of Environment and Heritage	No one	DELM	Catchment management authorities	Agriculture WA
	Natural resource agencies	NSW Agriculture		DNR	DEHAA*	No one specifically	Nothing overall	CALM
		NPWS*		QDPI			Flora and Fauna Guarantee Act	Water and Rivers Commission
		NSW Fisheries		QDPI Forestry				

Pollution/Water quality/Water temperature

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Local government authorities	EPA	Not raised as a major issue for this State	Department of Environment	SA Water	DPIF	No one	Not raised as a major issue for this State
	Water management agencies	State Water Monitoring Committee		Industry groups	PIRSA Fisheries	DELM		
	EPA	DLWC			EPA	Local government		
	National Land and Water Audit	Streamwatch						
Who decides on management policy?	National Water Quality Management Strategy	EPA	Not raised as a major issue for this State	Department of Environment	SA Water	DPIF	Don't know	Not raised as a major issue for this State
		State Water Monitoring Committee			MDBC	DELM		
		Water CEOs			EPA	Local government		

Reduced environmental flows

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Water management agencies	Water CEOs	Not raised as a major issue for this State	DNR	SA Water	DPIF	NRE	No one
		DLWC		CCISR		DELM	MAFRI	
	Water allocation agencies			James Cook University		Hydro-Electric Corporation	Is anyone?	
Who decides on management policy?	COAG water reform agenda	Water CEOs	Not raised as a major issue for this State	DNR	MDBC	DPIF	NRE	Water and Rivers Commission
		River Management Committee		Local government			Politicians	
	State agencies			QDPI Fisheries can advise DNR	SA Water		Regional water managers	
							MDBC	

Barriers to migration

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Fisheries agencies	State Fishways Program	DPIF	QDPI	SA Water	Not raised as a major issue for this State	No one	Water and Rivers Commission
	Natural resource agencies	Weir Review Program	Department of Lands, Planning		SARDI			EPA
								CALM
			Landholders					Fisheries WA
								University groups
Who decides on management policy?	All levels of government	Water CEOs	Mary River Working Group	Fisheries Act	No one	Not raised as a major issue for this State	State Fishway Program	Water and Rivers Commission
	Rural water agencies	Weir Review Program	Mary River Taskforce	QDPI			Water Act	EPA
	Landholders		Fish Passage Coordination Group					Fisheries WA
	Natural resource agencies							CALM
	Fisheries agencies							Community
	MDBC							

Introduced species/Carp**

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Fisheries agencies	CRCFE	DPIF	QFMA	SARDI	IFC	Not discussed	Fisheries
	Catchment management authorities	NSW Rivers Survey	Parks and Wildlife Commission	QDPI				Murdoch University
	Local government	University groups		University groups				
	Landcare groups			DNR				
	Agriculture departments							
	Environment Australia							
	MDBC							
Who decides on management policy?	State government agencies	NSW Fisheries*	DPIF	QFMA	PIRSA	IFC	Not discussed	Fisheries WA
	Environment Australia		Parks and Wildlife Commission	QDPI Fisheries	IFMC			Wildlife Protection Act (national)
	National Weed Strategy							AQIS (national)
	Fisheries agencies							
	NCCCG							

**Introduced species and carp have been combined for the purposes of this table.

Fishing

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Who monitors the problem?	Not discussed	Not raised as a major issue for this State	DPIF	Potential problem	No one	Not raised as a major issue for this State	MAFRI	Not discussed
Who decides on management policy?	Not discussed	Not raised as a major issue for this State	DPIF NT Government	Potential problem	Inland Fisheries Management Committee	Not raised as a major issue for this State	Fisheries Victoria	Not discussed

Appendix 13. Summary of the agencies involved in the monitoring and management of the overall six major threats (based on interviews with the State representatives and input from the Steering Committee).

Habitat degradation

	National
Who monitors the problem?	Catchment management authorities
	Fisheries agencies
	Water management agencies
	National Land and Water Audit
	Universities
	Natural resource agencies
	MDBC
	Community groups
	EPAs
	Local government
	Parks and Wildlife agencies
Who decides on management policy?	Catchment management authorities
	Natural resource agencies
	MDBC
	Agriculture departments
	Parks and Wildlife agencies
	Fisheries agencies
	Water management agencies

Pollution/Water quality/Water temperature

	National
Who monitors the problem?	Local government authorities
	EPAs
	Water management agencies
	National Land and Water Audit
	Natural resource agencies
Who decides on management policy?	National Water Quality Management Strategy
	Natural resource agencies
	Water management agencies

Reduced environmental flows

	National
Who monitors the problem?	State water management authorities with input from other State agencies
	Water allocation agencies
	Universities
	Hydro electricity generators
Who decides on management policy?	COAG water reform agenda
	State governments and agencies
	Water management agencies
	Local government
	MDBC

Barriers to migration

	National
Who monitors the problem?	Fisheries agencies
	Natural resource agencies
	MDBC
	Universities
	Landholders
	Parks and Wildlife agencies
	EPAs
Who decides on management policy?	Federal, State and Local Governments
	Rural water agencies
	Natural resource agencies
	Fisheries agencies
	MDBC
	Parks and Wildlife agencies
	EPAs

Introduced species/Carp*

	National
Who monitors the problem?	Fisheries agencies
	Catchment management authorities
	Local government
	Landcare groups
	Agriculture departments
	Environment Australia
	Universities
	Parks and Wildlife agencies
	Natural resource agencies
	MDBC
	CRCFE
Who decides on management policy?	State government
	Environment Australia
	National Weed Strategy
	Parks and Wildlife agencies
	Fisheries agencies
	Natural resource agencies
	NCCCG

*Introduced species and carp have been combined for the purposes of this table.

Fishing

	National
Who monitors the problem?	Fisheries agencies
Who decides on management policy?	State government
	Fisheries agencies

Appendix 14. Knowledge required to address the major threats (based on input from the Steering Committee).

