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Managing the Impacts of Carp

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Managing the Impacts of Carp

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The Bureau of Rural Sciences is a professionally independent scientific bureau within the Department of Agriculture, Fisheries and Forestry – Australia (AFFA). Its mission is to provide first-class scientific research and advice to enable the department to achieve its vision — rising national prosperity and quality of life through competitive and sustainable agricultural, fisheries and forestry industries.

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Foreword

Carp (*Cyprinus carpio*) have become the most abundant large freshwater fish in Australia and are considered a problem because of their perceived impacts on water quality, soft-leaved aquatic plants and native fish populations through competition and lowering habitat quality. Carp are also valued by those who fish them commercially or for recreation, and carp are used to produce fertiliser, pet food and bait and small quantities are sold in Australia and exported to European markets for human consumption.

There is little reliable information about the extent and nature of many of the problems caused by carp and how they can best be solved. This has led to diverse views about carp management.

Whether carp have simply taken advantage of poor habitat condition or whether they are a cause of it is subject to much debate. The reality is probably a combination of the two. Regardless, assessing and managing the impacts of carp cannot be considered in isolation from other water management issues. Carp management is just one of many factors which influence water quality and aquatic biodiversity.

This publication is one in a series of Bureau of Rural Sciences pest animal management guidelines which provides natural resource users, managers, advisers and funding agencies with ‘best practice’ national guidelines for managing the economic and environmental damage caused by carp. Others in the series include guidelines for managing feral horses, rabbits, foxes, feral goats, feral pigs, rodents and wild dogs.

The principles underlying the strategic management of vertebrate pests have been described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993) and in *Australia’s Pest Animals: New Solutions to Old Problems* (Olsen 1998). The emphasis is on managing of pest damage rather than on simply reducing pest density. The guidelines recommend that, wherever practical, management should concentrate on achieving clearly defined economic or conservation benefits.

This publication complements the National Management Strategy for Carp Control (NMSCC) developed by the Carp Control Coordinating Group (CCCG). The NMSCC describes a framework for a uniform national approach to the management of carp. Both documents have been produced under the Federal Government's Natural Heritage Trust.

The approach to managing carp damage set out in these guidelines has been approved by the Standing Committees on: Agriculture and Resource Management; Conservation; and Fisheries and Aquaculture.

These guidelines will help policy-makers and managers reduce the damage to water resources and the naural environment caused by carp through the use of scientifically-based management that is humane, cost-effective, and integrated with ecologically sustainable development.

Peter O’Brien

Executive Director
Bureau of Rural Sciences

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Several individuals from the Bureau of Rural Sciences deserve mention. Quentin Hart managed the overall publication production process and assisted with editing, design and print management. Lisa Curtin incorporated the numerous modifications to the final drafts, assisted with copy editing, typeset the document and had major responsibility for final production. Dana Bradford helped collate earlier drafts of the manuscript. Kim Tatnell redrew the figures and provided extensive design and typesetting input. Brett Cullen contributed to the design process.

To ensure that the guidelines are widely accepted as the basis for carp management, the draft manuscript was circulated to the following organisations for comment:

- Animals Australia
- Australian Conservation Foundation
- Australian Veterinary Association
- Carp Control Coordinating Group
- Commonwealth Department of Agriculture, Fisheries and Forestry
- Cooperative Research Centre for Freshwater Ecology
- CSIRO
- Environment ACT
- Environment Australia
- Fisheries Research and Development Corporation
- Fisheries WA
- Land and Water Resources Research and Development Corporation
- Murray–Darling Association
- Murray–Darling Basin Commission
- National Carp Task Force
- National Consultative Committee on Animal Welfare
- National Farmers' Federation
- Native Fish Australia
- Northern Territory Fisheries
- NSW Fisheries
- Queensland Department of Primary Industries
- Rural Industries Research and Development Corporation
- South Australian Department of Primary Industries and Resources
- Standing Committee on Agriculture and Resource Management
- Standing Committee on Conservation
- Standing Committee on Fisheries and Aquaculture
- Tasmanian Inland Fisheries Commission
- Vertebrate Pests Committee
- Victorian Department of Natural Resources and Environment.

We thank these groups and hope that this document will facilitate their involvement in more strategic management of carp impacts.

Summary

The introduced carp (*Cyprinus carpio*) is widely distributed throughout south-eastern Australia with smaller populations in Western Australia and Tasmania. Carp now dominate fish communities throughout much of their range particularly in the Murray–Darling Basin. Carp have the potential to spread through many more of Australia's water systems and could become even more widespread throughout the country.

Carp can damage aquatic plants and increase water turbidity. Their impacts on native fish species and other aquatic fauna are not well understood. Carp are also becoming a resource, and are fished commercially and to a lesser extent recreationally.

These guidelines are a comprehensive review of the history of carp in Australia, their biology, the damage they cause, and past and current management. The views of water and fisheries managers, conservationists, animal welfare groups, commercial and recreational fishers, Aboriginal peoples and other interest groups were sought during the production of these guidelines. Techniques and strategies for carp management are recommended and illustrated by case studies. Deficiencies in knowledge, management and legislation are identified.

The guidelines have been prepared primarily for State and Territory management agencies as a basis on which to consult with water managers and relevant interest groups and to prepare State, regional and local strategies for reducing the damage carp cause to the environment and industry. It is a technical document which provides the scientific basis for the National Management Strategy produced by the Carp Control Coordinating Group (CCCG).

The purpose of these guidelines is to assist in developing cost-effective strategies to reduce carp damage. Ideally, such strategies are based on reliable quantitative information about the damage caused by carp, the cost of control measures, and the effect that implementing control has on reducing damage. In developing these guidelines the authors have used all such available information. In some instances where reliable information is not yet available, managers responsible for carp management will have to make assumptions about carp impacts and the efficacy and cost-effectiveness of control techniques.

Carp introduction and spread in Australia

Carp are in the family Cyprinidae and originated in China. They successfully spread throughout Asia and Europe and developed as an ornamental and aquaculture species. Carp are closely related to goldfish, although the presence of two pairs of barbels on carp distinguishes them from goldfish. The first records of carp introductions in Australia come from Victoria in 1859 and New South Wales in 1865. These carp were released into ponds and did not spread into the wild. During the 1900s carp were released into the wild but did not become widespread. The Australian spread of carp largely began after they were released into the Murray River near Mildura, Victoria, in 1964. These fish came from carp bred at a fish farm at Boolarra, Victoria. The spread of carp throughout the Murray–Darling Basin, coincided with widespread flooding in the early 1970s, but carp were also introduced to new localities, possibly through their use as bait. Carp are now the most abundant large freshwater fish in the Murray–Darling Basin and are the dominant species in many fish communities in south-eastern Australia.

Economic and environmental impacts

Carp have the potential to cause major costs for both private and public sectors by lowering water quality and damaging aquatic habitats. Although there are few costings for carp impacts on industries, those that may be affected include domestic and irrigation water supplies, agriculture, and commercial and recreational fisheries. Because carp are not popular for eating or angling, most anglers have a negative image of them. Angling is one of the most popular recreational activities in Australia and the dominance of carp in many fish communities has the potential to reduce angler participation, particularly where numbers of preferred native fish species are also low. This could cause substantial losses to fishing equipment suppliers and tourist industries associated with recreational fishing.

Most perceptions of environmental damage by carp focus on their potential to damage wetlands, reduce water quality and harm native fish populations. Although carp are often regarded as having a harmful effect on aquatic habitats and native aquatic species, there is little information on the overall impact and the costs that may be incurred. There has been some limited research both in Australia and overseas on the potential environmental impacts of carp, but many of the impacts are not clear because they can also be caused by other factors. There is clear evidence that carp increase water turbidity and damage many aquatic plants, especially those with soft stems and shallow roots, and some evidence that carp increase water nutrient concentrations. Such damage can threaten endangered species, alter ecological functions and affect tourism and recreational values of otherwise scenic wetlands. Impacts on native fish fauna are less well documented, even though carp now dominate many freshwater fish communities. Declines in native fish populations in many areas occurred prior to the introduction of carp. Increases in carp populations were probably facilitated by the already reduced native fish populations, as opposed to a commonly held perception that carp caused these declines.

Resour ce value

Much of the commercial carp catch is used for low price products such as crayfish and lobster bait and fertiliser. There is currently little human consumption of carp in Australia and value-added products are only produced on a small scale. Commercial harvesting is only likely to contribute to the control of carp in certain localised areas and is unlikely to achieve wide-scale population reductions.

Biology and Ecology

The biology and ecology of carp are two of the major reasons for their success as a vertebrate pest in Australia. Carp have broad environmental tolerances and thrive in habitats which are disturbed by human activities, such as where river flows are altered, nutrients are enriched and streamside vegetation is cleared. Carp feed by filtering small particles from the water or by sieving food items from the bottom sediments. Juvenile carp feed mainly on small planktonic animals, smaller crustaceans and insect larvae. As carp grow they gradually eat larger crustaceans and aquatic insects, along with some plant material.

Female carp mature at 2–4 years and may produce more than one million eggs per year. Eggs are normally shed onto plant material in spring to early summer. Females may spawn several times in one season. Juvenile carp live in shallow floodplain habitats and are more abundant where the density of adult carp is low. Growth rates of carp vary greatly between different regions, depending on temperature, food availability and population density.

Survival of carp appears to be density-dependent. This means that although large numbers of juveniles are produced, only a small number of young survive. The implication of this for reducing carp populations is that the size of the reproducing population will need to be substantially reduced to have any marked effect on population growth rates.

Carp carry a number of disease organisms. Some of these, such as the Asian fish tapeworm (*Bothriocephalus acheilognathi*) now occur in Australia, and may pose a serious risk to native fish. In Europe, carp carry Spring Viraemia of Carp Virus (SVCV) (*Rhabdovirus carpio*), which causes Spring Viraemia of Carp disease. This disease causes high mortalities in cyprinids, but has not yet been detected in Australia.

Carp can migrate at any time of year. Some tagged individuals have moved over 200 kilometres in a few months. Large numbers of carp have been recorded moving upstream during periods with low flows and rising water temperatures.

Carp are not normally predators of other fish. Small carp may be an important part of the diet of larger predators, such as Murray cod (*Maccullochella peelii peelii*). Competition between carp and native species is poorly understood. By growing quickly to a large size, and feeding at low levels of the food chain, carp may act as an energy trap, preventing transfer of energy to populations of other large fish. The feeding activity and diet of carp may be an important factor in forming algal blooms.

Community attitudes and expectations

Most attitudes towards carp in Australia are negative. Many farmers and water authorities believe carp cause extensive damage to channel banks. Recreational fishers and conservationists perceive carp as a nuisance. However, many conservationists, scientists and people interested in native fish, including recreational and commercial fishers, believe that carp are often used as a scapegoat and are blamed for environmental problems which have other causes.

Due largely to negative media reports portraying carp as a major cause of environmental problems, there is overwhelming public opinion that action is needed to reduce carp numbers. Commercial harvesting is seen as one option. This is often proposed without consideration of the economic viability of commercial operators who generally only receive a low price for carp. A common opinion is that harvesting carp will at least reduce their densities and at best ensure establishment of a market that could maintain carp numbers below a level where they are a problem. But some community group representatives have expressed concern that establishing a carp harvesting industry might interfere with the ultimate control of carp. Some conservationists, recreational fishers and indigenous representatives also consider that the choice of control options for carp needs more emphasis on the role for rehabilitation of catchments and riparian areas.

Techniques to control carp

To date carp control has mainly consisted of commercial harvesting or poisoning. Whilst these options may reduce carp numbers, and poisoning may occasionally eradicate them from isolated areas, other options are being explored for more widespread control. Environmental rehabilitation is seen as a way of improving habitat quality to favour native fish. By potentially increasing native fish numbers, particularly larger predators, predation pressure on carp will be increased. The use of viral agents for biological control such as SVCV is considered to be unreliable for technical, commercial, conservation and logistic reasons. Some sectors of the public have expressed concerns about the use of viral control agents. Potential genetic manipulation approaches to carp control need to be explored. These techniques, together with harvesting, rely on an adequate understanding of the dynamics of carp populations. This information is currently not available. Potential molecular approaches include immunocontraception to reduce carp fertility and the introduction of a fatality gene to kill individuals at a later date. There are currently no biological or contraceptive control agents suitable for use against carp and gene technology is not yet at a stage where it can be used for carp control.

Development of a strategic management approach

In the past there has been no coordinated management of carp in Australia and carp control has been mainly undertaken by State agencies, predominantly fisheries agencies. The formation of the National Carp Task Force, as a result of public interest and pressure, has promoted a more coordinated approach and national focus on carp control. The CCCG has recently been formed with State, Territory and Commonwealth representatives to coordinate carp control on a national basis. There is now a need to progress towards more strategic and scientific management. Integrated management using a range of control techniques produces the best results, but a lack of reliable information on control costs is seen as a barrier to adoption of some techniques. This deficiency should be addressed if best practice management is to be widely adopted.

What is the strategic management appr oach?

The emphasis in these guidelines is on the strategic management of carp and their habitats to minimise the damage carp cause to aquatic habitats and conservation values, not merely to kill carp. Carp need to be considered as one factor in a complex and changing system which includes highly variable climate and river conditions, and environmental damage from other causes.

A strategic approach to the management of carp involves four key components:

Defining the problem — The problem first needs to be defined in terms of the impacts of carp on valued resources, whether economic or environmental. The next step is to quantify these impacts which will usually require experimental assessment of the damage.

Management plan — In developing a management plan, it is essential that clear objectives are established wherever practicable in terms of the desired production and conservation outcomes sought, relative to the costs of control. Options for carp management include preventing further spread, eradicating existing populations, sustained management, targeted management, one-off management or no management. Where feasible, it is desirable to develop an adaptive experimental management approach, based upon the techniques available for carp control.

Economic frameworks need to be developed to assist managers to assess the relative value of alternative control strategies. Such frameworks require: definition of the economic problem, data on relative costs and benefits of different carp management strategies, an understanding of why the actions of individual managers may not lead to optimum levels of carp control, and how such problems can be addressed.

Implementation — The most effective approach is to coordinate management of carp damage on a local and regional level, involving cooperative action by water managers, government agencies, industry and community groups.

Monitoring and evaluation — Monitoring has two aspects. Operational monitoring assesses the efficiency of the management strategy over time, particularly to determine whether it is being carried out in the most cost-effective manner. Performance monitoring gathers information to evaluate the effectiveness of the strategy in meeting the desired long-term production or conservation objectives. Both forms of monitoring can help determine if and how the management strategy should be modified. When adaptive experimental management has been implemented, such monitoring and evaluation will enable improved and more cost-effective carp management strategies to be developed.

The above approach has been adopted for developing these national guidelines. The information in these guidelines is designed to facilitate the development of strategies for managing carp at the local and regional level.

The futur e

More information in some key areas is essential if the strategic approach to carp management is to be developed further. Knowledge of many aspects of carp ecology in Australia is relatively limited. In particular, information on the dynamics of carp populations and their driving forces in the Australian environment is lacking. Such information is critical to the successful application of most management techniques. Further development is also required for many of the potential control techniques, including environmental rehabilitation, which may have widespread application.

Two of the basic weaknesses in being able to determine priorities for where to control carp in many areas of Australia are the lack of objective, quantitative data on the impact of carp on the environment and a means of determining the cost of this environmental damage.

There are few reliable data on the costs of carp control. Water managers need better information on the types and extent of damage caused by carp and on control costs. This will enable a change in management philosophy from one focussed on killing more carp to one focussed on cost-efficiently reducing the damage caused by carp.

Adoption of these national guidelines will require an improved understanding of the principles for managing carp as a vertebrate pest at various levels, ranging from water managers to policy makers and officers of State agencies. Currently, there are limited numbers of extension staff working on carp and few are trained in the principles of education, sociology or psychology, all key elements associated with facilitating a change in behaviour in individuals or groups.

Intr oduction

These guidelines for managing carp (*Cyprinus carpio*) are one in a series prepared by the Bureau of Rural Sciences (BRS) in cooperation with the Vertebrate Pests Committee of the Standing Committee on Agriculture and Resource Management. This volume in the series was produced under the agricultural component of the National Feral Animal Control Program (NFACP), a Natural Heritage Trust initiative. Other guidelines in the series include: feral horses (Dobbie et al. 1993), rabbits (Williams et al. 1995), foxes (Saunders et al. 1995), feral pigs (Choquenot et al. 1996), feral goats (Parkes et al. 1996), rodents (Caughley et al. 1998), and wild dogs and dingoes (Fleming et al. in press). The current publication is the first publication in the series which addresses an aquatic vertebrate pest.

A companion volume, *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993), explains the principles on which best practice pest animal management is based and should be read in conjunction with the guidelines. An overview volume, Olsen's (1998) *Australia's Pest Animals: New Solutions to Old Problems*, reviews the management of pest animals in Australia and promotes a more strategic approach for future management. The benefits of focusing on the damage caused by a pest and not the pest itself are explained. Olsen (1998) also explains the need to take into account the links between different feral animal species and other aspects of land and water management, consistent with the holistic approach to land management advocated under the Ecologically Sustainable Development Strategy and Landcare principles.

The objective of the national guidelines is to assist a change in approach to carp management from ad hoc measures by individual interest groups and agencies to a strategic management approach based on cooperative action. These guidelines will have succeeded in meeting this objective when the strategic approach they advocate is accepted and implemented by a significant number of agencies and stakeholder groups.

The strategic approach to managing carp involves four key components: defining the problem, developing a management plan, implementation, and monitoring and evaluation. These steps are outlined in Figure 1 and discussed in Chapter 8.

Defining the pr oblem

Carp are widely regarded as having harmful effects on the environment although there is little objective, quantified information. There are no estimates of the economic impacts of carp in Australia and few estimates of their environmental impacts. Determining the nature and extent of the economic or environmental threat caused by carp requires knowledge of their status and biology. Thus, Chapter 1 describes the history of their introduction, Chapter 2 their spread, distribution and abundance, and Chapter 3 their biology and ecology.

Public attitudes can strongly influence the perception of carp as a resource or as a problem, and these views are examined in Chapter 4. Chapter 5 reviews the evidence concerning the economic and environmental impacts of carp in Australia and also reviews commercial use of carp. Past and current management of carp and their legislative status are reviewed in Chapter 6. The impacts of carp can be assessed in several ways, and these are reviewed in Chapter 7, together with the efficacy of techniques to reduce these impacts.

Management plan

Several management options are identified and discussed in Chapter 8 including preventing further spread through precautionary management, local eradication, strategic sustained management, commercial harvesting and no management. There are several options for managing carp damage, including removal by harvesting or recreational fishing, environmental rehabilitation, exclusion and poisoning. Future options may include the use of viral control agents, molecular approaches such as chromosomal manipulation and gender manipulation or the introduction of inducible fatality genes and biomanipulation through predator stockings. Biotechnology options may not however be readily available for use by the community and must undergo stringent trials before being deemed acceptable. Ideally a carp management strategy will aim to achieve the desired reduction in damage by the most cost-effective means consistent with ecologically sustainable use of the management system. In many cases, lack of knowledge may initially prevent identification of the best strategy for carp management. An adaptive experimental approach, however, where the manager evaluates the benefits of a management action and continually modifies it in the light of experience (that is, 'learning by doing') is often the best approach. This is particularly applicable to carp, where many aspects of their ecology under Australian conditions are not well understood. Chapter 8 describes how such a management strategy can be developed.

Implementation

A national strategy for managing carp damage encourages local and regional level plans to be placed in a national context. This involves all managers and others with a significant interest in carp management cooperating at an early stage in planning and implementation.

At the national level, such an approach requires that the various roles and responsibilities of government agencies, groups and individuals are taken into account and integrated. The Commonwealth Government is involved in pest animal management through agencies such as: the Murray–Darling Basin Commission; BRS and the National Office of Animal and Plant Health in Agriculture, Fisheries and Forestry – Australia; and the Biodiversity Group in Environment Australia. The Commonwealth Government's responsibilities for pest animal management include: exotic disease preparedness and management, protection of overseas trade interests, and managing the threats that feral animals pose to such national initiatives as the National Landcare Program, the National Feral Animal Control Program, the Endangered Species Program and the National Strategy for the Conservation of Biological Diversity. State and Territory governments are responsible for providing the legislative and regulatory framework as well as facilitating and implementing management on private and public land.

Chapter 9 discusses the roles of local, State/Territory and Commonwealth governments and community groups in developing and implementing carp management plans and the role of extension services and group action for achieving effective carp management.

Monitoring and evaluation

Monitoring is an essential component of the strategic management approach. It enables managers to determine whether their management strategy needs to be modified. Operational monitoring aims to assess the efficiency of implementing the management strategy and to identify areas where efficiency can be improved. Chapter 7 reviews techniques for assessing the cost effectiveness of control. Performance monitoring seeks to evaluate the outcome of the management plan; that is, whether the goals set initially in terms of production or conservation outcomes are being met. Methods of evaluating such outcomes are also described in Chapter 7.

The futur e

A major impediment to effective carp management is a lack of information. There is still a great deal of uncertainty about what the impacts of carp are, which makes it difficult to set priorities for managing areas and to determine appropriate levels for carp reduction. Despite the widely held belief that habitat manipulation has the potential to improve the competitiveness of native fish relative to carp, this has yet to be proven on a large scale. There also needs to be further investigation of aspects of carp biology and ecology that offer a management target as well as target-specific, cost-effective control techniques. The population dynamics of a highly fecund species such as carp also need to be considered carefully to determine the potential of various control strategies to have a long-term impact on carp density and abundance. Chapter 10 highlights deficiencies in the current state of knowledge and looks to the research and management developments which are needed to improve future management.

The National Feral Animal Control Program

NFACP is a Natural Heritage Trust program which works with State, Territory and local governments to reduce damage caused by pest animals to agriculture and the environment. The agricultural component of NFACP is administered by BRS and the environmental component by Environment Australia. Under its component of NFACP, BRS is producing these national management guidelines for the major pest animal species of agricultural production and is also supporting projects to address the information, management and extension deficiencies the guidelines identify and to demonstrate the strategic management approaches they advocate.

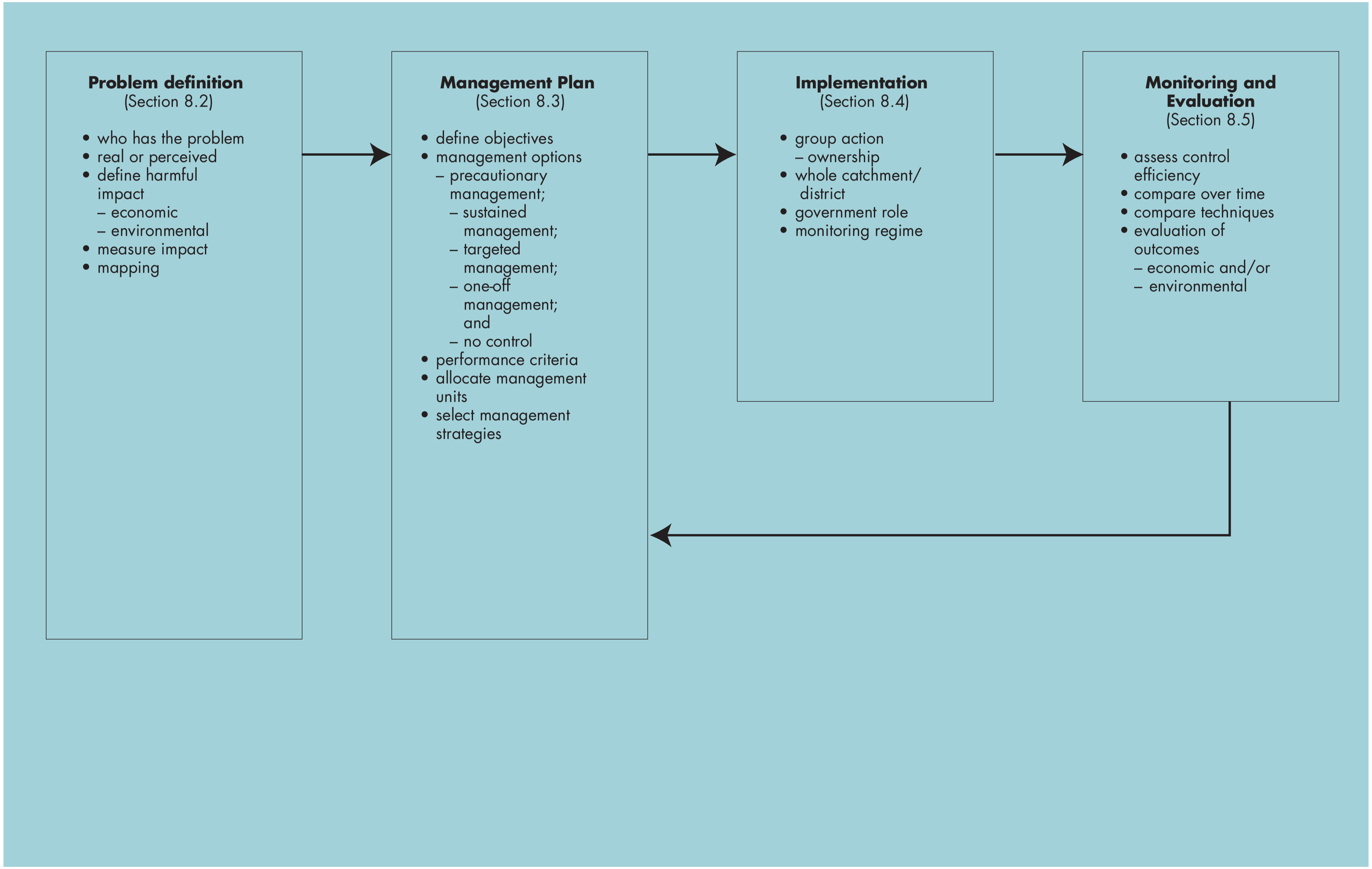
Linkage to the Carp Control Coordinating Group's National Management Strategy for Carp Control

The Carp Control Coordinating Group (CCCG) was formed by the Commonwealth Government in 1998 to provide national leadership and coordination in the development and implementation of carp management initiatives. CCCG has prepared a *National Management Strategy for Carp Control* (NMSCC) which provides a national framework for effectively managing carp in Australia. The BRS guidelines complement this document by providing a detailed discussion of the biological, economic and strategic management principles which should be taken into account in developing management and research strategies.

Associated with the NMSCC, CCCG has prepared two documents to guide the prioritisation and implementation of carp management and research in Australia:

- *Ranking Areas for Action: a Guide for Carp Management Groups* — sets out a process for establishing and ranking carp management units to prioritise resource allocation and provides a step-by-step process to develop and implement a management plan.
- *Future Directions for Research into Carp* — identifies key knowledge gaps and provides the basis for progressing management-based carp research.

All dollar values have been converted to 1999-2000 Australian dollars unless otherwise stated in the text.



Figur e 1: Strategic appraoch to managing carp damage (after Braysher 1993)

1. Taxonomy and history of intr oduction

Summary

Carp belong to the family Cyprinidae. The species originated in China and spread throughout Asia. They were introduced to Japan (Koi strain) and Europe where they were developed as both an ornamental species and as an aquaculture species for food. Carp are not native in North America or southern continents. Carp are closely related to goldfish and the two species are mainly distinguished by the presence of two pairs of barbels on either side of the carp's mouth.

In Australia, carp were first introduced to Victoria in 1859 and to New South Wales in 1865. Although these early introductions were intended to establish populations in the wild, these attempts failed and carp remained in ponds. Aquarium imports into Sydney in 1907 resulted in contained populations at Prospect Reservoir and Taronga Zoo. During the 1900s carp were again released into the wild into rivers of New South Wales. These may have been an Asian strain of Koi carp as this strain persists in some of the original mainland release sites in the Murrumbidgee Irrigation Area, and at Pooncarie in New South Wales. Koi carp also now occur in Tasmania, the Australian Capital Territory and Western Australia, probably from releases of Koi carp from ornamental collections.

The most successful and now widespread genetic strain of carp is known as the Boolara strain, and although the source of these fish is not verified, they were probably imported into Victoria from Europe and did not spread widely until after 1960.

1.1 Family Cyprinidae

The Cyprinidae is a diverse fish family with around 2000 species grouped into seven subfamilies (Howes 1991; Nelson 1994; Helfman et al. 1997). The fossil record for cyprinids dates from the Eocene age (58–37 million years ago) in Asia, from where they spread to Europe and North America. Fossil cyprinids also occur in Africa, India and south-east Asia as these fish extended their range when land masses moved. No cyprinids reached the Celebes, New Guinea or Australia because the ancient Gondwana landmass, which formed Australia and Antarctica, separated from the other continents before cyprinids evolved. Being primarily a freshwater species, cyprinids were unable to cross the sea (Berra 1981) (Section 3.5.5).

'Carp have been successfully introduced outside their natural distribution to both the tropics and temperate regions.'

China is the heartland of cyprinids with individual river basins having a diverse fauna (up to 111 cyprinid species in the Xi River basin). The central European rivers also have large numbers of cyprinid species (Banarescu and Coad 1991).

The largest subfamily, the Cyprininae (called carps), contains 33 genera, all of European and Asian origin (Howes 1991). The Cyprininae did not reach North America so it is speculated that this subfamily evolved after North America separated from Eurasia (Howes 1991). Many species in this subfamily have the word carp in their common name — for example, grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), mud carp (*Cirrhinus molitorella)* and common carp (*Cyprinus carpio*) (Table 1). In this book, the name 'carp' always refers to *Cyprinus carpio* (Table 1).

The name 'European carp', commonly used in Australia, is a misnomer. The genus *Cyprinus* orginated in east Asia. *Cyprinus* spread naturally through central and northern Eurasia from at least the Oligocene (24 million years ago) with evidence from a fossil *Cyprinus* in Siberia (Cavender 1991). In east Asia *Cyprinus* now has about 13 species including *C. Carpio* (Banarescu and Coad 1991). There are genetic differences between the strains of carp in China and Europe, despite their common Chinese ancestry (Shearer and Mulley 1978), but carp from both continents are recognised as belonging to the same species (Section 1.4). In their natural range carp coexist with a range of other cyprinid species. Carp have been successfully introduced outside their natural distribution to both the tropics and temperate regions (Howes 1991; Section 3.2)

Goldfish (*C. auratus*) (subfamily Cyprininae) are closely related to carp and have also been successfully introduced outside their natural distribution including into Australia (Howes 1991). Crucian carp (*Carassius carassius*) originated in Euro–Siberia where the Family Cyprinidae is the most diverse (Banarescu and Coad 1991). Crucian carp do not occur in Australia but have been confused with goldfish (Section 1.3.2). The rosy barb (*Puntius conchonius*) (subfamily Cyprininae) was reported in Queensland as having self-maintaining populations in Norman Creek, an urban stream in Brisbane, from 1970 until 1984 (McKay 1984) but the population has since died out (Brumley 1996).

Other cyprinids that have been introduced outside their natural range into Australia are from different subfamilies. They are roach (*Rutilus rutilus*) from the subfamily Leuciscinae (Howes 1991) and tench (*Tinca tinca*) from the subfamily Tincinae (Table 1 and Table 2).

Wild goldfish which have reverted to their natural olive-bronze colour are sometimes mistaken for carp, but can be easily distinguished by their lack of barbels. Source: A. Brumley, East Gippsland Institute of TAFE.

1.2 Carp in Eur ope and Asia

At least 80 species of cyprinids are used as a fishery resource, and many species are now exploited as a protein resource around the world. Cyprinids are important for commercial wild harvesting (Section 5.4) and subsistence and commercial aquaculture (Section 4.8.2), as a recreational fishing species (Section 4.9.2) and in aquarium culture as companion or show species (Section 1.3.2) (Cowx and Welcomme 1998). In North America, native cyprinid species are important for environmental monitoring and have high conservation value (Table 1). In Europe and Asia, both wild caught and cultivated carp are extremely important as food for human consumption (Table 1).

'In Europe and Asia wild caught and cultivated carp are extremely important as human food.'

Carp are native to China and Eastern Europe (Section 1.1), possibly as far west as the Danube River. In China about 3000 years ago, carp were first taken from the wild and reared in ponds for human consumption (Li and Moyle 1993). This was the first attempt at a managed aquaculture fishery to maximise production for food in China. Silver carp (*Hypophthalmichthys molitirix*), big headed carp (*Aristichthys nobilis*), grass carp and black carp were reared with carp as their different feeding habits allowed maximum use of food resources (Table 1). Carp probably grow more slowly than many of these other species but reproduce easily (Lin and Peter 1991). This practice is called polyculture and it still occurs in much of Asia for food production (Lin and Peter 1991). Carp may only comprise a small proportion of the total biomass. The traditional method involved the removal of large individuals and continual restocking with new small fish of all species during summer and autumn.

In the first century AD, carp gradually spread across Europe with the assistance of the Romans, who would have found carp in the Danube River at the western extent of their

Table 1: Species in the Cyprinidae family relevant to or discussed in text (after Howes 1991; Helfman et al. 1997; Cowx and Welcomme 1998).

Scientific name	Common name used in this book	Other common names and strains	Area/country of origin	Human use
Subfamily Cyprininae				
*Cyprinus carpio**	Carp	Common carp; European carp, scaled carp, mirror carp, king carp, leather carp	Asia	Aquaculture for food (Asia: China, Indonesia); Commercial fishing for food and recreational fishers, aquaculture for food (Europe)
	Koi carp	Koi, Japanese domesticated carp, fancy carp	China to Japan	Ornamental aquaculture (Japan, world-wide)
*Carassius auratus**	Goldfish	Golden carp, Crucian carp, native carp	China, Danube Basin	Ornamenatal aquaculture, recreational fishers for food
Carassius carassius	Crucian carp	Prussian carp	Europe, Siberia, China, Danube Basin, stocked in lakes in Poland	Coarse anglers, aquaculture, commercial fishing
Barbus barbus	European barbel		Europe	Coarse angling
Barbus (41 species)				
*Puntius conchonius**	Rosy barb			Ornamental aquaculture
Puntius (130 species)	Redtail black 'shark'	Bala 'shark'	South-east Asia	Ornamental aquaculture
Cirrhinus molitorella	Mud carp		China	Aquaculture for food, polyculture (detritivore)
Ctenopharyngodon idella	Grass carp		China to Hong Kong	Aquaculture (grass eater), control of aquatic weeds, (North America, New Zealand)

Scientific name	Common name used in this book	Other common names and strains	Area/country of origin	Human use
Mylopharyngodon piceus	Black carp		China	Aquaculture for food, polyculture (bottom feeder)
Subfamily Cultrinae				
Parabramis pekinensis	Bream		China	Aquaculture for food, polyculture (mid-water feeder)
Subfamily Leucisinae				
*Rutilus rutilus**	Roach		Europe	Coarse angling, aquaculture, commercial fishing in eutrophic lakes
Scardinius erythrophthalmus	Rudd		Europe	Coarse angling
Phoxinus phoxinus	Minnows	Dace	Europe	Coarse angling
Leuciscus cephalus	Chub		Europe	Coarse angling
Leuciscus leuciscus	Dace		Europe	Coarse angling, commercial fishing
Abramis brama	Bream	English bream, bronze bream	Europe	Coarse angling, commercial fishing
Blicca bjoerkna	White bream	Silver bream	Europe	Commercial fishing
Hypophthalmichthys molitrix	Silver carp		China	Aquaculture for food, polyculture
Aristichthys nobilis	Big-headed carp		China	Aquaculture for food, polyculture, (plankton eater), commercial fishing, angling

Scientific name	Common name used in this book	Other common names and strains	Area/country of origin	Human use
Ptychocheilus lucius	Colarado squawfish		North America	Angling, conservation as natural predator
Notropis spp.	Shiners		North America	
Phoxinus spp.	Minnows		North America	Conservation in natural environment
Pimephales spp.	Minnows		North Amercia	Bait, aquaculture
Pimephales promelas	Fat-headed minnows		North America	Conservation, environmental monitoring
Subfamily Gobioninae				
Gobio gobio	Gudgeons		Europe and Eurasia	
Subfamily Alburninae				
Pelecus cultratus	Chekhon		Baltic, Black and Caspian Seas	
Subfamily Tincinae				
*Tinca tinca**	Tench		Europe	Coarse angling, commercial fishing

*Introduced fish in Australia

Table 2: Summary of diagnostic characters of cyprinids in Australia and of crucian carp* (derived from Scott and Crossman 1973; Hume et al. 1983a; Breheny 1996; Brumley 1996).

Species		Colour	Lateral line scales	Anal fin rays	Barbels	1st gill arch raker count	Total length (millimetres)
Common name	**Scientific name**						
Subfamily Cyprininae							
Carp, also called common carp, European carp,	*Cyprinus carpio*	Wild and in aquaculture: bronze or olive-gold, lighter beneath	33–40 (usually 34–37) large scales or reduced number of scales	5–6	2 pairs (4)	16–20 (27)	Usually up to 600, maximum 1200
Koi carp		Ornamental: bright colours orange, white, black; sometimes mottled.					
Mirror carp, Leather carp		Wild: orange or olive-bronze; brown to black					
Goldfish, also called golden carp	*Carassius auratus*	Wild: orange or olive-bronze; brown to black. Aquarium: bright colours and orange; sometimes mottled.	26–30 (34)	5–6	0	35–40 (43)	Usually up to 200, maximum 400
Crucian carp*	*Carassius carassius*	Olive-green to reddish-brown dorsal; lighter ventrally. Possibly darker lateral spot near the tail.	35–38	6–8	0	26–31	Usually up to 200
Subfamily Leuciscinae							
Roach	*Rutilus rutilus*	Black olive-green body; silvery scales with reddish ventral fins and dusky dorsal and caudal fins	>40	10–11	0	short	Usually up to 200, maximum 450
Subfamily Tincinae							
Tench	*Tinca tinca*	Olive-brown to dark grey dorsally and lighter ventrally; body sometimes greenish gold to golden tan (rarely yellow-orange).	>60 up to 90–100, very small	6–7	1 pair (small)	12–15 long	Usually up to 300, maximum 700

* Often confused with goldfish and have never been verified as being present in Australia

range (Moyle 1984). Monks were the first Europeans to culture carp for food and they allowed carp escapees to spread into the river systems. Carp were well established outside of their original range across Europe by the 1200s and into England by the 1600s.

Wild carp are now caught in Europe for both recreation and food. Some European ethnic groups include carp as a traditional component of their diet originating either from commercial catches or pond culture. Carp are sought by English anglers as 'coarse' fish, as distinct from 'game' fish such as trout or salmon (Salmonidae). In a recent National Opinion Poll (1997) in the United Kingdom, carp were voted the most popular fish for recreational fishing (P. Smith, University of Liverpool, United Kingdom, pers. comm. 1998.) When bream (*Albamis brama*) and roach were removed from the Drayton Reservoir (United Kingdom) and it was restocked with carp, income from fishing increased from less than $5500 per annum without carp to $140 000 during the 1995–96 fishing year with carp present (P. Smith, University of Liverpool, United Kingdom, pers. comm. 1998.)

In Japan, carp have been domesticated for centuries for display as a result of their colour, beauty and longevity. The Ma-goi, or fancy carp, referred to in a book dated 714 AD, was derived from Chinese carp and was cultured in ponds and in holding cages in lakes (Takeshita 1969). Festivals, artwork and kites often carry a carp symbol. Worldwide, the genetic strain is called Koi, and in the past century many new Koi varieties have emerged. Koi breeding has become popular in many countries including Australia and the United States of America. Cross-breeding with European carp, including mirror carp (*Cyprinus carpio*) and leather carp (*C. carpio*) from Israel and Germany and Japanese Ma-goi, has produced new varieties of the Koi strain, including Doitsu, which has both large-scale and scaleless varieties.

1.3 Intr oduction of cyprinids to Australia

1.3.1 Victoria

Carp were imported to Victoria in 1859–1862 (Anon 1862), 1872 and 1876 (Hume *et. al* 1983a). The first record of an import was from 1859–60 (McCoy 1862) but this record is noteworthy because of the carp's lack of success at surviving in captivity. Despite this setback, importers persevered with importing carp. The next records of imports are by the Geelong and Western District Acclimatisation Society in 1872 and 1876 (Clements 1988) but if these fish were released into the wild, they apparently did not survive (Hume et al. 1983a). The only other mention of carp imports is into Melbourne. A tantalising paragraph in the London Times of 18 October 1859 records: 'Captain McMeckan did land 2 1/2 dozen carp from England with the object of domesticating them to Victoria. They are now in the care of Mr Brown of Como.' There are no Victorian records of this introduction except for a letter to the Argus in 1860 that five carp and seven goldfish had come by ship from Plymouth (Clements 1988).

The importation of carp was probably because of the desire of some of the colonists to imitate a European environment in Victoria. Between 1851 and 1861, Victoria was an expanding colony whose residents needed to gain wealth from control of resources and wanted pleasure and recreation (Gillbank 1996). New plants, animals and fish were needed to establish new resource-based industries and recreation activities. The Acclimatisation Society of Victoria (1861) which was established from the short-lived Zoological Society of Victoria (1857) aimed to offer salmon, trout, carp and other fish for anglers (Gillbank 1980). The first Annual Report of the Acclimatisation Society of Victoria included an address by Professor Frederick McCoy, Professor of Natural Sciences at Melbourne University, who said 'English bream, dace, tench, loach, roach and carp we have already imported and we are stocking the Yan Yean with tench' (Anon 1862). Perhaps the interpretation is that only tench were liberated while the other fish, all cyprinids (Table 1), remained in ponds beside the Yarra River in the Melbourne Botanical Gardens under the direction of Dr Ferdinand Mueller. There is evidence that ornamental carp persisted in ponds in Victoria including the Melbourne Botanical Gardens (Clements 1988). In an eradication program by the Victorian Government in 1962 (Section 2.1.1 and Section 6.3.1) many large coloured carp were killed in ponds of the Botanical Gardens (Clements 1988). Carp did not colonise natural water bodies in Victoria in the 1860s, while trout and tench did. Carp were not bred at any established trout hatcheries.

There are no further recorded attempts at introduction until the 1960s (Section 2.1.1).

1.3.2 New South W ales

The first carp brought into Sydney may have been a different genetic strain or species to carp found later in New South Wales. The New South Wales Acclimatisation Society was established in November 1861. Golden carp (*Carassius auratus*) and Prussian carp (*C. carassius*), which are mentioned in their fourth and fifth Annual Reports (Anon 1865; Anon 1866), were bred in ponds at Government House in Sydney and are likely to have been goldfish and carp of European origin. The Prussian carp may also have been crucian carp (Table 1). Sir John Young, the Governor, distributed these fish to creeks and lagoons between Sydney and Botany in 1866 (Strahan 1991). The 'council [Acclimatisation Society] hoped that they would multiply very rapidly, and be an ornamental fish for water reserves, as well as a palatable article of diet' (Anon. 1866; Strahan 1991).

The Sydney Aquarium Society was formed in 1907 and imports of many introduced fish began. Stead (1929) suggested that names of imported cyprinids of Europe and Asia were often confused with South American fish. In 1907, Stead purchased fish he identified as carp, despite their incorrect label and mixture with goldfish, from a dealer in George Street. Stead sent nine small carp to large trout ponds and an inlet pond above Prospect Reservoir. In 1908 Stead also purchased from a dealer six carp which he identified as mirror or king carp (*Cyprinus carpio*) which would have had large scales (Table 1). Stead stocked these in a race between two trout ponds. In 1910, the Board of Fisheries transferred the mirror carp to be with the others in the inlet pond above Prospect Reservoir. A confusion of names began when some Fisheries Department records called them crucian carp. Stead (1929) maintained they were all *C. carpio* and some fish were taken from the inlet pond to ponds at Taronga Zoological Park, Sydney. This is the first record of carp surviving in culture in Australia. Stead suggested a correction to the name but this was not undertaken, so that the name of crucian carp persisted (Whitley 1955, 1974).

Introduced fish taxa, with self-maintaining wild populations, listed by Weatherley and Lake (1967) included crucian carp, goldfish and carp as well as roach and tench. Tilzey (1980) said that wild goldfish colonies were common and considered their wild colouration (olive-bronze) probably caused wild goldfish populations to be misidentified as crucian carp (Table 2). Records of fish in the Australian Museum in Sydney and the Victorian Museum in Melbourne indicate that such misidentifications were made in the field. In 1980 museum curators and consultants in New South Wales, South Australia, Queensland and Victoria stated that they had never seen a specimen of crucian carp from Australian waters (J. Paxton, Australian Museum, NSW; J. Glover, South Australian Museum; M. Gomon, Victorian Museum and H. Midgley, Queensland Museum, pers. comm. 1980). It is now recognised that crucian carp do not exist in Australia.

1.3.3 South Australia

No records exist of carp in South Australia before 1960. Goldfish were brought in from China and kept in ponds along the River Torrens on the edge of the Adelaide Botanical Gardens from 1887 to 1896 (Rix 1978). Some goldfish may have escaped and been introduced to reservoirs (Mitchell 1979).

1.3.4 Wester n Australia

Between 1896 and 1907 the Western Australian Acclimatisation Society introduced many species of freshwater fish including eels (Anguillidae), Atlantic salmon (*Salmo salar*), perch, tench and carp, all of which failed to establish wild populations (Lever 1992). The only fish that established into the wild was brown trout (*S. trutta*) from fry imported from hatcheries in Victoria (Le Souef 1890; Lever 1992). Since then, several other species of freshwater fish have been imported into and have established in Western Australia. These include redfin perch (*Perca fluviatilis*), rainbow trout (*Oncorhynchus mykiss*), tilapia (*Oreochromis* spp.), gambusia (*Gambusia holbrooki*), guppies (*Poecilia reticulata*), sword tails (*Xiphophorus helleri*), and carp. In terms of impacts, it is possible that gambusia and tilapia pose a greater threat to aquatic ecosystems in Western Australia than carp.