	Barriers to migration	Reduced environmental flows	Fishing
Knowledge required	Determine when fish use a fishway to allow water managers to release water at the right times	Minimum standards for the monitoring of environmental flows	National survey of the status of the resource that is widespread and repeatable over time, this needs to include areas other than those where current commercial, recreational and indigenous fisheries operate and significant bodies of flowing water
	Methods to allow fish past high structures (>4m)	Use of fish and fisheries as indicators of the success of the management of environmental flows	National survey of which species is taken where
	Cost-effective ways to allow fish past low barriers eg on-stream farm dams		Data collection should include historical catch data and an attempt to establish the pristine stock biomass or carrying capacity
	Determine which fishways work in which situations	Methodologies for the preliminary assessment of flow requirements	Description of indigenous fisheries and their cultural significance (includes what is caught, where it is caught and for what reasons was it caught)
	Monitor effectiveness of fishways that are built		Social and cultural significance of fishing to communities
Possible management actions	Adaptive management	Adaptive management	Adaptive management
	Application of the knowledge we already have	Application of the knowledge we already have	Application of the knowledge we already have
	National coordination of research, fishway design and management	Adequate allocation to environmental flows from new dams to allow flexibility	Inclusive representation in decision making (includes all user groups)
	Formation of a national taskforce to investigate barriers		Improvement of the awareness of management authorities of social, cultural and economic implications of management
	Whole of catchment approach to the provision of fish passage on new and existing structures		
	Greater interagency and intergovernment cooperation		
	Improvements in the legislation regulating structures and barriers		

	Habitat degradation	Pollution/Water quality	Salinity
Knowledge required	National inventory of data on fisheries species as indicators of river and fishery health	Use of species important to fisheries as indicators to monitor the effectiveness of pollution management	Taskforce to design an approach to studying the effects of salinity on species important to fisheries
	Identify appropriate community groups to collect the data		Research into the most vulnerable life stages of species important to fisheries using the approach determined by the taskforce. We need to know the effect that salinity has on all stages of the life cycle
	Identify data that can be collected by those groups		Relate the knowledge obtained above to the distribution of salinity around the country
Possible management actions	National advisory program advising individual groups of rehabilitation techniques that have worked and showing people how to implement them; such a group could also identify knowledge gap, indigenous knowledge would be very useful here	Adaptive management	Not discussed
	National advisory program showing individual groups how to collect data for a survey on fisheries species as indicators of river and fishery health	Greater interagency and intergovernment cooperation	
	Greater interagency and intergovernment cooperation	Contingency plans to contain and treat point sources	
	Adaptive management	Improvement of pollution control licensing	
	Application of the knowledge we already have	Application of the knowledge we already have	

	Carp	Introduced species	Riparian vegetation degradation
Knowledge required	Method of control eg CRCFE/VBCRC project	Not discussed	Not discussed
Possible management actions	Not discussed	Harmonisation of management policies	Not discussed

	Wetland degradation
Knowledge required	Not discussed
Possible management actions	Not discussed

Appendix 15. Knowledge required to address the major threats identified in each State, possible funding agencies and management actions likely to result from the acquisition of this knowledge (based on interviews with the State representatives).

NSW

	Barriers to migration	Carp	Reduced environmental flows	Habitat degradation	Pollution/Water quality
Knowledge required	Applicability of deelder open fish locks	Determine the ecosystem response to carp removal	Monitoring to determine the outcomes of flow changes	Assessment of historical changes eg snag removal	Understanding of effective restoration methods
	Costs and benefits of fish bypasses	Determine the value of local direct control measures	Assess the social and economic costs of providing environmental releases	Knowledge of interactions within the ecosystem	Understanding of the impacts to the ecosystem and the extent of each of the major forms of pollution (see Primary Causes table)
	Effective, low cost solutions to high barriers	Develop effective control mechanisms including biological	Assess the response of river ecosystems to environmental releases	Responses to restoration techniques	
	Are fishways that are suited to swimming species of fish are also suitable for other fauna eg invertebrates?	Do we need to solve the problem? If flows are increased this may increase the water quality, which may decrease carp numbers, which may increase water quality, which may decrease carp numbers etc	Ecological studies of the interactions of all processes in the aquatic habitat, need to know details of the processes in the river so we can say that this will happen to the system if this much water is released	Determine the amount of the habitat that needs rehabilitating for a positive reaction from the ecosystem eg Is revegetating 60% of the streambanks enough or do we need 80% or 40%?	
	Modular removable fishway for inland regulators	Understanding of the strength of recruitment feedback on adult carp	Develop appropriate adaptive management to allow necessary changes to the water reform process	Understanding of freshwater ecology	
	Understanding of the general ecology of the system				
Possible funding agencies	CRCFE	Commonwealth Government	NHT	Commonwealth Government	NHT
	Owners of the structures requiring fish passage, those benefiting from the weirs	MDBC	Assessment procedures are being developed through the IMEF project of DLWC	Landcare	Cold water pollution - Owners of dams, irrigation industry (through DLWC or MDBC programs?)
	Inland fishing licences	NCCCG	FRDC	MDBC	
	MDB 2001 (NHT)	NHT	State Government - being funded through levy on irrigators	NHT - Rivercare	Acid sulfate soils - DLWC, EPA
	MDBC	State Government		State Government	Pesticides - Industry bodies (eg Cotton Australia, EPA)
	NHT		State Government		
	FRDC		CRCFE		
	State Fishway Program				
	State Government				

NSW (continued)

Possible management actions	Provision of fish passage while minimising the effects on the community	Development of Government sponsored carp control contractors for local work	Demonstrate that increasing the flows had a specific benefit	Control of the entry of weedicides into the aquatic ecosystem	Abatement/mitigation programs
	Change in policy with regard to providing fish passage	Nationally coordinated program of biological control	Adaptive management of environmental flow regimes	Refencing programs for riparian zones	Appropriate legislation to minimise impacts
	Increase in the number of fishways actually built, especially on high dams		Increase in flows that benefit the environment while still allowing the community to benefit from the maximum possible water allocation	Educate people that increasing the quality of the water is of benefit to them	Rehabilitation programs
	Nationally coordinated program of biological control			Resnagging programs	
				Minimise the cost to the community of increasing flows while maximising the benefit to the environment	

NT

	Barriers to migration	Fishing	Information gathering	Introduced species	Natural fish kills
Knowledge required	Life cycle and migration triggers for barramundi	Cost-benefit analysis of resource allocation	Baseline data for the monitoring of future problems	Ways and means of assessing potential threats	This is a natural event, they are not trying to solve this issue
	Specific habitats critical to the barramundi life cycle	Environmentally friendly fishing methods to avoid gillnet by-catch	Are the fish taken for the aquarium trade rare or endangered species		
		Exploitation levels, particularly in the recreational sector			
		Sustainability levels			
Possible funding agencies	FRDC	FRDC	NHT	NHT	–
	NHT	State Government		State Government	
	RIRDC				
	State Government				
Possible management actions	Any barriers that were built would have provision for fish passage	Possible changes to the allocation of the resource, cost/benefit analysis allows the input of economic and social factors into the decision making process	Improved management actions	Adaptive legislation and management regime	–
				Implementation of existing tools	
				Improved decision making tools	

	Wetland degradation	Salinity
Knowledge required	Identification of areas of important habitat	Linked to "Barriers to Migration"
	Understanding of ecological interactions	
Possible funding agencies	NHT are currently funding this work	–
Possible management actions	Ensure fish have access into and out of those areas	
	Ensure protection for significant habitats	–

QLD

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge required	Swimming abilities	Understanding of the systems on which fish depend	Population modelling of freshwater fish to determine if a particular fishery is sustainable	Carrying capacity of different habitat types	The effect of removing tilapia
	Flows required to trigger migrations	Basic biology of fish - migration, breeding and recruitment triggers		Case studies that have worked to show people the advantages of taking certain actions	Determine whether tilapia and carp are detrimental, if not may not need to do anything
	Monitoring of fishways	Understanding of natural variability and its impacts		Habitat requirements of various species	Education to prevent further translocations
				Data linking fisheries production with habitat to show its value	Practical methods of controlling species that become established in areas where they are not desirable
				Comparison of fish communities in degraded vs. non-degraded areas	
				Monitoring of fish communities before and after restoration to determine effects	Studies of population dynamics to determine which methods may be successful
				Connection between the work done by ICMs and Landcare and that done by Fisheries	Controlled experiments examining the interactions between tilapia and natives
				The amount of restoration required eg how much resnagging is enough?	Understanding of the biology of the introduced species to find a targetable weakness
				Ways to improve artificial impoundments for fish	
Possible funding	DNR	DNR	FRDC	DNR	LWRRDC (feral fish program)
	Local Government	Environment Australia		FRDC	National Carp Taskforce
	FRDC	FRDC		Industry groups eg power stations, cotton growers	NHT through the MDBC initiative to combat carp
	PhD student on scholarship or ARC grant	LWRRDC		MDBC	Vertebrate Biocontrol CRC
		MDBC		NHT	NCCCG
		NHT		QDPI	QDPI (pest control program)
		QDPI (internal funding)			
Possible management actions	Improved management of water releases so that they benefit fish	Improved in the management of water releases to have the least possible impact on fish populations	Improved management of fisheries	Changes in land use practices, this may improve riparian vegetation	Examine ways to minimise the ability of fish to move from one catchment to another
	Fishways that allow fish passage both up and downstream for all species would be built			Increase in the public perception of the value of rivers and fish stocks	Implementation of successful methods
	Coordination between biologists and engineers to ensure that fishways work as intended			Application of the knowledge we already have	Make it an offence to use noxious fish as bait
				Construction of artificial habitat	
				Decreased stock access	
				Resnagging	

QLD (continued)

	Pollution/Water quality
Knowledge required	Determining responsibility for specific problems (both point and diffuse sources)
Possible funding agencies	Department of Environment (determining pollution sources)
	EPA (pursuing "wrongdoers")
Possible management actions	Work through industry groups and local government to issue "pollution" permits
	Increase the awareness of the health hazards associated with pesticides and fertilisers

SA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge required	Adaptive management to determine the best to fish passage through barrages	Information on creating incentives in the community and in politics to implement the flows for joint benefit, this is social research	Identify the issues are and develop strategies to address them	Develop the best mechanisms for achieving action and incentives	Understanding of the impacts of the introduced species
	Determine where barriers exist and the benefits/costs associated with removing those barriers		Stock assessment data	Research what has been done by other Government departments	
Possible funding agencies	–	Water users	IFMC	–	-
Possible management	Would be able to implement fish passage up and down the river for adults and on and off the floodplain for juveniles	Augmenting flows when possible to achieve overbank flooding every 1 in 3 years	Data would be available for distribution to the public as required	Could estimate the sustainability of the fish stocks	IFMC would look at the species in question and deal with it either separately or as part of a current strategy
				Targeted work at specific sites on specific problems	
		Implement knowledge we already have	Allows development of a communication strategy for dealing with perception problems	Landholders and individuals are responsive if they can see the benefits to taking certain actions	

	Pollution/Water quality
Knowledge required	Establish the link between pollution and the resource, also needs to be linked with responsible parties
	Maximum level of pollutants in the river and the minimum level that the fish can take
Possible funding agencies	-
Possible management actions	Provide feedback to increase the quality of the water in the River Murray
	Discuss the relationship between the pollutant and the fishery with the other agencies involved
	Examine short and long term objectives and decide how to deal with the problem

VIC

	Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Knowledge required	Biological information eg swimming speeds of natives	Not discussed	Cost-benefit analysis of water use (use on high value products as opposed to low value ones)	Methodologies to determine whether the fish that are caught are wild or stocked	Understanding of the processes driving rivers
	Assessment of effectiveness of fishways		Evaluation of different flow release strategies		Understanding of the impact of threats on native species
	Determine which barriers require fish passage		Flexibility in reviews of bulk water entitlements in light of future studies		Evaluation of rehabilitation activities
			Examine agricultural water usage		Multidisciplinary studies examining rehabilitation
Possible funding agencies	Catchment Management Authorities	Not discussed	FRDC (if flows are aimed at restoring fisheries)	FRDC	Catchment Management Authorities
	NRE State Fishways Program		LWRRDC	Government agency core funds	Environment Australia
	Those using the water behind the barriers		MDBC		FRDC
			Resource managers		Landcare
	Water authorities		State Government		LWRRDC
			Water users		MDBC
					NHT
Possible management actions	Redesign of ineffective fishways	Not discussed	Adaptive management	Changes in stocking practice - may not need to continue stocking areas if mainly wild fish are caught	Increase the awareness of the interaction between the environment, habitat and fishery production
	Reprioritisation of the need for fish passage if it is not required at specific barriers		Make recommendations for similar flows in other areas if releases worked		
	Provision of fish passage including removal of barriers		Water saved through improvements in agricultural usage allocated to the environment		Transfer the message of successes and failures

	Riparian vegetation degradation	Water temperature
Knowledge required	Techniques for the regeneration of native vegetation	Ways to remove water from the top of a dam rather than the bottom
Possible funding agencies	NHT	Those using the water from the dam
		Water agencies
Possible management actions	Fencing and revegetation	Adaptive management

TAS

	Carp	Reduced environmental flows	Habitat degradation	Introduced species	Pollution
Knowledge required	An exploitable weakness in carp	Flow levels required, need to start with an environmental allocation and see what the environmental response is	Assessment of how far things have gone	Have most of the information required	Extent of the problem
			Assessment of priorities		
			Baseline for present conditions		
			Wide scale study of the extent of habitat degradation		
Possible funding agencies	Commonwealth Government	State Government	NHT	Commonwealth Government	Industry funding - remediation paid for by the key polluters
	State Government		State and Commonwealth Governments - depending on scale of the issue	State Government	
Possible management actions	Carp control	Environmental allocations	Specific actions would depend on available funding	Education of the public on the problems associated with introductions and translocations	Reduction in pollution

WA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Knowledge required	Requirements for small fish species to allow their movement through culverts and over gauging weirs in the southwest	Extent and effects of private dams	Not discussed	Habitat requirements for native fish and invertebrates	Biology of the introduced species to allow development of biological controls, this needs to be researched at a national level
				Baseline data to enable the changes that have and are occurring to be appreciated	
				Extent of the problem	Development of practical, cost-effective methods of control
Possible funding agencies	Water and Rivers Commission	NHT	Not discussed	NHT	Don't know
		Water and Rivers Commission			
Possible management actions	Improved fish passage	Constant releases from private dams	Not discussed	Identify areas of importance and preserve them before they are destroyed	Goldfish are a small problem, need to educate hobbyists
		Improvements in legislation		Replanting and fencing riparian vegetation	Implementation of control measures
				Replanting catchments	

Appendix 16. Knowledge required to address the overall six major threats and management actions likely to result from the acquisition of this knowledge (based on interviews with the State representatives and input from the Steering Committee).