1.3.5 Tasmania

Carp are reported to have been introduced to Tasmania in the mid-nineteenth century but there is no evidence of any established populations from these introductions (Diggle and Jarvis 1998). Carp were found in several farm dams in the north-west of Tasmania in 1974 (Figure 2) and these were thought to have established from Boolara stock (Chapter 4). These fish were soon eradicated (Section 6.3.5). In 1980, carp were found in the Stowport area and again were successfully eradicated. In 1995, carp were found in two lakes in the central highlands, Lake Crescent and Lake Sorell and attempts are being made to eradicate them (Section 2.2.8).

1.3.6 Queensland

No records exist of carp in Queensland before 1960. Carp are found mostly in the south-east of the State, including in the Albert, Brisbane, Condamine, Logan and Moonie rivers (National Carp Task force Carp Database: www.sunfish.org.au/recfish/NCTF/Carpdatabase.htm)

1.4 Genetic strains of carp in Australia

Using genetic techniques, Shearer and Mulley (1978) found two strains of carp were probably present for a considerable time before carp began their great expansion of range in New South Wales in 1964 (Section 2.1). These were the Prospect strain in Sydney and the Yanco strain, probably of Koi origin, in the Yanco region of the Murrumbidgee Irrigation Area (MIA). Neither strain became widespread but remained localised to those regions after which they were named (Table 3).

Translocations or introductions of carp probably occurred within the Murray–Darling Basin in the 1940s and 1950s (Brown 1996). There is also a New South Wales Fisheries report of 1931 that the Aquarium Society of New South Wales introduced upwards of 50 000 fish, including 'gold carp' from Singapore, presumably into closed waters of New South Wales (Clements 1988). Weatherley and Lake (1967) described carp as rare in the Murray River and the upper Murrumbidgee River and in irrigation channels in the 1950s and 1960s. There are records of low catches of carp in New South Wales commercial fisheries catches from 1952. The genetic strain represented by this population was probably the Koi strain from the Yanco region as identified by Shearer and Mulley (1978). Koi are often found with wild colouration and could be confused with other strains of carp (Table 2).

'There is little genetic variation among carp in south-eastern Australia, with the Boolara strain accounting for most carp in the Murray–Darling Basin.'

By 1960, carp populations existed in Victoria from the stocking of farm dams (Wharton 1979) (Section 2.1.1). These carp, and carp reported in Lake Hawthorn and the Murray River near Mildura, north-western Victoria, were said to have come from a Boolarra fish farm in Gippsland, Victoria (Wharton 1979) (Section 2.1.1). These were later called the

Table 3: Summary of known genetic strains of *Cyprinus carpio* introductions in Australia (using McCoy 1862; Stead 1929; Weatherley and Lake 1967; Shearer and Mulley 1978; Breheny 1996 and Davis et al. 1999b).

Strains	Date of introduction to water	Locality of introduction	Current distribution
Unknown	1859–1876	Melbourne, Victoria	Not established
Prospect	1907 & 1910	Sydney, New South Wales	Restricted
Yanco (Singapore, Koi)	Possibly 1930s & 1940s	Murrumbidgee Irrigation Area, New South Wales	Restricted Now in Pooncarie and Narrandera regions in New South Wales
Boolara	1962	Gippsland and Lake Hawthorn, Victoria	Became established in Murray–Darling Basin to be a dominant species Widespread throughout most of south-eastern Australia
Koi	1976	Lake Burley Griffin, Australian Capital Territory	Uncertain; in all urban lakes but could also be in Murrumbidgee System
Koi	1990s	Lake Crescent, Tasmania	Restricted
Koi	1990s	Coastal rivers near Perth, Western Australia	Restricted

Boolara strain (Table 3) by Shearer and Mulley (1978).

Shearer and Mulley (1978) examined carp from three main areas: weirs and dams throughout the Murray–Darling Basin, the MIA and Prospect Reservoir. They recognised three distinct strains of carp based on external colouration and electrophoresis protein analysis, which they referred to as the Boolara, Yanco and Prospect strains. Of these, Yanco carp from the MIA were the most distinct genetically and it was suggested these had Asian ancestry. Because the Prospect and Boolara strains differed at one locus only, Shearer and Mulley (1978) thought they were likely to be from similar European ancestry.

Genetic strains of carp in the Murray–Darling Basin were examined by Davis et al. (1999b) using newer techniques. By this time carp populations were established and interbred. In addition to the Yanco strain, Davis et al. (1999b) identified a wild Koi strain which accounted for 100% of the population at a Koi aquaculture facility in Bringelly near Sydney, 71% of carp in Lake Burley Griffin in the Australian Capital Territory, and 95% in Lake Crescent in Tasmania. The Yanco strain remains as a minor variant and only occurs at Narrandera (21% of carp sampled) and in the Darling River at Pooncarie (15%), (Davis et al. 1999b). The Koi strain, imported directly from Asia, has not become widespread in south-eastern Australia (Davis et al. 1999b). Koi carp are now found in Western Australia and were imported in the 1990s (Breheny 1996; Table 3; Section 2.2.6).

There is little genetic variation among carp in south-eastern Australia (Davis et al. 1999b) (Table 3). The Boolara strain is now found throughout the region and accounts for all carp in sites selected by Davis et al. (1999b) in the MurrayDarling Basin except for the few sites with Yanco or Koi strains. Davis et al. (1999b) did not collect carp from Prospect Reservoir where the Prospect strain identified by Shearer and Mulley (1978) may still be present. There is some evidence that there are genetic differences between the carp in the Logan and Albert rivers in south-east Queensland and the Boolara strain common in the Murray–Darling Basin. This may suggest they originated from a separate introduction (B. Pollock, Department of Primary Industries, Queensland, pers. comm. 1999).

It is likely that the successful strain of carp in Australia, held by Boolarra Fish Farms Proprietary Limited in 1960 (Section 2.1.1), was imported from Europe although this is not documented (Brown 1996). The carp were initially thought to be derived from those translocated during the 1900s (Shearer and Mulley 1978).

2. Dispersal, distribution and abundance

Summary

The wide-scale spread of carp in Australia began after they were released into the Murray River near Mildura, Victoria, in 1964. These fish originated from carp bred at a fish farm at Boolarra, in Gippsland, Victoria. Floods accelerated the spread of carp throughout the Murray–Darling Basin, but carp were also introduced to new localities, possibly through the use of small carp as bait. Carp are present in both natural and disturbed habitats and survive throughout the Murray–Darling Basin, which has been altered extensively by European settlement. Forms of disturbance in aquatic habitats include sedimentation, cleared banks, channel alteration, and increased nutrients due to land clearing and use. The most noteworthy habitat change is river flow alteration caused by dams and weirs and diversion of water from rivers, which has impeded the spawning, recruitment and migration of native fish and created habitats in which carp survive well. The overall effect of these disturbances is a loss of physical habitat for native fish. Carp are the most abundant large freshwater fish in the inland Murray–Darling Basin.

2.1 Factors contributing to the spr ead of carp

2.1.1 Hatchery pr oduction in Victoria in 1960

A carp (*Cyprinus carpio*) aquaculture venture was initiated by Boolarra Fish Farms Proprietary Limited at Boolarra in Gippsland, Victoria in the late 1950s. Hatchery-produced carp survived in the wild in Victoria when they were stocked into a fire service reservoir in Morwell, south-eastern Victoria in 1960. In the two years following establishment of carp populations in Morwell and distribution to other areas of Victoria, carp became established in the Yallourn Storage Dam and in 1962 spread to the La Trobe River and then to Lake Wellington. Public fear of carp disturbing wetland and riverine habitats of waterfowl and fish followed news of the spread of carp. This probably resulted in the publication of results from a visit to North America by the Victorian Director of Fisheries, and the resulting *Report of the State Development Committee (1961–62)* (State Development Committee 1962) (Section 6.3.1). The Director of Fisheries had heard evidence of destruction of wetland areas and increasing muddiness of water where carp were present. This aroused concern for the future of Australian waters even though many native fish species had already declined due to other factors (Section 3.5.5). The director lobbied to prohibit introduction of exotic food fish, including carp, to Australia, because of problems encountered in North America. An inquiry was held into possible effects of carp, and after twelve months the *Report of the State Development Committee, Victoria (1961–62)* made 24 conclusions that included:

'All European Carp and its domesticated forms now or in future present in Victoria whether occurring in private waters or in waters defined under the *Fisheries Act 1958* should be destroyed.'

'There is a need for legislative action to enable the prohibition of European Carp culture in Victoria.'

'There is a need for legislative action to authorise the destruction of European Carp and its domesticated forms in Victoria.'

Carp were subsequently regarded as a pest and declared noxious. The Victorian Department of Fisheries and Wildlife undertook an eradication program to kill all carp in farm dams with poisons (Section 6.3.1).

In 1964 and 1965 carp were reported in Lake Hawthorn near Mildura. This release originated from the Boolarra farm (Pribble 1979) and gave carp access to the Murray River. Over the next five years carp were reported in the Murray–Darling system radiating from the central Mildura area. The distribution of carp in 1970 is shown in Figure 2. These were carp of Boolara strain (Section 1.4).

2.1.2 Floods and droughts

Large floods in 1974 and 1975 in the Murray–Darling Basin facilitated the rapid spread of carp throughout that river system. Records to 1976–77 show a spread of carp to the mouth of the Murray River and upstream into the Darling River (Figure 2). Numbers increased throughout the Murray–Darling River system. By 1976, the Fisheries Department was concerned that carp had become an established species in Victoria (Wharton 1979).

'Floods give carp the ability to spread rapidly through a river, including anabranches, still waters and billabongs where they can become trapped when water levels recede.'

During 1993 extensive flooding also occurred in much of the Murray–Darling Basin. Although carp were already common in the Paroo, Murray and Murrumbidgee Rivers in the northern and eastern areas of the Basin, numbers caught rose dramatically during these floods (Gehrke et al. 1995). By 1998 carp were widespread throughout the Murray–Darling Basin (Figure 2). Koehn and Nicol (1998) found carp regularly moving through rivers both upstream and downstream under normal river conditions. Floods give carp the ability to spread rapidly through a river, including anabranches, still waters and billabongs where they can become trapped when water levels recede.

In the Queensland portion of the Murray–Darling Basin, carp are present in all of the major river systems (Paroo, Warrego, Condamine–Balonne and Macintyre). Their spread in the Condamine–Balonne appears to have been slowed by the presence of numerous weirs, and their 1998 range (Figure 2) appears to be limited to weirs in the vicinity of Millmerran (D. Moffat, Queensland Department of Natural Resources, pers. comm. 1998). The spread of carp upstream in the Condamine–Balonne is expected to continue with each successive flood and resulting weir drown-out (D. Moffat, Queensland Department of Natural Resources, pers. comm. 1998).

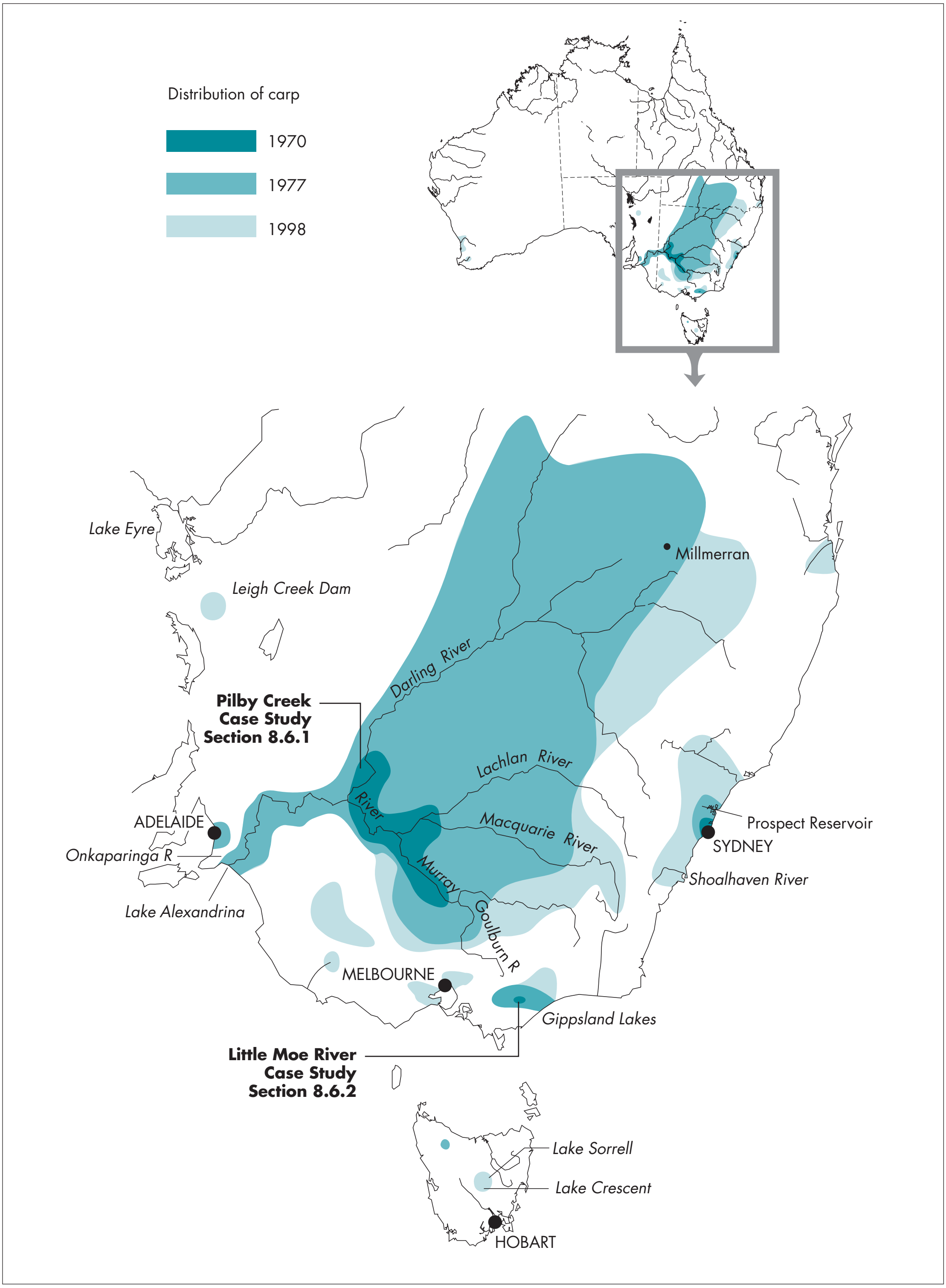
Not only were carp widespread by 1998 (Figure 2), but their relative abundance was high compared to other species. Carp and goldfish (*Carassius auratus*) were more abundant than any native fish in surveys of northern Victorian waters during 1979–83 (Brumley et al. 1987).

There appears to be little movement of carp out of wetlands back into main channels in times of drought. During drought years many carp often become trapped and die, revealing the large biomass densities and successful population growth in wet years. This first occurred in the mid 1970s and has occurred in subsequent droughts (Brown 1996; Hoy 1998; Barlow 1998a; Johnson 1998; Barlow 1998b; Wright 1998).

Drought conditions sometimes reveal the extremely high biomasses of carp that have established in some inland waterways. Source: A. Brumley, East Gippsland Institute of TAFE.

2.1.3 Deliberate introductions and use as live bait

Small carp have been regularly used as bait throughout the Murray–Darling Basin, particularly for catching larger species such as Murray cod (*Macullochella peelii peelii*). Carp now occur above the large impoundments such as Hume, Burrinjuck and many other smaller dams in New South Wales. Carp have appeared in the Wimmera River system of Victoria, in the Shoalhaven River in New South Wales and recently in Lakes Crescent and Sorell in Tasmania (Brumley 1996; Sanger and Koehn 1997). These introductions are likely to be a result of anglers using live carp for bait. Carp in Lake



Figur e 2: Distribution of all carp strains, predominantly Boolara strain (Koi in Tasmania and Western Australia) in 1970, 1977 and 1988.

Regulation of river systems by dams and weirs has had a detrimental effect on the life cycle of some native fish species but is likely to have favoured carp in some areas. Source: A. Toovey, NSW Fisheries.

Crescent have been identified as Koi carp (Section 1.4; Davis et al. 1999b) which may indicate an origin from mainland Koi. They may have been taken to Tasmanian lakes for use as bait in the trout fishery. The presence of carp in Leigh Creek Dam in the Lake Eyre drainage basin and the Onkaparinga River in South Australia (Figure 2) was attributed to either anglers or a deliberate release (Brown 1996). The number of coastal systems with carp has increased along the New South Wales coast (Figure 2) largely as a result of use of carp for bait and deliberate introductions (J. Harris, NSW Fisheries, pers. comm. 1995). It is thought that carp were first introduced into the ACT as a contaminant of releases of native fish (M. Lintermans, Environment ACT, pers. comm. 1999). Such contamination of stocks may have occurred elsewhere, and this would explain why carp now occur in many large impoundments in New South Wales. To avoid this problem, many hatcheries have installed devices and implemented quality control procedures to prevent carp and other unwanted species and disease organisms being accidentally stocked with live fish.

There is increasing concern among those responsible for managing carp that some coarse anglers might deliberately introduce carp to new areas to establish new carp fisheries. Carp have established populations in isolated locations in recent years, presumably as a result of accidental releases of small carp used for live bait, or following deliberate releases by people wanting to spread carp. Education of anglers about the potential harm caused by carp is needed to minimise these risks.

To assist in controlling the spread of carp, the use of live fish as bait is illegal in Victoria and New South Wales.

'There is increasing concern that some coarse anglers might deliberately introduce carp to new areas.'

Deliberate release of unwanted aquarium fish is often the cause of introductions of exotic fish to waters and this is the likely source of goldfish where they occur in the wild in Australia (McKay 1984; Brumley 1991). The presence of goldfish in the wild is of concern because goldfish can hybridise with Yanco and Boolara strains of carp (Shearer and Mulley 1978; Hume et al. 1983a) (Section 3.1). These hybrids are likely to be fertile.

2.1.4 Habitat disturbance

The invasion by carp has been associated with habitat disturbance caused by development and environmental exploitation of Australian waters during post-European settlement (Williams 1967; Cadwallader 1978; Lake 1980). This disturbance has favoured invasion by carp (Section 3.2) and made many habitats less suitable for native fish species. The following types of disturbance of inland waters occurred concurrently with, or preceded, the invasion of carp.

Development of water resources

Dams, weirs and large reservoirs with artificial canals were built to control water for agriculture, flood mitigation and hydroelectricity. Construction began in the 1850s and involved many large engineering feats from the 1890s to the 1950s. In rural districts, extensive networks of irrigation channels were built to distribute water to farms. By 1966, dams and weirs in irrigation and water trust schemes covered an area of 2.4 million hectares (Swan 1974). In other reaches not supplied by dams, irrigation companies pump vast quantities of water direct from the river. This development and exploitation of water resources has affected native fish by altering the frequency, duration, timing and size of low and high flow events, changing the natural seasonal flow cycle, providing cold water from low level off-takes, and producing barriers to movements and migration (Cadwallader 1977; Harris 1984; Koehn and O'Connor 1990a; Gehrke et al. 1995). Another effect of weirs is an increase in the extent of still-water habitats with macrophytes providing more spawning habitat for introduced fish, including redfin perch (*Perca fluviatilis*) and tench (*Tinca tinca*) (Cadwallader 1977) and probably carp. The salinity of the Murray River between Yarrawonga in New South Wales and Morgan in South Australia has increased at least 10-fold between 1878 and 1986 (Close 1990) because of increasing irrigation development. Carp are more resilient to salinity than many native Australian fish species (Section 3.2.2).

'Habitat disturbance has favoured invasion by carp and made many habitats less suitable for native fish species.'

Many wetlands have become more permanent because of artificial overbank flows from irrigation. These habitats not only lose their natural drying cycles but also provide permanent refuges and ideal spawning sites for carp (Fletcher et al. 1985). The variability of billabongs is diminished over time without the flooding and drying cycle, resulting in a loss of habitat diversity. Other factors may contribute to deterioration of pristine billabongs, including intrusion of cattle (Roberts 1997) and nutrient run off. The chemical nature of billabongs is variable and depends on the surrounding land. Sedimentation and subsequent turbidity can vary with the immediate soil types (King et al. 1997) and the hydrological patterns of the region (Fletcher et al. 1985). High turbidity reduces light penetration into the water, limiting growth of aquatic plants.

Wetlands drainage and catchment clearing

The Murray–Darling Basin was settled rapidly after the crossing by Hume and Hovell in 1824 and the journey of Sturt in 1829. Squatters spread along the river system with sheep and cattle and river traffic increased (Buxton 1974), and by 1850 most river frontage plots were settled. There was little attempt at resource management, with heavy stocking, land clearing and farming and forestry practices causing bank erosion, siltation and changed river productivity (Buxton 1974). Draining and levee construction around floodplain areas contributed to heavier flows within rivers and the deepening of rivers with unstable beds and incised channels.

Riparian vegetation is vital for river habitats. Koehn (1993) highlighted the value of native bankside, or riparian vegetation to provide: instream organic native fish habitat, organic matter for aquatic invertebrates, terrestrial insects for fish food, roots preventing bank erosion, buffer strips for catchment run off, and shading of the stream. Where riparian vegetation has been cleared, river banks have been scoured and collapsed, causing changes in river habitats and fish communities (Growns et al. 1998).

Sedimentation

In the 1860s, extensive land clearance was undertaken in Victoria to provide timber for mining operations and steam machinery. This resulted in erosion which carried large amounts of sediment into nearby rivers. Land clearance for agriculture continued into this century, further contributing to sedimentation in rivers. Sedimentation has also occurred from dam and road construction, unmade roads and cattle access points. Fine sediments increase the turbidity of the water, cover plants and rocky habitats and smother eggs, spawning sites, substrates and invertebrate food sources for fish (Koehn and O'Connor 1990a).

Snag and habitat removal

Where rivers have been thought of simply as distribution channels or navigable water bodies, many physical modifications such as straightening, desnagging and channel clearing were done in the name of 'river improvement'. In many rivers the removal of snags, or large woody debris, continued into the 1980s in the belief that the debris contributed to flooding and bank erosion and restricted the delivery of water downstream. Unless, however, the channel is fully blocked this practice has been discontinued. Removal of large woody debris has caused large-scale loss of habitat for fish and invertebrates and has often accelerated erosion. Snags are the main structural habitat component in lowland rivers and are used as habitat sites for refuge, territories, spawning and sources of food (invertebrates) by native fish (Koehn and O'Connor 1990a,1990b). The removal of riparian vegetation contributed to the loss of input of new material.

Timber harvesting

Campbell and Doeg (1989) demonstrated that logging operations increased the sediment and nutrient load, and altered discharge of streams in forested catchments. More light is able to penetrate streams after logging of surrounding vegetation, accelerating growth of algae or aquatic plants and changing the composition of invertebrate fauna. Natural shading prevents high water temperatures harmful to native plants and animals, and creates patchy light as habitat for predators and prey and is often lost by timber harvesting.

Pollution

Pollutants such as sewage, pesticides, industrial effluent and saline waters have been known to cause fish kills and lethal residues. Nutrients washed in from agricultural and urban areas have contributed to algal blooms and reduced water oxygen concentrations. Eutrophication is the increase in nutrients causing excessive growth of only a few tolerant taxa, for example, bluegreen algae (*Cyanobacteria*), larvae of midges (Chironomidae) and worms. Phosphorus and nitrogen availability are generally low in Australian waters, so that catchment clearing, application of fertilisers (especially superphosphate), irrigation, effluent from dairy farms, sewage and storm water with detergents have caused elevated nutrient levels in many rivers. Stock access to streams also leads to elevated nutrients, and increased bacterial and viral counts as a result of faecal contamination. Cold water pollution from low-level dam outlets often prevents spawning for many native warm water fish species (Koehn and O'Connor 1990a).

Introduction of exotic fish species

Introduced tench and redfin perch were already widespread when carp populations expanded in the Murray–Darling Basin. Brown trout (*Salmo trutta*) were also well established in upland streams above 300 metres. Redfin perch and trout (Salmonidae) competed with native fish and preyed upon some species. Native river blackfish (*Gadopsis marmoratus*) and native mountain galaxias (*Galaxias olidus*) suffered direct negative effects of predation and competition from introduced trout resulting in their decline (Jackson and Williams 1980; Fletcher 1986). There were large catches of redfin perch in the Murray River from 1919–49 which alternated with catches of native Murray River fish, hinting at competition and predation relationships.

Introduced plants

Introduced plants disturb stream habitats. Willows (*Salix* spp.), with fine spreading roots, can alter the course of the river and use excessive water. Poplars (*Populus* spp.) have shallow roots and can fall. The leaves of these species are not as suitable for aquatic invertebrates as the leaves of native vegetation. Terrestrial insects living in willows also differ from the insects that live in native trees (Campbell 1993) and the seasonality of leaf fall also differs, with willows being deciduous while native trees shed leaves throughout the year. Willow root masses trap silt, and invertebrates that occur in silt, such as chironomids and oligochates, are favoured by carp (Hume et al. 1983a). Many of these changes are detrimental to native fish whereas carp often occur in large numbers among dense stands of willows (Gehrke and Harris 1996).

Overfishing

The decline of native fish could have been affected in part by the exploitation of stocks by commercial and recreational fishing. Large numbers of Murray cod and golden perch (*Macquaria ambigua*) were harvested (Cadwallader 1977). In New South Wales native fish catches declined, after a peak in 1918, to a point in the 1930s where commercial fishing was unprofitable for large-scale operations (Rowland 1989).

Management of disturbed habitats

Catchment management aimed at addressing these problems has occurred since the 1940s but progress has been slow. It was not until the 1980s that the Victorian Government concluded that there was a problem with the State's rivers and recognised the full extent of the impact of past catchment practices (Anon 1983).

'Carp have benefited from the decline of native fish populations in an altered habitat.'

Management decisions followed the accurate environmental assessment that occurred in the 1980s in Victoria (Mitchell 1990). Current programs include the National Monitoring River Health Initiative, the New South Wales River Survey, and the New South Wales Water Reform process and Integrated Monitoring of Environmental Flows. Queensland water resources are currently subjected to assessment, accompanied by a Water Allocation Management Process, to document the attributes of aquatic habitats.

Carp have benefited from the decline of native fish populations in an altered habitat. The environmental changes that have occurred in over 200 years since European settlement cannot be reversed, although some of the effects may be reduced by implementing environmental flow regimes (Gehrke 1997b), restoring habitats and water temperatures, replanting of riparian fringing vegetation (Koehn and O'Connor 1990a) and other catchment rehabilitation programs.

2.2 Distribution and abundance

2.2.1 General distribution

In south-eastern Australia carp have become established in many rivers (Figure 2) and their associated aquatic habitats including anabranches, billabongs and backwaters. Floodplain wetlands and billabongs are important habitats in the life cycle of carp. Carp are dominant and widespread in billabongs in both dry and wet years (Walker and Hillman 1977; Fletcher et al. 1985; Gehrke et al. 1995; King et al. 1997). Juvenile carp are often extremely abundant in floodplain wetlands after inundation (Gehrke et al. 1995; Gehrke et al. 1999b).

Under natural conditions many billabongs with an assemblage of littoral vegetation and macroinvertebrates dry up and recycle nutrients from the decomposing plants. During the drying phase carp may become concentrated and can be observed in great numbers. These fish die if the wetland dries completely (Section 2.1.2). For this reason, the occurrence of carp in temporary wetlands can be highly sporadic and is strongly linked to the wetting and drying cycle (Gehrke et al. 1999b).

2.2.2 V ictoria

Rivers

In the Victorian Carp Program (1979-82), backwaters and anabranches in the Goulburn River catchment were selected as study sites for their dominance by carp (Hume et al. 1983a). Further sampling in Victoria to find native fish species in 16 tributaries of the Murray River found carp in 75% of sites, which was much more than any native species (Brumley et al. 1987). Sites that did not have carp were the lower reaches of the Wimmera River in western Victoria, upper reaches of Seven Creeks, King River and Cudgewa Creek in the north-west.

By 1998 carp were recorded in all but 7 of the 39 Victorian river basins and dominated the fish fauna in urban waters in Melbourne. Records of carp from the Otway coast river basin have not been substantiated. Carp were also reported from the Snowy River area (Malcolm 1971) but these may have been goldfish. The only catchments without carp in Victoria are now the far-eastern Snowy and east Gippsland catchments (T. Raadik, Freshwater Ecology, Department of Natural Resources and Environment, Victoria, pers. comm. 1998) (Figure 2). The far south-west of Victoria may also not have carp but there has been a recent unconfirmed report of carp near the Rocklands reservoir (T. Raadik, Freshwater Ecology, Department of Natural Resources and Environment, Victoria, pers. comm. 1998). Further spread to the upper Glenelg River catchment would be of concern.

Impoundments and artificial lakes

The majority of lakes are constructed impoundments. Myers (1981) classified 407 Victorian inland waterbodies ranging from less than 1000 megalitres capacity, to four dams of 1–5 million megalitres capacity (Dartmouth, Eildon, Hume and Thompson).

None of the larger still water bodies in Victoria are natural. Carp occur in most of these modified lakes and waterbodies (Brumley et al. 1987; T. Raadik Freshwater Ecology, Department of Natural Resources and Environment, Victoria, pers. comm. 1998; Gehrke et al. 1999b). The only lakes with carp are the Gippsland lakes and many deflation basins with intermittent river connections.

Carp are also comon in farm dams and irrigation channels in Victoria, but there are no estimates of their overall abundance in these waterbodies.

High Elevations

Carp can survive in high elevations where they occur in lakes and impoundments. However carp may be restricted to lower elevations within natural tributaries.

In a study of the distribution of all fish in the Seven Creeks system of the Goulburn Catchment in central Victoria, carp were only found at lower elevations (Cadwallader 1979), but this finding may be attributable to the barriers imposed by series of rocky waterfalls.

Estaurine systems and coastal lakes

Carp released into the La Trobe River, Gippsland, Victoria, soon spread downstream to Lake Wellington and the Gippsland lakes. These lakes were once freshwater but have increased in salinity since an artificial ocean opening was made in 1890s. Carp persist in salinities of at least 10–18 parts per thousand but move up the rivers into fresher water at higher salinities (A. Brumley, East Gippsland Institute of TAFE, Victoria, unpublished data, 1998).

2.2.3 New South W ales

Rivers

In New South Wales, carp occur throughout the slopes and lowland tributaries of the Murray–Darling system at elevations of below 700 metres (Gehrke et al. 1995; Harris and Gehrke 1997). In coastal rivers, carp have been recorded from rivers near major centres of human populations in the Shoalhaven, Hawkesbury–Nepean and Hunter catchments (Harris and Gehrke 1997).

Impoundments and artificial lakes

Some dams, such as the Menindee Lakes and Lake Victoria in New South Wales, were natural lakes that have now been modified by the water industries. These lakes contain carp.

Some water storages contain large populations of carp. In December 1997, a cyanobacterial bloom in Wingecarribee Reservoir in New South Wales was treated with copper sulphate. This caused a large fish kill including an estimated 15 000 carp weighing approximately 26 tonnes which were removed from the water. No estimates are available of the number of carp left in the lake (P. Gehrke, NSW Fisheries, unpublished data, 1998).

Carp are also common in farm dams and irrigation channels in New South Wales, but there are no estimates of their overall abundance in these waterbodies.

High Elevations

In a survey of New South Wales rivers, carp were rare at altitudes greater than 500 metres above sea level and were not recorded higher than 600 metres above sea level (Driver et al. 1997) (Section 3.2.1).

2.2.4 South Australia

Rivers

In South Australia, carp occur in the Murray River down to the barrages at the river mouth. There are also reports of carp in other rivers and streams, mostly in the south-east of the State, including in the Finniss, Gawler, Light, Marne, Torrens and Wakefield Rivers (National Carp Task Force, Carp Database: www.sunfish.org.au/recfish/NCTF/Carpdatabase.htm).

Estaurine systems and coastal lakes

Carp occur in Lake Alexandrina in South Australia behind the artificial barrages (Figure 2). When the barrages, built in 1930 to eliminate the brackish estuarine water, are open, allowing freshwater to flow into the Coorong lakes system, carp also move out with the freshwater but die if they move into more saline water (H. Jones, Southern Fishermen's Association, Meningie, South Australia, pers. comm. 1998).

2.2.5 Queensland

Rivers

In Queensland there have been reports of carp upstream of weirs at Millmerran in the Condamine–Balonne catchment but the fish are believed to be goldfish. Recent intensive sampling in the upper Condamine near Warwick has not recorded a single carp (D. Moffat, Queensland Department of Natural Resources, pers. comm. 1998). The cyprinid reported in past surveys of Queensland coastal streams is more likely to have been goldfish (R. Mackay, Queensland Museum, pers. comm. 1994). Carp have recently been reported in the Albert River catchment in south-east Queensland, where their numbers and distribution have steadily increased during the 1990s (M. Kennard, Griffith University, Queensland, unpublished data, 1999) (Figure 2).

The spread of carp in the Severn River, the main tributary of the Macintyre River in Queensland, appears to be restricted by a natural barrier of a large intermittent waterfall downstream of Stanthorpe (D. Moffat, Queensland Department of Natural Resources, pers. comm. 1998). Carp are not in the headwaters of the Warrego River in Queensland but this is probably an effect of intermittent water availability.

2.2.6 W ester n Australia

Rivers

Carp were said to occur in Western Australia in 1947 and 1957 in swamps and the main stream of the Swan River (Breheny 1996). Carp were reported to have spread widely (Twyford 1991), but many of the earlier reports throughout south-western Western Australia are likely to have been goldfish (Brumley 1991; Breheny 1996). Previous reports of crucian carp are likely to have been goldfish (Breheny 1996).

Breheny (1996) reported self-maintaining populations of Koi carp in the Blackwood River, but suggested that those in the Swan–Avon, Canning, Harvey, Murray and Wesley Rivers did not appear to be self-maintaining. The distribution of cyprinids now covers most of the south-west corner of the State, from Geraldton to Albany (Twyford 1991; Breheny 1996).

Fisheries WA is compiling a database on carp sightings. There are confirmed populations of carp in Yenchep National Park (Moore-River catchment) that have been established for at least 40 years and there are significant Koi carp populations in and around Rockingham and Mandurah. Carp appear to have self-maintaining populations in most of the freshwater streams which flow into the Swan River and associated wetlands. There are also populations of carp, including Koi carp, in water bodies in the south-west including the Blackwood River, Margaret River and nearby private dams.

Impoundments and artificial lakes

Many artificial lakes built in subdivisions for drainage purposes contain carp (for example, Alexander Heights, Emu Lake and others) which may have been introduced deliberately by developers and local residents.

Estaurine systems and coastal lakes

Koi carp are likely to have been stocked in the lakes along the coastal strip from the Swan River to the Murray River in Western Australia. A report of release of Koi carp by McKay (1977) was into an artificial pond created by road construction near the Swan River in 1971. This pond drained into the Swan River. Carp are now found in many freshwater bodies in south-west Western Australia.

2.2.7 Australian Capital T erritory

Rivers

In the Australian Capital Territory, carp are present in the Molonglo, Paddys, Cotter, Queanbeyan and Murrumbidgee Rivers. Carp are absent from the Cotter River upstream of Cotter Dam, which was constructed prior to the establishment of carp in the Australian Capital Territory (M. Lintermans, Environment ACT, pers. comm. 1998).

Impoundments and artificial lakes

In the Australian Capital Territory, carp occur in all three urban lakes. The status of carp in these urban lakes has been regularly monitored since the mid 1970s. Carp regularly contribute more than 80% by number of the catch, although numbers appear to have declined slightly in the 1990s (M. Lintermans, Environment ACT, pers. comm. 1998).

2.2.8 T asmania

Lakes

Carp were first found in Tasmania in 1974 (Figure 2) but were presumed to be eradicated after poisoning (Sections 1.3.5 and 6.3.5). However, carp were confirmed in Lake Crescent in the Great Lakes district of the highlands (Fulton and Sanger 1995; Diggle and Jarvis 1998). Further surveys confirmed the presence of carp in the adjoining Lake Sorell (Brumley 1996). Although naturally formed in the Great Plains, these lakes form part of a hydroelectricity scheme and are connected to other water bodies. The lakes are popular for trout fishing. Carp do not appear to have spread to surrounding waters but containment is likely to be difficult in the future (Section 6.3.5).

3. Biology and ecology

Summary

Carp are the largest member of the Family Cyprinidae in Australia and are often confused with goldfish. Interbreeding between carp and goldfish produces hybrid individuals which resemble both species. Carp typically have flexible habitat requirements and live in low-altitude rivers or standing waters in mid-latitude regions. They have broad environmental tolerances and thrive in habitats that have been disturbed by human activities, such as alteration of river flows, removal of instream habitat, reduced water quality, nutrient enrichment and removal of streamside vegetation.

Carp feed by filtering small particles from the water or by sieving food items from sediments. They have no teeth in their jaws to cut or hold food items, but have small, molar-like pharyngeal teeth in their throat to chew and crush food. In Australia, carp larvae feed on small zooplankton. As carp grow, they gradually take larger crustaceans and aquatic insects along with some plant material.

Female carp mature at between 2–4 years of age and may produce more than one million eggs each year. Eggs are normally shed on fibrous plant material in spring to early summer. Females may spawn several times in one season. Juvenile carp frequent both shallow floodplain habitats and river channels, and mortality may exceed 98% in the first year of life. Young carp are more abundant in habitats where the density of adult fish is relatively low. Growth rates of carp vary greatly between regions, depending on temperature, food supply and population density.

Survival of carp appears to be density-dependent. This means that when carp numbers are high, although large numbers of eggs and juveniles are produced, only a small number survive. The implication of this for reducing carp populations is that when the size of a population is reduced, survival rates of eggs and juveniles increase, and the populations rapidly recover.

Carp carry a number of disease organisms. Some of these now occur in Australia, such as the Asian fish tapeworm, and have potential to pose risks to native fish species. Others, such as the virus causing Spring Viraemia of Carp Disease, cause high mortality in Europe but do not currently occur in Australia.

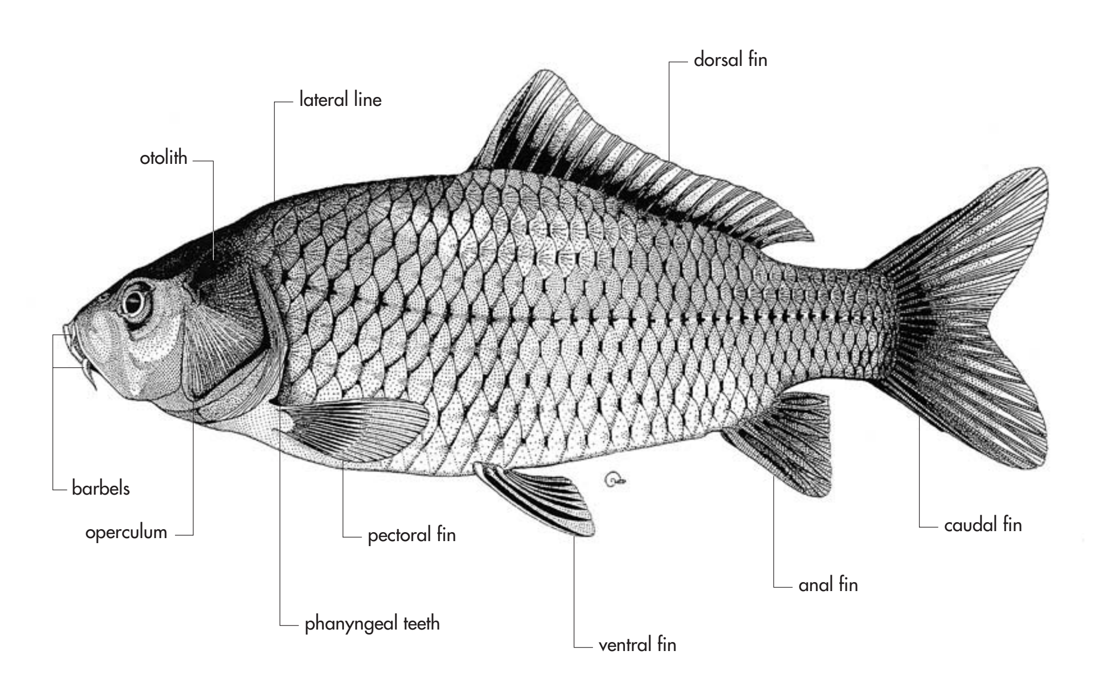
In Australia, carp migrate throughout the year, with some marked individuals recorded as moving over 200 kilometres in a few months. Large numbers of carp have been recorded moving upstream during low flow periods accompanied by rising water temperatures during spring and summer.

Carp are not normally predators of other fish, but small carp may be an important part of the diet of larger predators. Competition for food and space between carp and native species is poorly understood. By growing quickly to a large size and feeding at low levels of the food chain, carp may act as an energy trap, preventing transfer of energy to populations of other large fish.

Before carp began to spread in the late 1960s and early 1970s, aquatic environments in Australia were subject to numerous disturbances that contributed to the decline of native fish species. As populations of native fish have continued to decline, carp have become well-established, mostly in disturbed habitats, to the point where carp are now the dominant species in many fish communities in south-eastern Australia.

3.1 General description

Carp (*Cyprinus carpio*) belong to the Order Cypriniformes, which are characterised by having a protractile upper jaw, a mouth (jaws and palate) without teeth, no scales on the head, and usually lacking an adipose fin (Helfman et al. 1997). The Family Cyprinidae, to which carp belong, is further characterised by having from one to three rows of pharyngeal teeth, with never more than eight teeth in



Figur e 3: Key features of carp anatomy (sketch by Craig Mills)

any row. In addition to these features, carp have an elongated body with a slightly raised back. They possess a single dorsal fin with a stout, strongly serrated spine. Carp and their relatives lack the true spines of higher teleosts. The spines of carp are actually hardened bony structures modified from the first ray of the dorsal and anal fins. The dorsal fin originates anterior to the insertion of the abdominal pelvic fins, and consists of 3–4 spines and 15–24 soft rays. The anal fin is small with three spines and five soft rays. The pectoral fin consists of one spine and 15–16 soft rays. The scales are large and cycloid with 33–40 scales along the lateral line. The tail is deeply forked. Carp also possess two pairs of fleshy whiskers, or barbels, at either corner of the mouth, with the posterior pair being the largest (Figure 3). Carp posses three rows of pharyngeal teeth on the lower elements of the last gill arch on each side. The two outer rows contain only a single tooth, while the inner row has three teeth (Figure 4), giving a pharyngeal tooth formula of 1,1,3:3,1,1. This characteristic formula is important for distinguishing between carp and other cyprinids (Table 4).

Table 4: Length:width ratio of the large pharyngeal teeth in carp (*Cyprinus carpio*), goldfish (*Carassius auratus*) and hybrids (Pullan and Smith 1987). Reproduced with the permission of SIR Publishing.

Character	Carp	Hybrid	Goldfish
1st tooth	1.8	2.5	4.2
2nd tooth	1.5	2.8	5.0
3rd tooth	0.9	2.1	2.8
4th tooth	-	0.9	1.1

Some variation occurs in the degree of scale development. In the Murray–Darling basin, about five percent of individuals are not completely covered with scales. These fish have a smaller number of large, silvery scales along the mid-line or scattered elsewhere on the body, and are called ‘mirror carp’ (*Cyprinus carpio*) because of the reflective properties of these scales. Another form known as ‘leather carp’ (*C. carpio*) lack scales entirely, although this variant is particularly rare in Australia.

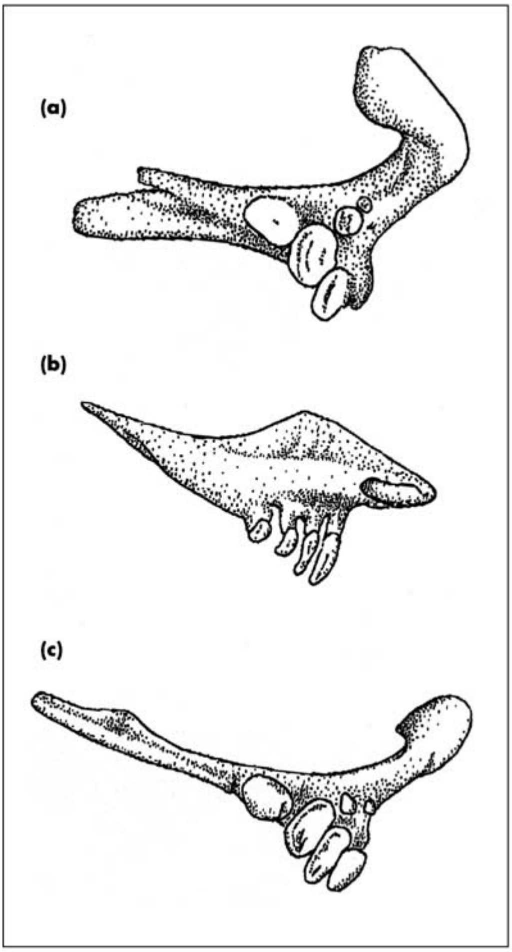


Figure 4: Pharyngeal teeth of: (a) carp (*Cyprinus carpio*); (b) goldfish (*Carassius auratus*) and (c) hybrid (Pullan and Smith 1987). Reproduced with the permission of SIR Publishing.