Steering Comm. = Steering Committee

Habitat degradation

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	National inventory of data on fisheries species as indicators of river and fishery health	Assessment of historical changes	Not raised as a major issue for this State	Case studies that have worked to show people the advantages of taking certain actions	Best mechanisms for achieving action	Wide scale study of the extent of habitat degradation	Multidisciplinary studies examining rehabilitation	Extent of the problem
	Identify appropriate community groups to collect the data	Knowledge of interactions within the ecosystem		Connection between the work done by ICMs and Landcare and that done by Fisheries	Things done by other Government departments	Baseline for present conditions	Biological information so we can better understand the impact of threats	Habitat requirements of native fish and invertebrates.
	Identify data that can be collected by those groups	Responses to restoration techniques		Ways to improve artificial impoundments for fish		Assessment of how far things have gone	Better understanding of the processes driving rivers	Baseline data to enable the changes that have and are occurring to be appreciated
		Determine the amount of the habitat that needs rehabilitating for a positive reaction from the ecosystem		Habitat requirements of various species		Assessment of priorities	Solutions to recognisable problems	
				Carrying capacity of different habitat types				
				Amount of restoration required eg how much resnagging is enough?			Evaluation of rehabilitation activities	
				Monitoring of fish communities before and after restoration to determine the effects of restoration			Increase the awareness of the interaction between the environment, habitat and fishery production	

Habitat degradation (continued)

Knowledge required (continued)				Comparison of fish communities in degraded versus non degraded areas				
				Data linking fisheries production with habitat to show managers the value of habitat				
Possible management actions	National advisory program advising individual groups of rehabilitation techniques that have worked and showing people how to implement them; such a group could also identify knowledge gap, indigenous knowledge would be very useful here	Refencing programs for riparian zones	Not raised as a major issue for this State	Increase in the public perception of the value of rivers and fish stocks	Landholders and individuals are responsive if they can see the benefits to taking certain actions	Actions would be taken, just what would happen would depend on the available funding	Can transfer the message of successes and failures	Replanting and fencing riparian vegetation
		Resnagging programs						Identify areas of importance and preserve them before they are destroyed
		Control of the entry of weedicides into the aquatic ecosystem		Changes in land use practices, this may improve riparian vegetation			Increase the awareness of the interaction between the environment, habitat and fishery production	
		Convince people that increasing the quality of the water is of benefit to them		Resnagging	Estimate the sustainability of the fish stocks			Replanting catchments
				Decreased stock access				
	National advisory program showing individual groups how to collect data for a survey on fisheries species as indicators of river and fishery health			Construction of artificial habitat	Targeted work at specific sites on specific problems			
	Greater interagency and intergovernment cooperation	Minimise the cost to the community while maximising the benefit to the environment		Apply the knowledge we already have				
	Application of the knowledge we already have							
	Adaptive management							

Pollution/Water quality/Water temperature

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	Use of species important to fisheries as indicators to monitor the effectiveness of pollution management	Understanding of the impacts to the ecosystem and the extent of each of the major forms of pollution	Not raised as a major issue for this State	Determining responsibility for specific problems	Maximum level of pollutants in the river and the minimum level that the fish can take	Actual extent of the problem	Ways to remove water from the top of a dam rather then the bottom	Not raised as a major issue for this State
		Understanding of effective restoration methods			Establish the link between pollution and the resource, also needs to be linked with responsible parties			
		Impacts of algal blooms, pesticides, nutrients, chemicals etc. on the aquatic ecosystem and the changes that are occurring over time						
		Thermal pollution - impact on flora and fauna other then fish and how to mitigate those effects						
Possible management actions	Adaptive management	Rehabilitation programs	Not raised as a major issue for this State	Issue "pollution" permits	Provide feedback to increase the quality of water in the River Murray	Reduction in pollution	Adaptive management	Not raised as a major issue for this State
	Greater interagency and intergovernment cooperation	Abatement/ mitigation programs		Increase the awareness of the health hazards associated with pesticides and fertilisers				
	Contingency plans to contain and treat point sources	Appropriate legislation to minimise impacts			Discuss the relationship between the pollutant and the fishery with the other agencies involved			
	Improvement of pollution control licensing							
	Application of the knowledge we already have				Deal with problem after examining objectives			

Reduced environmental flows

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	Minimum standards for the monitoring of environmental flows	Assess the response of river ecosystems to environmental releases	Not raised as a major issue for this State	Understanding of natural variability and its impacts	Information on creating incentives in the community and in politics to implement the flows for joint benefit, this is social research	Flow levels required, need to start with an environmental allocation and see what the environmental response is	Evaluation of different flow releases	Extent and effects of private dams
	Use of fish and fisheries as indicators of the success of the management of environmental flows	Assess the social and economic costs of providing economic releases		Understanding of the systems on which the fish depend			Cost-benefit analysis of water use	
		Develop appropriate adaptive management to allow necessary changes to the water reform process		Basic biology of fish - migration, breeding and recruitment triggers			Flexibility in reviews of bulk water entitlements in light of future studies	
	Methodologies for the preliminary assessment of flow requirements	Ecological studies of the interactions of all processes in the aquatic habitat					Examine the ways water is used for agriculture	
Possible management actions	Adaptive management	Adaptive management of environmental flow regimes	Not raised as a major issue for this State	Improved management of dams to cater for the requirements of native fish and the systems on which they depend	Augmentation of flows when possible to achieve overbank flooding every 1 in 3 years	Environmental allocations	Recommendations for similar flows in other areas if releases worked	Improvements in legislation
	Application of the knowledge we already have	Demonstrate that increasing the flows had a specific benefit					Adaptive management	Constant releases from private dams
	Adequate allocation to environmental flows from new dams to allow flexibility	Identify minimum flows of benefit to the environment while allowing the community maximum allocations			Implement the knowledge we already have		Water saved through improvements in agricultural usage allocated to the environment	

Barriers to migration

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	Methods to allow fish past high structures (>4m)	Effective, low cost solutions to high barriers	Life cycle and migration triggers for barramundi	Monitoring of fishways	Determine where barriers exist and the benefits/costs associated with removing those barriers	Not raised as a major issue for this State	Assess effectiveness of fishways	Requirements for small fish species to allow their movement through culverts and over gauging weirs in the southwest
	Determine when fish use a fishway to allow water managers to release water at the right times	Need to know if fishways that are suited to swimming species are also suitable for other fauna	Identify specific habitats critical to the barramundi life cycle	Flows required to trigger migrations			Biological information eg swimming speeds of natives	
	Cost-effective ways to allow fish past low barriers	Modular removable fishways for inland regulators	Details of soil and water conditions	Swimming abilities	Determine the best approach to fish passage through barrages		Determine which barriers require fish passage	
	Determine which fishways work in which situations	Costs and benefits of fish bypasses	Need to know if fishways that are suited to swimming species are also suitable for other fauna					
		Applicability of deelder open fish locks						
	Monitor the effectiveness of fishways that are built	Need to know more about the general ecology of the systems						

Barriers to migration (continued)

Possible management actions	Improvements in the legislation regulating structures and barriers	Change in policy with regard to providing fish passage	Provision of fish passage in all new barriers	Building of fishways that allow two way passage for all fish in the system	Implementation of fish passage up and down the river and on and off the floodplain for juveniles	Not raised as a major issue for this State	Provision of fish passage including removal of barriers	Improved fish passage
	Whole of catchment approach to the provision of fish passage on new and existing structures	Increase in the number of fishways actually built, especially on high dams	Determination of optimal barrier types	Coordination between biologists and engineers to ensure that fishways work as intended			Redesign of ineffective fishways	
	Formation of a national taskforce to investigate barriers			Fishways that actually allow fish passage both up and downstream would be built			Reprioritisation of the need for fish passage if it is not required at specific barriers	
	National coordination of research, fishway design and management							
	Greater interagency and intergovernment cooperation			Improvement in the management of water releases so that they benefit fish				
	Application of the knowledge we already have							

Introduced species/Carp*

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	Method of control eg CRCFE/VBCRC project	Understanding of the strength of recruitment feedback on adult carp	Ways and means of assessing potential threats	Practical methods of controlling undesirable species that become established	Understanding the impacts of the introduced species before dealing with it, if there is little impact does anything need to be done?	Have most of the information required	Not discussed	Biology of the introduced species to allow development of biological controls; this needs to be researched at a national level
		Develop effective control mechanisms		Understanding of the biology of introduced species				
		Determine the value of local direct control measures		Controlled experiments examining interactions between tilapia and natives				
		Impact of carp on the ecosystem		The effect of removing tilapia				
		Determine the ecosystem response to carp removal		Education to prevent translocations				
				Trialing various control methods				
				Population dynamic studies to determine which methods may be successful				
				Determine whether tilapia and carp are detrimental				
Possible management actions	Harmonisation of management policies	Development of Government sponsored carp control contractors for local work	Adaptive legislation and management regime	Minimise the ability of fish to move from one catchment to another	Fisheries Management Committee would look at the species in question and deal with it either separately or as part of a current strategy	Education of the public on the problems associated with introductions and translocations	Not discussed	Implementation of control methods
			Improved decision making tools	Make it an offence to use noxious fish as bait				Education of hobbyists
		Nationally coordinated program of biological control	Implementation of current solutions	Testing of control methods and implementation of successful methods				

*Introduced species and carp have been combined for the purposes of this table.

Fishing

	Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Knowledge required	National survey of resource status that is widespread and repeatable over time	Not raised as a major issue for this State	Sustainability levels	Population modelling of freshwater fish could determine if a particular fishery would be sustainable or not	Identification of the issues and development of strategies to address them	Not raised as a major issue for this State	Methodologies to determine whether the fish that are caught are wild or stocked	Not discussed
	National survey of which species is taken where		Exploitation levels, particularly in the recreational sector					
	Data need to include historical catch data and attempt to establish the pristine stock biomass or carrying capacity		Cost/benefit analysis on resource allocation		Stock assessment data			
			Environmentally friendly fishing methods to avoid gillnet by-catch					
	Description of indigenous fisheries and their cultural significance (what is caught, where and for what reasons)							
	Social and cultural significance of fishing to communities							
Possible management actions	Adaptive management	Not raised as a major issue for this State	Possible changes to the allocation of the resource	Improved management of fisheries	Distribute information to the public as required	Not raised as a major issue for this State	Changes in stocking practices	Not discussed
	Application of current knowledge							
	Representation of all user groups in decision making process				Develop a communication strategy for dealing with the perception problems			
	Improvement of the awareness of management authorities of social, cultural and economic implications of management							

Appendix 17. Summary of the knowledge required to address the overall six major threats and management actions likely to result from the acquisition of this knowledge (based on interviews with the State representatives and input from the Steering Committee).

Habitat degradation

	Nationwide
Knowledge required*	National inventory of fisheries species as indicators of river and fishery health
	Knowledge of the extent of habitat degradation (1)
	Biological and habitat information for fish and invertebrates (2)
	Indicators for use in adaptive management
	Identify data that can be collected by community groups as part of a national inventory of data on indicator fish species
	Understanding of processes driving rivers and their interactions with ecosystems
	The amount of habitat that requires rehabilitation for there to be a positive reaction from the ecosystem
	Carrying capacity of different habitat types and methods for demonstrating the value of habitat
	Identify appropriate community groups to collect data for a national inventory of data on fish species
	Methods to improve artificial impoundments for fish
	Mechanisms and incentives for achieving action from managers
Possible management actions**	Adaptive management
	Changes to land and water use practices (TCM)
	Construction of artificial habitat
	Greater interagency and intergovernment cooperation
	Management actions using the knowledge we already have - targeted work at specific sites on specific problems
	National program advising individual groups of rehabilitation techniques that have worked (3)
	National program advising individual groups how to collect data for a survey of indicator fish species
	Protection of representative areas
	Raise the level of awareness in the community of the benefits of rivers, water quality and fish stocks (4)
	Rehabilitation programs (5)

Pollution/Water quality/Water temperature

	Nationwide
Knowledge required*	Use of species important to fisheries as indicators of the effectiveness of pollution management
	Understanding the extent of direct and indirect impacts on ecosystems
	The link between pollution, the resource and the responsible parties
	Understanding of effective restoration methods
Possible management actions**	Adaptive management
	Contingency plans to contain and treat point sources
	Greater interagency and intergovernment cooperation
	Improvement in pollution control licensing
	Management actions using the knowledge we already have
	Rehabilitation programs

Reduced environmental flows

	Nationwide
Knowledge required*	The extent and effects of private dams, both on- and off-stream
	Methodologies for indicative assessment of flow requirements
	The response of the ecosystem to environmental releases (6)
	The social and economic costs/benefits of providing environmental releases
	Responses of fish and fisheries as indicators of the success of the management of environmental flows
	Information on the biology of fish species relevant to environmental flows (7)
	Ways to create incentives within the community and for politicians for the implementation of increased flows
	Understanding of natural variability and its impacts
	Understanding of flow-related interactions within the ecosystem
	Examination of agricultural water use and a cost/benefit analysis of such use
Possible management actions**	Adaptive management of flow releases and appropriate extrapolation of results
	Adequate and flexible allocation to environmental flows from new dams
	Allocating the increased water resulting from greater efficiencies in water use to environmental flows
	Constant releases from private dams
	Improvements in legislation
	Management actions using the knowledge we already have
	Management of water releases for maximum returns to fish populations
	Optimising flow regimes to benefit the environment while allowing the community to benefit from maximum possible allocations