'Carp can grow to large sizes, with reports of fish as large as 60 kilograms.'

The colour of carp is variable, and may be bronze or olive-gold dorsally, softening to pale yellow or whitish on the flanks and ventrally. Some individuals may have a relatively uniform, bright gold coloration. Koi carp are a selectively bred ornamental carp variant, originally from Japan. The domesticated forms of Koi carp have a broader range of colours and body-forms than the wild forms. The impacts and ecology of Koi in the wild are the same as other strains of carp.

Carp can grow to large sizes, with reports of fish as long as 1200 millimetres and weighing 60 kilograms (Brumley 1996). Fish up to 10 kilograms are relatively common in south-eastern Australia, but fish from 50 grams to 5 kilograms are more common.

'Carp are occasionally confused with goldfish which have reverted to their natural colouration of olive-bronze.'

In the wild, carp are occasionally confused with goldfish (*Carassius auratus*) which have reverted to their natural colouration of olive-bronze. Wild goldfish are often incorrectly called crucian carp (*Carassius carassius*). Goldfish are generally smaller, deep-bodied and plumpish in comparison to carp. Goldfish have 26–34 lateral line scales and a pharyngeal tooth formula of 0,4:4,0 (Table 4). The two species can be easily distinguished because goldfish lack barbels and their dorsal fin originates posterior to the insertion of the abdominal pelvic fin. The tail of goldfish is not as strongly forked as in carp.

Carp and goldfish occasionally interbreed, producing hybrid individuals which possess varying combinations of features of both species. Hybrids have reduced barbels or may lack barbels completely and have 29–35 lateral line scales. The pharyngeal tooth formula in hybrids can be either 1,4:4,1 or 2,4:4,2. Table 2 lists the diagnostic characters of carp and other cyprinids in Australia.

3.2 Habitats

Knowledge of the habitats in which carp occur, and conversely, those in which they do not occur, is important for developing strategies for managing the impacts of carp. Strategies may include rehabilitation of degraded environments to make habitats less suitable for carp and more suitable for native species. In habitats where carp do not yet occur, strategies to prevent carp invasion may be a high priority.

Evidence in Victoria that carp are not universally associated with degraded habitats: (a) Tambo River with carp, (Source: Keith Bell, K&C Fisheries), and (b) Wannon River without carp, (Source: Department of Natural Resources and Environment, Victoria).

3.2.1 Typical carp habitats

Carp are ecological generalists that live in a wide range of habitats in Australia and overseas. They typically inhabit mid-latitude, low-altitude, slow-flowing rivers as far downstream as tidal freshwaters and even enter estuaries. They also live in standing waters ranging from small billabongs and ephemeral wetlands to large lakes and reservoirs. In New South Wales, carp are rare at altitudes above 500 metres (Driver et al. 1997). They are less common in clear, cool swift-flowing streams. Carp are particularly tolerant to poor water quality, and can survive in low oxygen concentrations, turbid water and moderate salinities, and they have higher tolerances to toxicants than many other species. Carp are well adapted to feeding from the bottom, taking mouthfuls of sediment into their mouth and expelling inedible particles. This mode of feeding requires fine sediments and is not possible in habitats where the bottom consists of larger gravel or cobbles. Carp spawn in shallow vegetated habitats, such as flooded grasses around the fringe of billabongs, lakes and floodplains (Section 3.4.2).

'Regulation and diversion of river flows has allowed carp to establish in relatively stable environments.'

Koehn and Nicol (1998) found carp occupy a range of habitats, including woody debris and habitats preferred by native species. In rivers carp select slower water velocities close to the bank, and are also often found in still billabongs and backwaters. Juvenile carp often occur in large numbers in inundated floodplain habitats and ephemeral creeks following high flow events (Gehrke et al. 1999b).

Characteristics of disturbed habitats that favour opportunistic exotic species

Habitats that are moderately disturbed by natural events often have the highest species diversity because environmental variation prevents any one species from dominating other species (Connell 1978). Increased disturbance as a result of human activity is therefore likely to cause local extinction of more sensitive species. Reduced disturbance provides an opportunity for species that prefer stable conditions to become dominant in the new environmental regime. This concept, introduced by Connell (1978) as the intermediate disturbance hypothesis, provides some explanation as to why introduced species tend to become established in disturbed environments. In this way, both increased or decreased disturbance may allow exotic species to become established (Ross 1991). Regulation and diversion of river flows reduces the natural disturbance regime in riverine habitats and has allowed carp to establish populations in modified and relatively stable environments.

Types of habitat disturbances that are conducive to carp and other opportunistic introduced species have been recently summarised by Driver et al. (1997) and Harris (1997). In coastal rivers of New South Wales, carp were only found in lowland rivers where flows were regulated, and which are associated with large human populations. The broad environmental tolerances of carp suggest that the species may be less affected than other species by disturbances resulting from human activities. Disturbances may occur both within the aquatic system, as well as within the catchment. Studies in Australia and overseas have found that carp become more dominant in fish communities after disturbances to river flow, interference with stream connectivity, pollution and disturbance to habitat structure (Whitley 1974; Sparks and Starret 1975; Hoyt and Robinson 1980; Winston et al. 1991; Gehrke et al. 1995; Driver et al. 1997; Harris 1997).

In the Murray–Darling River system, flow regulation to provide water for irrigation and hydro-electricity has reduced the variability of many inland rivers, allowing carp to take advantage of a more stable environment (Gehrke 1997b). Gehrke et al. (1995) found that fish species diversity decreased directly with increasing disturbance of the natural flow regime. A main factor in this reduced diversity was an increasing dominance of carp. Gehrke et al. (1999b) also found that carp recruitment was greatest in rivers with altered flow.

In coastal rivers, such as the Hawkesbury–Nepean system near Sydney, multiple disturbances such as flow regulation for urban water supply, nutrient enrichment and removal of vegetation, have created highly disturbed sites where introduced species such as carp and gambusia (*Gambusia holbrooki*) are abundant (Growns et al. 1998; Gehrke et al. 1999a).

Hall (1981) noted that growth of the carp population in Lake Alexandrina in south-eastern South Australia was typical of introduced animals in a disturbed environment. The lake was formed at the mouth of the Murray in 1940 when barrages closed the mouth, changing the natural estuary into a freshwater habitat. Extensive macrophyte growth in the shallow, non-flowing freshwater environment probably did not suit the native fish adapted to either the river or the estuary, but allowed carp to flourish.

Catchment modifications such as clearing vegetation, nutrient enrichment, disturbing fine sediments and changes in stream morphology, all associated with agricultural and urban development, have contributed to the decline in native species distribution and abundance and an increase in carp abundance (Cadwallader 1978; Growns et al. 1998; Faragher and Harris 1994; Rinne 1990; Metzeling et al. 1995; Brierly et al. 1996).

3.2.2 Environmental tolerances

The ability of carp to survive periods of poor water quality gives the species a competitive advantage over many native fish species in Australia. Broad environmental tolerances also help explain the success of carp in Australia in regions where there is a high incidence of habitat disturbance (Harris 1997; Harris and Silveria 1999).

Temperature

Carp can adapt to water temperatures as low as 4°C and as high as 35°C. In Tasmania, carp have been recorded at water temperatures as low as 2°C, although these temperatures only persisted for two weeks (J. Diggle, Tasmanian Inland Fisheries Commission, pers. comm. 1999). Studies in Europe suggested an upper lethal temperature as high as 40.6°C for carp (Horoszewicz 1973). The actual temperature given as the lethal limit varies depending on the method used. Few native Australian fish are able to tolerate water above 35°C for any length of time. Carp have a greater tolerance of low dissolved oxygen conditions than many Australian species, surviving levels of oxygen availability as low as 7% saturation at 5°C (Ott et al. 1980). At higher temperatures oxygen requirements increase, so that survival near the upper thermal limit requires close to 100% oxygen saturation. However, the ability to survive in poorly oxygenated water is not determined solely by oxygen tolerances. Carp and some native species are able to respire from the thin surface film of water which contains more oxygen than water below the surface (Kramer and McClure 1982; D. McNeil, La Trobe University, unpublished data, 1999). Carp are often seen apparently gulping at the water surface. Many fish species have developed adaptations such as modified gills, swimbladders, and intestines for breathing air, but such adaptations have not been demonstrated for carp.

'The ability of carp to survive periods of poor water quality gives the species a competitive advantage over many native fish species in Australia.'

Salinity

In southern France, carp survive in a salt lagoon delta ecosystem where salinity is about 14% (parts per thousand) (Crivelli 1981), but their growth rates are poor and they return to freshwater to spawn. A similar tolerance of carp to 14% salinity is noted from the Caspian and Aral Seas (Banarescu and Coad 1991). Juvenile carp up to 40 millimetres long have been found at sea in the discharge plume of the Fraser River in Canada, at a maximum salinity of 13.9% (the salinity of seawater is 35%) (Barraclough and

Robinson 1971), suggesting that carp are capable of moving between adjacent rivers via the sea during floods.

In Australia, carp moved into the Gippsland Lakes system despite increasing salinity of the water (Section 2.2.2). Carp can be found in the Gippsland Lakes when salinity is in the range of 10–18% but move upstream into fresher water at higher salinities (A. Brumley, East Gippsland Institute of TAFE, unpublished data, 1998). The death of carp in the Gippsland lakes in 1998 in salinities of 16–18%, suggests that carp in Australia have similar salt tolerances to carp elsewhere in the world, and are capable at least of spreading between nearby rivers during floods.

Australian carp from the Murray River, South Australia, survived in salinities of 12.5% after a direct transfer and 50% of carp survived at salinities of 15% after acclimation (Geddes 1979).

pH

The recorded lower pH limit for carp in Europe is below 5.0, which is higher than for other European and North American species (Hellawell 1986), but their upper pH lethal limit is higher than most other species, at above 10.5.

Chemical pollutants

Carp tend to be more tolerant than other fish species in the northern hemisphere to chemicals such as chlorine, selenium, the herbicide 2,4-D, the organochlorine insecticide endrin, and synthetic pyrethroids (Hellawell 1986). Interestingly, carp appear to be slightly more sensitive to copper and toxaphene than some other species (Hellawell 1986).

3.3 Feeding behaviour and diet

An understanding of some of the impacts of carp in Australia and their ecological interactions with other species is provided by the types of food eaten by carp and the ways they capture and process their food. Carp feeding behaviour and diet may also provide opportunities to develop control methods that are highly selective for carp.

3.3.1 Food capture methods and food processing

Sarig (1966) suggested that the mouth structure of carp limits their ability to catch food straight from the water but many studies show that zooplankton (small crustaceans) are common in carp diets (Section 3.3.2). Carp mostly feed by either selecting or filtering small food particles from the water or ingesting sediments from the substratum and filtering out food items. In both methods food is sucked into the mouth along with water and sediments. At the entrance to the pharynx or throat, gill rakers form a meshed structure that can sieve out larger items from the ingested water and sediments, which are expelled through the opercular openings behind the gills. This behaviour can noticeably stir up fine sediments and increase turbidity (Section 5.3.3).

'Carp feeding behaviour and diet may provide opportunities to develop control methods that are selective for carp.'

Items down to 0.5 millimetre can be retained in the pharyngeal sieve formed by the gill rakers while smaller particles are expelled (Sibbing 1982). Because carp lack strong biting teeth to cut large food items into smaller ingestible pieces, the upper size of their food is limited by the relatively small size of their pharynx. Large inedible items are expelled through the mouth. The pharyngeal teeth of carp are flattened, molar-like structures that can process food items with a range of chewing and crushing motions, but they are not highly specialised to handle particular food types (Sibbing 1991). These teeth enable carp to eat small molluscs and insects and some plant material but give very limited ability to hold and swallow active, struggling prey such as small fish. In contrast, pharyngeal teeth of other fish can be highly evolved for either holding struggling fish, crushing molluscs, slicing flesh, chewing crustaceans, cutting plant material or sorting small food particles (Hyatt 1979). Carp do not have a true stomach to store swallowed food. Instead, they have a long intestine which enables them to digest food items that require long digestion times.

3.3.2 Diet

Carp are omnivores, eating any small food items that are plentiful. Their diet therefore varies between locations and from season to season, depending on food availability (Lammens and Hoogenboezem 1991). In overseas studies, benthic insects are consistently important dietary items both in wild and cultured carp (USA: Sigler 1958; USSR: Guziur and Weilgosz 1975; Israel: Kugler and Chen 1968; Zur and Sarig 1980; Indonesia: Vaas and Vaas Van Oven 1959). Carp were reported to have a preference for chironomid larvae (small worm-like larvae of midges) in lakes and ponds (Sigler 1958) and aquaria (Zur and Sarig 1980). Small carp are known to eat microcrustaceans (Matlak and Matlak 1976; Zur and Sarig 1980). Adult carp in marshlands in southern France fed on benthic insects and swimming insects (beetles), microcrustaceans, detritus and seeds (Crivelli 1981). Seeds contain carbohydrates and carp feeding on seeds may be preferentially seeking carbohydrate-rich high-energy food.

In Australia, Vilizzi (1998) found the diet of young carp in backwaters of the lower Murray River contain small crustaceans (cladocerans, copepods, ostracods, decapods), aquatic insect larvae (chironomids, corixids) and seeds. Older juveniles also had large quantities of sand in their guts, indicating that they had begun feeding from the bottom. Hume et al. (1983a) found carp of all sizes in billabongs, lakes and rivers in Victoria fed on a variety of small invertebrates. Copepods and cladocerans were dominant in the diets of small carp, while benthic insects, especially chironomids, dominated the diets of mid-sized carp (150–400 millimetres). Swimming insects such as corixids (water boatman), some molluscs (snails) and terrestrial insects were also eaten, reflecting the availability of all these food types in carp habitats at the time of sampling. Microcrustaceans, for example, were common in the water and diet in spring and summer. Molluscs were only eaten when they were available in large numbers. Aquarium experiments indicate that chironomids are a preferred food item. Hume et al. (1983a) found that carp in aquaria preferred to feed on chironomids, and only ate plant material such as pieces of plant tissue, seeds and filamentous green algae in the absence of chironomids.

'Carp in Australia eat much the same range of food items as carp in other countries.'

In Lake Alexandrina in South Australia, Hall (1981) found zooplankton formed a large proportion of the diet of small carp. The gap between gill rakers was proportional to the length of carp, so that large carp had relatively large gaps between gill rakers, preventing all but the largest zooplankton from being filtered out. Plankton samples revealed many taxa of microcrustaceans were present in the midwater. Cladocerans *Daphnia* spp. was a common food item in most sizes of carp, and was apparently selected when in short supply. In this study corixids were absent in the diet even when abundant in the water, whereas large amounts of detritus occurred in gut contents (Hall 1981). This suggests that the carp were feeding in midwater and from the bottom, but not swimming after fast-moving insects.

These studies show that carp in Australia eat much the same range of food items as carp in other countries, and that the range of prey species available in Australia has not caused any substantial change of diet.

3.4 Population dynamics

Many methods proposed for the control of carp populations and their impacts focus on reducing carp numbers. These methods share a common assumption that removing carp will cause a sufficient reduction in carp populations to reduce their impacts. However, if the number of carp removed is trivial compared to increases in carp populations through recruitment and immigration, then a great deal of effort can be expended for little or no reduction in impacts. Knowledge of the factors that influence the size and growth rates of carp populations is essential to guide decisions on managing carp impacts and to assessing the effectiveness of control strategies.

3.4.1 Population dynamics of fresh-water fish in lakes and rivers

A number of fundamental differences exist between fish populations in lakes and rivers. Rivers are generally considered to be open systems through which fish can migrate over many hundreds of kilometres. For this reason, fish populations at any location in a river are usually open to both immigration and emigration. The number of fish in the population, and their size and age distribution at any one time, is likely to be determined by recruitment rates (locally spawned fish), mortality rates, immigration and emigration rates.

In contrast to rivers, many lakes contain populations that are effectively closed. This means that the lakes are connected to nearby rivers or other lakes so seldom that immigration and emigration are effectively zero. Population parameters in these populations are more directly determined by recruitment and mortality rates and the influence of local environmental conditions. This makes the study and management of closed fish populations in lakes simpler than for open populations in rivers.

3.4.2 Reproduction

Male carp in New South Wales were found to mature at 2–3 years of age, while females mature at 3–4 years of age (Brown 1996). In Victoria, carp were found to reach maturity earlier, at one year for males and two years for females (Brumley 1996). In both States, age at maturity probably varies between habitats. The number of eggs produced by female fish varies considerable according to the size, age and condition of individual fish. Female carp produce from 80 000 eggs for fish of 1.25 kilograms, to 1 500 000 eggs for fish of six kilograms (Hume et al. 1983a). Even though most fish with external fertilisation achieve close to 100% fertilisation of the eggs, mortality of eggs and larvae is commonly high and may be density-dependent, making the number of eggs shed by a spawning population an unreliable indicator of the number of young fish surviving to enter the population.

Carp spawning behaviour in other countries is summarised in Breder and Rosen (1966), Scott and Crossman (1973), and Panek (1987). After migration to suitable spawning habitats, spawning usually occurs in late spring or early summer, in water depths ranging from so shallow that the fish can barely swim, to over one metre deep. Preferred spawning habitats usually have abundant plant material. Several males may pursue a single female, nudging her to apparently induce her to release eggs. During the pursuit, spawning fish may thrash around violently in the shallows, stirring up sediments as the backs and tails of the fish break the water surface. Eggs are 0.5 millimetre in diameter and become adhesive on contact with water. They are shed over aquatic vegetation, with eggs that do not stick to vegetation falling into the sediments. Males shed milt over the eggs as they are released. Development occurs rapidly, with eggs hatching in two days at 25°C and six days at 18°C. Although very large females may contain up to seven million eggs, not all the eggs are deposited at once, so that each female may produce several batches of eggs during one spawning season.

'Preferred spawning habitats usually have abundant plant material.'

In the Murrumbidgee Irrigation Area (MIA) near Griffith, New South Wales, Adamek (1998) observed aggregations of mature carp at the entrance to lateral irrigation drains at the end of September and in early October. Carp migrated into these drains during small rises in water level. In contrast to reports from other countries, spawning carp formed pairs swimming upstream. The male positioned his caudal peduncle over the female's and both eggs and sperm were released onto the grass substratum. In pond experiments, carp spawned on a variety of substrates, including: the aquatic plant *Myriopyllum papillosum* (common watermilfoil), live and dead grass and other terrestrial plants, river red gum (*Eucaplytus camaldulensis*) branches, and artificial plant substrata such as raffia mats, but did not spawn on muddy surfaces.

Adamek (1998) found carp eggs from one spawning amongst flooded grasses in Barren Box Swamp, but not on any other natural substratum. In Victoria, Hume et al. (1983a) also found carp spawning on fibrous material, with habitats containing grasses and *Juncus* spp. having the greatest number of eggs.

Spawning in Australia has been reported to occur from September to December, although the actual spawning period may be shorter in specific locations. Spawning in the MIA in 1997 was observed only from October to early November, when water temperatures were 19°C–29°C. In the Murrumbidgee River at Narrandera, carp spawned in late September 1993, with larvae collected in early October and juveniles only in November (P. Gehrke, NSW Fisheries, unpublished data, 1993). In contrast, the spawning period lasted from September to December in Victoria when water temperatures were 17°C–25°C (Hume et al. 1983a). Adamek (1998) suggested that warmer water temperatures may have caused the short spawning season in 1997.

'Spawning in Australia has been reported to occur from September to December.'

Although minimum water temperatures are often recorded as criteria for fish spawning, they are not an absolute requirement. For example, carp were observed to have spawned in the Murray River by 10 October in 1996 when water temperatures were still around 15°C (J. Koehn, Freshwater Ecology, Department of Natural Resources and Environment, Victoria, unpublished data, 1998). Carp larvae have normally been collected in the Broken and Campaspe rivers in north-eastern Victoria from October until December (P. Humphries, Cooperative Research Centre for Freshwater Ecology, NSW, pers. comm. 1999) and in the Ovens River during September at water temperatures of 13°C – 14°C (A. King, Cooperative Research Centre for Freshwater Ecology, ACT, pers. comm. 1999). Larval and early juvenile carp have been collected from the lower Murray River in October (Vilizzi 1998) and from the Paroo and Murrumbidgee Rivers and the Millewa Forest system in New South Wales between October and December (P. Gehrke, NSW Fisheries, unpublished data, 1992–95), indicating that spawning occurred before these times. Reports from the northern hemisphere suggest that the spawning season for carp may last as long as seven months (Crivelli 1981). During prolonged spawning seasons with warm temperatures above 20°C, carp in other countries may spawn several times, but subsequent spawning may be prevented by the onset of cooler temperatures. It has been suggested that water temperatures above 25°C after fertilisation may reduce hatching success and increase the incidence of deformities in newly-hatched carp larvae (Penaz et al. 1983) However, water temperatures above 25°C are common in much of the distribution of carp and sensitivity of eggs to temperatures above 25°C has not been confirmed for Australian populations.

'Fertility control techniques require an understanding of the timing, length and pattern of reproduction.'

An important aspect of carp spawning from the perspective of future control options using fertility control techniques (Section 7.3.8) is the timing, length and pattern of reproduction. Different approaches to fertility control might be needed for populations with individual females that do not shed all their eggs at once but spawn several times in one season, compared to populations with females that shed all their eggs at once but have different females shedding their eggs at different times. This aspect of carp reproduction in Australia is not well understood.

3.4.3 Recruitment

Recruitment occurs when the survivors from the period of high juvenile mortality become part of the adult population. Because juvenile mortality is usually high, recruitment is a far more reliable indicator of potential population growth than egg production.

Nursery habitats occur in either temporary or permanent waters which offer food and shelter for fish larvae and juveniles, and maximise their chances of survival. Large numbers of juvenile carp were found in ephemeral floodplain habitats in New South Wales (Gehrke et al. 1999b), although the proportion of juveniles in lake, river, creek and floodplain habitats varied greatly between river systems. In the semi-arid Paroo River system, juvenile carp were most abundant in a shallow, inundated floodplain habitat. In the Darling River around Menindee, the floodplain was not inundated, but juvenile carp were extremely abundant in an ephemeral creek. Riverine habitats consistently contained the fewest juvenile carp. Juvenile carp were also uncommon in the main channel habitats of the Hawkesbury–Nepean River system in coastal New South Wales (Gehrke and Harris 1996), supporting the notion that riverine habitats constitute poor nursery areas. However, larval and juvenile carp have been collected in the main channels of the Campaspe and Broken rivers over several years, indicating that recruitment can occur in river channels without floodplain inundation (P. Humphries, Cooperative Research Centre for Freshwater Ecology, NSW, pers. comm. 1999). Length–frequency distributions of carp in New South Wales (Harris and Gehrke 1997) suggest the existence of extensive recruitment zones for carp in lowland regions, with sites on higher altitude slopes offering little suitable habitat for carp recruitment.

Thus while carp can spawn and successfully recruit in the absence of floods, they are opportunistic and move into shallow floodplain habitats that contain relatively large amounts of submerged vegetation for spawning surfaces. These habitats also offer food and shelter for juveniles when suitable flows or floods occur. The increased availability of suitable habitats for spawning and recruitment during floods means that recruitment success is often much greater in years with large floods. Conversely, there is some evidence that carp do not spawn in dry years, which would prevent recruitment at these times (Hume et al. 1983a; J. Diggle, Tasmanian Inland Fisheries Commission, unpublished data, 1998). After floods, when zooplankton proliferate, carp abundance is likely to increase (Hume et al. 1983b; Gehrke et al. 1999b).

Fish recruitment is often related to the size of the spawning stock, in the form of a stock-recruitment curve (Figure 5), which describes the number of recruits in relation to the number of spawning fish in the population. Stock-recruitment relationships for

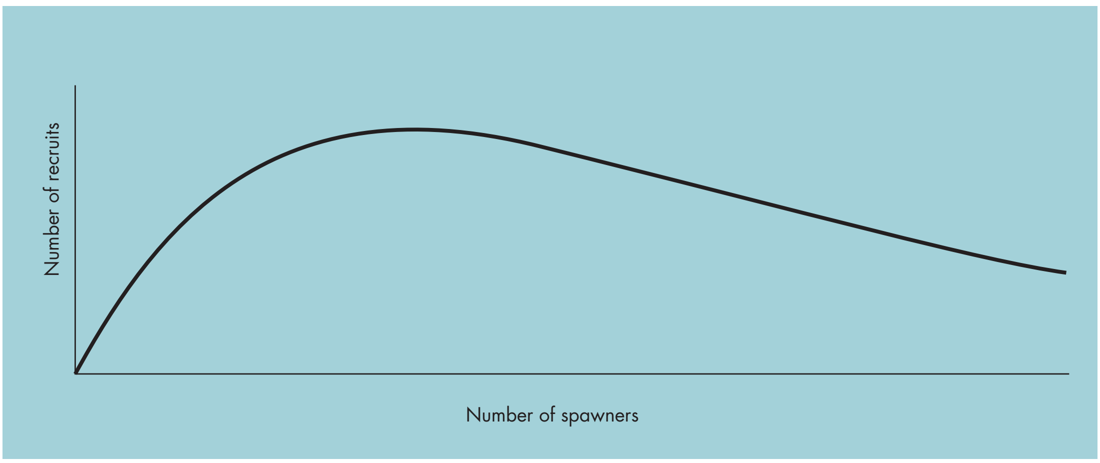


Figure 5: Theoretical stock-recruitment relationship for fish populations. At low population densities, small increases in the number of spawning females may result in large increases in recruitment. At high population densities, further increases in the number of spawners may lead to reduced recruitment. Conversely, at high population densities, a reduction in the number of spawning fish may actually allow increased recruitment to reduce or nullify the advantages of population reduction.

other fish species sometimes show a rapid increase in the number of recruits as the number of mature fish in the population increases. As the spawning population grows, the number of young fish that survive may level off, or even decline after reaching a maximum. Density-dependent factors may strongly influence juvenile survival, so that higher fish population densities do not necessarily produce more recruits, and the number of young fish surviving may actually decline. The implication of this for reducing carp populations is that the size of the reproducing population will need to be substantially reduced to have any marked effect on recruitment to the population. In a population simulation analysis, Thresher (1997) suggested that carp harvesting in the Murray–Darling system would need to reduce the population of carp to an unknown point somewhere below 10% of the pre-fished biomass to create a relatively stable, low population density for carp (Section 7.3.6). At such a low density, carp populations would be in the relatively flat part of the logistic population growth curve, so that only a small number of carp would need to be removed annually to prevent population growth. Stock-recruitment relationships may provide valuable information on the reproductive status of a population. However, actual data points around the curve may vary greatly as a result of density-dependent factors and environmental variations, so that the underlying stock-recruitment relationship may not be apparent in data collected from real populations.

'Increased availability of suitable habitats for spawning and recruitment during floods means that recruitment success is often much greater in years with large floods.'

Figure 6 shows a form of stock-recruitment relationship for carp in New South Wales rivers, using data from Harris and Gehrke (1997). Stock-recruitment relationships are usually fitted to data obtained over many years, but in this case, the relationship was fitted to carp populations at different sites

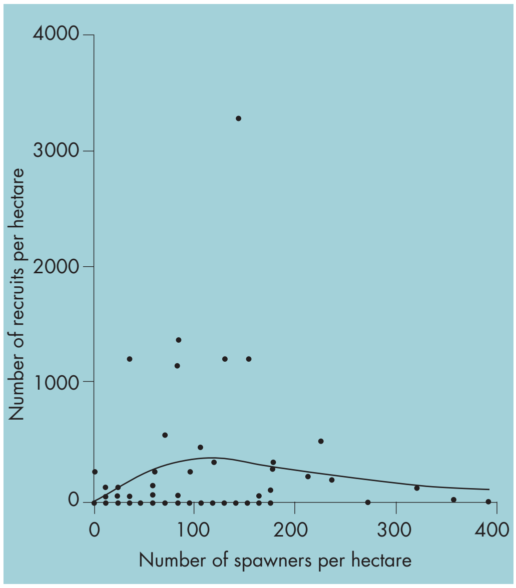


Figure 6: Relationship between carp recruitment and spawner abundance in New South Wales, based on data from Harris and Gehrke (1997). Each point represents one river site. Populations with high carp densities have relatively low recruitment, but recruitment to populations with intermediate densities varies greatly, from very low to maximum values.

because years of data were not available. For this analysis, all fish less than 155 millimetres, the average length of a one-year-old carp in the lower Murray (Vilizzi and Walker 1999), were considered to be recruits because the sampling methods used did not catch larvae and small juveniles. Similarly, all fish larger than the average length of a two-year-old fish were assumed to be sexually mature, and were considered part of the spawning population. The figure shows large variations from the fitted line, indicating both variable reproductive output and variable survival to recruitment, depending on environmental conditions. This relationship is also affected by unknown rates of immigration and emigration from each site. It suggests that sites with relatively large numbers of adult carp contain relatively few recruits, whilst maximum recruitment occurs in sites in the low to intermediate range of spawner abundance. However, sites with small to intermediate populations can also have very low recruitment, presumably depending on environmental conditions.

This example suggests that the density of mature carp needs to be reduced to below approximately 100 fish per hectare before further reduction can be expected to result in reduced recruitment under average conditions. Even then, however, high recruitment may still occur with numbers of mature carp as low as 35 fish per hectare. Therefore, reducing the size of the spawning carp population may not result in a noticeable reduction in carp recruitment unless the population can be reduced to a very small size. Similarly, reducing the number of carp that produce eggs, or reducing the number of eggs produced by fertile individuals by using some form of contraception (Section 7.3.8), might not result in reduced recruitment unless very high levels of infertility could be achieved.

'The ability to modify aquatic environments creates opportunities to significantly reduce carp recruitment, which may provide more effective population control than removing adult carp.'

Because the impact of environmental conditions on carp spawning and larval survival is so large, the ability to modify aquatic environments, for example, by altering flow, inundation or temperature regimes, creates opportunities to significantly reduce carp recruitment, which may provide more effective population control than removing adult carp.

Age and growth

The age of many species of fish can be estimated from banding patterns on scales, bones and otoliths (ear bones). Alternating periods of slow and rapid growth associated with seasonal conditions may produce bands on these hard structures that correspond to annual growth patterns. Carp in Australia have proven difficult to age accurately using scales (Hume et al. 1983a). Modern techniques based on otoliths tend to be much more reliable than earlier methods using scales. Vilizzi et al. (1998) and Vilizzi and Walker (1999) have recently developed procedures to estimate the age of carp from otoliths and opercular bones (Figure 7).

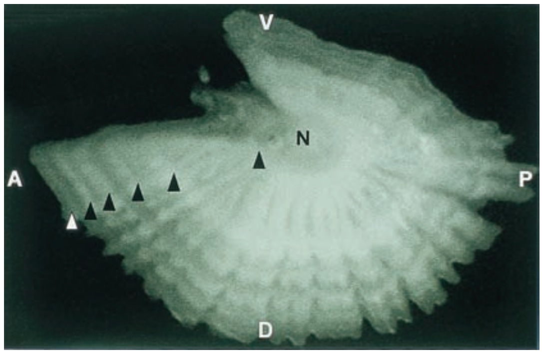


Figure 7: Otolith from a carp showing six annual growth bands (arrow heads). N nucleus, V ventral, D dorsal, A anterior, P posterior (photograph taken by L. Vilizzi).

'Growth rates of carp can be highly variable, depending on water temperature, food availability and fish density.'

Carp have been reported to live for more than 15–17 years (Sarig 1966), growing to a size of 18–26 kilograms. Anecdotal evidence suggests that ages of up to 60 years or more may be attained in Europe. The largest carp measured from the lower Murray River by Vilizzi and Walker (1999) was a female that weighed 6.88 kilograms which was only seven years old. The oldest fish in their study of 603 carp was a 15 year-old female that weighed 5.54 kilograms. Recently, a carp from the Murray River was estimated to be 23 years old based on otolith bands (P. Brown, Marine and Freshwater Resources Institute, Victoria, pers. comm. 1999).

Like other fish species, growth rates of carp can be highly variable, depending on water temperature, food availability and fish density. Carp in isolated water bodies, such as billabongs, may stop growing altogether as food resources become depleted. Growth may recommence rapidly when flooding stimulates food production (Hume et al. 1983a). Figure 8 indicates sizes that can be attained and the degree of variation in growth rates in different regions. Carp in Lake Crescent, Tasmania, appear to grow more rapidly for the first two years than

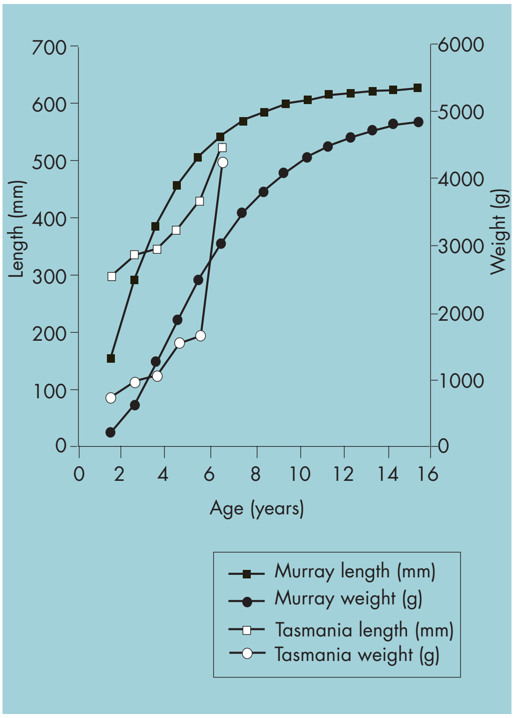


Figure 8: Average length (fork length) and weight of carp at different ages in southern Australia. Values for the lower Murray River from Vilizzi and Walker 1999. Values for Tasmania from Vilizzi and Walker 1998. Regional differences in fish sizes at a given age can be dramatic.

those in the lower Murray River, but by three years of age, fish from the Murray are larger (Vilizzi and Walker 1998, 1999). The cold temperatures in Lake Crescent would normally be expected to cause slower growth than in the Murray River. However, the low carp density and good food supply in Lake Crescent may have allowed faster growth. More recent data from Lake Crescent suggest that carp of all ages are now growing at similar or slightly slower rates to carp in the Murray River (J. Diggle, Tasmanian Inland Fisheries Commission, unpublished data, 1999). Carp of a given age in other locations may differ markedly from these estimates. For any given age, females tend to be slightly larger on average than males (Figure 9), although there is a large amount of variation both within and between sexes (Vilizzi and Walker 1999).

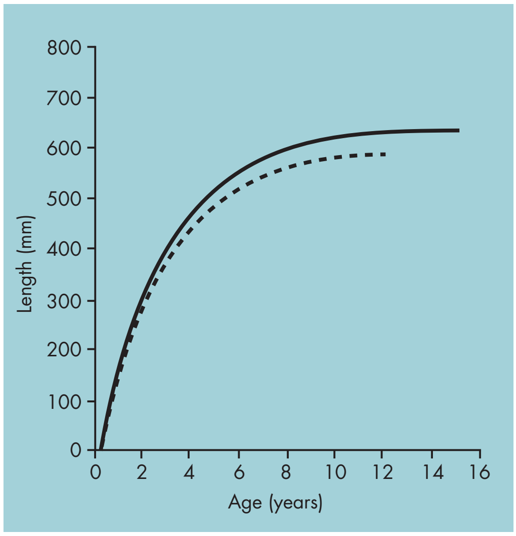


Figure 9: Predicted lengths (fork lengths) for female (solid) and male (dashed) carp at different ages from the lower Murray River (Vilizzi and Walker 1999).

3.4.4 Mortality — predators, fishing, diseases and parasites

Survival of carp in the Murray–Darling system appears to be strongly density-dependent so that even though large numbers of juveniles are produced, limited resources such as food, and high predation mean that only small numbers survive (Section 3.4.3).

Gehrke et al. (1999b) found large numbers of juvenile carp in four rivers of the Murray–Darling River system in New South Wales but relatively few older individuals (Figure 10). Using estimates of length for carp of different ages in the lower Murray River (Vilizzi and Walker 1999), mortality in successive year classes can be estimated. Estimates of mortality require making a number of assumptions about: (1) the number of fish originally produced in each age group (it is assumed that recruitment is constant from year to year), (2) the ability to sample all ages representatively, (3) emigration and immigration rates, and (4) growth rates for fish from different areas. All four of these assumptions require validation by further study. Because of these necessary qualifications, estimates given here provide only a possible indication of the rate of carp mortality in the Murray–Darling Basin, and more accurate figures are required.

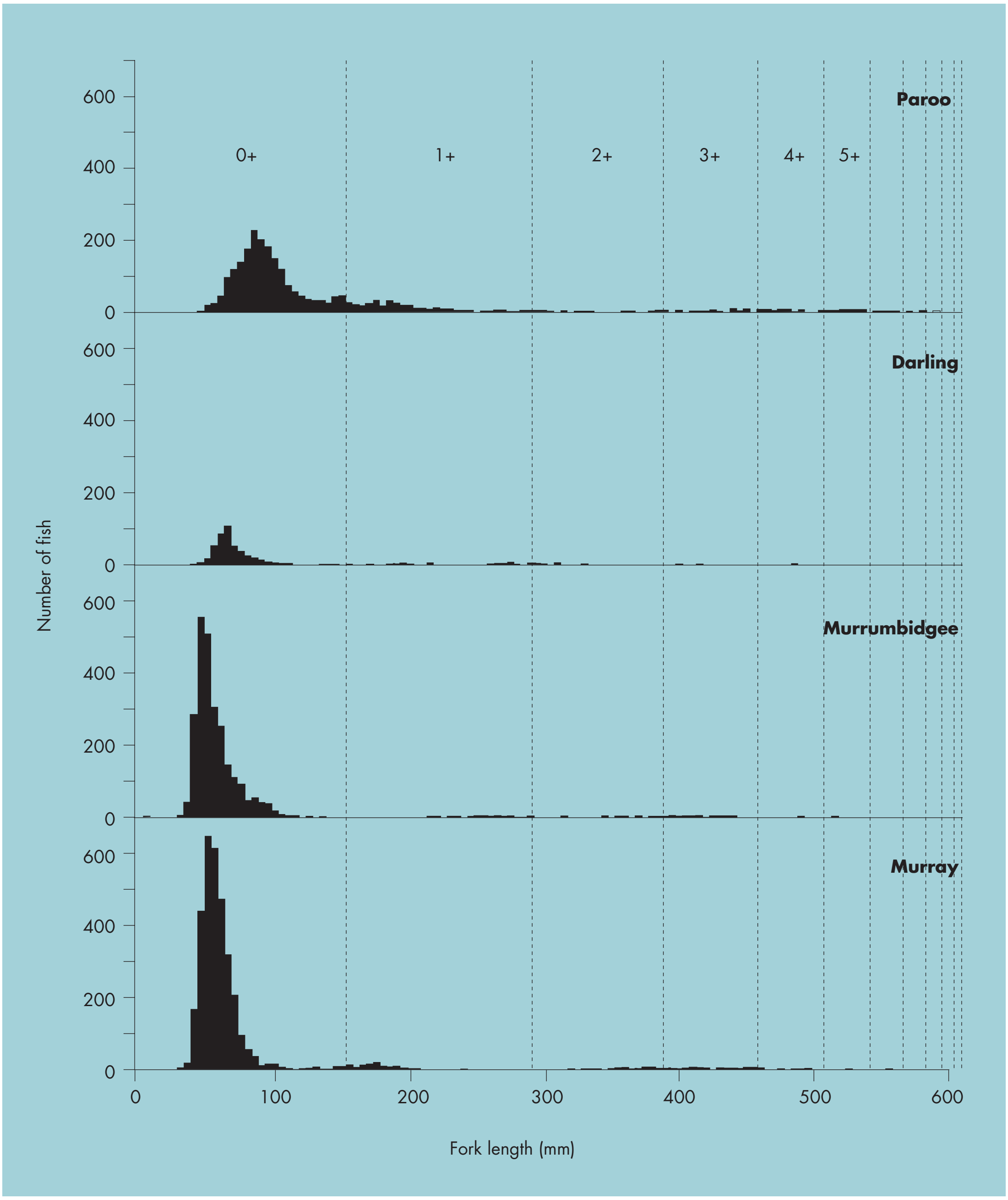


Figure 10: During a survey of habitats around the Paroo, Darling, Murrumbidgee and Murray Rivers from 1992 to 1995, juvenile carp up to one-year-old were abundant, but as a result of high mortality, older age classes were present in relatively low numbers (data from Gehrke et al. 1999b).

Of the four rivers considered, carp in the Paroo River had the lowest estimated mortality in the first year, at 83%, with values of 88% in the Darling, 96% in the Murray, and 98% in the Murrumbidgee Rivers. True mortality in the first year is almost certainly much higher than these figures suggest because the data include very few larvae and juvenile carp too small to be caught. However, these estimates illustrate the point that very few carp actually survive the first year. In the second year, mortality rates were generally lower, at 60%, 44%

and 60% for the Darling, Murrumbidgee and Murray Rivers, with only the Paroo River recording high mortality at 88%. After the first year, the average mortality rate, across all four rivers, was 52%. Environmental variability, such as droughts, floods, temperature fluctuations and extreme events such as algal blooms can dramatically alter fish mortality. For this reason, actual mortality may vary widely above and below estimated rates.

'Mortality of carp as a result of predation by native fish and birds may be a fruitful area for research into carp control.'

Juvenile carp are at the highest risk of predation by fish such as Murray cod (*Maccullochella peelii peelii*), golden perch (*Macquaria ambigua*) and redfin perch (*Perca fluviatilis*), and fish-eating birds such as cormorants (Pelecanidae) and pelicans (*Pelicanus conspicillatus*), but they grow rapidly (Vilizzi and Walker 1999) to a size where they have few predators. The abundance of piscivorous fish is now generally low (Harris and Gehrke 1997) so that the numbers of juvenile carp eaten by other fish may also be low relative to the size of the carp population. In contrast, large flocks of cormorants and pelicans are commonly seen feeding on carp in floodplain wetlands and below dams and weirs, where they may potentially cause high mortality. Mortality of carp as a result of predation by native fish and birds may be a fruitful area for research into carp control (Section 3.5.2).

In contrast to natural mortality, which is highest in larval and juvenile fish, mortality from human fishing targets adult fish. Because commercial fishing is restricted to certain waters and because markets for carp are underdeveloped, fishing mortality is low compared to the total population of adult carp. In areas where carp fishing is expanding, annual fishing mortality will increase, but there are no estimates available of the anticipated mortality as a proportion of the total population. As most carp caught by anglers are not returned to the water, mortality is undoubtably high, but the contribution of angling mortality to total mortality is unknown.

Carp are known to be susceptible to a range of diseases (Section 5.3.7, Table 5). In Europe, the Spring Viraemia of Carp Virus (SVCV) (*Rhabdovirus carpio)* has been identified as causing Spring Viraemia of Carp Disease, which occurs on carp farms in spring and early summer (Crane and Eaton 1997). The disease has not been recorded in wild carp populations. Mortality from the disease ranges from 5% to 100% of exposed fish, but is more commonly between 20% and 40% (Crane and Eaton 1997). SVCV has not been detected in Australia, but because carp have been brought to Australia from Europe as well as from other locations, it is possible that SVCV already exists in Australian waters (Crane and Eaton 1997). The virus is not specific to carp and can infect a wide range of species. The susceptibility of Australian native species has not been tested extensively. In Europe, Spring Viraemia of Carp outbreaks are most severe in years with long cool spring seasons where the water temperature stays between 10°C and 15°C and this environmental stress reduces the immunity of fish. Therefore, environmental conditions in mainland Australia, particularly the absence of severe winters and the long hot summers are unlikely to be conducive to outbreaks of the disease. The occurrence of clinical disease is a result of interactions between the host, pathogen and environmental factors. For this reason, occurrence of disease in natural systems can be very variable and the presence of a disease organism does not necessarily result in a disease outbreak.

Recently, a condition called Spring Carp Mortality Syndrome has been reported from England and Wales (P. Bolton, Environment Agency United Kingdom, pers. comm. 1999). This condition causes high mortality of wild carp in spring and summer, but the cause has not been identified and appears to be distinct from Spring Viraemia of Carp Disease.

A number of parasites and disease organisms identified in carp are listed in Table 5. Those currently known to occur also in native fish and which pose a risk to native species include: the fungus *Saprolegnia*; the protozoans *Myxobolus*, *Trichodina, Ichthyobodo, Cheilodonella, Ichthyophthirius* and *Apiosoma*; the monogeneans *Dactylogyrus* and *Gyrodactylus*; the cestode *Bothriocephalus*; and the copepod *Lernaea*. Other known parasites of carp may already occur in Australia but have yet to be identified.

Table 5: Disease and parasite organisms isolated from carp worldwide, effects of clinical disease, and known susceptibility of Australian native fish.