Barriers to migration

	Nationwide
Knowledge required*	Appropriate fishway design and assessment of the effectiveness of alternative designs
	Methodologies for determining fish passage requirements
	Information on the biology of fish species relevant to fish passage (8)
	Understanding the relationship between controlled releases and the time of use of fishways
	Benefits/costs associated with provision of fish passage, including removal of barriers
	Methods to allow fish past high structures (>4m)
	Cost-effective ways to allow fish past low barriers
Possible management actions**	Adaptive management
	Compulsory arrangements for fish passage
	Formation of a national taskforce to investigate management strategies for barriers
	Greater interagency and intergovernment cooperation
	Improvement of water release strategies
	Improvements in the legislation regulating structures and barriers
	Increase in the number of effective fishways
	Management actions using the knowledge we already have
	National coordination of research, fishway design and management
	Whole of catchment approach to the provision of fish passage on new and existing structures

Introduced species/Carp*

	Nationwide
Knowledge required*	Cost effective methods of control
	Methods to assess potential threats/uses
	Studies of population dynamics to determine which control methods may be successful
	Understanding of the impacts of introduced species
	Ways of increasing public awareness of the problems associated with introductions
	Effect of removing an introduced species
	Ways of minimising the movement of fish between catchments
Possible management actions**	Adaptive management
	Harmonisation of management practices between States
	Improvement of control measures
	Management actions using the knowledge we already have
	Raise public awareness

*Introduced species and carp have been combined for the purposes of this table.

Fishing

	Nationwide
Knowledge required*	Description of indigenous fisheries and their cultural significance (9)
	Status of the resource, including stock assessment and population dynamics (10)
	Social and cultural significance of fishing to communities
	Cost/benefit analyses of alternative resource allocations
	Details of which fish are taken where
	By-catch avoidance methods
	The pristine stock biomass and carrying capacity of at least representative areas
	Cost effective methods to determine if the fish that are caught are wild or stocked
Possible management actions**	Improvement of stocking practices
	Improvement in the awareness of management authorities of the social, cultural and economic implications of management
	Improvement in the management of fisheries - including adaptive management
	Inclusive representation in decision making
	Management actions using the knowledge we already have
	Raise public awareness of the value of commercial fishing

* Knowledge required is listed in decreasing order of priority as determined by the Steering Committee
** Possible management actions are not listed in any order of priority
1 Essential for current assessments and future comparisons
2 So we can better understand the impact relevant to individual threats
3 To show people how to implement them; such a group could also identify knowledge gaps and indigenous knowledge
4 To show people the benefits to be had from taking certain actions
5 Resnagging, fencing, replanting, control of pesticides entering the aquatic environment
6 Required for adaptive management
7 Migration, breeding and recruitment triggers
8 Life cycle and migration triggers, habitat requirements, swimming speeds
9 Includes what is caught, where it is caught and why it was caught
10 Such a survey needs to be widespread and repeatable over time, it needs to include areas other than those where current commercial, recreational and indigenous fisheries operate and should include significant bodies of flowing water

Appendix 18. Strategies which have addressed or are addressing the major threats (based on input from the Steering Committee).

Not all of the material discussed in the tables below is referenced, much is from the interviews.

	Barriers to migration	Carp	Reduced environmental flows	Habitat degradation
Strategy	Vertical slot fishways on dams, research into design, interstate cooperation with implementation, monitoring after completion	Netting off an area, killing everything with rotenone, and reintroducing natives	Prolonged environmental flow from Hume Dam on top of a natural flood	LWRRDC are producing a manual on river restoration
Where	NSW, QLD	Leigh Creek Retention Dam, SA	Murray River downstream of Hume Dam	
When	1990-	1996	Oct-Nov 1996	
How do we know it worked?	Fishways were monitored	There are no more carp in the area	Excellent recruitment of golden perch & Murray cod	
Transferable to other regions?	Yes	Yes (in contained situations)	Yes	
Strategy	Development of a database of barriers in QLD, NSW, VIC	Use of rotenone in farm dams	ARMCANZ initiative monitoring progress of implementation of environmental flows	Habitat restoration by Catchment Management Authorities
Where	Murray-Darling Basin	Tasmania	Nationally	Various areas in Victoria
When	1995-	1970s	September 1998-	Ongoing
How do we know it worked?	Fishways are being built on priority barriers	There were no more carp in the dams	–	Probably isn't being monitored
Transferable to other regions?	–	Yes (in contained situations)	–	Yes
Strategy			Assessing effects of environmental releases from hydro storages on fish and invertebrates	Water level management to prevent death of vegetation & subsequent algal blooms
Where			Mersey River, Tasmania	Lagoon of Islands, Tasmania
When			1997-	1990
How do we know it worked?			Ongoing	Fishery improved, no further algal blooms
Transferable to other regions?			–	Yes
References		IFC 1995	Ingeme 1996	River Murray Water Resources Committee
			Mitchell et al. 1996	
			Overman 1996	Ladson et al. 1996, 1997
			Wimmera and Glenelg Environmental Flows Intercatchment Advisory Group 1996	
			Chessman and Jones 1998	

	Wetland degradation	Fishing
Strategy	Closure, access by permit only	Not discussed
	Protection of areas	
Where	eg National Parks	
When	Various times	
How do we know it worked?	Wetlands are still there	
Transferable to other regions?	Yes	
References	South Australian River Murray Wetlands Management Committee c. 1994	

	Introduced species	Pollution/ Water quality	Riparian vegetation degradation	Salinity
Strategy	Prevention of introductions (Nile perch)	Demonstration of linkage between pesticide levels (cotton farms) and fish kills	Limiting speed and access of boats over a certain size	Earthen walls to prevent saltwater intrusion
Where	Nationally	Ord River, WA	Gordon River, TAS	Mary River, NT
When	Early 1980s	1973-74	About 1990	1990
How do we know it worked?	No Nile perch in Australia	Recovery of fisheries	Stabilisation of banks	Surveys show revegetation, increase in fish populations
Transferable to other regions?	Yes	Yes	Yes	Yes
Strategy	National foreign aquatic introductions assessment scheme by the former Advisory Committee on Live Fish for the Wildlife Protection Act	Goulburn/Broken water quality management strategy	Removal of exotic fish, the introduction of natural flooding and drying cycles and allowing natural rehabilitation	Saltwater interception schemes
Where	Nationally	Goulburn and Broken Rivers	Pilby Creek, Lock 6, Renmark, SA	Noora, Murray River
When	1970-	1994-	About 1995	?
How do we know it worked?	–	Reduction in nutrient levels	Area revegetated, water cleared, fish proliferated	Reduced salinity
Transferable to other regions?	–	Yes	Yes	Yes
Strategy	Willow replacement by West Gippsland Catchment Management Authority	Multi-level offtakes on several dams in NSW e.g. Chaffey, Split-Rock, Windamere	Fencing and revegetating of stream frontages, replacement of willows	Use of drip-fed, monitored irrigation
Where	West Gippsland, VIC	Several locations	Various locations in VIC	South Australia
When	About 1990	Ongoing	Ongoing	?
How do we know it worked?	Less willows, more native vegetation	Reduce thermal pollution if operated correctly	Native trees are growing	More efficient water use
Transferable to other regions?	Yes	Yes	Yes	Yes
Strategy	Translocation policies		LWRRDC initiative providing information on buffer strips, stock access etc	Replanting of deep-rooted, salt tolerant trees in commercial plantations to lower groundwater levels
Where	Nationally		Nationally	South west of WA
When	–		1995-	1990-
How do we know it worked?	–		–	Decline in salinity levels
Transferable to other regions?	-		–	Yes
Strategy	Eradication of tilapia from ponds using rotenone		Uncleared bankside reserves (20-50m) in clearfelling operations	
Where	Perth and Geraldton,		South west of WA	
When	1970, 1975		1980-	
How do we know it worked?	No further reports of Tilapia in these areas		Monitored by remnant bank vegetation, stream sedimentation, comparison with control areas	
Transferable to other regions?	Yes, in relatively small, contained situations		Yes	
References				CARE 1994 Engineering and Water Supply Department c. 1983 MDBC c. 1992, 1994