Group	Pathogen	Disease (common name)	Effects	Recorded in carp in Australia	Native species known to be susceptible	Reference
Viruses	*Rhabdovirus carpio*	Spring Viraemia of Carp Disease	Heavy mortality of juvenile carp	No	None	Crane and Eaton 1997
Bacteria	*Aeromonas salmonicida*	Goldfish ulcer disease	Visible red ulcers on body	Yes	Silver perch	Langdon 1989; Humphrey and Ashburner 1993; Daly et al. 1994
	Edwardsiella tarda	Emphysematous putrefaction	Small lesions progressing to abscesses and gas-filled swellings in muscles	No	None	Austin and Austin 1987; Fujiki et al. 1994
Fungi	*Branchiomyces sanguini*	Gill rot	Fungal hyphae invade and destroy gill epithelium, obstruct blood flow	No	None	Reichenbach-Klinke 1973
	Saprolegnia	Cottonwool fungus	Secondary infection following other stress	Yes	Bony herring, Murray cod	Reichenbach-Klinke 1973; Langdon 1989
Protozoa	*Cryptobia cyprini*	Weakness disease	Pathogenic blood parasite	No	None	Reichenbach-Klinke 1973
	Sphaerospora cyprini	Kidney disease	Kidney damage	No	None	Reichenbach-Klinke 1973
	Myxobolus muelleri	Tissue parasite	Cysts in carp skin	No	Similar species recorded in golden perch	Johnson and Bancroft 1918; Reichenbach-Klinke 1973
	Myxosoma dujadini, *Myxosoma encephalica*	Closely related to organism causing whirling disease	Cysts in gills, cerebral blood vessels	No	Similar species recorded in golden perch and Murray cod	Johnson and Bancroft 1918; Reichenbach-Klinke 1973; Ashburner 1978

Group	Pathogen	Disease (common name)	Effects	Recorded in carp in Australia	Native species known to be susceptible	Reference
Protozoa	*Eimeria cyprini, Eimeria subepithelialis*	Enteritis	Intestinal parasite, emaciation especially of young carp in pond hatcheries	No	Similar species recorded in golden perch and silver perch	Reichenbach-Klinke 1973; Molnar and Rhode 1988; Langdon 1989
	Trichodinella sp., *Trichodina domerguei*	Trichodiniasis	Ectoparasitic damage to gill epithelium	Yes	Trichodina spp recorded from Murray cod, trout cod, golden perch, silver perch, Macquarie perch, river blackfish, bony herring and western carp gudgeon	Reichenbach-Klinke 1973; Langdon 1989; Rowland and Ingram 1991
	Ichthyobodo necator		Skin haemorrhage leading to fungal infection	Not recorded but probably occurs	Murray cod, trout cod, golden perch, silver perch, Macquarie perch, river blackfish, bony herring	Reichenbach-Klinke 1973; Langdon 1989; Rowland and Ingram 1991
	Cheilodonella cyprini, Cheilodonella hexastichus	Cheilodonelliasis	Ectoparasitic damage to gill epithelium	Yes	Murray cod, golden perch, Macquarie perch, silver perch, Australian smelt, river blackfish and bony herring	Reichenbach-Klinke 1973; Ashburner and Ehl 1973; Langdon 1989; Rowland and Ingram 1991
	Ichthyophthirius multifilis	Whitespot	Ectoparasitic damage to gill epithelium	Yes	Murray cod, golden perch, Macquarie perch, silver perch, Australian smelt, river blackfish and bony herring	Reichenbach-Klinke 1973; Langdon 1989; Rowland and Ingram 1991

Group	Pathogen	Pathogen common name	Effects	Recorded in carp in Australia	Native species known to be susceptible	Reference
Protozoa	*Apiosoma piscicola*		Infection on body surface	No	Similar species found on western carp gudgeons	Reichenbach-Klinke 1973; Rowland and Ingram 1991
Monogenea	*Dactylogyrus anchoratus*, *Dactylogyrus vastator*, *Gyrodactylus* sp.	External gill parasite	Epithelial thickening of gills	No	Similar species recorded from golden perch and silver perch	Reichenbach-Klinke 1973; Rowland and Ingram 1991
Digenea	*Sanguinicola inermis*	Blood fluke	Obstruct blood vessels	No	No	Reichenbach-Klinke 1973; Richards et al. 1994
	Allocreadium isosporum, *Allocreadium carporum*	Gut flukes	Loss of nourishment	No	No	Reichenbach-Klinke 1973
	Neodiplostomum perlatum		Encysted larvae in skin and other organs	No		Reichenbach-Klinke 1973
Cestodes	*Caryophyllaeus laticeps*	Carnation-head tapeworm		No	No	Reichenbach-Klinke 1973
	Bothriocephalus acheilognathi	Asian fish tapeworm		Yes	Western carp gudgeon, Midgley's carp gudgeon, Lake's carp gudgeon, Flathead gudgeon, Australian smelt	Hoole and Nissan 1994; Dove et al. 1997.
Crustaceans	*Lernaea cyprinacea*	Anchor worm	Ectoparasite on gills, skin and fins	Yes	Murray cod, trout cod, golden perch, Macquarie perch, silver perch, river blackfish	Reichenbach-Klinke 1973; Ashburner 1978; Langdon 1989; Rowland and Ingram 1991

3.4.5 Migration

radiotracking by Koehn and Nicol (1998) showed carp are a mobile species. Large movements occurred both upstream and downstream, with individuals moving up to 230 kilometres between Yarrawonga and Barmah on the Murray River in only a few months. These movements occur throughout the year apparently independent of water temperatures as low as 8°C. Carp moved in and out of billabongs, anabranches and slower flowing or still waters. Unlike native species, they often became trapped in off-river habitats after water levels receded.

'Carp migration correlated with rising water temperature rather than increased flow.'

The scale of these movements mean that carp are capable of spreading quickly throughout river systems. This suggestion is reinforced by the disappearance of 350 tagged carp released into two small billabong anabranches connected to the Murray River. No recaptures were obtained over the next two years despite extensive fish surveys in the area (J. Koehn, Freshwater Ecology, Department of Natural Resources and Environment, unpublished data, 1998). Reynolds (1983) found that tagged carp in the lower Murray River showed no directed migratory behaviour, but moved either upstream or downstream for distances up to 80 kilometres, with most fish moving less than 10 kilometres from the point at which they were tagged. The fact that the lower Murray is heavily locked which impedes carp movements, and that the environment is more akin to a pond with low flows, and perhaps lacks a movement trigger, may have influenced carp movements (J. Roberts, CSIRO Land and Water, ACT, pers. comm. 1999). During Reynolds' study, native golden perch and silver perch (*Bidyanus bidyanus*) travelled hundreds of kilometres with some golden perch recaptured in Queensland after the 1974 floods.

Mallen-Cooper et al. (1995) recorded 16 000 carp passing upstream through the Torrumbarry fishway on the Murray River between February 1991 and July 1992, refuting Reynolds' opinion (1983) that carp were non-migratory. Mallen-Cooper et al. (1995) found that carp migration correlated with rising water temperature rather than increased flow. Carp continued to migrate when flows remained low and stable, similar to the flows created below irrigation storages. This suggests that regulation of river flows may favour carp over native species, whose movements appeared to be stimulated by increases in water levels (Mallen-Cooper et al. 1995).

Mallen-Cooper et al. (1995) recorded the highest numbers of carp moving during the lowest flows. High numbers of carp were recorded when rising temperatures reached 20°C. Carp continued to move when temperatures began to fall from the maximum of 25°C but there appeared to be a sudden decline in movement when temperatures decreased below 24°C. Koehn and Nicol (1998) also found that carp movements occurred over a wide range of temperatures. Carp appeared to prefer to move during the morning, or to a lesser extent the afternoon, rather than at dawn, dusk or during the night (Mallen-Cooper et al. 1995).

Juvenile carp move into shallow inundated floodplain habitats during high flow events in the Paroo, Darling, Murrumbidgee and Murray Rivers (Gehrke et al. 1999b). These lateral migrations provide small fish with direct access to rich supplies of planktonic food in floodplain habitats, as well as providing a refuge from stronger flows and predators in main-channel habitats.

3.5 Ecological interactions

No species can move into a new habitat without having some impact on the system. These impacts may be relatively minor, or they may lead to total removal of one or more original species and dramatically change the ecosystem balance. Carp in Australia now have roles as predators, prey, competitors and habitat modifiers that affect other species and ecological processes.

3.5.1 Carp as predators

In Australia, carp are often accused of damaging populations of native fish species by feeding on their eggs and larvae. However, the evidence available and the feeding morphology of carp (Sibbing 1988) suggest that fish are a negligible component of carp diets (Sections 3.3.1 and 3.3.2). Carp have relatively small, underslung mouths adapted for sucking in small food items from the bottom. In contrast, most fish that prey on other fish have large mouths, either without teeth to enable them to swallow large prey whole, or with teeth to grasp or bite chunks out of their prey. The size and shape of the pharyngeal teeth of carp make it difficult for them to grasp and handle large, struggling prey such as fish. However, large adult carp have been recorded with small fish in their guts on rare occasions (Hume et al. 1983a). Large carp have also been recorded herding schools of Australian smelt (*Retropinna semoni*) in the Murray River near Yarrawonga and apparently feeding on the smaller fish. Subsequent inspection found Australian smelt in the gut-contents of each of 12 carp examined (Garry Thorncraft, NSW Fisheries, unpublished data, 1998).

'Carp may consume large numbers of fish eggs.'

Scientists in several countries have hypothesised that carp populations have a negative feedback loop to suppress recruitment by preying on their own eggs or larvae. When adults are removed, predation on eggs and larvae is reduced, resulting in strong recruitment which rapidly replaces the removed fish. There are, however, other density-dependent processes capable of producing reduced recruitment at sites with high densities of adult carp without invoking adult predation on eggs and larvae (Section 3.4.3).

Carp are efficient grazers of zooplankton and biofilms attached to hard surfaces and may potentially consume large numbers of attached fish eggs. As juveniles, carp feed largely on zooplankton. As they grow beyond 150 millimetres, they progress to other forms of macroinvertebrates, while still retaining zooplankton as an important part of their diet (Hume et al. 1983a). Where carp occur in large numbers, it is possible they may reduce the standing stock of zooplankton to such a degree that the remaining zooplankton can no longer suppress algal growth by grazing, contributing to algal blooms (Gehrke and Harris 1994). Prey types found in the diet of carp are discussed in detail in Section 3.3.2.

3.5.2 Carp as prey

One of the few perceived benefits of carp in present-day aquatic ecosystems in Australia is their role as prey for piscivorous fish, such as Murray cod, golden perch and redfin perch, and piscivorous birds such as pelicans and cormorants. As populations of many small native species have declined (Harris and Gehrke 1997), their reduced availability as prey may have had an impact on predator populations. The increased abundance of carp juveniles may have compensated to some degree for the loss of native prey species. There is, however, no evidence that predator populations have improved as a result of the food supply presented by large numbers of small carp. It is more likely that the progressive decline in numbers of native piscivores has reduced predation pressure on carp, and assisted the expansion of carp populations. Large carp, too big to be consumed by fish and bird predators, are commonly the only dead fish found around the edge of receding waters (Brown 1996).

'The decline of native piscivores may have assisted the expansion of carp.'

In water storages where carp occur in large numbers, potential exists for predatory native fish to be stocked to limit carp recruitment by increasing predation. Australian bass (*Macquaria novemaculeata*) fingerlings were released into Fitzroy Falls Reservoir, near the town of Robertson in New South Wales, in an attempt to control carp and to improve angling opportunities. It is likely to take 1–2 years before the young bass are large enough to eat juvenile carp. This reservoir also contains rainbow trout

(*Oncorhynchus mykiss*), which may also eat small carp, but bass were stocked at the request of local anglers who thought that trout (Salmonidae) were not thriving in this habitat. Fish make up only a small proportion of the diet of bass (Harris 1985), and if trout appear ineffective at controlling carp numbers, then it is questionable whether stocked bass will provide any control of carp by predation. Stocking golden perch and Murray cod to control carp in Lake Burley Griffin and Lake Ginnindera in the Australian Capital Territory has had no obvious effect on thriving carp populations (Lintermans and Rutzou 1990, 1992).

While there is scope for stocking predators to control carp in impoundments, food chain manipulations have a chequered and controversial history (Sections 3.5.4 and 7.3.6) and may not achieve carp control. Ecological outcomes of stocking manipulations are difficult to predict and may range from qualified success requiring ongoing management to failure. Stocking fish is strictly regulated in most Australian States and Territories to avoid other potential problems with fish populations and to avoid creating additional pest populations.

3.5.3 Carp as competitors

Carp may compete with native fish for food (exploitation competition) and habitat space such as spawning sites (interference competition). Since carp begin spawning at lower water temperatures than most native fish, they spawn before many species and may exclude smaller species such as gudgeons (Eleotridae) and rainbowfish (Melanotaeniidae) from their preferred spawning areas in vegetated habitats. Suggestions that carp may interfere with the nesting sites of freshwater catfish (*Tandanus tandanus*) are highly logical. Such proposed interactions between carp and native species have yet to be confirmed (Section 5.3.4).

A degree of dietary overlap occurs between carp and native fish feeding on zooplankton and other invertebrates, but whether these food sources are available in such limiting amounts to cause competition is uncertain. Competition for food can occur if two or more species utilise a food source that is in short supply. Earlier analyses suggested that competition between carp and some native fish for food was unlikely, because native fish tend to spawn during floods when zooplankton are abundant in floodplain habitats (Reynolds 1987). However, recent evidence discounts this suggestion, as carp appear to be equally as capable as native fish of exploiting zooplankton blooms in shallow ephemeral habitats (Gehrke et al. 1999b). The Victorian Carp Program reported an overlap in the diet of carp with small native fish such as Australian smelt and western carp gudgeon (*Hypseleotris klunzingeri*). It has been suggested that carp may have an advantage over other species by spawning earlier, thereby giving larvae and juveniles access to food earlier than native species which spawn later (Roberts and Ebner 1997). While this suggestion appears logical, competition for limited food resources has not been demonstrated (Hume et al. 1983a; Gehrke et al. 1999b).

'Carp may have an advantage over other species by spawning earlier, giving larvae and juveniles access to food earlier than native species which spawn later.'

Competition between newly introduced species and native species is believed to be extremely common but is notoriously difficult to demonstrate (Li and Moyle 1993). Competition occurs when the niches of two or more species overlap. The niche of a species consists of the species' total requirements to survive under a range of environmental conditions throughout its distribution and includes habitat preferences, environmental tolerances, diet, feeding behaviour and spawning locations. Under any given environmental conditions, a species may use only a small part of its total requirements, for example, by feeding on only one type of prey even though other prey are available. For this reason, measuring the niche of a species can be difficult. Without fully defining the niche of two species, it is not possible to identify all the ways in which they may compete. Demonstrating unequivocally that competition actually occurs in wild populations is usually difficult. Consequently, while it is intuitive that carp compete with native fish species in many ways, as illustrated above, there are currently no clear examples.

3.5.4 The role of carp in aquatic food webs

Carp can attain immense biomass densities as a result of their large body size and great abundance. Reid and Harris (1997) estimated carp population density in the Bogan River at 11 316 fish per hectare, while biomass density estimates as high as 3 144 kilograms of carp per hectare have been made for the Lachlan River (Driver et al. 1997). It has been suggested that carp may act as an energy trap, limiting the transfer of energy to successively higher levels in the food chain (Roberts et al. 1995, Gehrke 1997a). Carp obtain their energy from lower levels in the food chain than large-bodied, piscivorous native species such as Murray cod and golden perch. However, because carp grow rapidly (Brumley 1996; Vilizzi and Walker 1999) to large sizes that reduce the risk of predation, and are relatively long-lived, the energy in their bodies is not as readily available to higher predators as an equivalent biomass of small native species. High population densities of large carp therefore represent a large pool of energy that is only transferred to other parts of the food chain when carp die. The dominance of carp in lowland rivers may therefore contribute to the observed decline in species richness with increasing distance downstream (Gehrke 1997a).

'Carp may act as an energy trap and alter nutrient transfer through aquatic ecosystems.'

Carp may also alter nutrient transfer through aquatic ecosystems through five possible pathways that contribute to algal blooms: (1) direct predation of algal grazers (Section 3.3.2), (2) resuspending nutrients by disturbing sediments (Section 5.3.3), (3) excreting nutrients into the water, (4) direct damage to aquatic plants (Section 5.3.5), and (5) suppression of aquatic plants by turbidity which reduces light penetration (Gehrke and Harris 1994, Section 5.3.3). There is growing interest both in Australia and overseas in manipulating the composition of fish communities to reduce predation pressure on zooplankton. In theory, this should allow zooplankton populations to expand, and in turn, graze algae to low densities where they are unlikely to develop problematic blooms. However, the validity of the concept is highly controversial at both international (Carpenter and Kitchell 1992 versus De Melo et al. 1992) and national (Boon et al. 1994 versus Matveev et al. 1994) levels. While not directed specifically at carp, these examples illustrate the effects that fish with diets similar to carp can have on the ecology of food webs in lakes. Similar interactions occur in rivers. Riverine food webs, however, are more difficult to manipulate experimentally than food webs in lakes because of the complex nature of river flows and the ability of organisms to migrate upstream and downstream.

3.5.5 Carp replacing native freshwater fish

Gondwanaland separated from the other continents about 100 million years ago and Australia separated from Gondwanaland about 45 million years ago. Hence, the freshwater fish fauna of Australia evolved in relative isolation from other continents and Australia escaped the rapid, large-scale evolution of primary freshwater fish (that is, species groups that evolved in freshwater), such as carps and freshwater catfish, that occurred in the tropics and throughout south-east Asia. Instead, freshwater fish communities in Australia were dominated by other families of recent marine origin such as basses and cods (Percichthyidae), grunters (Haemulonidae), freshwater catfishes, rainbowfishes, hardyheads (Atherinidae) and gudgeons.

Australian rivers are amongst the most variable in the world (Puckridge et al. 1998) and fish species have had to adapt to erratic and unpredictable riverine environments in order to survive. Although the total number of freshwater fish species native to Australia is small, at between 180 and 200 species (Merrick and Schmida 1984; Allen 1989; Paxton et al. 1989; McDowall 1996), this number of species in relation to catchment area is typical for regions with similar climates world-wide (Gehrke and Harris 2000).

The decline and conservation status of native fish species

Concern about declining numbers of native fish was raised as early as 1936 when fisheries agencies from New South Wales, Victoria and South Australia met to develop plans to protect fish in the Murray River (Anon 1936). By the time carp began their rapid expansion in the late 1960s and 1970s, declining populations had become critical for many native species, and commercial catches of Murray cod, golden perch and silver perch had already declined (Figure 11 Reid et al. 1997). In addition, migratory species such as golden perch had become locally extinct upstream of major impoundments (Weatherley and Lake 1967), Macquarie perch (*Macquaria australasica*) had dramatically declined in distribution (Cadwallader and Rogan 1977; Cadwallader 1981), distribution of Murray cod had become restricted, and trout cod (*Maccullochella macquariensis*) were reduced to only two small remaining populations (Cadwallader and Gooley 1984).

Within the Murray–Darling Basin, widespread catchment changes over the past 100 years, and changes to river habitats such as nutrient enrichment, removal of bankside vegetation, pollution, siltation, construction of dams and weirs, and flow alteration have contributed to the decline in native fish species (Frith and Sawer 1974; Cadwallader 1978; Harris 1984; Harris and Mallen-Cooper 1994; Harris and Gehrke 1997; Section 2.1).

More than one-third of Australia's freshwater fish species are considered to be under threat (Koehn 1995). Of these, 20 species are considered to be affected by interactions with introduced species. The majority of these threatening interactions are however, with species other than carp, including gambusia and trout. Reasons for this include the widespread nature of gambusia, the more direct, predatory impacts of trout and the lack of evidence for the impacts of carp (Wager and Jackson 1993, Koehn 1995). Carp do, however, co-occur with six endangered species: Murray hardyhead (*Craterocephalus fluviatilis*), golden galaxias (*Galaxias auratus*), trout cod, southern purple-spotted gudgeon (*Mogurnda adspersa*), Macquarie perch, and Oxleyan pygmy perch (*Nannoperca oxleyana*), as well as a further seven species considered to be vulnerable: silver perch, Darling River hardyhead (*Craterocephalus amniculus*), Yarra pygmy perch (*Nannoperca obscura*), Dwarf galaxias (*Galaxiella pusilla*), Murray galaxias (*Galaxias rostratus*), non-parasitic lamprey (*Mordacia praecox*), and the Australian grayling (*Prototroctes maraena*). The interactions or impacts of carp on these species are unquantified as causal links have not been established.

'Carp could establish in tropical Australia.'

It has been suggested that as a result of the decline of native species, aquatic habitats in some areas are under-used by fish, and that carp have been successful in these areas because they have not had to compete against other species (Harris 1997). Similarly, disturbance may alter aquatic habitats, making resources such as habitat space or food more suited to invasive species such as carp as opposed to native species (Section 2.1.4).

Fish have been introduced successfully to many habitats around the world that have not been greatly disturbed by humans and which have diverse faunas. Where natural variation prevents any species from becoming dominant, and disturbance is at an intermediate level, mixed assemblages of native and introduced species are more likely to co-exist (Li and Moyle 1993). In Australian rivers, flow alteration and catchment disturbance have reduced the natural level of variability, contributing to the decline in native species, and creating conditions that favour establishment of introduced species (Gehrke et al. 1995; Puckridge et al. 1998). The lack of native species with a similar niche to carp, which might otherwise provide strong competition, has also favoured carp becoming established (Section 3.5.3).

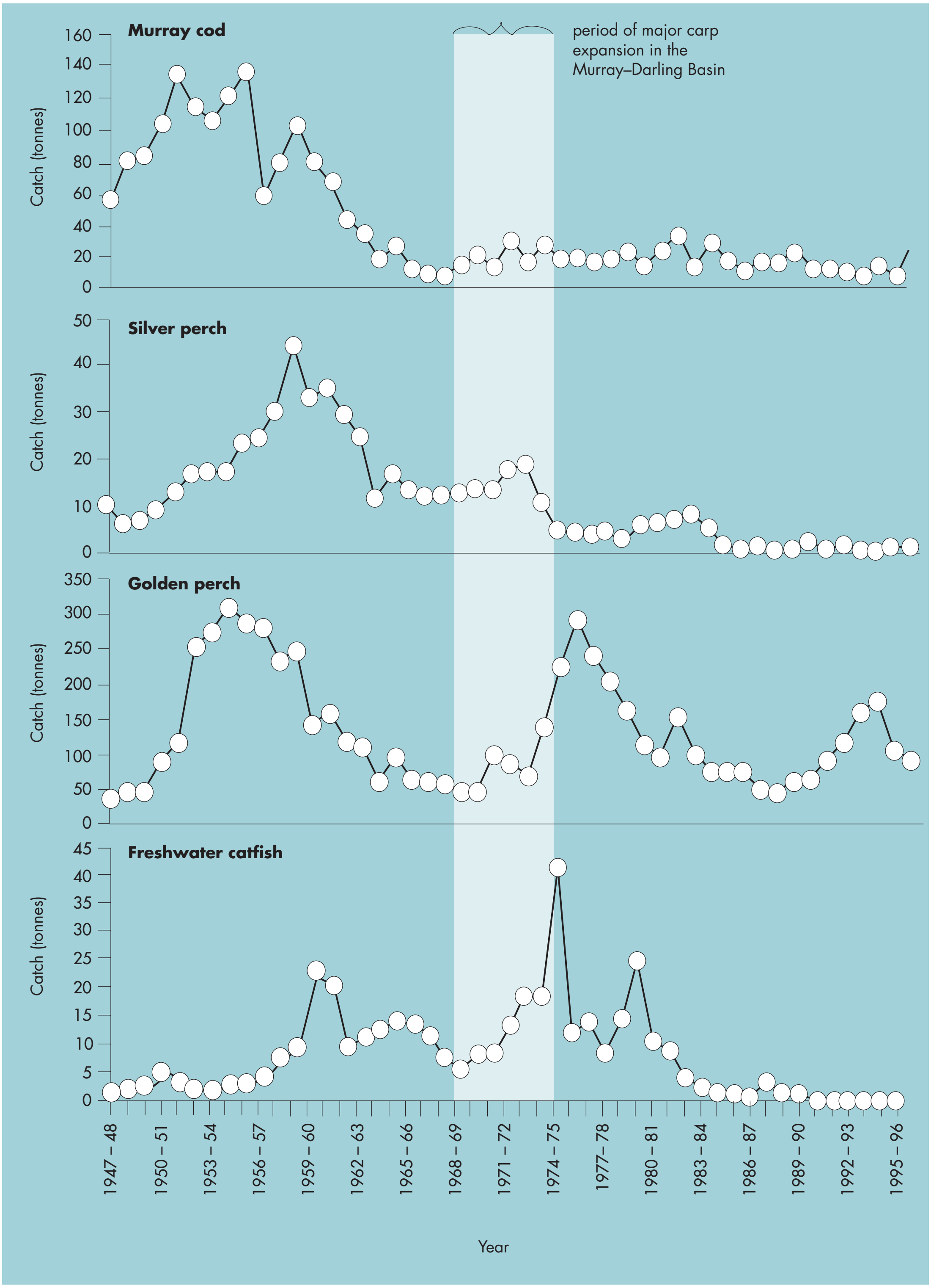


Figure 11: Commercial catches of Murray cod, silver perch and golden perch in New South Wales declined in the early 1960s before the expansion of carp, disproving claims that the decline of native fish was caused by the major expansion of carp throughout the Murray–Darling basin coinciding with widespread flooding in the early 1970s. Good catches of golden perch and freshwater catfish were taken following record floods in 1974-75, but later declined (after Reid et al. 1997). Note varying scale on y-axes.

Carp extend through most lowland and slopes rivers of inland south-eastern Australia, overlapping with native species such as Murray cod, trout cod, golden perch, Macquarie perch, freshwater catfish, bony herring (*Nematalosa erebi*), silver perch, spangled perch (*Leiopotherapon unicolor*), river blackfish (*Gadopsis marmoratus*) and smaller species such as various gudgeons, hardyheads, galaxiids (Galaxiidae), Australian smelt and rainbowfish.

In coastal rivers in south-eastern Australia, the distribution of carp now overlaps the range of native species such as Australian bass, estuary perch (*Macquaria colonorum*), both long-finned (*Anguilla reinhardtii*) and short-finned (*A. australis*) eels, small galaxiid species, Australian smelt, Australian grayling, various gudgeons, mullet (Mugilidae) and river blackfish. Many forms of habitat alteration, including modified river flows and proximity to large human population centres, are features of coastal rivers where carp have become established (Driver et al. 1997; Harris and Gehrke 1997; Marsden et al. 1997; Gehrke et al. 1999a; Section 2.1.4).

Carp have not become established in the rivers of tropical Australia, where the diversity of freshwater fish species is greatest (Beumer 1980; Bishop and Forbes 1991; Pusey and Kennard 1996). Rivers in this region retain much of their natural variability, are currently not regulated to the same degree as rivers in the south-east, and human population centres are smaller, creating less catchment disturbance. The tropical riverine environments support a proliferation of predatory fish species such as barramundi (*Lates calcarifer*), mangrove jacks (*Lutjanus argentimaculatus*), saratoga (*Scleropages leichardti*), ox-eye herring (*Megalops cyprinoides*), jungle perch (*Kuhlia rupestri*) and various grunters, along with a diverse array of smaller perchlets (Kuhliidae), rainbowfish, hardyheads and gudgeons (Pusey and Kennard 1996; Bishop and Forbes 1991). Other predators include both freshwater (*Crocodylus johnstoni*) and estuarine (*C. porosus*) crocodiles and a wide variety of fish-eating birds. Several species of fork-tailed catfish (*Arius graeffei*), mullet and bony herring which feed largely from the bottom are also common. Ecological theory might, therefore, suggest that the combination of predation pressure, competition, high species diversity, low levels of human disturbance, environmental variability and water temperatures (Section 3.2.2) may help to prevent carp from becoming established in tropical Australian rivers.

However, there is no room for complacency based on these facts. In Papua New Guinea, carp are spreading in the lowland reaches and floodplain habitats of the Sepik River system following their escape from aquaculture ponds in the highlands (Ulaiwi 1990). This is despite the Sepik River containing a broad range of tropical predatory species. This tropical example, combined with the abundant aquatic vegetation in many tropical Australian rivers suggests that carp could establish in tropical Australia.

'There is no documented evidence of native fish species being displaced or totally replaced by carp in Australia.'

In summary, carp co-occur with native fish species and may compete in many ways, but there is no documented evidence of native species being displaced or totally replaced by carp in Australia. Declines in native fish species, in conjunction with extensive habitat disturbance, are likely to have facilitated the expansion of carp populations. As an opportunistic species, carp have exploited this situation to become well-established in Australia.

3.6 Current research

For a number of reasons that are not particularly clear, there was little interest in carp research in Australia until the early 1990s (Roberts and Tilzey 1997). Fortunately, this situation is changing to meet the knowledge requirements for proper identification, management and monitoring of problems associated with carp (Table 6).

Table 6: Examples of current carp research in Australia

Category	Research area	Organisation
Monitoring	Surveys of carp populations, changes in carp densities, and recruitment patterns	NSW Fisheries, CRC for Freshwater Ecology, Queensland Department of Natural Resources, Griffith University, Tasmanian Inland Fisheries Commission
	Trends in commercial carp fishery	NSW Fisheries, CRC for Freshwater Ecology
Impact (assessment)	Effects of carp on plants and sediments	CRC for Freshwater Ecology
Control methods	Effects of river management options, such as temperature regimes and environmental flows, in controlling carp and rehabilitating native fish populations	NSW Fisheries, CRC for Freshwater Ecology
	Methods for reducing carp abundance and measuring environmental benefits	NSW Fisheries, CRC for Freshwater Ecology
	Carp control strategies	Tasmanian Inland Fisheries Commission
	Hydrologic manipulation as a carp control strategy	CRC for Freshwater Ecology, Tasmanian Inland Fisheries Commission
Ecological processes	Age and growth of carp	CRC for Freshwater Ecology, University of Adelaide
	Physiological tolerances of fish in billabongs	CRC for Freshwater Ecology, La Trobe University
	Downstream transport of larval and juvenile fish	NSW Fisheries, CRC for Freshwater Ecology
	Effects of drying on lake ecology	CRC for Freshwater Ecology
	Diets and competitive interactions between carp and other species	CRC for Freshwater Ecology, University of Western Sydney
	Growth, reproduction, mortality and population structures of carp	Victorian Department of Natural Resources and Environment
	Carp recruitment sources and movements	Victorian Department of Natural Resources and Environment
	Early life history and environmental tolerances of carp	CRC for Freshwater Ecology, University of Adelaide

A Strategic Research Plan for carp is being developed as part the National Management Strategy prepared by the Carp Control Coordinating Group. The plan will set priorities and focus carp research on the information needs of the National Management Strategy, and on knowledge gaps identified in this book.

The Fisheries Research and Development Corporation has established guidelines for carp research as part of their funding programs, but these guidelines have not been linked to other agencies, such as the Land and Water Resources Research and Development Corporation. The Natural Heritage Trust provides some funding for carp research through the Murray–Darling 2001 FishRehab Program as well as through RiverCare and the Fisheries Action Program.

Carp research is now being conducted by the Cooperative Research Centre for Freshwater Ecology, State natural resource and water management agencies in Queensland, New South Wales, Victoria, Tasmania and South Australia, CSIRO and a number of university research teams. A number of community groups are also conducting management-oriented research.

Areas for research (Sections 10.2–10.6) include:

- basic biology and ecology
- population dynamics
- population genetics
- habitat requirements
- distribution and abundance
- interactions with native species
- impacts
- control techniques
- recovery of aquatic ecosystems following carp control.

The range of issues currently being investigated is indicated by the examples in Table 6.

4. Community attitudes and expectations

Summary

In contrast to the positive attitudes held towards carp in Europe and Asia, carp are perceived as a pest in Australia. This attitude ranges from agriculturists and water authorities, who believe carp cause extensive damage, to attitudes of most recreational fishers and conservationists who consider carp a nuisance. Many groups, including conservationists, scientists and those concerned for native fish, such as recreational and commercial fishers, believe that carp are often a scapegoat for other environmental problems. Many people believe that carp cause declines in aquatic plants and native fish and increase water turbidity. Some people also believe that carp increase bank erosion and water nutrient concentrations. Scientific evidence supporting or refuting these negative perceptions is not always available.

There are many people who are unaware that carp are an introduced species which causes environmental problems. Carp have now been established for long enough to allow a generation to have seen the species as a normal occurrence. Recreational 'coarse' fishers consider carp desirable and may be translocating them to new waters.

Most people who consider carp to be a problem would like to see them controlled. Commercial harvesting of carp is considered a valid control option by many who believe harvesting will at least reduce carp densities and at best ensure establishment of a market that could maintain carp numbers below the level where they are a problem. This viewpoint does not always adequately consider whether high levels of commercial harvesting could achieve this goal. There are also serious concerns that establishing a commercial carp harvesting industry may hinder effective control mechanisms, possibly leading to claims for compensation if an effective control method is developed. Many conservationists, recreational fishers and indigenous people consider that the choice of control options for carp needs to include rehabilitation of the catchments and riparian areas concerned.

4.1 Attitudes from the northern hemisphere

Initial Australian attitudes to carp (*Cyprinus carpio*) were influenced by those attitudes prevalent in the Northern Hemisphere. This began with a positive view of carp as a species to import during the time of the Acclimatisation Societies of the 1860s to 1880s. Carp were still favourably viewed at the turn of the century (Stead 1929) when native fish were actually removed from Prospect Reservoir, a large water storage dam near Sydney, and carp and goldfish (*Carassius auratus)* stocked. Europeans regard carp highly both as a target species for anglers and as a table fish (Section 1.2). An aquaculturist of European descent initiated the spread of the Boolara strain of carp in Australia in the belief that he would be able to breed up carp and sell them to farmers. His business intention was to make money from farmers wishing to clear their dams and watertanks of algae and plants.

In North America in the 1960s, the public attitude to carp was negative following reports of detrimental impacts on vegetation, native fish and water quality (Tryon 1954; Hendricks 1956; Mraz and Cooper 1957). Such detrimental impacts were also attributed to carp in Australia even before investigation on their effects began (Butcher 1962 & 1967; Wharton 1979). This was a change in attitude to carp by Australians, as the lack of survival of carp in 1860 had been viewed as a failure. The successful colonisation of carp in the 1960s, as an introduced fish species with possible detrimental effects, was seen as a disaster.

Although North Americans and Australians are now concerned about the impacts of carp (Chapter 5), the attitude towards carp in Europe and Britain has remained favourable. Carp have not increased to undesirable numbers in European waters. Several cyprinid species naturally coexist with carp and all have predators such as pike (*Esox lucius*) (Smith et al. 1997). In Europe and Britain carp are perceived to be in acceptable numbers and considered highly desirable by coarse anglers. A minority of anglers in Australia share this attitude, and concerns have been expressed at the establishment of new carp populations for angling (Section 4.9.2).

4.2 Public attitudes in Australia

The media has promoted the perception of carp as an undesirable introduced species. A common view held in the general community is that carp contribute to the degradation of river environments and that the problem of reducing carp numbers needs public support (Easton and Elder 1997). Generally there may be a lack of public knowledge about carp and that it is an introduced fish. Carp have been established for long enough that a generation has now seen the fish as a 'normal' component of fish communities in their local waters.

Sectors of rural communities in New South Wales, including irrigation and dryland agriculture groups and angling associations were surveyed on their opinions about carp and related issues (P. Gehrke, NSW Fisheries, unpublished data 1998). The questions specifically avoided mentioning particular problems so that the responses reflected either personal opinion or hearsay. Issues raised in responses are grouped into categories listed in Table 7. Because of the small number of respondents (27), these results should be taken as an indication of what people think about carp, rather than a complete list of opinions.

These issues, especially those ranked 1 to 7, reflect opinions commonly held about carp in other States of Australia. Some of these problems may be caused by other factors. For example, one response to the survey in New South Wales commented that carp are the single most stressful factor affecting river health, however the same response ignored the effects of large-scale water extraction and heavy use of agricultural chemicals in the river system in which the respondents lived.

The less widely held opinions (rank 11–15) include some misconceptions. Some farmers in Victoria complain that carp undermine riverbanks causing erosion and trees to fall in, although this seems quite improbable and is likely to be a misconception (W. O'Connor, Department of Natural Resource and Environment, Victoria, pers. comm. 1998). Problems with blooms of bluegreen algae (*Cyanobacteria*) in the Gippsland lakes, in Victoria, linked with nutrient increases, are attributed by many of the public to increases in the number of carp in the lakes (M. Rankin, Gippsland Coastal Board, Victoria, pers. comm. 1998). In both these instances, maybe carp are being used as a scapegoat for river health problems, especially uncontrolled stock access to water bodies (W. O'Connor, Department of Natural Resource and Environment, Victoria, pers. comm. 1999).

Some of the opinions from the New South Wales survey, which were not widely held (rank 16), such as increased soil salinity because of carp, and difficulties in watering livestock because carp scare animals away from watering points, are not strongly supported by public opinion and have no scientific basis (Table 9; Section 5.3).

The policy of the Murray–Darling Association, a local government group, which represents many water users in the Murray–Darling Basin, is: 'Carp is a major cause of the decline in the Murray–Darling Basin river system and unless solved will render efforts to improve river health ineffective. A major integrated effort to eliminate carp should be commenced' (L. Broster, Murray–Darling Association, South Australia, pers. comm. 1997).

'Evidence indicates that carp may contribute to these problems under some environmental conditions, but carp alone do not cause the problems.'

Jerry Killen, a spokesperson for the Irrigators Association of NSW and a Water Users Advisory Board member, considers that carp have negative impacts and that their undermining of river banks make them the scourge of inland water bodies (*Carpe diem*

Table 7: Problems associated with carp by landholder and angler organisations in New South Wales. The problems are listed in decreasing order of the number of times each problem was mentioned by respondents (P. Gehrke, New South Wales Fisheries, unpublished data 1998)

Problem	Rank
Major problem and should be discouraged or eradicated	1
Increase bank erosion by undercutting	=2
Increase turbidity	=2
Reduce macrophytes	4
Compete with native fish	5
Fishways and other measures needed to help native species compete against carp	6
Disturb bed sediments	=7
Activate phosphorus in sediments	=7
Reduce native fish numbers	=7
Reduce river health	=7
Increase frequency of tree collapse	=11
Increase nutrient loading	=11
Cause poor water aesthetics and dirty water	=13
Resource value of carp not fully recognised	=13
Increase silting of shallow reaches	15
Widen river channels	=16
Overpopulate channels	=16
Increase salinity/waterlogging of soil by causing channel leakage	=16
Scare livestock from watering points	=16
Prevent vegetation regrowth by eating seeds	=16
Increase algal blooms by preying on algal grazers	=16
Damage wetlands	=16
Decrease biodiversity	=16

documentary 1998). He believes that environmental problems caused by carp are widespread and include eutrophication of waters and blooms of blue-green algae. Scientific evidence indicates that carp may contribute to these problems under some environmental conditions, but carp alone do not cause the problems (Section 4.3).

Some community groups undertake habitat restoration projects in the belief that their efforts will reduce the impacts of carp and improve conditions for native fish. For example, Settlers Creek Landcare Group, in South Gippsland Victoria, has implemented a restoration project in a small stream as they believe that carp harm aquatic habitats and may have a negative effect on river blackfish (*Gadopsis marmoratus*). This type of work will help determine whether the presence of carp or the lack of riparian vegetation is the most important factor in causing instability of riverbanks and subsequent undermining (W. Brown, Settlers Creek Landcare Group, Victoria, pers. comm. 1997) (see case study in Section 8.6.2).

The National Carp Task Force (NCTF) has implemented a carp education strategy posing the question of whether carp are really the villains they are portrayed as, or rather are scapegoats for 200 years of inappropriate river management. The aim is to improve community awareness of facts about the spread of carp as an introduced fish and their impacts as well as other factors involved in degradation of river habitats. Networking of those already involved in carp research and commercial activity is also a high priority. Myths and misconceptions about carp in Australia, as known by Australian scientists, have been summarised in Table 9. Much of the accurate information has not been spread to the general public (Chapter 9).

In Victoria, the Waterwatch Program included awareness of carp as the main activity for Water Week in October 1998. Carp fishing competitions have been organised in many areas in New South Wales, Victoria and South Australia to raise public awareness. Community groups are often willing to work together and to cooperate with government departments to address a common problem such as carp. The newsletter of the NCTF aims to consolidate community energy by providing accurate information to all interested groups. The intention is not to eradicate carp, but to facilitate carp control through community cooperation.

In addition to becoming involved in habitat restoration and carp removal, the community has a valuable role to play in monitoring of water quality and other aquatic ecosystem indicators (Section 8.5.1) and early detection and reporting of the establishment of carp populations in new areas. As part of the latter, local communities could erect signs indicating carp-free areas, with a carp diagram and contact phone number to allow positive identification and reporting of carp sightings. Such signs would increase awareness and community ownership of the issue.

4.3 Attitudes of environmental authorities in Australia

Many stream ecologists claim there is no supporting evidence for claims by landholders that carp cause bank collapse and topple trees (W. O'Connor, Department of Natural Resources and Environment, Victoria, pers. comm. 1998). There is reliable evidence that other factors such as uncontrolled stock access (Robertson 1997, 1998) and clearing of riparian vegetation (Growns et al. 1998) have had a devastating effect on rivers and native fish (Sections 2.1.4 and 3.5). Federal and State government natural resources agencies have adopted policies encouraging better management of riparian zones to enhance bank stability. Bank stability is essentially a function of the native vegetation cover on the banks, and not the presence or absence of carp in the stream. For example, the lower Glenelg–Wannon system in Western Victoria has no carp and is severely eroded because of over clearing of riparian vegetation, stock access to the water's edge and de-snagging. In contrast, the lower Ovens River (northern Victoria) has substantial carp populations and has stable banks. This is because there is an intact native riparian forest, abundant instream snags and grazing by stock is limited. For these reasons the Ovens also has the best population of Murray cod (*Maccullochella peelii peelii*) in Victoria (W. O'Connor, Department of Natural Resources and Environment, Victoria, pers. comm. 1998).

'Water authorities vary in their attitudes to the presence of carp in channels.'

Water authorities vary in their attitudes to the presence of carp in channels. Their views range from complacency about the presence of carp, to seeking funds to reduce their numbers by using them as a commercial resource. One water authority in Victoria believed the changes to water quality caused by carp justified expenditure for their removal (Section 5.4.4; Box 2).

Catchment Management Authorities (CMAs) in Victoria are responsible for managing catchments and water bodies. Included in their objectives is the development of integrated strategies for pest animal control by government agencies and landholders. The Boards that preceded the CMAs published strategies that mention carp as a pest because of their detrimental effects in undermining river banks (A. Roder, Mitchell River Management Board, Victoria, pers. comm. 1996). While works were underway attempting to restore river habitats, carp were seen to be a threat to stable banks.

Some carp control methods may have undesirable environmental impacts. For example, one concern is that methods causing rapid and high mortality rates could cause tonnes of putrefying carp in some aquatic habitats (A. Baxter, Fisheries Victoria, Department of Natural Resources and Environment, pers. comm. 1999).

4.4 Conservation gr oups

4.4.1 General opinions

Conservation groups in Australia generally see carp as an environmental pest that may contribute to undesirable changes to natural ecosystems, but recognise carp as a symptom rather than a cause of major environmental damage. They consider that carp have often been used to divert attention away from the real but larger and more difficult environmental problems, such as reduced river flows and lack of willingness to finance habitat restoration. Conservation groups also view the damage caused by carp in the context of damage caused by other introduced species such as gambusia (*Gambusia holbrooki*), redfin perch (*Perca fluviatilis*), brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) (Tilzey 1976; Fletcher 1986).

Whilst favouring eradication of carp, or management for population control where eradication is not possible, many conservationists believe carp control should be placed well down the list as a priority for river management. Any carp control activities must be undertaken in conjunction with other river rehabilitation measures (Roberts and Ebner 1997).

Control techniques to reduce carp populations favoured by conservation groups include:

- habitat rehabilitation (Section 7.3.2) including improved river flows (Section 7.4.2)
- revival of native fish populations to increase predation (Section 7.3.2)
- genetic or immunocontraceptive carp control methods (if these techniques become available) (Section 7.3.5 and 7.3.6).

'Management options that offer long-term solutions, have a sound ecological basis, and which are complemented by environmental rehabilitation that may enhance native fish populations, are favoured.'

Generally, conservation groups prefer control techniques which cause minimal environmental damage and pose a low risk to native species. The use of viruses as biological control agents was viewed as dangerous in inland waters because of their potential to affect native species. Conservation groups would like the use of chemicals for carp control to be subjected to environmental impact statements (T. Fisher, Australian Conservation Foundation, Victoria, pers. comm. 1998). Carp control is particularly favoured in areas of high conservation value, degraded habitats, or where endangered species might be affected. Management options that offer long-term solutions, have a sound ecological basis, and which are complemented by environmental rehabilitation that may enhance native fish populations, are favoured (T. Fisher, Australian Conservation Foundation, Victoria, pers. comm. 1998).

Cynicism was expressed at the prospect of carp control ever receiving comparable expenditure and support to that spent on fox, rabbit and weed control, given the apparently smaller effects of carp on agricultural productivity. Suggestions were made that major river users such as the irrigation industry and anglers should make some contribution to control efforts. Anger was expressed at the promotion of coarse fishing and re-release of carp during coarse fishing competitions (T. Fisher, Australian Conservation Foundation, Victoria, pers. comm. 1998).