Appendix 19. Strategies which have addressed or are addressing the major threats identified in each State (based on interviews with State representatives).

Not all of the material discussed in the tables below is referenced, much is from the interviews.

NSW

	Barriers to migration	Carp	Reduced environmental flows	Habitat degradation	Pollution/Water quality
Strategies	Demolition of redundant structures eg slot cut in Bomaderry Weir	Nothing yet	NSW Water reforms process beginning 1998-99 irrigation season, an ongoing process in 5 year cycles	Fencing riparian zones - is there any monitoring to determine the effects of this?	Fitting top release systems to dams eg trunnion on Ben Chifley Dam, Macquarie River
	Building of appropriate fishways - vertical slot, Denil, rock ramp			NSW Rivercare: erosion control, riverbank management etc. - not really done with fish in mind	Multi-level offtakes on dams eg Split Rock Dam, Namoi River
	Weir Review Program		COAG agreement on the Murray-Darling Basin cap	Debate of snagging policies between DLWC, MDBC and NSW Fisheries	Water pollution legislation
					Water reform process
					Improved land management
References	Berghuis et al. 1997	-	DLWC 1997b, c, 1998a, b, c, d	Cod Radiotracking Project 1995	DLWC 1997b
	DLWC 1997d		EPA NSW et al. 1997	Sedgwick 1995	EPA NSW et al. 1997
				DLWC c. 1997	
				NSW Fisheries 1998	

NT

	Barriers to migration	Fishing	Information gathering	Introduced species	Natural fish kills
Strategies	Construction and monitoring of spillways	Use of stock assessments to determine that yields and effort levels are sustainable	Not discussed	Physical removal	Examination of the factors involved to ensure that man does not exacerbate the problem eg clearing, over-stocking
				Mimosa - slashing, burning, biological control	
	Determination of the optimal barrage height to allow water movement as well as fish passage	Stabilisation of catch and effort levels in the 1980s through buy-out of commercial licences by the NT Government		Salvinia - containment, biological control, education to prevent spread, spraying	
				Having a robust natural environment as opposed to a stressed environment	Not trying to solve this problem
References	Northern Territory of Australia 1998	Johnson 1996	-	-	-
		Fallu 1997b			
		Walters et al. 1997			

	Salinity	Wetland degradation
Strategies	Construction of barrages to prevent saltwater intrusion	Construction of barrages to prevent saltwater intrusion
References	-	Griffin 1995a
		Northern Territory of Australia 1998

QLD

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Strategies	Increasing the understanding that fishways can be of use	Several strategies are currently underway	This is a potential problem	Wetland rehabilitation in cane fields	Legislation to making it illegal to translocate fish
	Documentation of barriers to movement and recognition of barriers other than obvious ones			QDPI Forestry have set aside areas of riparian vegetation to protect Mary River cod and banned fishing in those areas	Educating people of the problems associated with inappropriate stocking
	Demonstrating that new fishways are working				Eradication of spot infestations with rotenone
	Legislation allowing QDPI to decide if a new barrier requires a fishway			Mary River Cod Recovery Team is examining habitat rehabilitation - fencing, revegetation, breeding; group formed about 3 years ago	
	Designing and building appropriate fishways				
References	Berghuis et al. 1997	-	-	Digman 1998	Freshwater Fisheries MAC 1996
	Stuart 1997				

	Pollution/Water quality
Strategies	Integrated Catchment Management and Landcare groups are encouraging people to change farming practices and decrease sediment loads
	Reduction in fertiliser and pesticide runoff - people are realising that it's not economical to have them running off their property
References	Hunter et al. 1996

SA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Strategies	Changes allowing fish access on and off the floodplain, since these changes (1996-97) there have been fewer strandings after water levels drop	When large flows are moving downstream in the Murray River they could be augmented with water from Lake Victoria etc. to allow the full benefits of flooding to be realised	A stock assessment is underway	Fencing	Don't know of any
	Opening the Murray Mouth barrages at the top of the night tidal phase to allow fish passage			Removal of feral goats	
References	Southern Fishermen's Association et al. 1998	Only a fraction of this work has been published	In progress	No formal documentation available	–

	Pollution/Water quality
Strategies	Removal of feral goats
References	No formal documentation available

VIC

	Barriers to migration	Carp	Reduced environmental flows	Fishing	Habitat degradation
Strategies	Rock ramp fishway at Dyke Falls on the Yarra River	Not discussed	A study of the Campaspe River before and after changes to flows	Stocking of salmonids based on reports from the stock assessment team	Fisheries Act
	Rock ramp fishway on the Barwon River at Geelong		Implementation of a nominal flow regime to maintain conditions and prevent complete drying		Rehabilitation works on Broken River involving Catchment Management Authorities, Landcare, MAFRI, environment agencies - resnagging, recreating habitat etc
	Removal of some road culverts		There has been little attempt to release supplementary flows for rehabilitation		
	Vertical slot fishways on Broken Creek		There is essentially no monitoring of environmental releases to determine if they work or not		Flora and Fauna Guarantee Act for the legislative recognition of threats; threatened species, threatened communities and threatening processes can be listed
References	Bennett 1997	-	CRCFE c. 1998	Brown and Douglas 1998a	National Landcare Program
	Brown et al 1997a, b			Brown and Vallis 1998	Brown and Douglas 1998b
					O'Brien 1998a, b
					Parliament of Victoria 1998a, b

	Riparian vegetation degradation	Water temperature
Strategies	Defining and fencing areas Revegetation through replanting or natural regrowth	Variable level offtake on Thompson Dam
References	-	Report never completed

TAS

	Carp	Reduced environmental flows	Habitat degradation	Introduced species	Pollution
Strategies	Eradication of carp from farm dams in the 1970s using rotenone	Individual agreements on a localised basis	Many small scale projects	Use of rotenone to remove mosquito fish from farm dams about 10 years	Mining rehabilitation e.g. Mt Lyell, Kew River
	Radio-tracking and targeted fishing to reduce numbers		Mining rehabilitation e.g. Mt Lyell, King and Queen Rivers	Use of rotenone to remove redfin from farm dams 2-3 years ago	Installation of water treatment plants
	Habitat manipulation to reduce spawning areas		Sediment removal and trapping in the Cornelian River	Enhancement of a barrier on Blue Tier Creek about 3 years ago to prevent the upstream movement of trout into an area with *Galaxias fontanus*	Introduction of new technology in industry to upgrade treatment processes
	Screening the outlets of Lakes Sorell and Crescent to prevent movement out of these areas			Management of a lake as a brook trout fishery preventing the entry of brown trout, this also protects *Galaxias johnstoni*	
References	IFC 1995, 1996, 1997	Don't know of any	Davies et al. 1996	Sanger and Fulton 1991	Davies et al. 1996
				Sanger 1996	

WA

	Barriers to migration	Reduced environmental flows	Fishing	Habitat degradation	Introduced species
Strategies	Nothing on large dams	Releases from North Dandalup Dam (ongoing)	Not discussed	State Forests Clearfelling Streamside Reserve policy	Use of rotenone to eradicate tilapia from backyard ponds
				Fencing and replanting of water courses by Landcare and Streamlining	AQIS for the removal of illegal entrants
					Translocation policy
				National parks and reserves	Wildlife Protection Act - national
References	-	-	-	Fisheries Department of WA 1997a, b	-

Appendix 20. Strategies which have addressed or are addressing the overall six major threats (based on interviews with the State representatives and input from the Steering Committee).

Steering Comm. = Steering Committee

Habitat degradation

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Production of a river restoration manual by LWRRDC	Fencing of riparian zones	Not raised as a major issue for this State	Wetland rehabilitation in cane fields	Fencing	Many small scale projects	Fisheries Act	National parks and reserves
Habitat restoration by catchment management authorities	Debate of snagging policies between DLWC, MDBC and NSW Fisheries		Mary River Cod Recovery team is examining habitat rehabilitation	Removal of feral goats	Mining rehabilitation	Flora and Fauna Guarantee Act for legislative recognition of threats	Fencing and replanting of water courses by Landcare and Streamlining
Management of water levels to prevent death of riparian vegetation and subsequent algal blooms	NSW Rivercare program		QDPI Forestry have set aside areas of riparian vegetation to protect Mary River cod and banned fishing in those areas		Sediment removal and trapping in the Cornelian River	Rehabilitation works on the Broken River involving several agencies	State Forests Clearfelling Streamside Reserve policy

Pollution/Water quality/Water temperature

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Demonstration of the linkage between pesticide levels from cotton farms and fish kills	Water reform process	Not raised as a major issue for this State	Integrated Catchment Management and Landcare groups are encouraging people to change farming practices and decrease sediment loads	Removal of feral goats	Mining rehabilitation	Variable level offtake on Thompson Dam	Not raised as a major issue for this State
	Water pollution legislation				Installation of water treatment plants		
	Improved land Management				Introduction of new technology in industry to upgrade treatment processes		
Goulburn/Broken water quality management strategy	Fitting top release systems to dams						
Multi-level offtakes on dams	Multi-level offtakes on dams		Reduction of fertiliser and pesticide runoff				

Reduced environmental flows

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Prolonged environmental flow from Hume Dam on top of a natural flood	NSW Water reforms package	Not raised as a major issue for this State	This issue hasn't been seriously addressed, several strategies are currently underway	Augmentation of large flows moving downstream in the Murray River with water from Lake Victoria etc. to allow the full benefits of flooding to be realised	Individual agreements on a localised basis	Study of the Campaspe River before and after implementation of flow changes	Releases from North Dandalup Dam
ARMCANZ initiative monitoring the progress of the implementation of environmental flows against national policy	COAG agreement on the Murray-Darling Basin cap						
Assessing the effects of environmental releases from hydro storages on fish and invertebrates						Implementation of a nominal flow regime to maintain conditions and prevent complete drying	

Barriers to migration

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Vertical slot fishways on dams up to 4m in height, research into their design, interstate cooperation with implementation, monitoring after completion	Demolition of redundant structures	Construction and monitoring of spillways	Increasing the understanding that fishways can be of use	Changes allowing fish access on and off the floodplain	Not raised as a major issue for this State	Rock ramp fishway at Dyke Falls on the Yarra River	Nothing on large dams
	Building of appropriate fishways - vertical slot, Denil, rock ramp	Determination of the optimal barrage height to allow both water movement and fish passage	Documentation of barriers to movement and recognition of barriers other than obvious ones	Opening the Murray Mouth barrages at the top of the night tidal phase to allow fish passage		Rock ramp fishway on the Barwon River, Geelong	
Development of a database of barriers in QLD, NSW, VIC	Weir Review Program		Design and building of appropriate fishways			Vertical slot fishways on Broken Creek	
			Demonstrating that new fishways are working			Removal of some road culverts	
			Legislation allowing QDPI to decide if a new barrier requires a fishway				

Introduced species/Carp*

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Prevention of introductions	Nothing yet	Physical removal	Legislation making it illegal to translocate fish	Don't know of any	Removal of mosquito fish, redfin and carp from farm dams using rotenone	Not discussed	Wildlife Protection Act national
Use of rotenone in contained areas		Salvinia - containment, biological control, education to prevent spread, spraying	Educating people about the problems associated with inappropriate stocking		Radio-tracking and targeted fishing to reduce carp numbers		AQIS for the removal of illegal entrants
National foreign aquatic introductions assessment scheme by the former Advisory Committee on Live Fish for the Wildlife Protection Act					Habitat manipulation to reduce spawning areas for carp		Translocation policy
		Mimosa - slashing, burning, biological control	Eradication of spot infestations with rotenone		Screening the outlets of Lakes Sorell and Crescent to prevent movement of carp out of these areas		Eradication of tilapia from backyard ponds with rotenone
Willow replacement by West Gippsland Catchment Management Authority		Having a robust natural environment as opposed to a stressed environment			Enhancement of a barrier to prevent the upstream movement of trout into an area with *Galaxias fontanus*		
					Management of a lake as a brook trout fishery preventing the entry of brown trout, this also protects *Galaxias johnstoni*		

*Introduced species and carp have been combined for the purposes of this table.

Fishing

Steering Comm.	NSW	NT	QLD	SA	TAS	VIC	WA
Not discussed	Not raised as a major issue for this State	Use of stock assessments to determine that yields and effort levels are sustainable	This is a potential problem	Stock assessment	Not raised as a major issue for this State	Stocking of salmonids based on reports from the stock assessment team	Not discussed
		Stabilisation of catch and effort levels in the 1980s through buy-out of commercial licences by the NT Government					