4.4.2 Professional organisations

The Australian Society for Fish Biology (ASFB) has a membership of over 600 fisheries professionals and students. The ASFB considers that carp are an undesirable introduced species and that steps should be taken to control them (D. Pollard, Exotic Fishes Sub-Committee representative, NSW, pers. comm. 1998). The ASFB considers appropriate control methods need to be determined although the harvesting of carp could be undertaken as an interim measure to reduce numbers in localised areas. Eradication or control techniques should be combined with habitat rehabilitation to restore the natural balance in favour of native fish species, which may then exert competition and predation pressure on carp to help provide a long-term solution.

4.4.3 Other organisations

Native Fish Australia (NFA) represents up to 20 000 people through affiliated angling clubs. NFA considers that carp are a symptom of degraded rivers and aquatic habitats. NFA members have witnessed the decline of native species which they perceive is caused by alterations in river flows, altered water temperatures and lack of flooding (G. Creed, Native Fish Australia, Victoria, pers. comm. 1998). The decline of trout cod (*Maccullochella macquariensis*) has caused particular concern in many areas. NFA believe that the decline of some native fish such as freshwater catfish (*Tandanus tandanus*) and silver perch (*Bidyanus bidyanus*) may be caused by carp competing for food.

NFA would prefer to see carp eradicated from Australia but believe carp control should be considered in the context of other introduced species which should also be controlled. NFA considered the attention focussed on carp distracts from the real environmental issues such as river flows and habitat rehabilitation. In line with the view of conservation groups, NFA considers that the cost of carp control should be justified against other priority riverine issues. Rehabilitation of river habitats, in particular flows, was seen as a real solution to the decline of native fish populations. Strong native fish populations could then exert predation pressure on carp populations and be the most important factor in their control (N. Thorn, Native Fish Australia, Victoria, pers. comm. 1998).

NFA considers that the decision by the Victorian Government to give permits for re-release of carp by coarse anglers during competitions (Section 4.9.2) is against the principles of carp control.

'Carp control should be considered in the context of other introduced species which should also be controlled.'

The South Australian Field and Game Association (SAFGA) believe that carp cause damage to wetland habitats of native birds. They requested the Murray–Darling Association (MDA) to support a forum on carp (P. Teakle, South Australian Field and Game Association, pers. comm. 1995) which subsequently took place at Renmark, South Australia (Murray–Darling Association 1995). The group believes that habitats will be restored if carp are removed, so they established large-scale works to manage the water levels and to exclude carp at Pilby Creek, an anabranch of the Murray River near the South Australian and New South Wales border. The alliances of the SAFGA with other groups such as the MDA have resulted in national funding for specific works. The results, described in Section 8.6.1, Box 9, demonstrated that in the absence of carp aquatic vegetation became abundant.

4.5 Indigenous communities

Members of some indigenous communities hold strong opinions on the need to 'get rid of carp' (M. Morgan, Yorta Yorta community, Victoria, pers. comm. 1998). Community elders of the Yorta Yorta community have observed changes to habitats, native fish numbers, bird habitats and bird breeding areas which they attribute to the introduction of carp along the Murray River in New South Wales and in the Barmah Forest. Elders expressed a great desire for eradication or 'total control', and showed interest in becoming involved in such efforts if this were possible. Few people from indigenous communities known to the Yorta Yorta have used carp as food and generally they just 'chucked them on the bank'.

'A decline in the environment may be equated with a decline in the standards of indigenous culture and community.'

Along the Darling River, New South Wales, various indigenous communities have witnessed the increase in numbers of carp (V. Crawford, Waterwatch Facilitator for indigenous people of the Darling catchment, Bourke, NSW, pers. comm. 1998). Indigenous communities along the Darling regard carp as a problem because they have replaced valued populations of native fish.

A unique effect of carp on indigenous peoples is the influence on their culture. As laws and cultural conditions are often related closely to the land and the environment, changes to that environment cause changes to traditional, laws, customs and traditions. This leads to a loss of many of these attributes (M. Morgan, Yorta Yorta community, Victoria, pers. comm. 1998). Some indigenous people see both themselves and biodiversity as mutual and important components of the environment. Therefore, a decline in the environment may be equated with a decline in the standards of indigenous culture and community. This is in contrast to the European view of using the environment rather than being part of it. The indigenous community see themselves as protectors of the environment. They have to modify their culture because of environmental changes such as the introduction of carp. This is not a universal belief amongst Australian Aboriginal peoples. For some, abundance is more important than diversity, so that these people do not necessarily distinguish between native and introduced species (Tilmouth 1995).

The role of the irrigation industry in reducing flows in the Murray River is seen by some indigenous peoples as a major factor contributing to the decline of native fish populations and the increase in carp (M. Morgan, Yorta Yorta community, Victoria, pers. comm. 1998). The lack of seasonality in the drying and flooding of wetlands provides carp with extensive permanent spawning and rearing areas.

Control methods are readily sought, although the Yorta Yorta people are concerned at the possibility of further biological introductions or controls which have no guarantee of not having adverse effects on native species. This concern is heightened by the history of the effects of viruses and other diseases introduced to Australia by Europeans and the devastating effects they had on indigenous people.

Strong concern was also expressed at the possibility of the development of carp harvesting as an industry which could be seen as sustainable, as this may in turn hinder their eradication because of the effect on investment and livelihoods of those involved in a carp industry. If population control methods were to be implemented potential litigation or compensation claims could occur – for example, complaints from the rabbit industry following the release of control viral agents (M. Morgan, Yorta Yorta community, Victoria, pers. comm. 1998).

Commercial harvesting of carp is seen to raise several other concerns including:

- risk of injuries to non-target native species by capture techniques
- illegal capture of native species
- insufficient reduction of carp populations to reduce damage

- diversion of attention from other underlying environmental problems and the promotion of carp harvesting as a solution to the carp problem.

Changes to flow regimes, environmental rehabilitation and removal are all favoured as control options. There is also strong support for further research, particularly into breeding patterns, so that management decisions can be made with better understanding (M. Morgan, Yorta Yorta community, Victoria, pers. comm. 1998).

4.6 Animal welfare and animal rights

Animal welfare organisations aim to protect animals from cruelty and unnecessary suffering. There are a variety of opinions from these groups in relation to the killing of animals as a control option. Generally animal welfare groups have a preference for control methods which do not kill animals or cause animal suffering. Attitudes to killing fish are sometimes, although not always, less stringent than those expressed against killing larger terrestrial animals.

Some general principles adopted by animal welfare groups include:

- avoidance of pain or suffering if at all possible
- the use of humane killing methods
- targeted actions which do not adversely affect other species
- the need to demonstrate planned management.

4.6.1 Animal rights and animal liberation organisations

Opinions given by a campaign coordinator for Animal Liberation (R. Linden, Animal Liberation, Victoria, pers. comm. 1998) suggest that:

- There is a significant qualitative difference between the humane management of species in large numbers which threaten a system's environmental and ecological balance and a public call for extermination of the same species. There may be a tendency to exaggerate damage done leading to unchecked cruelty in killing practices. This calls for innovative strategies for population control or humane euthanasia of individuals.
- Placing a bounty on the head of a pest species by means of commercial exploitation will create a commodity of the species and lead to greater excesses in their harvesting. It may well become a self-defeating control strategy if an industry arises around carp control that demands continual supply of stocks (Section 7.3.1).
- All species evolve when new resident species adapt to each other. Strategies should aim to restore a level of balance.
- Angling, harvesting (commercial or scientific), viral, chemical and molecular control options were rejected for being inhumane and for having potential detrimental impacts on non-target species.
- A contraceptive approach was considered to provide the most humane control option, perhaps in combination with mechanical control strategies such as environmental manipulation or exclusion as long as these did not threaten the well-being of existing carp but acted to reduce numbers over time. Similarly, predator stockings would be acceptable if this did not result in a 'cane toad' effect with the resultant need to control the predator.

The basic premise of most animal rights organisations is that no animal's interests are served by it being killed. Animals should only be killed if there is some reason which is thought to override the animal's interests

(Russell and Pope 1993). Some recreational fishers who regard themselves as coarse anglers also hold this belief and prefer to release carp alive (Section 4.9.2).

4.7 Commer cial fishing industry

There is a range of attitudes within the carp commercial fishing industry. Many perceive carp as a potential source of quick money because of the large numbers present in many places. A commercial seine operator in New South Wales (*Carpe diem* documentary 1998) has moved from the coast, where commercial fishing is declining, to northern New South Wales to establish a carp fishery. He believes that harvesting carp for human consumption will yield better money than the coastal fishery and has spent two years setting up this potential business.

'The only way to profit from carp harvesting is to use methods of capture and handling that ensure a high-grade product.'

Most inland commercial fishers support the eradication of carp, which they view as a low-value nuisance fish that damages gear used for harvesting high-value native species. Very few commercial licence holders currently target, or make most of their income opportunities from, carp. Many commercial fishers consider that both rivers and native fish populations would be better off without carp. The use of chemicals and viral agents are not favoured because of possible effects on native species. All other control options are viewed as possible, including harvesting using seine nets and electrofishing. The best carp control options are seen to be: long-term solutions which promote native fish species, including the provision of fishways; restoration of environmental flows at the appropriate times of the year; and habitat rehabilitation (Chapter 7).

Carp have moved further into the Gippsland lakes in the past ten years (Section 2.2.2) but are not commercially viable for most fishermen (A. Allen, East Gippsland Estuarine Fisherman's Association, Victoria, pers. comm. 1998). Only one operator, K&C Fisheries in the Gippsland Lakes, currently makes a living from carp (Section 5.4.3). K&C Fisheries managers consider that the only way to profit from carp harvesting is to use methods of capture and quality handling that ensure a high-grade product goes to fish markets.

A South Australian commercial carp harvester believes that the food chain has been affected by carp to the extent that native fish such as silver perch, freshwater catfish, congolli (*Pseudaphritis urvillii*) and yabbies (*Cherax destructor*) have probably decreased (Jones 1995). Human disturbances such as locks, barrages, pollution, river traffic and fishing have also contributed to the decline of native fish. Jones (1995) considers that carp numbers could be controlled by commercial fishing if there were sufficient markets.

An operator on the Murray River sells carp to the South Australian crayfish industry as bait (Section 5.4.1) but this is not a constant market and he sees the need for an enhanced industry with alternative markets for other times of the year (S. Hounsell, Commercial Fisherman, Swan Hill, Victoria, pers. comm. 1997).

R. McFarland (Lachlan River Management Committee, NSW**,** National Carp Summit, pers. comm. 1995), who is a carp fertiliser processor, believes that government assistance should be given to harvesting and processing of carp. He considers that it is widely accepted that carp are a huge ecological problem to the quality of inland waters and that further scientific studies on their effects are not warranted. Incentives for the carp industry would drive an increase in harvesting which he believes would reduce carp populations and the damage caused by carp. The National Carp Task Force recognises that commercial exploitation has a place in managing the numbers and impacts of carp and supports the economic development of commercial operations for carp at a regional level to reduce damage (L. Broster, National Carp Task Force, South Australia, pers. comm. 1999).

The New South Wales Department of Regional Development (*Carpe diem* documentary 1998) encourage and facilitate the commercial use of carp. They believe a carp harvesting industry will generate jobs and help to protect the environment.

East Gippsland Shire and the East Gippsland Coastal Board were the innovators in forming a network for stakeholders to share information to define the extent of damage caused by carp and to work strategically in making management decisions (M. Rankin, East Gippsland Coastal Board, Victoria, pers. comm. 1997).

There is a difference in opinion between states as to the potential use of large numbers of carp removed from inland waters during recreational fishing competitions. In Gippsland, Victoria, the commercial sector believes that the carp brought in by competitions are of poor quality and unusable by the markets. At a series of competitions organised by the Gippsland Lakes and Catchment Action Group during 1996–98 (Section 4.9.2) carp could be put in 'carp only' rubbish bins emptied by the East Gippsland Shire and taken to a landfill area. In South Australia, the commercial and recreational sectors have agreed that commercial fishers will process carp taken during fishing competitions for cray bait or other markets. The aim was to add value for carp in South Australia rather than producing landfills of buried carp (Pierce 1996). A network meeting of commercial stakeholders from Victoria, New South Wales and South Australia was held in 1998. They believed that carp harvesting as a control measure should be managed according to established fishing industry business principles and not an ad hoc community exercise or one-off control for a pest (G. Gooley, Marine and Freshwater Resources Institute, Victoria, pers. comm. 1998).

4.8 Other businesses

4.8.1 Tourism

The damage caused by carp, and tourists' perceptions of water quality, can have a negative effect on tourism businesses such as accommodation and services (Section 5.2.1). The tourism industry believes that anglers targeting native species will bring in more tourist dollars than those targeting carp. Many angling clubs travel in groups to areas to target native fish in warm waters and to target trout in cool waters. Not many anglers spend money in travel, accommodation and tackle to catch carp. This contrasts to attitudes in Britain where recreational carp fishing is highly regarded and a valuable industry (Section 1.2). In Tasmania, the threat posed by carp to the valuable trout fishery is a major economic consideration (Section 6.3.5).

In Victoria 87% of anglers presently target introduced trout (Salmonidae) and redfin perch while about 7% target carp, sometimes because of a current lack of opportunities to catch native fish (A. Baxter, Fisheries Victoria, Department of Natural Resources and Environment, Morgan omnibus polls 1996–98, pers. comm. 1999). Consequently the tourism industry is dependent on these introduced species. If carp were to threaten the trout, redfin and native fish fisheries this would affect the tourism industry to a greater degree than any reduction caused to angling activity that would occur if carp numbers were controlled. Substantial amounts of money are spent on fishing tackle. Fisheries Victoria is stocking Murray cod, golden perch (*Macquaria ambigua*), silver perch, Macquarie perch (*Macquaria australasica*) and bass (Percichthyidae) as well as raising the profile of native fish to maintain recreational angling.

High quality, potable water is important for tourism and aquatic recreation. A major tourist attraction in eastern Victoria is the Gippsland Lakes. If tourists perceive that carp are having a detrimental effect on water quality, the Regional Tourism Board will support applied research into carp (R. Fordham, Gippsland Regional Tourism Board, Victoria, pers. comm. 1997). Other Chambers of Commerce in rural New South Wales believe carp are linked to declines in local tourism business and may support ventures to control or eradicate carp.

4.8.2 Aquacultur e

The value of carp as a display and ornamental fish is recognised by the Koi Society of

Australia. The brightly coloured Koi are bred on farms and have been highly valued worldwide since the 1930s (Copperfield 1987; Section 1.2). There are many clubs of enthusiasts for breeding and keeping Koi carp especially in New South Wales.

Koi can only legally be bred in some States (Table 13) and cannot legally be imported from overseas (Section 6.2). In Victoria, it is illegal to keep Koi carp and potential enthusiasts believe that the State should have less restrictive laws to match other States and Territories.

Koi carp breeding in the aquarium industry produces many thousands of small carp. There are reports the fish are sorted to remove low value juveniles and these may be being released into aquatic habitats (G. Robertson, Fisheries WA, pers. comm. 1999). There is a need to regulate the disposal of these unwanted carp.

Carp have too low a value for human food to be suitable for high volume commercial aquaculture in Australia. If a high price for carp was attainable an export market would be possible (K. Bell, K&C Fisheries, Victoria, pers. comm. 1997). Some believe that if wild harvested carp were to become a viable export industry there might be a need to have a supporting aquaculture industry of carp kept in a controlled environments (G. Gooley, Marine and Freshwater Resources Institute, Victoria, pers. comm. 1998).

The technology of intensive carp aquaculture is well known worldwide (Section 1.2), and if this could be undertaken in an environmentally sensitive and secure way, there may be several opportunities such as the integration of carp production into wastewater treatment systems and their use and production in rice fields could have economic benefits for wastewater use and integrated farming practices. Carp are also a low cost source of pet food which could replace declining wild fishery products (Newman 1998). If a genetic control technique were developed for carp there might be a need for carp aquaculture to breed up genetically modified stocks (Newman 1998).

4.9 Recreational fishers

4.9.1 Recreational fishing groups

Many recreational fishers consider carp to be an unwanted pest species and they often blame carp for the declines in the populations of other recreational fish species. Carp are believed by some groups to be the most significant factor affecting recreational fishing (G. Creed, RecFish (formerly Australian Recreational and Sport Fishing Confederation), Victoria, pers. comm. 1995). Many groups believe that carp compete with popular angling species for space and food. In New South Wales, the Recreational Anglers Association (RAA) believe that carp exclude native fish from their preferred habitats (S. Ryder, Recreational Anglers Association spokesperson, NSW, pers. comm. 1998). The Victorian Recreational Fishing Peak Body (VRFish) perceives carp as a pest species (R. Page, Executive Officer VRFish, Victoria, pers. comm. 2000). The policy of VRFish regarding carp in Victoria is:

'Many recreational fishers blame carp for the declines of other recreational fish species.'

'Eradication is not viewed as possible by this organisation and commercial harvesting should be undertaken to use carp as a substitute for pilchards and Australian salmon in uses such as pet food. The removal of their noxious status is suggested as a mechanism to enhance their marketability. Carp are viewed as a national problem in need of a national coordinated solution. Removal of carp by commercial fishing and angling are supported as control options, as are immunocontraception and genetic manipulations providing there are no threats to the environment. Use of poisoning and viral agents is not favoured.'

There is an expectation by many angling groups that removal of carp would improve the quality of water and aquatic habitats. Experiments such as Pilby Creek (Section 8.6.1) led the Far West Anglers Association (FWAA) to believe that carp are the main

Coarse angling is a pastime which values large fighting fish including carp. Source: A. Toovey, NSW Fisheries.

cause of bank degradation, turbidity, water quality and riparian vegetation degradation (C. Mansell, National Carp Summit, Renmark, South Australia, pers. comm. 1995). Their attitude, therefore, is that no more money should be spent on carp research but rather on control of carp.

'There is an expectation by many angling groups that removal of carp would improve the quality of water and aquatic habitats.'

Most recreational fishing groups and individuals see carp as a problem and want them removed. Opinions differ as to whether this removal is the responsibility of government agencies, commercial operators or individuals. RecFish states that carp are good eating, and an implication from this is that carp should be used for commercial fishing and by anglers. RAA support a carp industry to remove large numbers of carp to allow the return of native fish. Very few anglers use carp for food and in some States and Territories where it is illegal to return carp to the water alive, anglers often bury carp or leave them on river banks.

The issue of declining habitat because of poor catchment management is seen as central by some angling clubs and other recreational groups. These groups recognise that the persistent multiple impacts of catchment use are such that the removal of carp alone is unlikely to trigger a resurgence of native species.

4.9.2 Carp as a targeted recreational catch

The term 'coarse fishing' was coined in England to distinguish it from the so-called 'gentleman's sport' of angling for salmonids (Salmonidae). The term 'coarse' may come from the English phrase 'in-course' meaning ordinary as it meant all fish that were not salmonids (Clements 1988). 'Coarse fish' include the cyprinids roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*), chub (*Leuciscus cephalus*) and dace *(Leuciscus leuciscus*) (see also Table 1). Coarse fishing has a long history, being undertaken for food by Europeans, and eventually becoming a popular recreation in the United Kingdom and other countries. A more recent philosophy of coarse anglers is to practice catch-and-release of live fish. In Europe, carp up to 20 kilograms are caught using bait and burley through a variety of techniques. The sport is also growing in the United States of America.

Coarse fishing clubs in Australia now exist in New South Wales, the Australian Capital Territory, Victoria and South Australia. A group in Australia called the Australian Federation of Coarse Anglers Association (AFCAA) have a policy of catch-and-release of carp (B. Dimmack, Chair Australian Federation of Coarse Anglers Association, Victoria, pers. comm. 1998) which is controversial (Section 4.4.3). In one competition held in March 1998 between 18 Australian and New Zealand teams, a total of 605 kilograms of carp were caught in 12 hours in the Barwon River in Victoria. All carp were returned to the water alive under a special permit issued by Fisheries Victoria that allow participants in AFCAA events to hold live carp and return them within 10 metres of the point of capture. (A. Baxter, Fisheries Victoria, Department of Natural Resources and Environment, pers. comm. 1999) (Section 6.3.1). The specified waters in Victoria for 1998 to 1999 also included the public waters of Lake Eildon, Yarra River, Maribyrnong River and Eummerring Creek. The Hazelwood Pondage close to the site where Boolara carp were first released in Gippsland is also a site for AFCAA events. AFCAA see carp as a resource that has not been exploited and believe that the industry for recreational carp fishing that has grown in the United Kingdom could be mirrored in Australia.

In fishing competitions held in Canberra in 1999, a total of 3600 kilograms of fish were removed by 50–70 anglers over four days and were then released back into Lake Burley Griffin. At least 95% of these fish were carp, which is an average of nearly 15 kilograms of carp per angler per day (Lintermans 1999).

In contrast to activities by the coarse anglers, the FWAA believes that catch-and-release of carp should be illegal (C. Mansell, Far West Anglers Association, Victoria, National Carp Summit, pers. comm. 1996). Other anglers believe their attempts to increase the survival of native fish are hampered by coarse anglers returning carp to the water (G. Creed, Native Fish Australia, Victoria, pers. comm. 1998). Concern has also been expressed by many anglers about the deliberate transfer of carp to new waters to establish new coarse fisheries.

'A more recent philosophy of coarse anglers is to practice catch-and-release of live fish.'

The attitude of coarse anglers is that fishing is a sport with a need to respect the fish as an animal. Some believe that it is cruel to tether carp and to leave carp to die (S. Roberts, member of Sydney Coarse Angling Club, NSW, pers. comm. 1998). Some coarse anglers are upset at the needless and cruel death of many carp and believe that this disrespect has resulted from widely held views that carp are villains that have caused all the catchment problems (B. Waldock, Australian Federation of Coarse Anglers Association, Victoria, pers. comm. 1998).

Some angling clubs promote carp as an interesting target species because of their fighting abilities and also encourage people to fish for carp as a removal measure. A member of the Johnsonville Angling club has supported the Gippsland Lakes and Catchment Action Group in running a continuous two-monthly competition. Prizes are given for a mystery fish in each competition to encourage people to bring in all fish caught. As most carp would not be consumed a waste bin is provided. The club also aims to contribute to scientific data and for this purpose records the measurements of all carp caught.

'Some angling clubs promote carp as an interesting target species because of their fighting abilities and also encourage people to fish for carp as a removal measure.'

A view held by some recreational fishers is that there is no reason to go fishing anymore because all they catch is carp, and they do not like to eat carp (C. Easton, NSW Department of Land and Water Conservation, pers. comm. 1999). Some groups are attempting to change such attitudes. In 1996, the Executive Director of the South Australia Recreational Fishing Advisory Council reported on the recreational possibilities of carp fishing (Winwood 1996). He suggested that carp fishing can be enjoyable and that burley and bait can be used to successfully catch carp, especially if light gear is used.

4.10 Carp for human consumption

4.10.1 Local markets

Carp are high in protein, nutritious, and in the opinion of many people in Europe and Asia, tasty to eat. Most Australians, however, either regard the fish as a poor quality food, because of its low price, or believe that carp are unsuitable for eating. Usually only people of recent European or Asian origin purchase carp for food in Australian markets. The noxious status of carp and the belief that they are taken from muddy or even polluted waters may have influenced perceptions held by some people. The sale of carp for human consumption is limited, even when the carp are of high quality. Hence carp are one of the cheapest fish because of low demand. Carp sold at the Sydney Fish Markets currently total 110 tonnes per year and fetch an average wholesale price of $1.25 per kilogram (*Carpe diem* documentary 1998). Carp sold at the Victoria Market, Melbourne, have fetched up to $1.50 wholesale per kilogram since commercial catches began in 1970s (Section 5.4). Retail prices for carp are usually $4–$6 per kilogram.

The range of carp food products has increased in the last five years and many recipes for cooking carp may be found in newspaper columns, fishing magazines and recipe books. The aim of many such publications is to raise awareness of carp as a serious environmental problem which people can help solve by removing carp and eating them (Easton and Elder 1997).

4.10.2 Export markets

Positive attitudes held in many European and Asian countries towards consumption of carp may offer export opportunities. One Australian operation currently exports to Poland (Section 5.4.2). K&C Fisheries aims to export $5 million worth of carp each year for human consumption in Europe (Ashley-Griffiths 1998) (see also Section 5.4.2). However, most potential importers are currently offering prices that are too low to support a profitable Australian export industry.

4.11 Carp action gr oups and catchment management

The first major forum for public discussion on carp was in Wagga Wagga in June 1994 (Murrumbidgee Catchment Management Committee 1994). In 1995, a two-day forum on carp was held in Renmark. It was organised by the Murray–Darling Association and was seen to be a Summit following a series of similar workshops (Murray–Darling Association 1995). The proceedings of the forum reflected the opinions of various stakeholders. One outcome was the formation of the National Carp Task Force (NCTF). The aim of the NCTF was 'to eradicate carp from all Australian inland waters through a coordinated action plan that promotes coordinated research, provides good information, explores commercial opportunities and seeks complementary legislation' (National Carp Task Force 1996a; Section 6.2.1).

A total catchment approach was taken by the River Basin Management Society Incorporated. At a forum for algal and nutrient management in 1995, carp were seen to be less of a problem than turbidity, blue-green algae (*Cyanobacteria*), river regulation, water quality, catchment degradation and other introduced species (McNee 1995). The philosophy underlying this approach was that carp should not be the scapegoat for other river problems and that the community perception needs to recognise that carp are part of a bigger problem of poor land and water management. Community perceptions often focus only on the physical presence of carp.

'Carp control is unlikely to rectify all apparent problems.'

Many action groups and those that come together at forums (Section 6.1) feel that the general public is unaware of the serious threat to aquatic systems posed by carp. Most groups mention at least one other factor affecting aquatic environments, such as altered water flows and increase in nutrients. Less likely to be mentioned are presence of cattle, land clearing, removal of streamside vegetation, previous decline of native fish, removal of instream habitats for native fish and the creation of still water habitats. There may be agreement that nutrients have increased but whether this is from agricultural fertilisers, cattle or urban effluents and run-off may vary with the locality.

It is widely assumed by catchment action groups that efforts to reduce factors that degrade river health (such as altered flows, land clearing, and nutrient increases), will help reduce catchment problems that are sometimes attributed to carp. If carp control is implemented it will be important to monitor changes in river health (particularly aquatic plants, native fish, turbidity and bank erosion) to determine if the expected benefits are realised (Section 8.5.2). Carp control alone is unlikely to rectify all apparent problems.

5. Economic and environmental impacts and commercial use

Summary

Carp can inflict major economic and environmental costs on both the public and private sectors by reducing water quality and degrading aquatic habitats. Industries which are affected include water suppliers for domestic and industrial users, agriculture, commercial and recreational fisheries and tourism. Although carp are often regarded as having a harmful effect on aquatic habitats, there has been little quantitative evaluation of the damage they cause to either the economy or the natural environment in Australia. The distribution and abundance of carp, and their dominance of fish communities across their range is well-described on a large scale, but their status in many individual sub-catchments is uncertain. There are also important knowledge gaps about the biology of carp under Australian conditions and their impacts on Australian aquatic ecosystems.

Although many of the potential impacts of carp have received some study both in Australia and overseas, the scale of many of the impacts is not clear because they can also be caused by other factors. Evidence exists for increases in water turbidity in the presence of carp, although the extent appears to be site specific. This increase is partly caused by the resuspension of sediments when carp feed. Their method of feeding is also responsible for the destruction of many aquatic plants, especially those with soft stems and shallow roots. There is some evidence that carp cause elevated nutrient concentrations. Impacts on native fish fauna are less well documented even though carp now dominate many freshwater fish communities. Declines in native fish populations in many areas had already begun prior to the expansion of carp and so the specific impacts of carp are difficult to ascertain. It is probable, however, that the reduced abundance of native fish species aided the establishment of carp. Changes in macroinvertebrate populations have occurred following the expansion of carp but these effects appear to be site specific and the mechanisms are not well understood.

Much of the commercial carp catch is sold for low price uses such as crayfish and lobster bait and fertiliser. There is currently little human consumption of carp in Australia and any value-added products are currently only produced on a small scale. Commercial harvest is only seen as contributing to the control of carp in certain areas and is unlikely to achieve wide-scale population reductions.

Carp are perceived negatively by most anglers because they are not popular for angling or eating. Angling is one of the most popular recreational sports in Australia and the dominance of carp in many fish populations has potential to reduce angler participation, particularly where numbers of preferred native fish species are low. Declining angler participation could cause substantial losses to fishing supply and associated tourist industries. However, 'coarse angling' for carp is gaining popularity.

5.1 Introduction

In order to predict the benefits of reducing carp (*Cyprinus carpio*) to lower densities, there is a need to understand and quantify the damage they cause at a range of densities, so that managers can determine whether the benefits of control justify the costs. The impacts of carp need to be considered in relation to information given in other sections, especially those relating to their control (Section 7.3) and to other influences on the natural environment (Section 3.5).

No study has been undertaken to quantify any economic effects, and although the environmental effects of carp have been widely debated, there have been few controlled scientific studies to quantify these effects and few attempts to extrapolate any impacts throughout the range of carp in wetland or river habitats (King 1995).

5.2 Economic impacts

Economic impacts of carp could impose major costs on both the public and private sectors. As most waters are 'owned' or controlled by government agencies, most costs associated with carp control would be borne by government. Some of these costs may be passed on to water users. There is a need to assess the economic and social costs of carp, the likely benefits of implementing control and the costs of damage where control is minimal. Analyses of the costs and benefits of carp control are needed on both a local and regional basis and for different types of economic damage inflicted by carp. Impacts on the environment also need to be considered if no carp control is undertaken.

To date, control or eradication of carp has only been attempted on a local scale with relatively little government expenditure. There has been no analysis of economic losses associated with carp and no economic assessments of reduced damage as a result of localised carp control.

5.2.1 Impacts on industry

Carp have potential to increase costs to several industries including:

- domestic and irrigation water suppliers
- agriculture
- recreational fisheries
- commercial fisheries
- tourism.

It has been suggested that carp may be a significant cost to the water industry because when they feed by sifting through the substrate they cause erosion and slumping of irrigation delivery channels (Eagle 1994; Jackel 1996; Section 4.2). Although repair to irrigation channels through bank stabilisation works is a substantial cost, these problems are unlikely to be caused solely by carp and other factors are probably more significant causes (Section 4.3). Other problems attributed to carp are increased suspended sediment loads, increased nutrient concentrations and algal densities which can clog water delivery machinery, such as pumps and filters, and increase pump wear and the cost of water treatment. Other costs caused by the impacts of carp on the agricultural industry could include damage to river frontages (Section 4.2) and loss of water quality for cattle. However, as most of these impacts are also caused by factors other than carp, it is difficult to apportion the costs directly attributable to carp.

Recreational fishing is one of the most popular participator sports in Australia and supports an industry worth millions of dollars per annum. The contribution of the recreational fishery (including support industries) to the Victorian economy is estimated to be about $1.3 billion per annum and generates about 27 000 jobs, although inland fishing accounts for less than 25% of this (Unkles 1997). To date only a small proportion of anglers actively seek carp and this is largely restricted to specialised 'coarse' anglers who follow European traditions including catch and release. Some ethnic groups selectively fish for carp for human consumption. A recent survey of recreational fishers in Victoria reported that in 1996 only 6.7% of freshwater anglers sought carp as a preferred species (Unkles 1997). This figure is expected to include some anglers who realistically assumed that carp was the species they could expect to catch and, given a choice, they would prefer other species. There are no comparative figures nationally, although given the ethnic mix of the Victorian population and the widespread availability of carp in comparison to other native species, any preference for this species in Victoria is likely to be higher than the national average.

Reductions in angling participation caused either by angler attitudes to carp or by carp-induced reductions in native fish populations would have significant negative flow-on effects to the tourist industry. Particular concern has been expressed in Tasmania, where the image of a high quality trout fishery has been tainted by the introduction of carp. During the enforced closure of Tasmanian lakes containing carp, some local economies were badly affected (A. Sanger, Tasmanian Inland Fisheries Commission, pers. comm. 1997). Costs to the tourist industry and the revenue of Tasmania have not been assessed but licence figures have not shown a decline since carp were discovered (W. Fulton, Tasmanian Inland Fisheries Commission, pers. comm. 1998). In an analysis of the effects of carp in the Gippsland Lakes in Victoria, it has been estimated that the costs to the community over five years are $175 million (Gippsland Lakes and Catchment Action Group 1996). This included losses to the native commercial fishery and losses to recreational fishing, tourism and commerce. Mechanisms for these losses were not explained.

'Reductions in aquatic plants, increased turbidity and effects on recreational fishing may all reduce the tourism potential of an area.'

Potential negative impacts of carp on recreational fishing for desirable species is likely to be substantial. In contrast, any gains from anglers actively seeking carp are likely to be localised and minimal. Any impact of carp on native commercial fisheries could cause significant commercial losses although such impacts have not been quantified. Because carp create a negative environmental image for some people (Chapter 4), waters with high carp numbers which are readily visible can be viewed as 'degraded'. This perception, together with reductions in aquatic plants, increased turbidity and effects on recreational fishing may all reduce the tourism potential of an area.

5.3 Envir onmental impact

The effects of carp overseas were reviewed by Fletcher (1979), King (1995) and Roberts and Ebner (1997). Although environmental impacts of carp have not been well studied in Australia, similar detrimental effects on aquatic plants and increases in water turbidity have been attributed to carp (Table 8; King 1995). Australian aquatic ecosystems differ substantially from temperate Northern Hemisphere ecosystems where carp have been more intensively studied. For this reason, it may be inaccurate to extrapolate any conclusions drawn from overseas studies to Australian conditions.

Table 8 indicates that impacts of carp are hard to establish in riverine systems, and many impacts have been inferred from studies in wetlands.

There is considerable discussion and anecdotal evidence as to the environmental impacts of carp and a considerable number of perceptions which have little or no basis. Whilst the facts as known to Australian scientists are outlined in Sections 1 – 3, Table 9 provides a summary of some common public perceptions compared to scientific facts.

There is little Australian research quantifying the impacts of carp on various ecosystem components. Major projects which have been completed include: the Victorian Carp Program undertaken from 1979 to 1982 (Hume et al. 1983b; Fletcher et al. 1985); some farm dams (Malcolm 1971); billabong and pond experiments (Robertson et al. 1995; Roberts et al. 1995; King et al. 1997); studies of irrigation drains (Bales 1994; Bowmer et al. 1994; Meredith et al. 1995); and rivers (Driver et al. 1997). There are unpublished studies which have investigated the effects of carp on plant communities (J. Swirepik, unpublished data, 1998). Most of these studies focus on water quality issues.

5.3.1 Difficulties assessing, assigning and valuing envir onmental damage

A key difficulty in assessing environmental costs is determining the actual environmental effects caused by carp. Figure 12 illustrates some of the direct and indirect impacts that carp may have on environmental variables. Many of the potential effects of carp could also be caused by other factors and because causal links are often unclear, quantification of the potential damage has not been attempted. This makes it difficult to assess environmental damage.

Even if the negative effects of carp on the natural environment and native species were

Table 8: Summary of supporting evidence for suggested impacts of carp in aquatic habitats. Point scale: * anecdotal evidence only, ** survey and/or dietary studies, *** artificial and tank experiments, **** field experimental studies (adapted from King 1995).

Location	Habitat type	
	Still water (lentic)	River (lotic)
a. Overseas studies		
Turbidity	****	*
Macrophytes	****	*
Macroinvertebrates	****	*
Phytoplankton concentrations	****	*
Interactions with native fish	*	*
Stream bank erosion	*	*
Nutrient concentrations	***	***
b. Australian studies		
Turbidity	****	**
Macrophytes	****	**
Macroinvertebrates	****	*
Phytoplankton concentrations	****	*
Interactions with native fish	**	**
Stream bank erosion	*	*
Nutrient concentrations	****	*

well described and quantified, assigning value would be difficult. While there are methods for estimating the cost of environmental damage, they are generally not universally accepted (Braysher 1993). An assessment of the impact of pest fish species is, in effect, an ecological analysis of the nature and results of interactions between the pest and native fish species and their habitats (Taylor et al. 1984) or other components of their environment. Research must progress through the stages of:

- determining which interactions occur
- describing and measuring them
- determining their significance.

Assessing the significance of interactions requires extrapolation across temporal and spatial scales and relies on designed experimental studies, usually conducted in more than one location. In Australia, such studies have only recently moved beyond the initial stage of identifying interactions and into the further stages of description and measuring. Few studies have been undertaken on the effects on ecosystems and therefore an overall assessment of impacts is not possible at present (Roberts and Ebner 1997). These issues of scale often mean that the impacts of carp can be obscure and difficult to ascertain (Driver et al. 1997).

5.3.2 Erosion

Jackel (1996) made anecdotal observations on the effects of carp ‘causing’ erosion to the banks of irrigation channels but these were not extrapolated to river systems. Many landholders also believe that carp in channel and river systems are causing damage to banks (Eagle 1994; R. McFarland, Lachlan River grazier, NSW, pers. comm. 1998; Section 4.2). Roberts and McCorkelle (1995) investigated the role of carp in channel bank erosion by excluding carp from sections of bank over the nine month irrigation season.

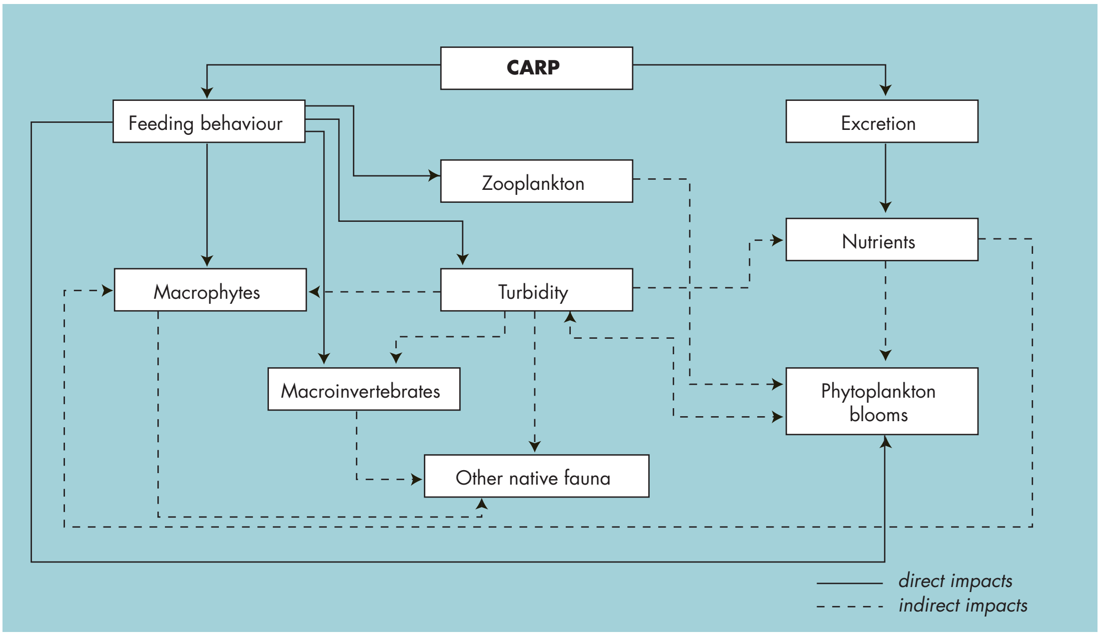
Table 9: Common perceptions versus facts about carp in Australia.

Common perceptions	Scientific facts
Carp spawn every year	Carp do not necessarily spawn or successfully recruit every year
Carp lay millions of eggs	Carp are very fecund and can lay millions of eggs per year
Eggs are spread by birds feet and are able to survive in mud and in the water to be fertilised at any time	Carp eggs only survive out of water for a short time and are usually attached to plants (Adamek 1998; Section 3.4.2). Unfertilised eggs soon die
Carp can survive in seawater	Carp cannot survive in seawater but are tolerant to half seawater salinity
Carp can swim away and survive even after they have been cut open	Carp may swim away using reflex actions but almost certainly die later
Carp stay alive in mud	Carp cannot live in mud
Carp undermine river banks	Carp feed by sifting through mud but there is no evidence that they undermine river banks
Carp cause trees to fall into rivers	There is no evidence for this
Carp damage aquatic plants	Carp uproot soft-leaved plants (Fletcher et al. 1985; Roberts et al. 1995; Section 5.3.5)
Carp spread diseases	A large number of parasites, diseases and viruses (Sections 5.3.7 and 3.4.4) have been associated with carp but there have been no specific reports of deaths of native fish caused by carp-borne diseases in Australia (Roberts and Ebner 1997)
Carp flesh is not good food	Carp flesh is nutritious and can be eaten and refined into many fish products for human consumption
Carp eat native fish and eggs	Carp may eat small numbers of eggs or larvae of certain species but these are likely to be taken incidentally and is unlikely to reduce populations of these species

Undercutting and bank slumping was observed to occur, in all sections studied, including where carp were excluded, and so these effects could not be attributed to carp. This highlights one of the problems in isolating the effects of carp from other effects such as high flows, excessive water extraction, lack of riparian vegetation and livestock access, which can all damage river banks.

5.3.3 Water quality

Many of the effects of carp on water quality can be related to their feeding behaviour (Section 3.3.1). Carp feeding activity increases turbidity by continually resuspending sediments. Both overseas and Australian studies demonstrate increased turbidity in the presence of carp (Fletcher et al. 1985; King et al. 1997). In flowing waters, increased turbidity associated with carp density can persist for



Figur e 12: Model of the major effects of carp on structural and process components of the aquatic environment (adapted from King 1995).

large distances downstream. The magnitude of effects can also in many instances be site specific (Fletcher et al. 1985; King et al. 1997).

Lougheed et al. (1998) used carp of different densities in enclosures in a marsh in Canada to show that turbidity, total phosphorus and total ammonia concentrations all increased as predicted with increases in carp biomass.

Roberts et al. (1995) found that experimental ponds in western New South Wales, when stocked with carp at densities of 510 and 226 kilograms per hectare, showed an increase in turbidity from 7 to 73 Nephelometric Turbidity Units (NTU) respectively, over only four days. Malcolm (1971), working in Gippsland in Victoria, found a general trend indicating an increase in turbidity in farm dams with the presence of carp. The removal of carp was followed by a reduction in turbidity.

Fletcher et al. (1985), in a study of billabongs, found the highest turbidity occurred in a small shallow billabong where carp were present at a density of 15–20 kilograms per hectare. In contrast, the billabong with the highest carp density (690 kilograms per hectare) had a significantly lower turbidity (mean value 47 NTU) than other sites.

Robertson et al. (1997) and King et al. (1997) adjusted carp in billabongs to be at densities of 1180, 1000, 715 and 310 kilograms per hectare. Carp were found to have a significant effect on the rates of sediment resuspension. Carp accounted for 60% of overall variance in turbidity in a silty billabong, and in the treatment with the highest biomass of carp, they were by far the major factor influencing turbidity.

'Turbidity, total phosphorus and total ammonia concentrations increased with increases in carp biomass.'

Increased turbidity reduces light penetration, which can lead to lower photosynthetic production, and may have detrimental effects on fish which rely on sight to feed. When sediments settle again, they may smother attachment sites for invertebrates and spawning sites for fish.

Turbidity can be caused by many forms of environmental degradation, particularly of riparian zones and catchments. Many Australian inland lakes and river systems are naturally turbid because of their extensive floodplains and the types of clay present. On a floodplain, a turbidity reading of less than 17.5 NTU would be considered low (Ladson and White 1999). In a two-year study of the Broken River, Fletcher et al. (1985) found turbidity increased downstream from 23 to 46 NTU, correlating with increased carp catches. A maximum value of 75 NTU occurred when water levels rose because sediments were washed in from the catchment. In Australia storm events deliver the major sediment loads to Australian streams (Cosser 1989; Donnelly et al. 1997), with increased inputs downstream associated with land clearing and erosion. During low flows clay particles may flocculate and settle to the bottom. It is in these still waters that carp may act as an agent for resuspending sediments but carp are not the original cause of the sediments being present. A difficulty with most studies of carp-induced turbidity is that turbidity caused by other fish species is ignored, so that effects caused by carp alone tend to be overestimated.

Robertson et al. (1995) also found that carp had a negative impact on the development of epiphytic algae, probably because of decreased light penetration caused by carp increasing turbidity. Robertson et al. (1995) found that concentrations of total phosphorus were usually greater with higher carp densities, but there was no consistent patterns for dissolved phosphorus. High carp densities were also associated with more frequent and intense phytoplankton blooms. Concentrations of chlorophyll *a* (algae) in the water column were greatest where carp numbers were highest.

Carp have also been reported in overseas studies to increase phytoplankton concentrations, with an increase in nutrients from excretion suggested as the most likely mechanism (Lamarra 1975). One review has suggested that this mechanism may be partly responsible for the intensity of algal blooms in some Australian rivers (Gehrke and Harris 1994). There is certainly a public perception of a causal link between increases in cyanobacterial blooms and increases in carp numbers as both events occurred over similar time periods. There has been no research conducted in Australia to test this hypothesis.

5.3.4 Impacts on native fish

The role of carp in the decline of Australian native fish populations has been the subject of much speculation, but scientific evidence is lacking (Harris 1994). There has been consideration of declining catch rates of commercial native fish species such as Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*) over the same period as increases in catch rates of carp, but this correlation does not include a causal link as many other factors were operating on these native fish species at the time (Section 2.1.4). Examination of the declining commercial catches of silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*) in New South Wales by Reid et al. (1997) and Clunie and Koehn (1998) found that major declines in both native species had occurred well before any increases in the catch of carp. Similarly, declines in catches of both Murray cod and golden perch occurred during the 1950s, well before the expansion of carp populations (Derwent 1994; Reid et al. 1997). The diet of carp includes macroinvertebrates (Section 3.5.1), which may lead to competition with many native species, but few native fish species (with the exception of freshwater catfish) feed on the benthos in the same way as carp.

Whilst there may be some competition between carp and native fish for both food and space, dietary overlaps appear minimal and the effects of habitat interactions have not been quantified. There is little evidence that carp eat native fish (Section 3.5.1). Benthic feeding carp could, however, ingest demersal eggs of some species. For example, considerable concern has been expressed over the potential effects of carp on the behaviour of freshwater catfish spawning, guarding nests and the survival of eggs deposited in the nests (S. Rowland, NSW Fisheries, pers. comm. 1998), but such interactions have not been tested. This concern is not evident in the Hawkesbury River where these two species coexist (Gehrke and Harris 1996).

Koehn and Nicol (1998) found overlap in habitat use by native species and carp, with both using snags and areas of slower flowing water. Another pressure on habitat use for native species may be behavioural pressure exerted by large schools of large carp, which may force smaller native fish from their preferred habitat areas. The high biomass of carp reported for many areas (Section 3.5.4) may have the effect of physical exclusion from habitats for native species.

'Declines in catches of both Murray cod and golden perch occurred during the 1950s well before the expansion of carp populations.'

Benthivorous feeding and destruction of aquatic vegetation by carp may reduce the suitability of habitat for native fish species. Wager and Jackson (1993) suggested carp as one cause of the decline of several threatened species including: dwarf galaxias (*Galaxiella pusilla*), trout cod (*Maccullochella macquariensis*), Yarra pygmy perch (*Nannoperca obscura*) and variegated pygmy perch (*Nannoperca variegata*).

Gehrke et al. (1996) found recruitment of golden perch and bony herring (*Nematalosa erebi*) declined in rivers where carp recruitment was high, but these authors attributed the trends to flow modifications rather than to a direct effect of carp. It has also been suggested that carp act as an energy trap, limiting the amount of energy available to predators higher up in the food chain (Gehrke 1997a; Section 3.5.4).

'Benthivorous feeding and destruction of aquatic vegetation by carp may reduce the suitability of habitat for native fish species.'

Carp are also prey for many native species including Murray cod, golden perch, trout cod, (Section 3.5.2) water rats (*Hydromys chrysogaster*), and birds such as pelicans (*Pelicanus conspicillatus*) (Kailola et al. 1993). Although populations of these species may benefit from the abundance of carp, their reliance on carp as a food source has not been investigated.

As the causal links for the decline of native fish populations and fisheries are not fully understood, it is difficult to forecast the degree of benefit to native fish populations if carp numbers were to be reduced. If carp really are a symptom of river degradation rather than a cause, other measures will also be needed to allow recovery of native fish populations.

5.3.5 Impacts on native plants

Carp have a major effect on aquatic ecosystems by reducing the density and biomass of macrophytes through both direct grazing and by physically uprooting plants when feeding (Winfield and Townsend 1991). Several experimental studies have been conducted overseas which have quantified such effects:

- King and Hunt (1967) reported increases of 30% and 75% in the dry biomass of plants in the first and second years of excluding carp with quadrat cages in a lake marsh in Michigan, United States of America. An increase in the diversity of plant species was also recorded. When they completely removed carp from the marsh by poisoning, a 30-fold increase in the biomass of the attached algae (*Chara* sp.) was recorded over an eight week period.

- In France, Crivelli (1983) found that when carp were enclosed in cages at densities of 450 kilograms per hectare, 68% of the aquatic vegetation persisted. He proposed that carp had not affected vegetation in natural European habitats where carp densities were less than 59 kilograms per hectare.

- Winkel and Muelemans (1985) conducted an experimental study in the Netherlands and reported dense mats of the attached algae (*Chara* sp.) appearing after three weeks of the exclusion of carp in exclosure experiments. This vegetation disappeared again when the cages were removed. Other plant species also recovered when carp were excluded.

- Meijer et al. (1990) also reported increased abundance of the attached algae (*Chara* sp.) after two months of carp removal in half of two lakes. After a further 16 months, the lake vegetation was dominated by a soft-stemmed pondweed (*Potamogeton pectinatus*) and the density of a filamentous algae (*Spirogyra* sp.) had also increased.

- Richardson et al. (1990) used 18 large experimental ponds with manipulations of presence and absence of carp to show that carp caused a decrease in the amount of algae. It is unclear whether this was caused by direct feeding or by an indirect effect caused by increased turbidity.

- Lougheed et al. (1998) linked reductions in numbers of plant species to increases in water turbidity in enclosures stocked with different densities of carp in a marsh in Canada.

- Lundhom and Simser (1999) reported large increases in submerged macrophyte population densities in Lake Ontario, Canada, when carp densities were reduced from 700 kilograms per hectare in 1996 to 50 kilograms per hectare in 1997.

Studies on the effects of carp on Australian aquatic plants include:

- Fletcher et al. (1985) concluded from field studies with carp added to billabongs in northern Victoria, that carp were generally not responsible for destruction of macrophyte beds. They did find a decrease in the abundance of some macrophytes in billabongs following an increase in carp numbers and suggested that high densities of carp could eliminate susceptible plant species such as pondweed (*Potomogeton* spp.).

- Roberts et al. (1995) added carp to small ponds in the Riverina in New South Wales and showed that carp at a biomass of 226 kilograms per hectare significantly reduced the number of ribbonweed (*Vallisneria* sp.) plants.

- Bales (1994) and Bowmer et al. (1994) conducted a preliminary experiment in equal halves of an irrigation drain in the Riverina, New South Wales. They observed new growth of macrophytes after the removal of carp from a section of irrigation drain. The interpretation of this study was complicated by the presence of carp prior to the experiment.

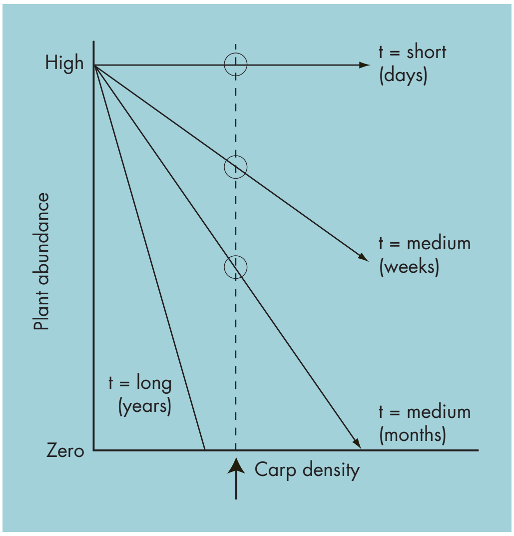
- Roberts and Sainty (1997a, 1997b) recorded an oral history of the Lachlan River provided by local residents. Many local residents reported the loss of aquatic vegetation during the time which coincided with the occurrence of carp. Causal links, however, could not be proven.

- J. Swirepik (NSW Environment Protection Agency, pers. comm. 1998) conducted experiments by adding carp to large-scale ponds in the Riverina of New South Wales and recorded poor macrophyte regrowth in ponds with carp compared to dense regrowth in ponds where carp had been excluded.

Although all types of macrophytes have not been studied, these studies indicate that shallow-rooted, soft-leaved and submerged vegetation (including attached algae *Chara* sp.) are the growth forms most likely to be affected by carp.

'These studies indicate that shallow-rooted, soft-leaved and submerged vegetation are most likely to be affected by carp.'

It is difficult to study the temporal dynamics of aquatic ecosystems because of the long time scales over which they change naturally. For this reason, it can be difficult to understand and predict the responses of rivers to threats and disturbances like carp. Roberts and Ebner (1997, Figure 13) provide a simple model which illustrates potential relationships between carp density, impact and duration of impact, in order to show the problems of using experiments and experimental time frames to reveal real impacts.



Figur e 13: Effect of exposure time on the relationship between carp density and plant biomass remaining. A hypothetical series of plots, showing the cumulative effect of carp on four time scales (t), ranging from days to years of exposure. Field impact experiments are typically of medium length. For a specific carp density (indicated by arrow on x-axis), there is a huge variation in observed impact, changing from insignificant (high plant abundance) to catastrophic (zero plant abundance), depending on the exposure time (Roberts and Ebner 1997).

5.3.6 Impacts on macr oinvertebrate communities

Although the diet of carp consists mainly of zooplankton and macroinvertebrates (see Chapter 3), there are few quantitative studies of the impact of carp on macroinvertebrate communities. Carp have, however, been implicated as a secondary factor in the decline of indigenous gastropods in the Murray River, through changing the food supply (Sheldon and Walker 1993).

Overseas research from lentic habitats, includes:

- Guziur and Wielgosz (1975) recorded considerable decreases in the total numbers and biomass of benthic macroinvertebrate fauna in a lake following the introduction of carp at a density of 153 carp per hectare. The greatest decreases in benthic fauna were recorded for chironomids and gastropods.
- Richardson et al. (1990) recorded reductions in chironomids, coleopterans, trichopterans, hemipterans and gastropods in experimental ponds following the introduction of carp.
- Wilcox and Hornbach (1991) recorded changes in community diversity, richness and evenness, but not total densities of invertebrates, at different densities of carp in cages in the backwaters of a lake in the Mississippi catchment, United States of America.
- Tatrai et al. (1994) used experimental ponds stocked with different densities of bream (*Abramis brama*) and carp, finding a decrease in total biomass of benthos with increasing abundances of carp. This was presumably because of predation by carp, and a change in community structure to species with rapid life cycles such as oligochaetes and chironomids.
- Lougheed et al. (1998) reported that carp of different densities in enclosures did not have a direct effect on the zooplankton community structure, but increased turbidities and nutrient loads associated with carp activity resulted in a reduced total zooplankton biomass. They then developed a relationship between species richness and water turbidities for 19 wetlands in the Great Lakes Basin with an apparent turbidity threshold of 20 NTU.

Australian studies include:

- Hume et al. (1983b) studied carp diets in the field, but not their effect on macroinvertebrate communities, and found they fed mainly on algae and zooplankton as juveniles (less than 150 millimetres in length), on benthic insects and detritus as young fish (150 to 400 millimetres in length) and added occasional plant matter to these items when they became adults (greater than 400 millimetres in length).

- Robertson et al. (1995) added and removed carp to billabongs in the Riverina, New South Wales and found that the community structure of epifaunal and infaunal macroinvertebrates were altered significantly by the carp biomass. The species richness of the epifauna was not correlated with carp abundance but epifauna densities decreased at high carp densities. Infaunal densities were not consistently affected, but densities of the macroinvertebrate families Leptoceridae and Ceratopogonidae were greater with higher carp densities, possibly because of increased algal cell detritus following phytoplankton blooms. Carp were also found to affect benthic macroinvertebrate densities.

5.3.7 Diseases

Pathogens associated with carp are reasonably well known and include 226 parasites, fungal diseases such as that caused by *Saprolegnia*, eight different bacterial diseases and two viral diseases (Jeney and Jeney 1995). The presence of a pathogen, however, does not necessarily result in clinical disease. Whilst carp have been implicated in the world-wide distribution of parasites and pathogens (Hoffman and Schubert 1984), only a few outbreaks of disease in freshwater fish in Australia have been attributed to carp (Laurence 1995), with no specific reports of deaths linked to carp-borne disease (Roberts and Ebner 1997). It is, however, possible that such impacts may pass undetected if they occur. Goldfish ulcer disease (*Aeromonas salmonicida*) infects goldfish (*Carassius auratus*) as well as roach (*Rutilus rutilus*), carp and the native silver perch (Humphrey and Ashburner 1993). Hume et al. (1983a) found a low parasite load in carp specimens collected from north-eastern Victoria, including the parasitic copepod *Lernaea*, as well as several protozoans. The Asian fish tapeworm (*Bothriocephalus acheilognathi*) has been found in carp, as well as in other introduced fish species, such as gambusia (*Gambusia holbrooki*), redfin perch (*Perca fluviatilis*), goldfish and the native western carp gudgeon (*Hypseleotris klunzingeri*). This tapeworm may cause high mortalities and is known to affect carp but its effect on native fish is unknown (Dove et al. 1997).

Spring Viraemia of Carp Virus (SVCV) is not specific to carp (Section 3.4.4). SVCV has been isolated from ten fish species from four different families (Crane and Eaton 1997) and is also able to infect fruit flies (Bussereau et al. 1975). However, testing of Australian native fish for susceptibility to the virus, conducted in England, found that river blackfish (*Gadopsis marmoratus*), flathead gudgeon (*Philypnodon grandiceps*), golden perch, silver perch, Murray cod, southern pygmy perch (*Nannoperca australis*) and dwarf galaxias were not sensitive to SVCV (Hume et al. 1983a). These results need to be treated with caution because apart from native fish, tests in England also found that goldfish were not sensitive to the virus. Since then, goldfish have been found to be susceptible (Crane and Eaton 1997), so that the apparent lack of sensitivity to the virus in native fish cannot be taken for granted. To date, outbreaks of Spring Viraemia of Carp Disease in wild carp have only occurred rarely if at all.

5.3.8 Conservation values

Carp have a major impact on the composition of freshwater fish communities because they completely dominate both fish numbers and biomass in many areas. This, together with the removal of aquatic plants and changes to invertebrate fauna and habitats, is likely to have altered many of the ecological relationships and ecological processes within aquatic communities. The impacts of carp on aquatic habitats and the benthos have been described in this chapter (Sections 5.3.3 to 5.3.7) and there are many impacts on the conservation status of several threatened fish species (Wager and Jackson 1993).

5.3.9 Links with other issues

Carp are successful colonisers and flourish in degraded environments. Poor water quality, high nutrient loads, frequent algal blooms, high water turbidity and bank erosion are caused by a number of factors in addition to carp (Section 2.1.4). Alterations to flow regimes and lack of drying of wetland areas have also caused changes to aquatic environments. The establishment of carp populations has been assisted by a multiplicity of degrading processes. In essence, carp are an indicator of a wide range of environmental problems and, especially in high densities, also contribute to some of them.

5.4 Resour ce value and commer cial use

Carp are considered a resource in many parts of the world. The potential value of commercial exploitation of carp in Australia is unknown. Estimates have been made but the only data available are from a few limited ventures at selected sites. Expansion has been limited by lack of additional markets for Australian carp. These markets may be for either human consumption or use in products such as fish oils, cattle food, pet food, fertilisers and fish 'leather'. There is potential to enhance carp products by value adding. The value of all carp products is generally low at present which means large numbers need to be caught to make an operation viable. Carp can be difficult to handle, as their dorsal spines can catch on nets, so capture methods must be labour efficient.

'It is necessary to determine whether commercial harvesting reduces a pest's density sufficiently to achieve desired reductions in environmental damage.'

The commercial use of pest animals has been considered to reduce the density of land vertebrates such feral goats, (Parkes et al. 1996) and feral pigs (Choquenot et al. 1996). It is necessary to determine whether commercial harvesting reduces a pest's density sufficiently to achieve desired reductions in environmental damage. This has not been investigated for carp. The problem for commercial operators has been low return for a high workload with low carp prices deterring most operators. There is also an expectation of an increase in effort for a lowered catch if fishing off-take reduces carp densities. Commercial operators can face a range of market problems (Table 10).

Kriz (1996) reported findings from market research that outlined the future of carp for the domestic market (Table 11). If the weaknesses and threats listed in Table 11 can be converted into strengths and opportunities then there is a possibility of economic expansion. The poor public perception of carp is being addressed with tastings of carp and carp products (Easton and Elder 1997). More work is being undertaken on the cost of value-added products and export opportunities (K. Bell, K&C Fisheries, Victoria, pers. comm. 1998).

5.4.1 Curr ent Australian markets

Human food

Human consumption of carp is limited in Australia. In 1997, approximately 30% of carp harvested in Australian were sent to the Sydney and Melbourne fresh fish markets (Gooley 1997). Carp are sold from these markets mainly to European and Asian ethnic groups. The wholesale price paid at fish markets varies from $0.50 to $1.85 per kilogram. Market fish are sold whole but if the carp are also filleted there is greater opportunity for other products. Some prices are given by Gooley (1997) in Table 12.

Commercial fisherman and restauranteur of 25 years, Henry Jones, has served carp in his Yabby City restaurant in Clayton, South Australia, for the past four years. This is believed to be the only restaurant in the country which actively promotes carp as a fine eating fish. Recipes include crumbed carp, carp in oregano with olive oil, carp kiev, vinigarettes, rollmops, smoked carp and carp pate. The popularity of carp dishes has steadily increased and now accounts for more dishes than any other fish species (H. Jones, Southern Fishermen's Association, South Australia, pers. comm. 1998). Yabby City also provides fish and advice on the preparation of carp dishes to other restaurants for special occasions such as ceremonies for overseas guests. Filleting carp properly results in large, boneless fillets and

Table 10: Problems and potential solutions for carp marketing in Australia.

Market problem	Potential solutions
Low market price of carp	Use only cost-effective harvesting in selected area. Development of value-added products. Increase quality of product. Ensure correct industry and marketing approach to prevent 'flooding'.
Poor domestic market	Develop export markets. Increase product knowledge in targeted local markets. Develop new products.
Lack of reliability of supply for markets	Increase freezer holding capacity. Schedule harvesting.
Competition from imported fish	International negotiations regarding the development of new industries and products. Better marketing.

Table 11: SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of the carp market conducted by Kriz (1996).

Strengths	**Weaknesses**
Supply is plentiful at present	Future supply is unknown, catch rates are variable and often unknown. Uncertain supply makes marketing difficult.
By-products such as skin	–
Low prices compared to other commercial species	Limited export, carp are easy to culture overseas
Positively regarded by Asians and Europeans as food	Poorly regarded by Australian consumers as food. Taste of carp is masked in other parts of the world. Complex bone structure gives poor fillet yields. Processing is the only alternative.
Potential use in feeds and fertilisers	Supply is unknown. Market difficulties
Useful in value-added products, such as smoked or dried products	Little is known about processes and costs for value-added products
Opportunities	**Threats**
Niche market for skinless, boneless and branded fillet that is low priced	Aquaculture carp production is efficient and widespread in carp-producing countries
Carp as raw material for surimi	Imports of carp may increase by establishing a market for the product
Processed products for human consumption such as fish cakes, fish balls, canning or other processing	Negative public perceptions may persist despite active marketing of carp products

Table 12: Values of carp (after Gooley 1997). Point scale: * good quality off fillet (estimated 15–20% of total catch); ** gilled and gutted; *** gutted; Prices are wholesale (delivered) in dollars per kilogram (unless otherwise stated).

Human consumption	**Dollars per kilogram**
Chilled and smoked whole fish**	0.80
Chilled and smoked prime-cut fillets (skinless, boneless)	2.50
Tinned fish	0.32
Fish balls, cakes and mince	no figures available
Cured (smoked or marinated) small goods	no figures available
Dried whole fish and sprinkle type seasoning	no figures available
Surimi	2.50
Fish protein concentrate***	0.11
Non-human consumption	
Fish meal	0.15
Fish oil	0.11
Liquid fertiliser	0.15-0.20
Stock and fish food ingredient (wet or frozen biomass)	0.03
Tanned fish skins	0.50 per skin*
Crayfish bait	0.30-0.50
Processed recreational fishing bait	0.15
Pet food ingredient (wet or frozen biomass; replacement for mackerel and pilchards	no figures available

High standards of post-harvest handling are critical to maximise the commercial value of carp. Source: A. Toovey, NSW Fisheries.

Despite having a complex bone structure, proper filleting of carp can produce large fillets and boneless strips suitable for a wide range of fish dishes. Source: A. Brumley, East Gippsland Institute of TAFE.

boneless strips suitable for a large range of fish dishes. Yabby City is operated in conjunction with a commercial operation, fishing for both native fish and carp in the lower Murray River, and sells carp directly as a table fish or a range of other products. Fresh boneless carp fillets are sold for $6.50 per kilogram whilst smoked carp can fetch up to $10 per kilogram. Retail prices for whole carp are up to $7 per kilogram in some Sydney shops.

Carp for the domestic market come mostly from two lake areas in Australia: the Coorong and Lake Alexandrina area in the lower Murray River in South Australia and the Gippsland Lakes in Victoria. In South Australia, some 30 licensed commercial operators target a range of native and introduced species, mainly with mesh nets. The carp from Lake Alexandrina are transported to Adelaide and then to the Sydney market (H. Jones, Southern Fishermen's Association, South Australia, pers. comm. 1998). In Victoria, the 18 operators in the Gippsland Lakes mainly use mesh nets and large seine nets to target native fish, especially black bream (*Acanthopagrus butcheri*). If carp are caught in small numbers they can be sent for domestic use. Smaller quantities of carp are caught commercially from rivers and lakes in New South Wales.

In the Gippsland Lakes, commercial operators selling carp to wholesale markets between 1993 and 1998 obtained prices of $0.20–$1.50 per kilogram (D. Allit, Gippsland Lakes Fisherman, Victoria, pers. comm. 1998). Generally the prices are extremely low, less than $1 per kilogram, compared to the native black bream which fetches $8–$10 per kilogram. Commercial exploitation is not possible by operators who only catch carp as a non-target species.

Carp dominate the catch from the Gippsland Lakes area. In 1995, the commercial catch of carp was 334 tonnes of the total 653 tonnes of fish. One operator (K&C Fisheries, Section 5.4.3), solely targets carp and supplies markets in Melbourne and Sydney. Quality fish, handled appropriately, fetch higher prices. Carp are placed in ice slurry to preserve flesh quality and flavour and to prevent bacterial growth (K. Bell, K&C Fisheries, Victoria, pers. comm. 1998). Carp from the Gippsland Lakes often come from brackish water, which may enhance their eating qualities, although this has not been tested.

Crayfish and rock lobster bait

About 40% of Australian carp harvested are sold for bait to the rock lobster industry (Gooley 1997). Small carp are frozen into blocks and transported to the fishing ports of south-eastern Australia. The peak of demand coincides with the summer catches for rock lobster and is zero during the winter off-season. Prices for this market range from $0.30 to $0.50 per kilogram (K. Bell, K&C Fisheries, Victoria, pers. comm. 1998).

In South Australia, the availability of carp as crayfish bait has been variable. Larger storage freezer facilities are needed to ensure a more constant supply (H. Jones, Southern Fisherman's Association, South Australia, pers. comm. 1998). Even carp used for cray bait need to be fresh because mucus promotes bacterial growth which makes the bait less attractive. It is a misconception that waste carp can be marketed for cray bait and other products (K. Bell, K&C Fisheries, Victoria, pers. comm. 1998).

Fertiliser

The amount of carp used in the production of liquid fertiliser is currently low but is increasing. One product, 'Charlie Carp' targets the domestic nursery and home garden market. Made from pulped carp and rice fibre, the liquid fertiliser is sold for home gardeners in one litre retail bottles or 20 litre containers for farm use. As the price paid to the commercial harvester for this product is as low as $0.15 per kilogram (Table 12), large quantities of fish must be readily available for harvesting to be economically viable. Fish needs to be fresh to ensure the fertiliser is of a satisfactory quality.

Cattle feed

A report of an enterprise manufacturing cattle feed from carp made in 1997 (*Water Rabbits* documentary 1997) indicated the average price paid was $0.10 to $0.35 per kilogram of carp (Wilson 1998), which showed a need for large quantities of carp at low prices. Fish of all sizes could be used for this product, but again they must be fresh.

5.4.2 World markets and world pr oduction

Carp are easy to produce and are a good source of protein with the main production of carp for human consumption occurring in China (Lin and Peter 1991). Chinese carp production from aquaculture was estimated to be 3 275 000 tonnes in 1990 (Kriz 1996). The dominance of carp production in China is overwhelming, although India, Bangladesh and Indonesia also produce carp through pond aquaculture. Even though these countries produce less carp than China, production in India is still approximately twice that of individual European countries. In Japan, there is strong consumer demand for marine fish products, so carp are not produced for food as much as in other Asian countries. The Koi strain of carp features in Japan as an ornamental fish.

Aquaculture is also a large industry in most European countries today. Total production of carp in 1990 ranged from 7000 tonnes in Bulgaria to 392 806 tonnes per annum in the USSR (Kriz 1996). Research on carp includes aquaculture with other species (polyculture), conservation of the gene pool and productivity of ponds and natural ecosystems. In the Czech Republic, the Research Institute of Fish Culture and Hybrobiology aims to improve the culture of common carp (Z. Adamek, University of Southern Bohemia, Czech Republic, pers. comm. 1997). Carp are frequently stocked into eutrophic reservoirs of central and eastern Europe to enhance fish production (Bninska 1991). In 1990, trout accounted for 81% of aquaculture fish production in Europe with carp constituting 13% (Kriz 1996). The low production of carp in aquaculture in Europe may be partly attributable to the dominance of cyprinids in the wild fishery. The production of wild salmonids (Salmonidae) has diminished in Europe compared to the cyprinids. Wild fishing for carp still occurs in Europe in the Caspian and Black Seas and eastern Europe (Bninska 1991, Z. Adamek, University of Southern Bohemia, Czech Republic, pers. comm. 1998).

Value of Australian exports

A marketing study conducted by Kriz (1996) concluded that the export of carp from Australia for human consumption was not viable because they are cultured easily in many other countries. The production of carp in countries where carp are desirable must be high to meet the demand. Cultured carp in these countries are being used to restock natural waters for recreational catches.

In Poland, the 1990 production of carp was 20 000 tonnes (Kriz 1996). In 1997, a Polish importer recognised it was economically viable to import Australian carp (Keith Bell, K&C Fisheries, Victoria, pers. comm. 1998). In January 1998, a contract was signed with K&C fisheries to export a minimum of 300 tonnes to Poland over the following 12 months. These carp come from the clean waters of the Gippsland Lakes where they are collected with high standards of handling and ice preservation. The carp, of up to six kilograms in weight, are headed, gutted and tailed, then exported frozen. The process follows strict license requirements from the Australian Quarantine and Inspection Service (AQIS).

'The fact that Australian carp are grown in rivers and not farmed is seen as an advantage for the German market.'

An Australian company, Australian Abalone Exports Pty Ltd, has established companies in Germany, Israel and Spain to export a range of value-added carp products. The German company, called Australian Gourmet Imports, uses the brand name River Gold and a marketing spiel of '*Cyprinus carpio, simply the best*'. The range of carp products includes canned, smoked and dried carp, carp jerky, a soup additive, carp au naturel, carp in abalone sauce, carp in piquant sauce and a product developed in accordance with Jewish kosher requirements. The fact that Australian carp are grown in rivers and not farmed under aquaculture conditions is seen as an advantage for this market (F. Glasbrenner, Managing Director, Australian Abalone Exports Pty Ltd, Victoria, pers. comm. 1999).

5.4.3 Curr ent Australian pr oduction

The standing stock of carp in Australia is not known, but is thought to be in the order of tens of thousands of tonnes (Gooley 1997). An assessment of the carp stock in New South Wales of 76 000 tonnes was produced by Wilson (1998) using carp population and distribution estimates from Harris and Gehrke (1997). Wilson's estimate includes carp in dams and water storages not included in the population survey and is likely to be far higher than any estimate of potential harvest because much of the resource is in remote areas where full exploitation would be difficult. Carp fisheries have not been subjected to stock assessments in Australia. Carp production levels reflect demand: where profitable markets exist, production occurs (Table 10). Gooley (1997) gave an estimate of 5000 tonnes of carp per annum to be the accessible and biologically sustainable yield across south-eastern Australia.

Total Australian carp production in the 1990s has ranged from 900 to 1675 tonnes per annum with the approximate breakdown by State as follows:

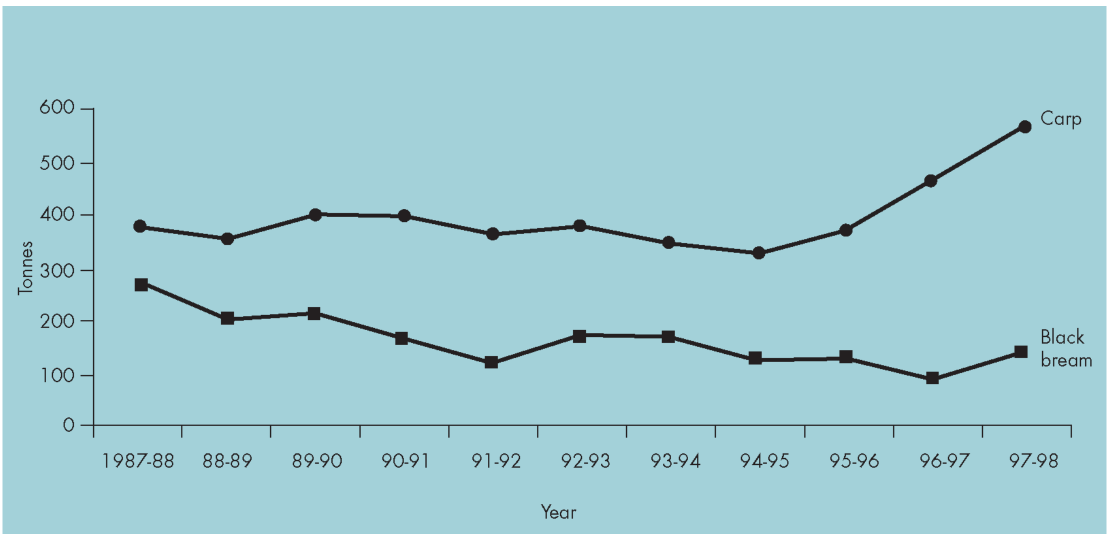
- Victoria, 300–600 tonnes per annum
- South Australia, 500–1000 tonnes per annum
- New South Wales, 100–175 tonnes per annum.

It appears that there are sufficient wild stocks of carp available in Australia to satisfy an expansion of existing markets.

Professional commercial fishing operations based solely on carp have occurred in South Australia and Victoria along the Murray River. In Victoria, carp have been harvested from the Gippsland Lakes for the past 14 years. The Gippsland Lakes carp fishery was worth $375 000 in 1996–97 with a total catch of 478 tonnes. This represented 85% of the total carp catch in Victoria, a proportion that has been consistent over ten years (Figure 14; Keith Bell, K&C Fisheries, Victoria, pers. comm. 1998). The catch of carp reflects the market demand but not necessarily constant carp numbers. The black bream catch in the Gippsland lakes (Figure 14) has declined during the same time (Coutin et al. 1997).

Markets for carp are discussed in a case study of the main commercial operation in Victoria (Box 1) (K. Bell, K&C Fisheries, Victoria, pers. comm. 1998). Important features of this successful carp harvesting operation are:

- large numbers of carp are caught efficiently
- methods are available to handle the huge weight of fish
- methods are available to avoid the carp's spines



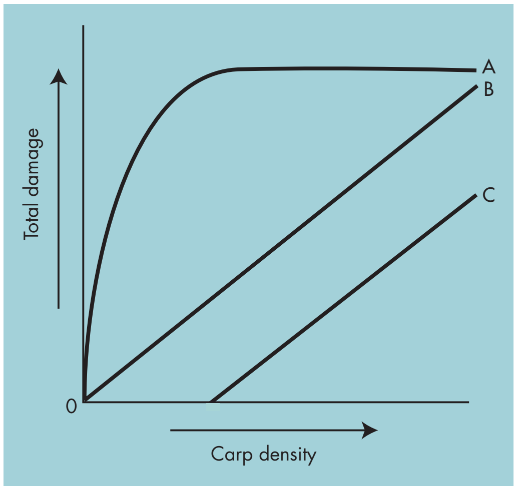
Figur e 14: Catches of carp and black bream in Gippsland Lakes, Victoria, from 1987–88 to 1997–98 (Department of Natural Resources and Environment, Victoria 1998). Reproduced with the permission of Department of Natural Resources and Environment, Victoria.

- fresh fish are sent to market in constant low amounts
- handling methods ensure quality is maintained for carp for all markets
- some carcasses are put to multiple use for a range of products
- storage and freezing facilities are available for non-peak times for some markets
- research is conducted into new markets and value adding
- efficient transport is available to capital cities.

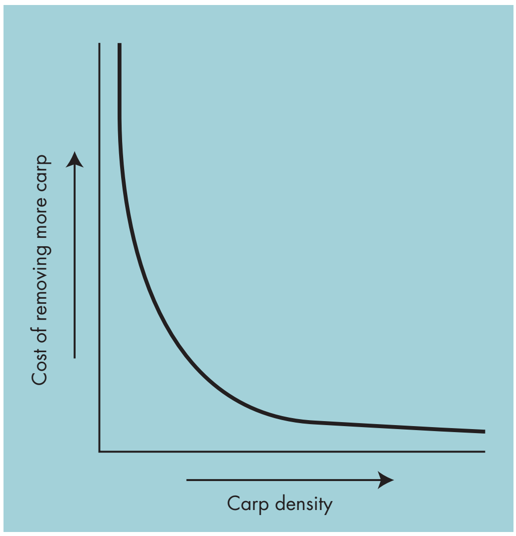
Further details of carp harvesting and marketing operations are given in the damage control case study (Box 2; Section 5.4.4).

5.4.4 Commer cial harvest as damage contr ol

If ongoing commercial harvesting is to be a viable control method, it must reduce and sustain carp densities at levels where damage is reduced to acceptable levels. Determining these levels requires better knowledge of carp density–damage relationships (Figure 15, see also Appendix A, Step 3) so that a target carp density can be set to meet resource protection goals (Bomford and Tilzey 1997; Choquenot and Parkes, in press). If the carp density required to achieve damage control goals is relatively low (Figure 15, line A), it is likely to be uneconomic for commercial harvesting in most areas unless the profitability of the industry, particularly the product value, increases dramatically. This is because, as carp density declines, the cost of harvesting additional fish increases steeply (Figure 16, Bomford and Tilzey 1997). If, on the other hand, carp only cause unacceptable damage when their density is high (Figure 15, lines B and C), then commercial harvesting to meet resource damage control objectives may be economic, because harvesting would not be required at the low densities where the cost of removal is high (Figure 16,



Figur e 15: Possible relationships between carp density and the damage they cause. For example, line A might represent the damage carp cause to an aquatic plant that carp disturb even when they are at low densities. Line B could represent direct competition between carp and native fish for a limiting resource. Line C could occur if there is little or no competition between carp and native species for habitat when carp are at low densities. The shape of these lines will depend on the type of resource being affected and other variables such as interactions between species and seasonal conditions.



Figur e 16: Relationship between carp density and cost of removal using conventional commercial harvesting techniques.

Bomford and Tilzey 1997). Fortunately it is likely that, for most forms of environmental damage, at the low densities when costs of removal are high (Figure 16), damage levels are also usually low (Figure 15, lines B and C).

To estimate the stock of a fish, recruitment rates need to be known. These are not known for carp (Thresher 1997) and only predictions based on populations that follow density-dependent limitations have been used. It is likely that carp populations are also vulnerable to environmental variations (Section 3.4.3). Spawning and successful recruitment may be linked to floods and there are also periods of slow growth (Section 3.4.3), so that predicting a carp stock in any one year may be difficult. Roberts and Tilzey (1997) gave a high priority to the need to understand carp population dynamics. Population parameters for different areas and habitats are needed to assess the effects of carp harvesting as a control measure. In some areas, a one-off harvesting operation may be allowed with an understanding that fishing may not continue.

'Commercial operations may need to be supplemented by additional carp removal to keep densities below damage control thresholds.'

Whilst commercial harvesting is not feasible on a widespread basis (Section 7.3), it may be used as a form of carp management to reduce damage caused by carp in some restricted areas. At low densities, commercial carp harvesting is not profitable and so will often fail to reduce carp densities enough to meet damage control goals. In such cases commercial operations may need to be supplemented by additional carp removal to attain and keep densities at (or below) damage control thresholds.

Commercial harvesting for carp is restricted in many areas by both legal and logistic reasons. Only about 5% of rivers in New South Wales were accessible to commercial fishers until 1999, when area restrictions were lifted for carp harvesting. About 30% of the Murray River in South Australia is currently open to commercial fishing. Commercial fishing is even more restricted in Queensland and limited to restricted waters in Victoria. Many of the waters which contain carp have limited access and are difficult to fish. Large snaggy rivers and billabongs are especially difficult to fish with labour efficient gear such as large seine nets. Remote locations add costs for refrigeration, handling and transport. Commercial harvesting would not solve the problem of future recolonisation by carp.

The question of how to reduce carp numbers in strategic places and continue to maintain viable markets needs to be addressed. The two goals may be mutually incompatible and theoretically commercial use should have no ongoing value for damage control. It would be counter-productive if the need to protect investments and maintain markets leads to harvesters objecting to carp control strategies being implemented. The demand by consumers also needs to meet the level of production which will coincide with the desired level of carp abundance. Commercial harvesting could possibly manage and minimise carp impacts in some areas if these levels coincided. The establishment of a carp harvesting industry based on ongoing and sustainable catches however, is only likely to hinder the control of this species in the long term.

The role of commercial harvesting as a population control is discussed in Sections 7.3 and Box 1. It will be necessary to monitor carp stocks to identify changes in age and size structure, reproduction and longevity and mortality resulting from control efforts (Section 10.2.2).

Key aspects regarding the future of carp use were identified by Gooley (1997). The following features would need to be integrated into a plan if commercial carp use was added to damage control goals:

- carp use requires value-adding
- Quality Assurance Programs are integral to value-adding
- cost-benefit varies with markets and harvesting costs
- carp production is a business.

To date most commercial harvesting has occurred in limited areas where high numbers of carp are readily available. Given the low current price for carp, opportunities to expand harvesting into new areas with lower population densities are limited.

Box 1: Case study of large carp harvesting operation: sustained control

K&C Fisheries, based in Sale, Victoria, has been run by Keith and Cate Bell since 1984, refining methods for targeting carp. Keith uses a 732 metre seine net (Figure 18) in Lake Wellington, where much of the lake is relatively shallow and has few snags, allowing the hauling of a seine. For most of the year, he hauls in about 18 tonnes of carp a week. The efficiency is increased with the use of a large storage boat which can be trailered to his premises.

Electrofishing is one of the carp harvesting techniques employed by K&C Fisheries. Source: Lisa Crisp, East Gippsland Catchment Management Authority.

A boat with electrofishing equipment has been specially designed for harvesting carp in the lakes and its tributaries so that carp can been exploited when they occur in large numbers. As the salinity of the lakes system fluctuates, carp move out of brackish into fresher areas where electrofishing is possible. Up to three tonnes of fish can be removed in one day using an operational boat and a small boat which can hold nearly one tonne of fish.

There has been extensive ongoing capital investment in special equipment, including a seven tonne capacity fishing vessel, large-scale, purpose-built nets, a large blast tunnel freezer to snap freeze large quantities and a large capacity storage freezer. In 1999, K&C Fisheries produced more than 900 tonnes of carp for the export and Australian domestic market.

K&C Fisheries carp processing factory. Source: A. Brumley, East Gippsland Institute of TAFE.

The carp are held in ice slurry in the vessel and transported to the processing plant where the ambient temperature is 5°C. A special room to head, scale and gut the fish for export has AQIS approval.

The company provides a wide range of high quality carp products including fresh table fish for the Melbourne and Sydney markets, prime cut fillets for seasoning and various smoked and dried carp speciality lines. Non-human uses which provide markets include rock lobster bait and fertiliser. Having researched the potential for exporting carp into Asia and Europe they now supply carp to Poland for human consumption. In 1998, 300 tonnes were exported. Such exports could significantly expand production with a target of 1000 tonnes set for 2000.

Even before the stringent requirements for an export licence with AQIS were met, the business was established with the Quality Assurance Program consistent with Australian seafood industry standards. High quality handling and use of ice have ensured the high value of their products. Packaging and domestic freight services are specialised to ensure maximum quality control over their products. Keith Bell believes that the quality of carp meat has a lot to do with post-harvest handling, sometimes more so than the quality of the water from which the carp are sourced.

Box 2: Commer cial harvest as one-of f damage contr ol in Sewerage Ponds, Linder now, East Gippsland W ater .

(J. Kostarakis, Technical Manager, East Gippsland Water, Victoria, pers. comm. 1999)

Site

East Gippsland Water has responsibility for water and waste water services in many towns throughout the East Gippsland area. One of these towns is Lindenow, where the Authority manages a waste water system with some 125 connections.

Problem

Waste water is pumped from the town to treatment works consisting of three lagoons which hold 11 megalitres of effluent and waste water. Effluent from these lagoons is discharged to a confined wetland. An Environment Protection Authority licence, which sets parameters for the quality of effluent discharged to the wetland, covers operation of the whole system.

Occasionally, testing the effluent has detected failure to meet licence requirements for suspended solids.

One-off control

It was suspected that these failures may be due to the presence of carp in the lagoons which stir up sediments, with fine particles becoming suspended in the treated effluent, so it was decided to remove carp from the lagoons.

A contractor, K&C Fisheries from Sale, was engaged to net the carp using a seine net. A total of 53 carp, up to 10 kilograms in weight, were removed from the lagoons. The operation cost $1000. The contractor removed the carp from the site and they were used for making fertiliser.

Evaluation

- The low operational cost was possible because the carp were sold for making fertiliser.
- In the four months preceding removal of carp, two of the four monthly samples failed the licence limits for suspended solids. In the six months following the removal of carp, all six monthly samples passed the licence limits for suspended solids.
- The time it will take for carp populations in the lagoons to recover will determine the cost-efficiency of the operation. If carp increase and cause future problems, another control operation will be needed.

6. Past and curr ent management

Summary

In the past there has been no coordinated management of carp in Australia and carp control has been mainly undertaken by State and Territory agencies, predominantly fisheries agencies. Carp are declared noxious (or equivalent) in Queensland, Victoria, Tasmania, and South Australia, with supporting regulations and penalties for possession. Management has been minimal in most cases, except for some new invasions where eradication has been attempted. Other management approaches include encouraging commercial harvesting and recreational fishing to remove fish. In recent years the formation of the National Carp Task Force, as a result of public interest and pressure, has promoted a more coordinated approach and national focus on carp control. A Carp Control Coordinating Group has also recently been formed with State, Territory and Federal government representatives to coordinate carp control on a national basis.

6.1 Public pr essur e for action

Following the publicity accompanying the rapid expansion of carp (*Cyprinus carpio*) in Australia during the 1970s and early 1980s, public interest waned until the 1990s. The Victorian Carp Project conducted from 1979 to 1982 found little direct evidence linking carp to environmental degradation. Those results led government agencies to adopt policies which treated carp as a nuisance that had to be lived with and could be commercially exploited in some circumstances (Hume et al. 1983a; Reynolds 1987), rather than as a species that caused widespread environmental damage requiring active management. More recently there has been a growing ground swell of popular opinion, increasing awareness of environmental damage to river systems from a variety of causes, and scientific evidence of damage caused by carp, which has led to an increase in public and government activities in relation to carp management.

Following community meetings and public discussions on the problem of carp during the early 1990s and the 'national carp summits' in 1994 and 1995, public interest and media attention to carp has grown enormously. This public attention and pressure has prompted government agencies to acknowledge carp as a possible pest species and to examine options to address perceived problems caused by carp. The resurgence of interest in recent times is similar to the interest exhibited in the late 1970s following the rapid spread of carp through many river systems.

'Public attention and pressure has prompted government agencies to address perceived problems caused by carp.'

6.2 National management

The need for a national approach to carp management has only emerged recently and is still being developed and refined. Until recently, management of carp has not been coordinated on a national or even a regional scale. Generally carp management has been restricted to sporadic attempts to eradicate new invasions and opportunistic commercial exploitation. The management of carp has been perceived by many as the responsibility of State and Territory agencies, mainly fisheries departments (Table 13).

Importation of live carp is restricted because carp are not listed on Schedule 6 under the *Wildlife Protection Act 1982* which contains a list of species approved for import by Environment Australia. Goldfish (*Carassius auratus*) are listed, although there is currently a review of ornamental fish import regulations following the detection of Spring Viraemia of Carp Virus (*Rhabdovirus carpio*) in goldfish in Hong Kong. Spring Viraemia of Carp disease has the potential to affect carp populations (see Chapter 7) should the disease enter Australia. Import risk analyses

Table 13: Status of carp, responsible managing agencies and relevant legislation for carp management in Australia.

	Commonwealth	QLD	NSW	ACT	VIC	SA	TAS	WA
Status of carp	Import of live carp prohibited	Noxious	Not declared noxious, but recognised as a pest by policy	Not declared a pest	Noxious	Exotic	Controlled fish	Not declared a pest
Responsible management agencies	CCCG, MDBC, AFFA, Environment Australia	DPI for QFMA	NSW Fisheries	Environment ACT	Fisheries Victoria, Department of Natural Resources and Environment	SA Fisheries, South Australian Research and Development Institute	Inland Fisheries Commission	Fisheries WA
Actions undertaken	Checks by customs and quarantine officers	Enforcement, education, raising of community awareness	Enforcement, education, raising of community awareness, inter-agency cooperation	Education, raising of community awareness	Enforcement, education, raising of community awareness. Fisheries enforcement officers to check use of live bait and transport	Enforcement, education, raising of community awareness	Enforcement, education, raising of community awareness	Enforcement of non-translocation law, education, raising of community awareness
Relevant legislation	*Wildlife Protection (Regulation of Exports and Imports) Act 1982*	*Fisheries Act 1994*	*Fisheries Management Act 1994*	*Fisheries Act 1967*	*Fisheries Act 1995*	*Fisheries Act 1982*	*Fisheries Act 1995*	*Fisheries Act 1994*

being undertaken may indicate the need for health checks of imported goldfish to ensure that there is no clinical evidence of disease (P. Durham, Animal Quarantine Policy Branch, Australian Quarantine and Inspection Service, ACT, pers. comm. 1998).

6.2.1 National Carp Task Force

The National Carp Task Force (NCTF) was established in January 1996 to consolidate and focus community energy on the growing problem of carp. The Task Force was formed following a second National Carp Summit held by the Murray–Darling Association in Renmark in October 1995. This summit built on other community meetings about carp which had been held across the Murray–Darling Basin in 1995 and followed on from the first summit in Wagga Wagga in 1994.

The aim of the NCTF is to eradicate carp from all Australian aquatic habitats through a strategic action plan that promotes coordinated research, provides good information, explores commercial opportunities and seeks complementary legislation. The NCTF believes that control will be best achieved through a natural resource management strategy, using pest management principles, rather than relying only on fisheries techniques.

The NCTF has membership from Commonwealth and State and Territory agencies with an interest in carp, researchers, recreational and commercial fishers, local government and the angling community. The Murray–Darling Association currently convenes the NCTF and provides secretarial support with funding provided through the Murray–Darling 2001 FishRehab program.

In 1997, the NCTF developed an action plan which has research, information, commercial exploitation and legislation objectives as follows:

Research — To promote research into the control methodology of carp. The role of the NCTF is to coordinate and facilitate, not carry out, research work.

Information — To facilitate the open exchange of information regarding carp and to facilitate the development of a series of major field projects which identify and publicise the positive impacts of the removal of carp. Information on current projects has been placed on a database. The NCTF produces a public newsletter *Cyprinus* (National Carp Task Force 1996a,1996b) which provides information on carp.

Commercial exploitation — The intention of assisting and coordinating the commercial exploitation of carp has been enhanced by the inclusion of two commercial operators on the NCTF. The NCTF has also made small amounts of funding available for the development of business plans for groups or individuals who wish to exploit carp for commercial use and to individuals or groups who wish to develop concept plans for the reduction of carp in wetlands.

Legislation — The NCTF aims to collate all legislation relating to carp and provide its views on areas where legislation could be appropriately amended.

6.2.2 Carp Control Coordinating Group

In response to an earlier agreement by the Murray–Darling Basin Ministerial Council for the Murray–Darling Basin Commission (MDBC) to take a leading role in the coordination of appropriate action for the control of carp, a proposal for the formulation of a Carp Control Coordinating Group (CCCG) was developed and discussed with Commonwealth agencies in 1996. In January 1997, the Standing Committee on Fisheries and Aquaculture endorsed this approach in a letter from the Ministerial Council on Forestry, Fisheries and Aquaculture (MCFFA) and nominated representatives from fisheries agencies in the States and Territories and the Commonwealth. At a MDBC Meeting 42 in 1997, Commissioners noted that the coordination role for the Commission was in providing a Secretariat and Chair to the CCCG, and that resourcing this arrangement would rely on funding from the $13 million contained in the Commonwealth's Natural Heritage Trust for Water, the Environment and Fish Management (now called the Murray–Darling 2001 FishRehab Program).

The objectives of the CCCG are set out in the following Terms of Reference:

- review available information to determine the impacts of carp
- develop a national strategic research plan for carp control and management that establishes research needs and priorities for:
  - defining the economic and ecological impacts of carp
  - developing carp control methods
- review current management strategies, prepare an interim national management strategy and recommend appropriate management plans for the long-term control of carp
- advise the NCTF on the preparation of material to inform the community on carp related issues
- promote effective liaison between groups conducting carp research, management or control
- report to the relevant Ministerial Councils (Murray–Darling Basin Ministerial Council, MCFFA, Agriculture and Resource Management Council of Australia and New Zealand, Australia and New Zealand Environment and Conservation Council) with a national strategic research plan and an interim management strategy.

Intended outcomes of the CCCG include:

- improved awareness and coordination of activities relating to the research and management of carp across all relevant Ministerial Council sub-committees and State and Territory managing agencies
- a national strategic approach to addressing the carp issue.

A Memorandum Of Understanding exists between the NCTF and CCCG and each has membership with the other body.

6.3 State and Territory management

Carp are declared noxious pests in Queensland and Victoria and are considered exotic in Tasmania and South Australia, so in all these States it is illegal to keep, release or transport carp. Carp are acknowledged as pests in New South Wales, and transport and release of live carp is prohibited. The spread of carp is not considered desirable in any State or Territory and some States have attempted eradication programs on a local scale. The responsibilities of the managing agencies vary with the status of carp and the associated legislation (Table 13). Legislation by itself, however, is not an adequate response to managing the damage caused by carp and probably has little effect on carp populations. While it is not the role of the managing agencies to remove carp, some agencies organise fishing competitions and/or encourage commercial harvesting. There are no size or bag limits for carp, or waters closed to the taking of carp, in any Australian State, but there is an overall bag limit for fish caught in the Australian Capital Territory (Kailola et al. 1993). New fisheries legislation was tabled in March 2000 which will remove the overall bag limit in the ACT (M. Lintermans, Environment ACT, pers. comm. 2000).

6.3.1 Victoria

The Fisheries and Wildlife Department discouraged a proposed venture to import carp into Victoria from Germany for the purpose of aquaculture in 1960. However, while the *Fisheries Act 1958* prohibited the stocking of non-indigenous fish, including carp, in public waters, it did not prohibit this in private waters. By 1961, carp had been imported, sold and liberated into farm dams in many parts of Victoria. The then Director of Fisheries visited the United States (State Development Committee 1962) to assess the potential impacts of carp and by December 1961 their sale had been prohibited. Debate about carp led to an inquiry and the declaration of the *Noxious Fish Act 1962* which had penalties for the possession of carp and allowed Fisheries and Wildlife officers to enter private property and destroy carp. In May 1962, a carp-kill program began to attempt to eradicate carp before they could breed in spring. More than 1300 dams were poisoned and later tests of 200 of the treated dams did not find carp and so the eradication was deemed to be successful. Unfortunately, carp had either escaped into the La Trobe River or had been stocked illegally into other waters and the spread of carp continued (Clements 1988; Victorian Fisheries 1991a).

'Carp are defined as being pests when they occur in biomass greater than 450 kilograms per hectare.'

The Victorian Fisheries Policy issued in 1988 and revised in 1990 and 1991, *Statement on Noxious Fish — Carp* (Victorian Fisheries 1991b), states that: 'Because carp *Cyprinus carpio* have the potential to cause ecological and environmental problems, legislation has been enacted to prevent their spread in Victorian waters. Carp will be treated as both a resource and an occasional pest. Carp are defined as being pests when they occur in biomass greater than 450 kilograms per hectare in ecologically, recreationally or economically valuable water bodies, unless there are strong arguments for acting at lower biomass densities. Regional staff will be responsible for making the biomass estimates and for reducing the biomass density in the approved waters. The Department will not remove carp from private waters, except in an isolated water body located in a previously carp-free catchment. Carp will remain on the noxious fish list. This policy covers all varieties of *Cyprinus carpio* including Koi, mirror and leather varieties. The Department supports commercial harvesting of carp, subject to regional supervision.'

The *Fisheries Act 1995* was amended in 1997 with noxious species being covered under Sections 75, 76 and 81. Proposed Fisheries Regulation (1998) 530 (2) states that: 'a person must not use live carp (including goldfish) as bait in inland waters'. Carp are also included under the *Flora and Fauna Guarantee Act 1988* where the 'deliberate or accidental introduction of live fish into public or private waters within a Victorian river catchment in which the taxon to which the fish belongs cannot reliably be inferred to have been present prior to the year 1770 AD' is listed as a Potentially Threatening Process. The listing of this process means that a management plan must be produced by the Department of Natural Resources and Environment to outline how it intends to manage introduced fish species.

Fisheries Victoria is currently active in promoting the commercial exploitation of carp. As part of this they are undertaking an assessment of the economic basis and markets for the carp industry. Fisheries Victoria has produced issues of their widely distributed Victorian Fish Notes and Infosheets which relate to carp. Victorian Fish Notes number 14 *'Carp in Victoria'* (Victorian Fisheries 1991a) provides a history of carp in Victoria, early management and some results of research into carp. The Fisheries Management Infosheet Number 8 '*Policy Statement, Noxious Fish — Carp*' (Victorian Fisheries 1991b) outlines policy, a brief history and biological facts and potential methods for control of isolated populations. Infosheet Number 10 '*Removal of carp from farm dams by poisoning*' (Victorian Fisheries 1991c) outlines methods and procedures for this control method.

Coarse angling for carp (Section 4.9.2) has also had some limited support in Victoria with special permits being issued by Fisheries Victoria for some coarse fishing events. These permits are only issued to the Australian Federation of Coarse Anglers Association for fishing competitions held in specified waters where carp numbers are high. The permits allow members to release live carp back into waters after their capture at competitive fishing events (R. Winstanley, Recreational Fisheries, Fisheries Victoria, pers. comm. 1999). Coarse angling was also promoted in a front page feature in the June 1998 issue of '*Fishing Lines*', the newsletter of the peak angling body in Victoria (VRFish 1998).

6.3.2 New South W ales

Carp management has become an increasingly important issue in New South Wales as knowledge and understanding of carp impacts has slowly improved and the community have demanded greater action. This change is evident when comparing the policy outlined in the original NSW Fisheries AgFacts on *European Carp* by Reynolds (1987), which suggested that the detrimental effects of carp were doubtful, and in the updated version by Brown (1996), which identified environmental damage caused by carp. Although the *Fisheries Management Act 1994* provides for the declaration of noxious fish species, carp have not been listed to date.

'A Carp Assessment and Reduction Program (CARP) was implemented in 1998 to run over three years.'

A $1 million Carp Assessment and Reduction Program (CARP) was implemented in 1998 to run over three years. This project is managed by NSW Fisheries with the support of a steering committee including representatives of the NSW Department of Land and Water Conservation, NSW Agriculture, NSW National Parks and Wildlife Service, and the NSW Department of State and Regional Development.

The CARP program aims to reduce carp populations and impacts in New South Wales, through:

- developing a commercial carp fishery
- developing a recreational carp fishery
- educating the community about carp impacts and control methods.

Research on carp impacts and control methods

Current NSW Fisheries carp research projects are focused on improving carp management by:

- identifying fishing gear and methods most suited to large-scale carp removal
- identifying cost-effective levels of carp control relative to the degree of environmental benefit achieved
- providing guidelines for water managers, community groups and other organisations on the most efficient and cost-effective approach to controlling carp populations in enclosed water bodies.

Commercial carp fishing

The Carp Production Incentive Scheme (CPIS) aims to facilitate the development of new and existing markets for carp and carp based products through enhanced commercial fishing. This is undertaken with a view to establishing a self-supporting commercial carp fishery.

In 1998, four licenses were established for carp harvesting teams to participate in a limited duration subsidy program. Each team received payments of 25 cents per kilogram for carp caught during 1999, up to a maximum of 250 tonnes. This was designed to offset the cost of developing fishing methods, transport systems, processing techniques and markets for carp. Payments will be reduced to 15 cents per kilogram in 2000 and 10 cents per kilogram in 2001. Carp harvesting teams have access to a wider range of fishing methods and geographical areas than other fishers in order to maximise carp production. However, at the time of publication, only three licenses have been issued.

The CPIS has a number of important differences from conventional bounty schemes. Firstly, its main objective is to support the expansion and development of the commercial carp industry in New South Wales. Secondly, the amount of the payment reduces on a sliding scale over three years, providing incentive for the industry to become self-supporting in that time. Thirdly, although an expanded carp fishery will remove greater numbers than the current fishery, a reduction in carp numbers is not critical to the success of the subsidy. Rather, the success of the scheme will be determined by the increase in carp catches, and the increased value of the catch relative to the cost of the subsidy. For these reasons, the scheme is clearly an industry development incentive, and distinct from the traditional bounty schemes assessed by Hassall and Associates (1998).

It is unlikely that bounties or incentives for carp harvesting will be any more successful at carp control than those for other vertebrate pests (Section 7.3.1). Irrespective of the success of the carp industry development incentive in expanding the carp fishery in New South Wales, the analyses of Hassall and Associates (1998) and Thresher (1997) strongly suggest that commercial harvesting is only likely to reduce carp numbers in localised areas.

The recent restructure of the New South Wales Inland Commercial Fishery will result in fishing effort being directed exclusively towards carp and yabbies, when commercial fishing for native species is closed on 1 September 2001. The area open to commercial fishing has been gradually reduced to around 5% of inland waters over the last 50 years (Reid et al. 1997). Seasonal closures between September and November have been introduced to protect mature fish from fishing pressure during the peak spawning period. Closure of this fishery will potentially expand the areas and methods available to remaining carp fishers.

A number of other commercial fishers hold permits to participate in small-scale carp removal projects on behalf of local government, other land managers such as Australian Water Technologies, The Centennial Park Trust in Sydney and a retirement village. Carp populations can be significantly reduced in relatively small enclosed water bodies. Although the success of these operations is difficult to measure, land managers are satisfied with the cost relative to the perceived benefits.

Recreational carp fishing

Carp are not only considered to be an under-used commercial fishery resource but also an under-used recreational fishery resource. In 1998 a State-wide 'Great Carp Fish Off' competition was sponsored through the CARP program. Heats were held in 26 regional centres across coastal and inland New South Wales, with the finals held on Australia Day. In total several thousand people participated in the event, although not all as competitors, and some 34 000 kilograms of carp were caught. This competition may have encouraged recreational carp fishing. However, another key aim was to raise community awareness and understanding of the carp problem. Recreational carp fishing competitions are also identified as one method to educate the community and foster involvement in broader land and water management activities.

Broader land and water management issues

The New South Wales Water Reform Process has included a review of water management policies, provision of environmental flows for rivers, changes to the pricing, trading and allocation of water rights, identification of stressed river and groundwater systems, funding to improve the efficiency of irrigation, and increased study and monitoring of river health through the Integrated Monitoring of Environmental Flows program.

Development of the New South Wales Weirs Policy under the water reform process may provide outcomes which favour native species, and which may be detrimental to carp. In the longer term these and other changes may have a significant impact on carp populations.

NSW Fisheries will review carp research and management actions to ensure consistency with the National Management Strategy for Carp Control being developed by the CCCG, and with associated guideline documents.

Current regulations relevant to carp are:

- no size or bag limits exist for carp, nor are there any seasonal closures
- a New South Wales Recreational Fishing (Freshwater) Licence is required to catch carp in non-tidal or inland waters
- an appropriately endorsed commercial fishing licence and or permit is required to take carp for sale in New South Wales
- live fish including carp are not to be used as bait in inland waters.

Fishers are also encouraged not to return live carp to the water.

Carp management is being developed as one component of a holistic approach to managing rivers. The New South Wales Water Reform Fact Sheet 15 *Solving the carp problem* (NSW Department of Land and Water Conservation 1997) summarises the whole of government approach to carp in New South Wales.

6.3.3 South Australia

Carp have been successfully eradicated from many isolated locations by poisoning (Hall 1988). Between 30 and 120 small populations have been eradicated, mainly in small dams in the Adelaide Hills. A major example of selective harvesting was undertaken using the receding floodwaters of the Chowilla Floodplain (B. Pierce, South Australian Research Development Institute, pers. comm. 1998).

Carp are declared an exotic species in South Australia under the Fisheries Act 1982 and it is illegal for them to be released back into the water alive or transported. Carp cannot be held without a permit. Special regulations have been in place for six years to allow the use of bow and arrow hunting for carp: 'A bow and arrow may be used during daylight hours for the taking of European carp in the waters of the Murray River, other than the main stream. This activity may be only undertaken when at least 50 metres from all other persons not involved in that fishing activity. Note, no other species may be taken by this method' (South Australian Recreational Fishing Guide 1998).

The Fisheries Branch of Primary Industries and Resources South Australia (PIRSA), promotes commercial and recreational exploitation of carp, and in cooperation with commercial fishers, has promoted such fishing to be continued even when densities have been reduced to levels below those which are commercially viable. Commercial harvesting is promoted and addressed as a specific management option in the management plans for the fisheries in the Lakes and Coorong (Southern Fishermen's Association 1998). Efforts are also being undertaken to further develop markets for carp. South Australian commercial fishers are also encouraged to promote sustainable harvesting and markets for higher priced native fish species. The exploitation of all introduced fish species is encouraged. The South Australian Research and Development Institute is also attempting to enhance populations of predatory native fish to control carp. This included a temporary moratorium on the taking of Murray cod (*Maccullochella peelii peelii*) and the provision of fish passage to reduce fragmentation of native fish populations. Chemical poisoning of carp is still undertaken when they are introduced into watersheds where they have not been previously recorded. A high priority is given to the eradication of carp if they are detected in new areas such as the Cooper Basin in the north of the State.

'Between 30 and 120 small populations have been eradicated.'

Wetland management, including measures to control carp, is often undertaken by non-government agencies. An example of this is given in the case study for Pilby Creek (Section 8.6.1) where carp have been removed from wetlands which are monitored to record changes to aquatic vegetation.

Carp have been highlighted in the South Australian Recreational Fishing Guide (1998). Publicity was conducted over one year to emphasise the benefits of lower carp numbers. This included a major story on 'River Rabbits' (Winwood 1996).

6.3.4 Australian Capital Territory

A stocking campaign using golden perch (*Macquaria ambigua*), a predatory native species, was undertaken in Lake Burley Griffin following the establishment of carp in the mid 1970s. A similar stocking regime was also employed in Lake Ginninderra following its construction in 1976. Murray cod were also stocked in both lakes in the late 1970s in a further attempt to develop a substantial population of predatory fish but unfortunately neither species appears to have had much impact on carp populations (Lintermans and Ruzou 1990, 1991).

'Environment ACT has promoted angling for carp in Canberra's urban lakes with many large fishing competitions organised since the late 1970s.'

Environment ACT manages the catchment of Googong Reservoir in adjacent New South Wales and has been successful in preventing the establishment of carp in this reservoir. This has required the eradication of carp from several farm dams in the catchment as well as a public education program of the benefits of keeping Googong 'carp-free'.

Environment ACT has promoted angling for carp in Canberra's urban lakes with many large fishing competitions organised since the late 1970s. Methods for preparing and cooking carp have been promoted. A relatively recent development has been the advent of coarse fishing competitions, with Environment ACT providing exemptions for such competitions in regard to rod limits and keeping fish in keep nets.

'Commercial operations for carp have not been supported because of the lack of suitable locations for such operations and the potential impacts on non-target species.'

Carp are not declared noxious in the ACT under the *Fishing Act 1967*, but new fisheries legislation recently tabled contains provisions for this to occur (M. Lintermans, Environment ACT, pers. comm. 2000). Currently there is a mixed bag limit of ten fish per angler per day and this includes carp. It is proposed that the new fisheries legislation being drafted will remove this bag limit for carp. It is illegal to transfer fish from one water body to another which limits the potential spread of fish and diseases.

There are no commercial fishing operations in the ACT although expressions of interest have been received for commercial harvesting of carp. Commercial operations for carp have not been supported by Environment ACT because of the lack of suitable locations for such operations and the potential impacts on non-target species.

6.3.5 Tasmania

Carp are reported to have been introduced to Tasmania in the mid-nineteenth century but there is no evidence of any established populations from these introductions (Diggle and Jarvis 1998). Carp were found in several isolated farm dams in the north-west of Tasmania in the 1970s and were thought to have been established from Boolara stock. The eradication of these carp using rotenone poisoning was undertaken by the Inland Fisheries Commission (IFC). This swift action prevented the spread of carp from those locations (Sanger and Koehn 1997). In 1980, carp were found in the Stowport area and again were successfully eradicated. In 1995, carp were found in two lakes in the central highlands, Lake Crescent and Lake Sorell (Section 2.2.8) prompting the immediate organisation of the 'Carp Management Program' (Diggle and Jarvis 1998) within the IFC to undertake carp management. This program team reports to a 'Carp Working Group' comprising State government departmental representatives.

Carp are declared as 'controlled fish' in the noxious fish provisions under Sections of the *Fisheries Act 1995*. The current provisions were declared prior to the recent discovery of a reintroduction of carp into Tasmania in 1995. Under these provisions a person may not possess, control, consign, convey or release carp. The IFC must be notified of any possession of carp and any IFC officer may seize, remove and destroy any controlled fish. A person must comply with any direction by the Commissioner in relation to these matters.

'The strategy is to keep the lake level below the marshes over the summer and hence not provide access to potential spawning areas.'

The strategy for carp management in Tasmania, following their recent reintroduction, is one of containment and population reduction, and ultimately eradication if possible. The IFC has undertaken a detailed study of the options for eradication of carp in Tasmania. Other management options have included further surveys to determine the extent of the distribution, removal of carp by electrofishing and netting using radiotracked 'Judas' carp (over 6355 fish to date) (IFC 1999), research into carp populations, the closure of the lakes to fishing, the provision of an inspector to ensure compliance and capital works to assist management. Works have included the installation of screens (Section 7.3.7) to attempt to prevent the downstream spread of both eggs and fish, and earthworks and the restructuring of outlet facilities have been undertaken so that lake levels can be manipulated.

Data collected during the 1997–98 summer suggest such manipulation may have contributed to unsuccessful spawning. The strategy is to keep the lake level below the marshes over the summer and hence not provide access to potential spawning areas (IFC 1999).

Population estimates indicate there may only be 350–400 adult carp remaining in Lake Crescent with an estimated 90% of the population (4572) having been removed. Radiotracked carp have allowed information to be collected on their habitat preferences throughout the year and also enabled the

Outlet weir from Lake Sorrell showing flow-through screens and trap which have been constructed to restrict carp movement. Source: A. Brumley, East Gippsland Institute of TAFE.

detection of carp aggregations, enhancing the number of fish which can be captured (IFC 1999). A total of 1796 juvenile fish have also been removed, with an estimated 1500 remaining. The total remaining carp population in Lake Crescent is thought to be less than 1900 individuals.

Lake Crescent remains closed to fishing whilst Lake Sorell was re-opened for the 1995–96 season. Since the discovery of carp in Tasmania, the IFC publication '*On the Rise*', has devoted extensive coverage to carp in these two lakes. Media coverage of this introduction of carp into Tasmania has been widespread.

6.3.6 Wester n Australia

There is growing concern about the impact of carp on the aquatic environment in south-west Western Australia, although Fisheries WA is equally concerned about the possible impacts of other introduced fish species including goldfish, gambusia (*Gambusia holbrooki*), redfin perch (*Perca fluviatilis*) and tilapia (*Oreochromis* spp.). There have been some isolated eradications of carp in the past but there is no commercial fishery or widespread removal.

Carp are not declared noxious and there is no specific carp policy although there is general agreement that further spread is undesirable. Fisheries WA has established a reporting system linked to a database, and has recently prepared a public information kit to help identify introduced freshwater pests. Licences are issued for individuals to produce goldfish for the aquarium trade and some public confusion remains about how to distinguish between goldfish and carp.

Carp management is minimal although there are frequent public requests to Fisheries WA for their removal from water bodies. It is an offence under the *Fisheries Act 1994* to translocate any fish without the approval of the Director of Fisheries. A publicity campaign was undertaken in 1997 regarding the policy of not allowing translocations of fish into or within Western Australia. The example of the spread of carp in the eastern States and Territories was used as an example of the need for this.

Recently, there has been some concern in the dairy industry of south-western Western Australia because carp in farm dams are being reported to increase water turbidity. Many of the dams are used as a source of clean water for washing down dairy sheds and thus the water needs to meet quality standards. Many dairy farmers now have to treat the water with flocculants to remove suspended matter (G. Robertson, Agriculture WA, pers. comm. 1999).

'Education has concentrated on public information to raise awareness to prevent the spread of carp.'

Fisheries WA intends to adapt the Bureau of Rural Science's carp management guidelines and the CCCG National Management Strategy (Section 3.6) and associated documents to develop a framework to deal with the issue of introduced freshwater fish.

6.3.7 Queensland

As carp have only recently expanded their range into Queensland in substantial numbers, mainly through their spread in the Murray–Darling Basin, past management actions have been minimal.

Carp are declared 'a noxious fisheries resource' in Queensland under Part 11, Section 74 of the *Fisheries (Freshwater) Management Plan 1999*. Provisions under the *Fisheries Act 1994* relating to 'a noxious fisheries resource' include the requirement to destroy and notify an inspector of any such resource within two days of taking possession and prohibition on bringing or causing such resource to be brought into Queensland. Possessing, rearing or selling carp, releasing, placing or causing carp to be released into Queensland waters is illegal. This makes it an offence to possess carp in Queensland either alive or dead. The intention of this is to prevent any intentional or unintentional transfer of fish or eggs. It is currently proposed that the legislation be amended so that it is not an offence to possess dead noxious fisheries resources. Thus a recreational angler would have to kill any captured noxious fish such as carp.

The responsibility for managing carp in Queensland lies with the Queensland Fisheries Management Authority (QFMA). Aspects of carp management are undertaken by the Department of Primary Industries (DPI) on behalf of QFMA. As carp are now widespread, eradication is not currently being attempted, but efforts would be made to prevent any expansion of its range. To date the QFMA has not received any formal applications to commerically harvest carp. Any such applications would be considered under the QFMA's Exploratory and Development Fishing Policy.

'There is a growth in fishing competitions for carp.'

There is also a growth in fishing competitions for carp where prizes are awarded for the greatest weight of fish. Although these competitions are privately organised, QFMA is supportive of the concept.

DPI has included carp in extension activities and posters regarding other introduced fish species which alert the public to their presence, legislation and potential impacts. DPI is developing a *State Strategy for the Control of Exotic Pest Fish* due out in 2000. There is also a Community Consultative Committee (CCC) for the Control of Exotic Pest Fish that meets three times a year. This committee is made up of government and community representatives. The CCC has released an education and extension strategy which is currently being implemented (B. Kerby, Queensland Fisheries Management Authority, pers. comm. 2000).

7. Techniques to measure and manage impacts and abundance

Summary

Estimates of carp abundance are normally only general indicators of actual numbers or densities. The extra effort required to obtain accurate estimates of total numbers is rarely justified. Carp abundance can be estimated from catches from recreational fishing events, commercial fishery statistics, biological surveys using an array of sampling gear, mark–recapture and sequential depletion methods.

Impacts of carp are often indirect and can be associated with other disturbances in the catchment. Detection of carp impacts can be made difficult by the lack of information from similar areas without carp. A better approach is to assess the reduction in carp impacts by comparing habitats in which carp are being managed against similar habitats in which carp are not managed. However, the presence of other disturbances, critical thresholds and natural stabilising influences means that even after carp removal, the habitat or native fish populations may not return to the condition they were in before invasion by carp.

Impacts and abundance of carp can be reduced by: capture and removal of carp, environmental rehabilitation, environmental manipulation, food chain manipulation, application of poisons, and carp exclusion devices. Potential future biological control methods such as diseases, bio-vectored fertility control and molecular control approaches require further development and it is too early to assess their value for reducing carp impacts. Existing carp control methods are relatively affordable on a small scale, but rapidly become too expensive to apply across the entire range of habitats in which carp are found.

Monitoring carp populations and their impacts is an essential part of a carp control program. Monitoring must begin before the management program is implemented, and should be scientifically designed to maximise the ability to detect reductions in the impacts of carp. Data from long-term monitoring are needed to evaluate the effectiveness of carp management programs.

7.1 Estimating carp abundance

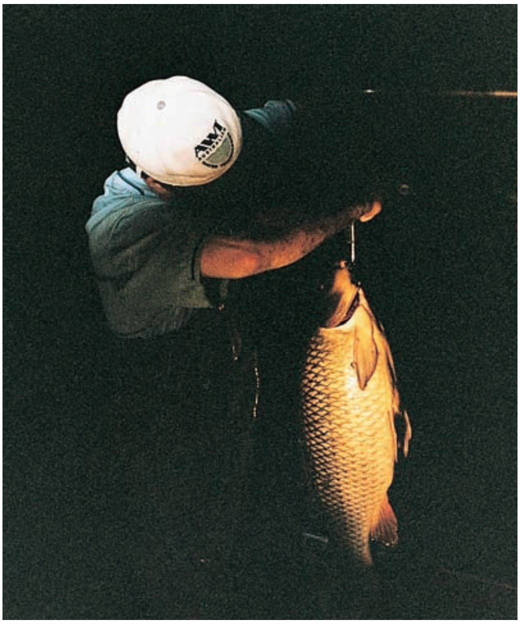
Methods for estimating the abundance of carp (*Cyprinus carpio*) generally fall into one of two categories: (1) estimates of *absolute abundance* to measure the total number of fish in a particular site; or (2) estimates of *relative abundance* to provide an index of carp numbers which can be used to compare populations at different sites or at different times. Although estimates of relative abundance are typically less precise, the additional cost of estimating total numbers of fish with accuracy is rarely warranted for population management.

The decision to measure absolute or relative abundance is commonly influenced by the management goals and the spatial scale of interest. For example, estimating the total number of carp in a small pond may be important to determine the likely ease or difficulty of removing all the fish. However, with large areas such as the Murray–Darling River system, an index of carp numbers, and where they occur in the greatest densities, is sufficient to determine appropriate control actions.

Estimates of carp abundance are needed to identify suitable management strategies and to monitor the effectiveness of carp management programs.

7.1.1 Methods for estimating carp abundance

Carp often live in turbid waters, so that direct observation techniques usually cannot be used. Instead, relative carp abundance is usually estimated from data on catch-per-unit effort. These data come from recreational fishing catches, commercial fish catches and standardised biological surveys. Catch



Standardised information on carp population variables, including density, age, weight and sex, is needed to determine the impacts of different population structures and the effectiveness of management programs. Source: A. Toovey, NSW Fisheries.

rates and total catches achieved by all methods can be greatly affected by prevailing conditions. For example, gill nets and drum nets rely on fish swimming into the net, with the result that these methods catch more fish during the times of greatest fish movement. Beyond estimates based on simple numbers of carp, it is also useful to know the total weight, or biomass, of carp in an area. The impacts of 1000 juvenile carp weighing 50 grams each feeding in the water are likely to be quite different from the impacts of 10 adult carp weighing 5 kilograms each feeding extensively from the sediments, even though the total biomasses are the same. Consequently, it is necessary to estimate both the number and biomass of carp in a habitat to estimate likely impacts.

Hook and line

Recreational fishers commonly catch carp by hook and line, either intentionally or while targeting other species. In organised fishing competitions, the numbers and size of carp caught and the fishing effort can be recorded over a number of years to estimate population changes in areas fished. As an example, NSW Fisheries organise 'Basscatch' competitions in coastal rivers to monitor the condition of Australian bass (*Macquaria novemaculeata*) populations. If similar events are to provide reliable data on changes in carp populations, it will be necessary to standardise each year's catch data for differences in angling ability and hours fished. These factors make correct interpretation of angling catches difficult. Careful attention to quality control is needed to obtain good data over a number of years to quantify differences not related to population size.

As an example, the results of Basscatch events conducted by NSW Fisheries in the Hawkesbury River over seven years since 1988 are shown in Figure 17 (J. Harris, NSW Fisheries, unpublished data, 1997). The catch-per-unit effort, measured as fish per angler hour, shows a variable, but relatively stable population of Australian bass after the first competition. Importantly, the average length of fish caught shows that bass are surviving longer and growing to larger sizes since the adoption by anglers of a catch-and-release philosophy coupled with size limit and bag limit restrictions. Properly organised carp competitions may provide similar information on changes in carp populations.

'To provide reliable data on changes in carp populations, it will be necessary to standardise each year's catch data for differences in angling ability and hours fished.'

Current public carp fishing competitions, popularly referred to as 'carp-a-thons', typically have little control over factors such as methods used, baits, line types, angler experience and fishing effort. Consequently, catches can vary greatly between events for reasons that have nothing to do with the size of the carp population, making this type of competition of limited value in assessing changes in carp populations. In contrast, scientifically planned angling events that control many of the variables associated with angling, can be invaluable stock assessment

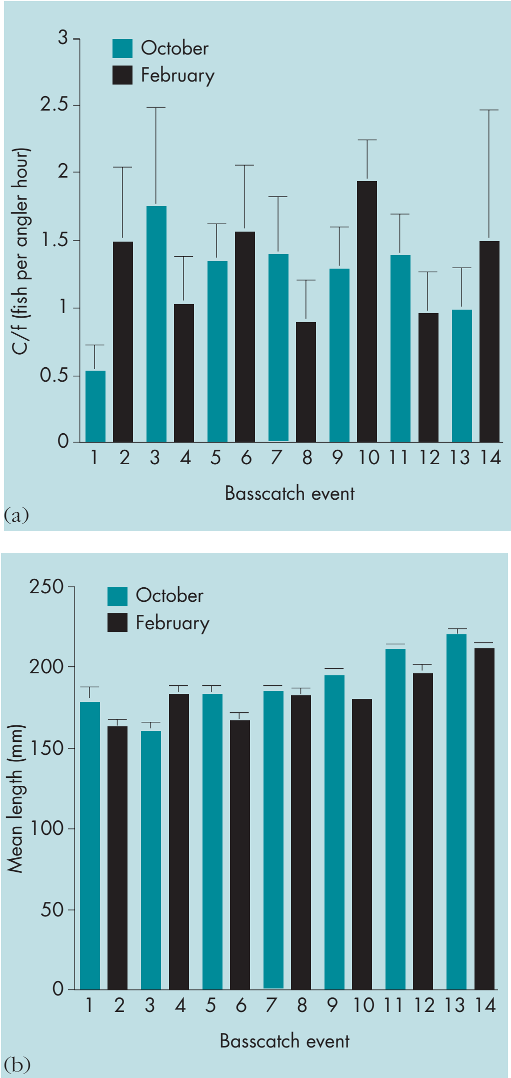


Figure 17: (a) Stable catches of Australian bass by anglers in the Hawkesbury-Nepean River system indicate a relatively constant population over seven years. (J. Harris, NSW Fisheries, Unpublished data 1997).

(b) Changes in size of Australian bass in the Hawkesbury-Nepean River system, based on anglers catches, indicate improved growth and survival. (J. Harris, NSW Fisheries, unpublished data 1997).

exercises for monitoring carp populations. With careful planning and commitment by participants, carp angling events provide excellent opportunities for local scale participation in carp population monitoring.

Nets and traps

Nets are commonly used by commercial fishers and researchers to catch carp (Figure 18). Gill nets catch fish that swim into the net and become wedged in the meshes of the net. Drum nets are a form of cone trap designed to catch fish, usually as they swim upstream. Fyke nets are a smaller form of cone trap that usually contains more internal cones than drum nets. Seines are long rectangular net panels with a small mesh to prevent targeted fish from becoming wedged in the meshes, and are towed through the water to either enclose a school of fish or to drag them onto the bank. Some seines have a pocket to help retain fish as the net is pulled through the water. Commercial fishers use gill nets, a drum net or seines to target carp. Researchers use these methods as well as fyke nets and various other traps. The size of fish caught using most of these methods is largely determined by the mesh size of the nets used, with larger meshes catching the larger fish whilst allowing smaller fish to slip through. Therefore, estimates of carp abundance may need to use a range of methods and mesh sizes to sample all sizes of carp. Because these methods vary in the sizes and numbers of fish that they catch, catch data need to be adjusted to account for these differences when estimating the total size distribution of carp in populations sampled.

'Constant catches, despite decreasing fishing effort over the last ten years, may indicate an increase in carp numbers in the waters open to commercial fishing.'

Commercial catch records are routinely kept by State fisheries agencies and can sometimes provide a longer time-series of information on individual species than are available from other sources. Catches of carp in New South Wales increased dramatically following the record floods in 1974–75 to a peak of 548 tonnes in 1977–78, and since then have remained at relatively stable levels of around 150 tonnes per year (Figure 19; Reid et al. 1997). The fishing effort in New

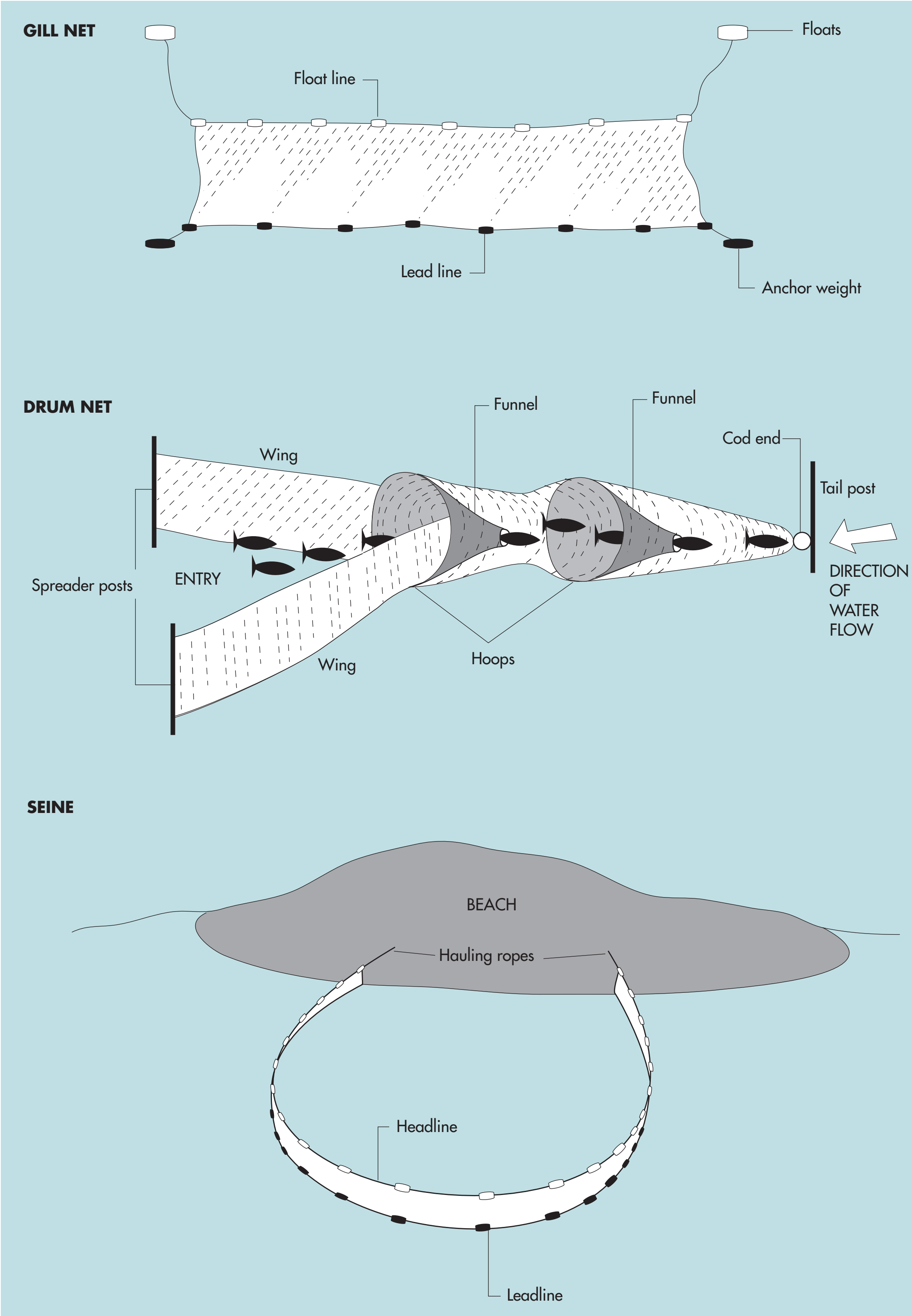


Figure 18: Diagram of gill net, drum net and seine used to catch carp.

South Wales declined dramatically after a peak in 1977–78, and continued to decline from 1985–86 to 1995–96. Constant catches, despite decreasing fishing effort over the last ten years, may indicate an increase in carp numbers in the waters open to commercial fishing.

Stratified habitat sampling

One of the shortcomings of using recreational or commercial fisheries data to estimate carp abundance is that these fisheries typically operate only in selected habitats suited to the types of gear used. Another is that both methods are selective towards larger fish. Consequently, catches obtained from these fisheries need to be interpreted with caution because they do not represent the entire carp population in an area or river system. Because carp live in a wide range of river, creek, floodplain, billabong and lake habitats, a true index of their relative abundance and size distribution in a river system can only be obtained by sampling all habitats and size classes using a stratified survey design. This approach is normally undertaken independently of a fishery and usually provides a useful check on fishery-based information.

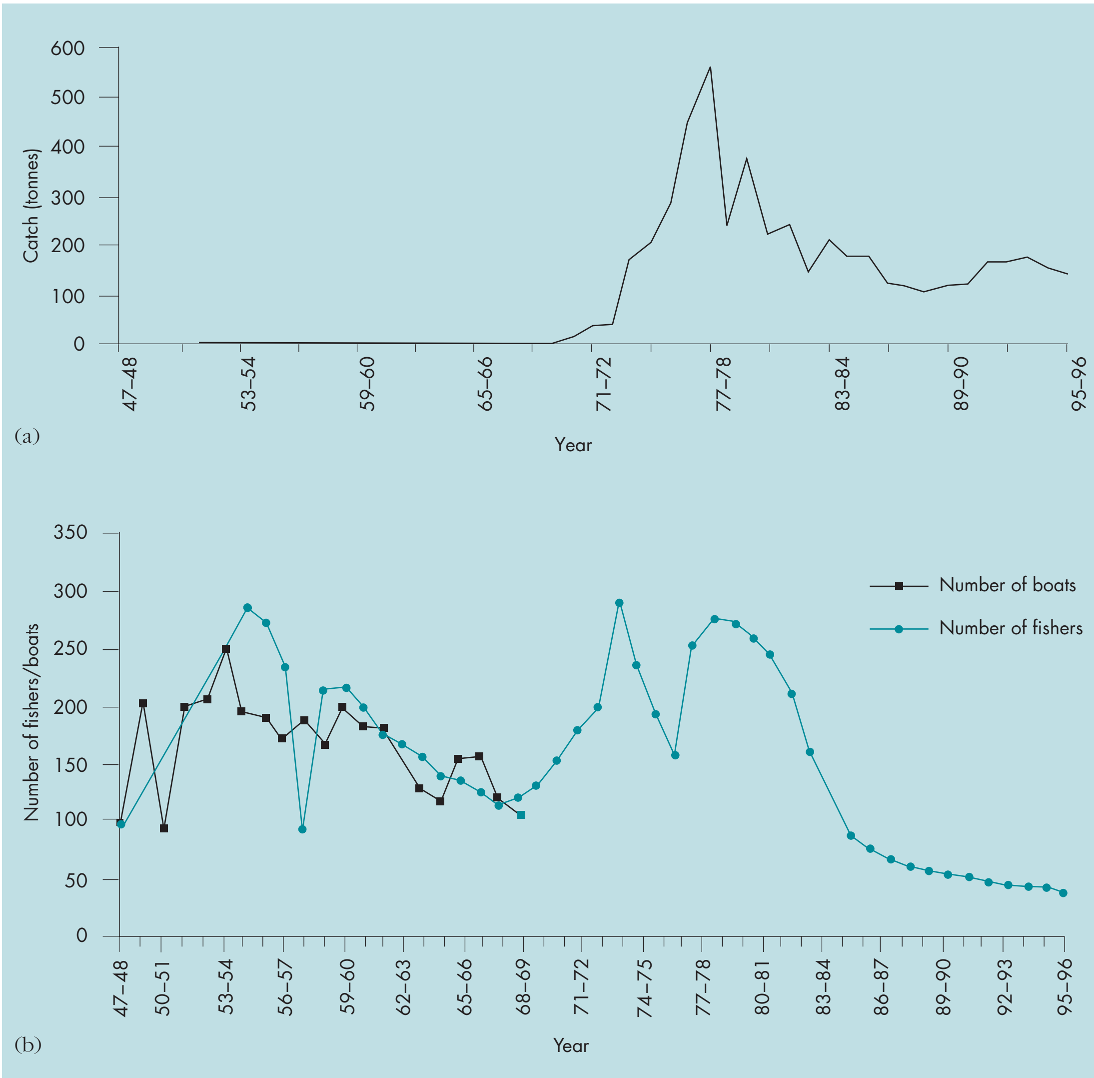


Figure 19: Carp catches (a) and changes in fishing effort (b) in New South Wales from 1947–48 to 1995–96 (Reid et al. 1997).

Electrofishing

While no single fishing method is equally effective in all habitats, electrofishing is an effective method in a greater range of habitats than other methods and also catches fish of all sizes, although larger fish are more susceptible. Compared to netting and angling methods, electrofishing is less influenced by changes in carp behaviour associated with seasonal temperatures, river flows, feeding and reproduction.

'Electrofishing is effective in a greater range of habitats than other methods.'

Electrofishing uses an electric current (most commonly pulsed direct current) in the water to create an electric field which attracts and immobilises the fish so they can be easily removed from the water. Electrofishing units can be powered by a generator in a boat or mounted on the shore, or by a battery or generator attached to a backpack unit. The effectiveness of electrofishing is strongly influenced by the type of current used, the shape of the output wave and the output frequency, as well as the conductivity, turbidity and temperature of the water and the behaviour patterns of different fish species.

Although electrofishing attracts fish, like most other fishing methods, it can potentially cause injuries. Most common injuries are compressed vertebrae or haemorrhages caused by excessive muscle contractions. The risk of damage to native fish means that electrofishing is generally only used by research teams or approved operators who are trained to minimise damage to fish. Because it requires the use of high voltage electricity in and around water, electrofishing equipment is highly specialised and relatively expensive. The risk of injury to both operators and observers is such that an *Australian Code of Electrofishing Practice* has been established and was approved by the Ministerial Council on Forestry, Fisheries and Aquaculture in 1997.

Electrofishing allows relatively selective sampling and removal of carp. Source: J. Koehn, Department of Natural Resources and Environment, Victoria.

Electrofishing is generally not species-specific. This means that all fish species and other aquatic vertebrates in the electric field may be affected. By adjusting the voltage, frequency, duty cycle, shape of the output wave and the method of applying current to the water, it is possible to increase selectivity for larger or smaller fish to some degree. However, contrary to popular opinion, there is no ideal combination of settings that catch only one species, such as carp.

Other methods

Somewhat more novel, high-technology methods of estimating carp abundance are video and sonar-based techniques. Fish counters can be installed at strategic sites, such as fishways, where images of fish passing a fixed point can be identified to species and counted over time. This technique has potential to provide accurate numbers of carp migrating upstream past key points in river systems but is still under development and not yet widely available. Similar techniques based on sonic imaging using side-scan sonar also enable numbers of carp and other species to be estimated without the need to catch fish. To be most useful, these methods need to be linked to image recognition software that distinguishes between different species and provides separate counts for each species detected. The difficulty in developing new software, or in recalibrating existing software to recognise Australian species, has prevented the widespread adoption of this technology in Australia.

Hybrid methods combining two or more established methods for catching fish can sometimes be highly effective. For example, combining seine nets with electrofishing technology has resulted in electric seines which are currently being evaluated by NSW Fisheries for their effectiveness in catching carp (C. Schiller, NSW Fisheries, pers. comm. 1999).

7.1.2 Estimates of absolute abundance

Absolute carp abundance can be estimated using two well-established techniques commonly used in fisheries management: mark–recapture and sequential depletion.

Mark–recapture methods

Mark–recapture techniques rely on a known number of individuals being captured, marked and released. The proportion of marked individuals in a second sample can then be used to estimate the total number of fish in the population (Box 3).

Sequential depletion methods

Sequential depletion methods work by repeated sampling of a known habitat, without replacing caught fish. Catches commonly decline with consecutive samples, enabling the total number of fish to be estimated (Box 4) (Reid and Harris 1997).

In isolated habitats such as wetlands, weir pools or water storages, draining the water from the habitat for ecological or operational reasons often strands significant numbers of carp, allowing numbers to be estimated or counted. Similarly, chemical treatment of water storages can sometimes cause fish kills, enabling total numbers of carp to be estimated, as can the targeted use of piscicides.

7.2 Measuring the impacts of carp on the environment

Many factors make it difficult to accurately assess the impacts of carp. Changes in land use, run-off and sedimentation, clearing of bankside vegetation, stock access and altered river flows all contribute to some of the impacts also attributed to carp, such as bank erosion and slumping, and increased turbidity (Chapter 5). Some assessments of

Box 3: Estimating carp abundance: single mark–recapture method

Example: Carp smaller than 100 millimetres in the Bogan River, New South Wales (Reid and Harris 1997).
Equation: Chapman-Petersen Estimator (Seber 1982).

Abundance estimate:

$$N^* = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

Variance:

$$v^* = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}$$

Where N* is the abundance estimator, n^1 is the number of fish originally marked and released, n^2 is the number of fish in the second or successive sample(s), m^2 is the number of marked fish in the second sample and v* is the estimation variance.

On the first day in our example, 140 carp were caught, and 68 of these were marked and returned to the population. In subsequent sampling 535 fish were caught, 19 of which were marked (n^1=68, n^2=535 and m^2=19).

With substitution:

$$N^* = \frac{(69)(536)}{(20)} - 1 \qquad v^* = \frac{(69)(536)(49)(516)}{(20)^2(21)}$$

$$N^* = \frac{(36984)}{(20)} - 1 \qquad v^* = \frac{(935103456)}{(8400)}$$

$$N^* = 1848 \qquad v^* = 111321.84$$

This provided a population estimate (N*) of 1848 fish. The variance of 111321.84 provides a 95% confidence interval for the population estimate of between 1181 and 2515.

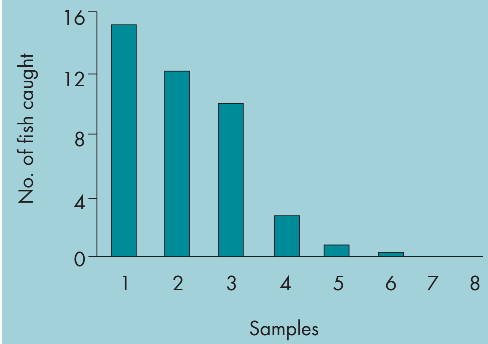
Assumptions:

- The population is closed, so that N is constant.
- All fish have the same probability of capture in all samples.
- Marking does not affect the behaviour or catchability of a fish.
- The second sample is random, that is, marked fish have fully mixed with the population being sampled.
- Fish do not lose their marks between samples.
- All marks are reported on recovery in the second or successive sample(s).

The assumptions involved in mark–recapture studies are often taken for granted. However, if for example, marked fish are more easily caught than unmarked fish, marked fish will be over-represented in the second sample, resulting in a low estimate of the population size. On the other hand, if many of the marked fish lose their marks before they are recaptured, then the number of recaptured fish recorded will be small and will result in the population being over-estimated. Like any other investigation, mark–recapture studies to estimate population size need to be properly planned if the final result is to be accurate and cost-effective.

Box 4: Estimating carp abundance: sequential depletion method

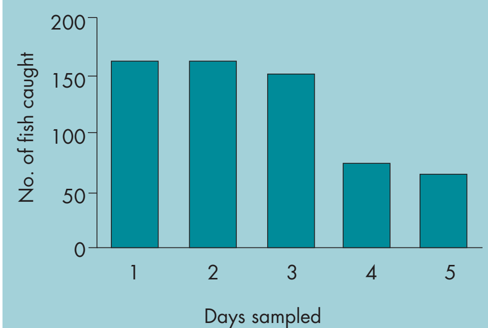
Hypothetical example: A small, closed population is sampled eight times without replacement. The results are as follows:



Because of the small size of the population and the zero results in the last 2 samples, we can assume that the whole population has been sampled. Abundance calculation is simplified as the sum of the results of all samples. Hence: 15+12+10+7+3+1+0+0= 48

However, sampling a much larger population reduces the accuracy of such a calculation.

Example: Carp larger than 100 millimetres in the Bogan River, New South Wales. Source: Reid and Harris (1997).



In this example, carp were caught and removed from the Bogan River in New South Wales on five consecutive days. The carp population was estimated using the same principles as the above example, but using a more complex statistical method in the computer program CAPTURE (Otis et al. 1978). The size of the carp population in this section of river was estimated to be 868 individuals, with 95% confidence limits from 808 to 947 fish.

carp impacts can be made by comparing environmental variables between habitats with high densities of carp and those with low carp densities. However, carp impacts can be difficult to distinguish from other disturbances in this form of comparison unless the sites are chosen carefully to eliminate potentially confounding sources of variation. Alternatively, sections of a habitat may be fenced off with fine-meshed netting to exclude carp (King et al. 1997). Comparison over time of habitat conditions between nearby carp exclusion and non-exclusion zones may enable changes directly attributable to carp to be estimated. A variation of this approach is to use multiple dams or billabongs in similar condition and to reduce carp numbers in some of them. The exclusion method has a potential drawback in that by excluding carp, other fish and animals may also be excluded, which may lead to other changes not caused by carp. Despite this complication, large differences in water quality, sediment disturbance and growth of aquatic vegetation have been observed in experimental ponds and billabongs where carp have been excluded (Section 5.3).

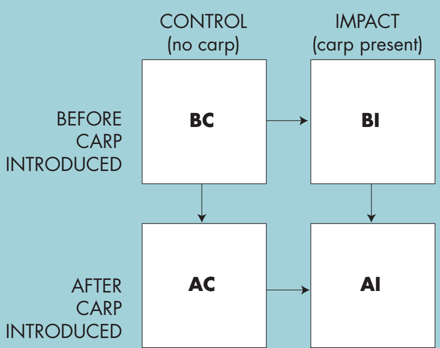
Another difficulty in assessing carp impacts occurs in rivers where carp can move over large distances. In contrast to standing waters with closed populations, carp in rivers are able to move upstream or downstream so that the population at any one site might vary greatly during the period of measurement. In such cases, even though a difference might be detected between carp exclusion zones and non-exclusion zones, it can be difficult to attribute changes to carp unless carp numbers in the non-exclusion zone are known at the same time.

'Studies are most likely to be useful in areas where carp do not yet occur and where they might be expected to occur within a few years.'

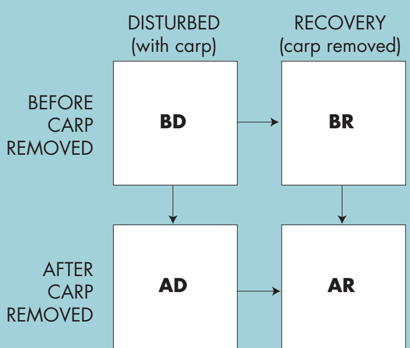
None of these difficulties make it impossible to measure impacts of carp in aquatic systems, but failure to address potential sampling problems can result in large expenditure of time and money for results that cannot be properly

Box 5: Before-After-Control-Impact (BACI)

The simplest form of Before-After-Control-Impact design looks for differences between sites with carp (Impact) and without carp (control), before and after carp have been introduced. The analysis compares groups of sites arrowed. Under ideal conditions, there would be little difference between sites BC and BI, and little difference over time between treatments BC and AC. If changes between BI and AI, or between AC and AI, are greater than changes between BC and BI, or between BC and AC, then an impact caused by carp has been detected. This design is often impractical because there are no comparable sites without carp to use as controls, and it is unusual to have useable data from a time before carp were introduced.



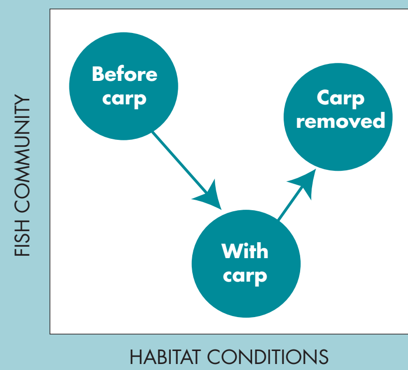
Recovery studies may follow the same design, but use disturbed sites with carp as controls, and sites from which carp are to be removed as impact sites. The ability to detect either impact or recovery is greatly improved by increasing the number of sites and the number of times sampled before and after removing carp.



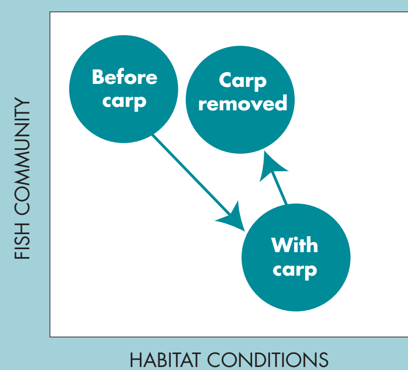
The arrows signify the direction of change in either a spatial scale (for example control ⟶ impact, disturbance ⟶ recovery) or temporal scale (before ⟶ after).

Box 6: Differences between impact and recovery studies

The changes that occur following carp removal may be different from those that occurred after the introduction of carp. This can reflect other changes since the introduction of carp, such as catchment disturbance, clearing vegetation, desnagging, altered river flows and changes in water temperatures. Environmental variability will also influence how a system stabilises after carp have been removed. In the first example below, the habitat conditions and fish community following carp removal are quite different to the situation before carp became established.



In other cases, carp removal may allow a system to return to something close to the state that existed before carp became established. A return to near previous conditions is more likely in relatively simple systems where other disturbances are minimal.



interpreted. Powerful statistical methods now used widely to detect environmental impacts, adopting Before–After–Control–Impact (BACI) and related experimental designs (Underwood 1996; Box 5), still have several limitations in detecting impacts caused by carp. Importantly, it is often impossible to study the condition of habitats before carp became established. If control sites without carp are fundamentally different from sites with carp, the comparison between sites is meaningless in relation to carp impacts. For these reasons, BACI studies are most likely to be useful in areas where carp do not yet occur and where they might be reasonably expected to occur within a few years.

Recovery studies provide an alternative to impact studies. Instead of attempting to detect the impact of a disturbance such as carp, recovery studies remove the source of disturbance, that is, carp, and the investigation focuses on detecting recovery from disturbance (Roberts and Ebner 1997). This form of assessment is free of many of the constraints of assessing the impact of an introduced population of carp, and has been applied successfully in Australia (King et al. 1997; Robertson et al. 1997). Recovery studies can be planned to suit most accepted experimental designs for impact assessment, and are particularly valuable in demonstrating the benefits of management actions to reduce carp (Roberts and Ebner 1997). However, there is an important distinction between impact and recovery studies. The changes that occur after carp have been removed are not necessarily the reverse of the changes that follow carp introduction. Environmental variability and other forms of disturbance may result in habitat conditions following carp removal that are noticeably different from the conditions that existed before carp (Box 6). Futhermore, ecosystem components that may have been affected by carp, such as seedbanks of aquatic plants, may not recover without active intervention to re-establish pre-impact conditions.

Reliable detection of environmental impacts and recovery is now a highly specialised area of ecology and it is strongly recommended that proposals for carp management be referred for professional advice before embarking on a program in order to maximise the ability to detect real changes resulting from efforts in carp control.

7.2.1 Water quality

Increased turbidity is the main aspect of water quality most commonly attributed to carp. But the turbidity of a water body can change because of high flows, sediment inputs from run-off or through wind and wave action disturbing sediments. The size of sediment particles also influences the rate at which they settle out, so that neighbouring billabongs may show differences in turbidity simply because of different sediment compositions (King et al. 1997). In the study by King et al. (1997), carp increased turbidity outside the range normally encountered in billabongs without carp, although wind and sediment run-off may also have contributed. Turbidity varies naturally along the course of a river and over time. For example, in five billabongs near Albury studied between 1982 and 1986, turbidity averaged 23.1 Nephelometric Turbidity Units (NTU) and ranged from 0.9–217.5 NTU (Boon et al. 1990). Flow conditions dramatically affect turbidity, with floodwaters picking up large amounts of fine particles upstream, and depositing them further downstream as the water velocity slows.

Turbidity can be measured with readily available electronic meters. However, there are two distinct components of turbidity with respect to carp. Sediments stirred up by feeding carp contribute directly to turbidity. Algal turbidity may also increase as a result of carp activity, through nutrients released from the sediments or from excretory products. To assess changes in turbidity attributable to carp control, it is desirable to obtain separate measurements of these different sources of turbidity.

7.2.2 Other factors

Other environmental factors associated with carp impacts are sediment deposition, phosphorus availability, substrate pock marks created by carp and changes to macrophyte density (Roberts and Ebner 1997). Harris and Gehrke (1997) suggested that the incidence of external lesions in native fish is correlated with carp density, although this needs to be confirmed by further investigation.

Rates of river bank erosion and slumping can be measured and associated with carp density, but this would need to be examined on a large spatial scale over a relatively long time to detect the contribution made by carp. Recent investigations of bank erosion and slumping in irrigation channels and in the Darling River were either inconclusive (Roberts and McCorkelle 1995) or suggested that factors other than carp were involved (Thoms 1997).

Most of the impacts of carp are relatively easy to establish in controlled experiments in ponds or billabongs, but the need to conduct experiments on an appropriate spatial scale makes carp impacts in rivers much more difficult to evaluate. Consequently, the true impact of carp on flowing water habitats will always be difficult to estimate.

Impacts of carp on native fish, through predation, competition and disease, have been claimed to occur for some time (see Chapter 3 and Section 5.3.4). However plausible such claims may be, there is no direct evidence in Australia that carp have caused the widespread decline of native fish species. Evidence from commercial fishery statistics shows clearly that native species were declining in some areas, probably as a result of fishing pressure and multiple habitat disturbances, well before carp became established (Reid et al. 1997). However it is likely that high carp numbers are now instrumental in keeping the number of native fish at a low level (Gehrke 1997a). Direct effects of carp through interference competition and exploitation competition can be determined by manipulative experiments in both field and pond environments.

7.3 Population contr ol techniques

Much of the debate about carp management centres around population control rather than impact reduction, particularly for waterways in public areas with high carp densities. This focus may hinder seting priorities for carp management (Section 8.3.3) where management of more susceptible and inherently valuable areas with lower carp densities may provide a greater return on investment. Strategies that focus on impact reduction may also prove more effective and economic in the long-term compared to ongoing carp removal. At the same time, carp removal may change the age structure of the population and therefore the nature of impacts (Section 3.3.2) and the fecundity of remaining fish which may be advantageous.

7.3.1 Captur e and r emoval

Capture and removal is a common method for attempting to control some feral animal species and this approach is also perceived as an option for reducing carp populations. Fishing, in all its forms, is by far one of the world's most popular and, arguably, successful techniques for reducing the abundance of fish. The history of the fishing industry contains a number of examples of species that have been fished to dangerously low levels, such as gemfish (*Rexea solandri*) in eastern Australia, southern bluefin tuna (*Thunnus maccoyii*) in the Indo-West Pacific region, and northern cod (*Gadus morhua*) off the Canadian east coast. Most of these populations, however, inhabit open oceans or coastal waters where commercial or recreational fishing is one of the few ways that fish populations can be managed (Thresher 1997). In contrast, carp live in rivers and lakes of all sizes where methods other than direct removal also allow fish populations to be controlled.

'Commercial carp harvesting has been conducted in the Gippsland lakes at signficant levels for the past decade with no apparent reduction in carp biomass.'

Carp removal can be achieved through both commercial and recreational fishing, as well as through dedicated removal operations. Whilst commercial fishing can remove relatively large numbers from some areas (Section 5.4.3), it is an impractical form of removal in many areas, especially in inaccessible river

Some states encourage removal of carp by recreational line fishing. Source: A. Brumley, East Gippsland Institute of TAFE.

reaches or habitats far from markets, or where the population consists largely of individuals of unmarketable size. The ability of dedicated carp removal teams to reduce carp numbers effectively depends upon the methods which can be used, which often depend in turn on the size and structure of the habitat.

Angling is an exceptionally popular pastime in Australia, with many anglers living near or willing to travel to relatively remote areas. Anglers use a wide variety of baits to catch carp, with canned corn, bread crust and boiled potatoes common choices in countries where carp fishing is popular (Spitler 1987). Although the diet of wild carp is based on zooplankton and insects with some plant material, corn products (for example, canned corn, corn meal, corn syrup, corn germ) feature strongly in lists of carp attractants used by anglers. The ability to attract carp using products that are readily available to anglers, but which do not occur naturally in their diet may provide options for selective removal of carp from some habitats. However, removal of carp by angling will usually have little effect on carp populations.

The extent to which removal reduces carp populations depends on the scale of the removal and the dynamics of the population. Unfortunately, little is known of the population dynamics of carp populations in Australia and the factors which drive population increase in the wild. The natural variability of Australian rivers also makes it difficult to predict or model wild carp populations. Physical removal on a large scale could have value as a control technique where numbers are already low or where the population is suffering from poor recruitment as a result of unfavourable environmental conditions. Even in these cases, removal will need to be continued indefinitely at levels beyond those which would be commercially viable, because even heavily fished carp populations return rapidly to pre-fished levels once harvesting stops (McCrimmon 1968). The target population size required to produce a relatively stable, low population density in the Murray–Darling River system has been estimated at less than 10% of the unfished biomass (Thresher 1997). This estimate is consistent with the adult population density needed to limit recruitment to low levels (Section 3.4.3). To achieve such a large reduction in carp numbers, the removal effort must target all carp habitats, not just those in which carp can be easily caught. Otherwise, immigration from unfished areas, combined with compensatory reproduction and survival, will cause a rapid return to previous population levels. In contrast, capture and removal of mature individuals from small populations in confined habitats is likely to significantly reduce the reproductive capacity of the population.

The ability of commercial carp harvesting to have a significant impact on carp populations even in enclosed waters is questionable. For example, commercial carp harvesting has been conducted in the Gippsland lakes at significant levels for the past decade (Section 5.4.1), yet it appears sustainable with no apparent reduction in carp biomass.

Bounty schemes have been used throughout the world as a financial incentive to induce control of many vertebrate pest species (Hassall and Associates 1998). In Australia, bounty schemes or harvesting subsidies have been used for pest species including goats (Parkes et al. 1996), pigs (Choquenot et al. 1996) and foxes (Saunders et al. 1995), but have often been discontinued as they have been considered to be of doubtful value as a form of pest control (Parkes et al. 1996). In a review of bounty schemes, Hassall and Associates (1998) concluded that most had been condemned by their implementing agencies as a 'costly, misguided and ineffective tool for addressing pest problems'. Reasons have included fraudulent practices and the failure to provide relief from pest impact. Another reason is the targeting of the pest where they are in the greatest densities and hence where they are the most easily caught, rather than where control is most effective in reducing impact (Whitehouse 1977; Saunders et al. 1995; Smith 1990; Choquenot et al. 1996). Hassall and Associates (1998) concluded that bounty schemes were unlikely to result in significant or long-term pest damage reduction.

It is unlikely that bounties or incentives for carp harvesting will be any more successful at carp control than those for other vertebrate pests. Irrespective of the success of the carp industry development incentive in expanding the carp fishery in New South Wales, the analyses of Hassall and Associates (1998) and Thresher (1997) strongly suggest that commercial harvesting is likely to reduce carp numbers in localised areas only and have little effect on the control of carp populations on a wide scale.

7.3.2 Envir onmental r ehabilitation

Whilst physical removal of carp is a direct method of control, restoring ecological processes in aquatic ecosystems may impose an indirect form of control (Harris 1997). It is accepted that many Australian rivers and lakes have been severely degraded (Williams 1980; Harris and Gehrke 1997) and their native fish faunas depleted (Cadwallader and Lawrence 1990; Harris and Gehrke 1997; Gehrke et al. 1999a). Environmental disturbance has been recognised as favouring the establishment of new species (Tilzey 1980; Li and Moyle 1993) and disturbances to both coastal and inland river systems have been widespread in Australia. Examples of disturbances include toxic pollution, thermal pollution and other changes to water quality, destruction or removal of fish habitats, changes to flows including reduced flooding and altered flow variability, and barriers which alter both longitudinal and lateral connectivity within river systems. These changes have been demonstrated as having detrimental effects on aquatic fauna, especially native fish species (Cadwallader 1978; Harris 1984;

Re-establishment of riparian vegetation and improving other aspects of aquatic ecosystems may decrease the competitive advantage of carp over native fish species. Source: A. Brumley, East Gippsland Institute of TAFE.

Koehn and O'Connor 1990a; Gehrke et al. 1995; Gehrke et al. 1999a).

Driver et al. (1997) suggested that improved river management would be effective in reducing carp densities, resulting in improved water quality and stronger native fish populations. Suitable management options include: limiting carp spawning habitat (Section 3.4.2); restricting carp dispersal (Sections 3.4.3 and 3.4.5); reducing catchment-wide effects of agriculture, such as siltation and land clearing (Section 3.2.1); and restoring natural flow regimes (Section 3.2.1). Other options to reduce levels of catchment disturbance may also limit carp populations in urban areas (Sections 2.1.4, 3.5.5 and 6.3.2).

'Aquatic ecosystems with natural levels of disturbance and with established native fish populations are more resilient to invasive species such as carp.'

Carp have high tolerances to poor water quality conditions and therefore have a greater ability to exploit polluted habitats than many native species (Hume et al. 1983a; Growns et al. 1998; Gehrke et al. 1999a; Section 3.2.2). They also have broader habitat preferences than many native fish species (Koehn and Nicol 1998). Mallen-Cooper et al. (1995) (Section 3.2.1) found carp could negotiate some obstacles that posed serious barriers to migrating native fish species. Reduced variation in flow also favours carp which are more adapted to constant flows. Studies in the Murray–Darling Basin show that carp numbers are higher in catchments where river flows have been most altered (Gehrke et al. 1995; Gehrke et al. 1999b). These factors all favour carp over native fish, as well as having direct detrimental effects on native species by directly modifying their habitats, restricting their breeding (Harris and Gehrke 1994) and limiting their ability to recolonise habitats (Harris and Mallen-Cooper 1994). Reductions in the numbers of large native fish, such as Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*), have also modified aquatic food webs by severely reducing predation pressure on other species including carp (Gehrke 1997a).

Aquatic ecosystems with natural levels of disturbance and with established native fish populations are more resilient to invasive species such as carp. Adopting an ecosystem approach to carp control works to re-establish the resilience to invasion within the natural system while other strategies focus more directly on reducing carp numbers. Restoring such ecosystem attributes as habitat structure, bed contours, substrate type, flow regime, water quality, aquatic plants, riparian vegetation and connectivity between habitats can make conditions less favourable for carp and is likely to enhance native fish numbers. Examples of the types of habitat restoration works that may be undertaken, focussing on European fish species, are given in Cowx and Welcomme (1998). Many of these principles can be modified and applied to Australian conditions and fish species.

7.3.3 Envir onmental manipulation

Complete removal of carp can be achieved by draining and drying isolated habitats. Carp have been shown to be less adept at returning to the river from off-stream flood waters than many native fish species (Koehn and Nicol 1998) and often become trapped in these waters. Selective carp removal has also been undertaken on the Chowilla floodplain in South Australia through reductions in water levels (B. Pierce, South Australian Research and Development Institute, pers. comm. 1998). Measures need to be undertaken to prevent reintroductions where anabranches reconnect to rivers. Whilst this is possible for adult fish by using screens, it is difficult to prevent smaller fish from re-entering the cleared habitat, where they may eventually establish another population.

Another form of environmental manipulation involves drawing down the water level in lakes and impoundments to prevent access by carp to littoral habitats which offer submerged vegetation for spawning habitats. This approach appears to have been successful in Tasmania, although complete data are not yet available (J. Diggle, Tasmanian Inland Fisheries Commission, pers. comm. 1999; Section 6.3.5).

7.3.4 Chemicals

Poisons have been used to reduce populations of many terrestrial vertebrate pest species on a wide scale. However, widespread use of poisons is not possible in aquatic habitats, because species-specific poisons for carp are not yet available (Marking 1992) and the risk to non-target native fish species is unacceptable in most cases.

'The recent discovery of carp in Tasmania highlights the danger of reintroductions by human translocation even if eradication is achieved.'

Carp have been successfully eradicated from isolated waters in several locations using chemical poisoning (Sections 6.3.3 and 6.3.5). Poisoning is not always effective on a wider scale, however, as was shown in Victoria where carp eventually became established in the La Trobe River. The recent discovery of carp in Tasmania also highlights the ever-present danger of reintroductions by human translocation even if eradication is achieved.

Other introduced fish species, such as gambusia (*Gambusia holbrooki*), redfin perch (*Perca fluviatilis*), brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) have been eradicated from certain areas by chemical poisoning (Sanger and Koehn 1997).

Only a few products are available for poisoning fish. The best known is rotenone. Rotenone poisoning has been the method most widely used by fisheries agencies in Australia to remove unwanted fish from freshwater habitats. Rotenone is produced from the roots of several different plants, most commonly derris root (*Derris* spp.), which gives rise to the name 'Derris Dust' commonly used as a garden insecticide. It is one of the safest pesticides available and is labelled for use on young domestic pets as a flea powder. It is an organic odourless yellow crystal or powder which is insoluble in water.

Rotenone can be applied to fish by suspension in water, by injection or by ingestion of an oral bait. In suspended form, rotenone enters the fish through the gills as the fish respire. It is carried through the entire body of the fish and causes the fish to suffocate because oxygen in the blood is not released to the tissues. In commercial preparations, rotenone is commonly mixed with a synergist which prevents the fish from detoxifying the rotenone. Addition of the synergist means that less rotenone is required to kill fish. A solvent is also often added to dissolve the rotenone in liquid preparations to assist application to water. Fish that have not acquired a toxic dose of rotenone in their bodies can be revived by removing them to clean aerated water but once a toxic level has accumulated the fish will die. Potassium permanganate can be applied to de-toxify water treated with rotenone but cannot revive affected fish.

'Better knowledge about carp biology may enable existing chemicals to be applied in innovative ways that deliver the poison to carp without placing other species at risk.'

Rotenone is more toxic to fish in acidic water and in waters with low hardness. It is more toxic at higher temperatures, but also breaks down more rapidly, reducing the time of effectiveness. Sunlight also accelerates breakdown of rotenone. Turbidity caused by clay particles in the water can adsorb rotenone, effectively reducing its concentration. Species such as carp that stir up sediments can increase turbidity to the extent that it affects rotenone treatment. Because rotenone enters the body via the gills and not across the skin, vertebrates other than fish have little risk from exposure, except for amphibians (frogs, toads and their tadpoles) which are highly susceptible.

In addition to the powder and liquid forms available, rotenone has also been formulated into baits for oral application and into a form that can be delivered by helicopter. When applying rotenone, operators should avoid contact with the skin and avoid breathing its dust or vapour. Exposed areas should be washed with water for 10–20 minutes. No human deaths have been reported from rotenone use but it may cause liver damage and irritate the skin and eyes (Rotenone product information, Prentiss Incorporated, USA).

Other chemical products include endosulfan, antimycin, acrolein and copper sulphate, with each having advantages and disadvantages. These chemicals were developed for purposes other than poisoning fish and are not approved for use as fish poisons in Australia, although fish kills resulting from their use have been reported. Application of copper sulphate to Wingecarribee Reservoir, south-west of Sydney, in December 1997 to control nuisance algae resulted in the death of approximately 15 000 carp (P. Gehrke, NSW Fisheries, pers. comm. 1998). Research is continuing into other applications with new fish management baits and alternative preparations being developed in North America (Sanger and Koehn 1997).

The use of chemicals is often controlled by environmental regulations which over-ride fisheries agencies and so their use must be well justified. This provides environmental safe guards against unauthorised use of chemicals, but delays could prove critical if potentially controllable populations spread before permission is given and action is taken. The use of poisons also causes widespread public concern and can be a high-risk strategy unless well planned and implemented.

The application of chemicals in small isolated waters such as farm dams is relatively straightforward as there is little chance of a spill and neutralisation of the chemical can be allowed to occur naturally. Large-scale rotenone treatments in reservoirs have been conducted worldwide, with the most notable examples coming from the United States (Sanger and Koehn 1997). A recent review found that about 48% of large-scale rotenone applications had achieved their goal (Meronek et al. 1996). The largest documented application in Australia was in Leigh Creek Retention Dam in South Australia (Hall 1988) where the dam was successfully treated with rotenone to kill carp and prevent their escape into the Cooper Creek system. The use of chemicals in flowing waters holds more problems because the chemicals must be broken down or de-toxified to prevent killing non-target organisms downstream.

Unlike most other forms of fish removal, poisoning has special significance in terms of public perception, the risk of downstream kills and the effects on other fish species present. The prospects for large-scale use of rotenone or other poisons are limited. The cost, and availability of rotenone, environmental risks and problems of ensuring a complete eradication whilst eliminating the risks of reintroduction all weigh against this method of removal. Mass kills of carp could also pose pollution problems and this is an issue for other potential lethal techniques including viruses and fatality genes. However, rotenone application may be readily justified as a rapid response to control carp outbreaks beyond their current distribution. Small-scale use of rotenone will continue in controllable environments such as farm dams and small reservoirs. Larger reservoirs may be treated more cost-effectively when water levels are low.

Novel uses of rotenone, such as baits prepared to improve species selectivity, require further development and testing. Prentiss Incorporated in the United States market a rotenone-based bait to control grass carp (*Ctenopharyngodon idella*), and are developing a similar product for carp which is not yet commercially available. It is unlikely that chemicals will be identified that are selective to carp alone. Better knowledge about carp biology and physiology may enable existing approved chemicals to be applied in innovative ways that deliver the poison to carp without placing other species at risk.

7.3.5 Viral contr ol agents

Biological control of carp with a virus was suggested during the rapid spread of the species during the 1970s. The agent suggested was Spring Viraemia of Carp Virus (SVCV) (*Rhabdovirus carpio*) which causes a haemorrhagic disease that had been isolated in farmed carp in Europe (Crane and Eaton 1997). The possibility of using SVCV as a biological control agent was also raised at carp forums held in 1994 and 1995 (Hindmarsh

1994; Crane 1995). To date, consideration of the use of viral control agents has focussed almost exclusively on SVCV.

In order to assess the potential of such a method of biological control it is important to understand its functioning and limitations. All rhabdoviruses isolated from fish are currently considered to be exotic to Australia. As carp in Australia originated from Europe, it is possible that SVCV may already be present in this country (Crane and Eaton 1997). Spring Viraemia is considered to be a disease of farmed carp and is rarely observed in wild populations. It can affect carp of all ages and exhibits clinical signs that are typical of any systemic infection: pale gills, haemorrhages, dark skin colouration, abnormal swimming and depressed respiration. Mortality is usually in the range of 20–40% although it may reach 100%. Most, if not all, cyprinid species are likely to be affected to some degree by this virus (Crane and Eaton 1997; Section 3.4.4). Consequently, other cyprinids currently in Australia would also be at risk if the virus were released.

'Intense scrutiny would be given to the release of viral control agents, especially those which may be water-borne.'

The effects of SVCV on carp populations under Australian conditions are not known. Improvements to carp farming conditions in Europe, including reducing fish stress, have reduced mortalities caused by SVCV. There appears to be little environmental stress on wild carp populations in Australia, even though carp populations here may not have been subjected to the virus before. In the Murray–Darling Basin, carp are not subjected to severe, cold winters, spring is relatively short and summers are long and hot, all conditions which are not particularly favourable to this virus (Crane and Eaton 1997).

Following the public controversy surrounding the release of the rabbit calicivirus, intense scrutiny would be given to the release of any further viral control agents in Australia, especially those which may be water-borne. Authorisation for its release would almost certainly be required under the *Biological Control Act 1984*. Such authorisation could give indemnity against legal action for compensation to the agency that released the virus. Compensation might otherwise be claimed by commercial carp harvesters and processors and others who profit from the presence of carp in Australia. As Spring Viraemia of Carp Disease is a notifiable disease in Europe, its release in Australia would mean that Australia would no longer be considered free of the virus, which may have implications for trade in ornamental fish (Crane and Eaton 1997) or fish products.

7.3.6 Biomanipulation

Biomanipulation is the practice of deliberately manipulating the interrelationships among plants, animals and their environment to achieve a new ecological balance. This is usually attempted in lakes to control problems such as aquatic plants or algae. For example, recurrent algal blooms can sometimes be controlled by increasing the density of grazing zooplankton. Simplified stages of biomanipulation that involve fish are: (1) reducing populations of zooplanktivorous fish to low levels, and (2) stocking the system with predators to suppress subsequent growth of the zooplanktivorous fish population. While a single manipulation may result in a stable system, either or both phases may need to be repeated annually or on an ad hoc basis to maintain the desired balance. The goal of the exercise is to change a system from an undesirable steady state to another, more desirable, steady state that will not revert readily to its previous condition. The concept of biomanipulation is directly relevant to reducing the environmental impacts of carp in closed systems such as lakes and ponds. However, it is much more difficult to achieve a desirable, managed outcome by manipulating the food chain in flowing-water environments.

Several overseas studies have shown reductions in the recruitment of cyprinids following stocking with predatory pike (Prejs et al. 1994; Berg et al. 1997). Whilst stocking Australian waters with such introduced predatory species is not a sound ecological option, the use of native predatory species may be likely to have similar effects and warrants serious scientific evaluation.

'Biomanipulation control of carp requires habitat restoration to support native species, the ability to reduce carp numbers to a low level, and the ability to greatly increase numbers of predators.'

Although predation on carp, especially young fish, by predatory native fish such as Murray cod and golden perch occurs, no scientifically conducted trials have been undertaken to ascertain the potential of this method for controlling carp. Native fish species are stocked mainly for species conservation and to support recreational fisheries by fisheries agencies in Queensland, New South Wales, the Australian Capital Territory and Victoria. The added advantage of carp control from these stockings is often mentioned, although not evaluated. Because carp recruitment in large populations is likely to be density-dependent, and because large mature carp have very few predators in Australia (Section 3.4.4), predation on small carp is unlikely to have any appreciable effect on adult carp populations. Hence the level of carp control from such stockings may be minimal. If, however, the existing adult population was severely reduced, for example, to less than 10% (Thresher 1997), then a stocked population of predators might have a high chance of suppressing the carp population over a long time scale. Despite its apparent appeal, biomanipulation is a highly controversial area of ecology, and should not be undertaken lightly with unrealistic expectations of success. There is, however, scope for such manipulations to be evaluated on a small scale in enclosed waters to explore the problems likely to be encountered and the likely impacts on carp populations before wider application.

In contrast to the situation in lakes or impoundments where fish populations are typically closed to immigration and emigration, fish in rivers are able to migrate extensively. This makes the task of reducing carp populations via a biomanipulation exercise difficult because carp from other areas can rapidly replace those removed. It also requires much higher stocking densities of predators to replace those which emigrate. The decline of most native fish populations in south-eastern Australia began as a result of exploitation and habitat changes before carp populations expanded. Stocking large numbers of fish into riverine habitats which can no longer support large populations is more likely to further destabilise the system, with unpredictable and potentially undesirable results, than it is to effectively control carp. For biomanipulation control of riverine carp populations to be effective, substantial habitat restoration to support native species, the ability to reduce carp numbers to a low level, and the ability to greatly increase numbers of predators without destabilising the system, are essential pre-requisites. The capacity to implement these changes currently exists only for very small rivers in isolated catchments.

7.3.7 Carp exclusion devices

In contrast to methods for controlling carp impacts by reducing the size of existing populations, carp exclusion devices are intended to prevent carp from establishing populations where they do not exist, or in habitats from which carp have been removed. Barriers in the form of 'fish screens' have been used in Tasmania to attempt to prevent the spread of carp from Lake Sorell and Lake Crescent. The success of these screens has not been determined but carp have not spread to date (W. Fulton, Tasmanian Inland Fisheries Commission, pers. comm. 1998). Screens may prevent movement of larger fish but it is difficult to prevent movement of eggs, larvae or juvenile fish. Screens were also used in Pilby Creek in South Australia and a wetland near Bairnsdale in Victoria (Section 8.6.1, Box 9) to prevent carp from re-entering habitats. Such screens are not effective in times of flood.

Other forms of barriers, such as electric barriers, bubble curtains and sonic barriers have been used in other countries to exclude fish from structures such as industrial cooling water intakes, but their effectiveness against carp is unknown.

7.3.8 Emerging biological control technologies

Recent advances in molecular biology and biotechnology have provided opportunities to attempt the development of new biological control agents. The new control agents could be live, naturally disseminating immunocontraceptives or artificially enhanced pathogens which specifically kill or disable the target pest species (R. Seamark, Vertebrate Biocontrol Centre, ACT, pers. comm. 1999).

Immunocontraception

The Cooperative Research Centre for the Biological Control of Pest Animals is investigating the potential of immunocontraception to prevent population growth in feral pests (Tyndale-Biscoe 1994, 1995). The approach involves the delivery of a gene which blocks reproduction mechanisms (usually via a species-specific reproductive protein) when the host is infected by a recombinant virus. This approach is currently under development for mice, rabbits and foxes and is high risk in terms of achieving a practical outcome that reduces the environmental and economic damage caused by these pests. Immunocontraception requires a multi-disciplinary team to focus on the problem at many levels: molecular biology, immunology, virology, reproductive biology, field ecology and population dynamics. The aim is to produce a species-specific infertility agent that will have a significant effect on the pest species without any effects on non-target species (Hinds and Pech 1997).

The immunocontraception antigen would have to induce an effective immune response which affects fertility to a level that reduces the abundance of carp to desired levels. The delivery system would need to be practical, cost-effective, species specific and affect a sufficiently large proportion of the target population to reduce impacts. A delivery system which could meet these requirements may include the release of a genetically modified organism. Primary reproductive processes that may be targeted to impair fertility include the development of the gametes and the functioning of the gonads. Delivery mechanisms for the antigen include the use of baits that may be designed to match the feeding behaviour of carp. The risks and benefits of any such release would need to be assessed.

'Extremely high infertility rates would need to be achieved for fertility control to have any useful effect on carp populations.'

The use of any reproductive control mechanism must be evaluated using information on the ecological processes determining the distribution and dynamics of carp populations in Australia. Modelling of both the fish populations and the epidemiological processes is required. The value of fertility control for carp management depends on the effectiveness of the techniques developed and the levels of control required (Hinds and Pech 1997). A critical issue in fertility control for carp is the huge number of eggs produced, compared with the small number of young produced by most terrestrial vertebrate pests and the density-dependent mortality of juveniles (Sections 3.4.2 and 3.4.3). Because the number of spawning fish need to be reduced greatly to reduce the number of young carp subsequently recruiting to the population, the capacity exists for non-affected females to produce sufficient viable eggs to maintain current population levels (Hinds and Pech 1997). Consequently, extremely high infertility rates would need to be achieved for fertility control to have any useful effect on carp populations.

Molecular approaches

Recent advances in molecular biology offer a number of potential approaches for controlling carp. These include chromosomal manipulation, gender manipulation and the introduction of inducible or programmed fatality genes (Grewe 1997). These methods can briefly be summarised as:

Ploidy/chromosomal manipulation — Used to induce sterility.

Controlling sex composition of populations — Single sex populations have been achieved by treating gametes prior to fertilisation under laboratory conditions.

Hormonal treatment — Treatment with the male hormone testosterone can produce all male fish, including some which are chromosomally female but which function as fertile males.

Transgenic manipulation — New genetic material can be inserted deliberately into the target species for example, to change sex functioning.

Fatality Gene (FG) — It has been considered that this method has considerable advantages over others as a long-term application with 100% security if correctly implemented (Grewe 1996).

Two forms of 'fatal' genes have been suggested. Inducible Fatality Genes (IFG) involve breeding carp with a genetic, fatal weakness to an otherwise benign 'trigger' substance, such as dietary zinc. After breeding this gene into the carp population over several generations, a trigger can be applied, for example in the form of zinc-laden pellets, which activates the gene and kills fish carrying the gene. Programmed fatality uses a similar idea, but the fatal gene is triggered at a specific life history stage, such as the onset of sexual maturity.

Development of fatal genes involves several distinct steps (from Grewe 1997):

- identify and select appropriate genetic material for transfer. This must include the fatality gene and a reporter gene
- incorporate this genetic material into the carp genome
- deliver the material at a population scale. This includes stocking carp with the modified genome
- monitor the spread of IFG through natural populations via the reporter gene
- activate the trigger to activate the fatality gene once the gene has spread through the population to a predetermined level.

Each of these steps presents its own technical and logistical challenges, such as safety testing, the longevity of the gene, the impact of stocking millions of genetically-modified carp, and the environmental impacts of killing huge numbers of carp. If these challenges can be overcome, then fatal gene technology appears to be a viable and perhaps long-term strategy for environmentally benign control of carp in Australia.

Mathematical models have been used to assess the potential of fatal genes or inducible sterility genes to control carp and other species (Davis and Fulford 1999; Davis et al. 1999a). The results suggest that these methods may provide long-term control, but the rate of spread of these genes into feral populations is likely to be slow.

Sterile ferals

This approach is being investigated by CSIRO based on recent developments in molecular biology and population genetics. The concept is based on being able to influence population dynamics by introducing an inducible sterility gene that renders individuals within a population sterile. Like inducible fatality genes, this approach is futuristic and contains many challenges before it might be able to be applied to wild populations, but these approaches represent a range of previously inconceivable options that may become practical with further advances in biotechnology.

7.4 Methods for impact reduction

7.4.1 Fishways

The term fishway refers to any device that allows fish to negotiate a barrier that would otherwise block fish movement. Several designs of fishways are currently in use in Australia. On low barriers, such as weirs up to six metres high, fishways are usually passive devices, relying only on the flow of water to allow fish to move upstream. Larger barriers such as major dams must usually provide active assistance for fish attempting to move upstream, by lifting or pumping fish up over the wall.

Trap-and-truck fishways allow carp to be removed and native fish to be placed upstream of dams and weirs. Source: A. Toovey, NSW Fisheries.

The most common design of fishway for native fish on larger rivers in Australia is the vertical-slot fishway (Mallen-Cooper 1994; Mallen-Cooper et al. 1995) (Figure 20). This design features a series of pools and weirs, with a vertical rectangular orifice in each weir through which water passes down to the next level. It allows fish to ascend a barrier by negotiating a number of small increases in water level without needing to jump. These fishways work on a range of slopes from 1:18 for adult and large juvenile fish, to 1:30 where there are large numbers of small juveniles. The cost of a vertical-slot fishway depends on the height of the weir and may range from $250 000 to $750 000 (Mallen-Cooper and Harris 1990).

Denil fishways consist of a channel filled with closely spaced U-shaped baffles that angle upstream (Figure 20). The baffles create an area of low velocity near the base through which fish ascend. This design can be used on steeper slopes than the vertical-slot fishway, with a gradient of 1:12 being ideal. It is therefore cheaper to build than a vertical-slot fishway.

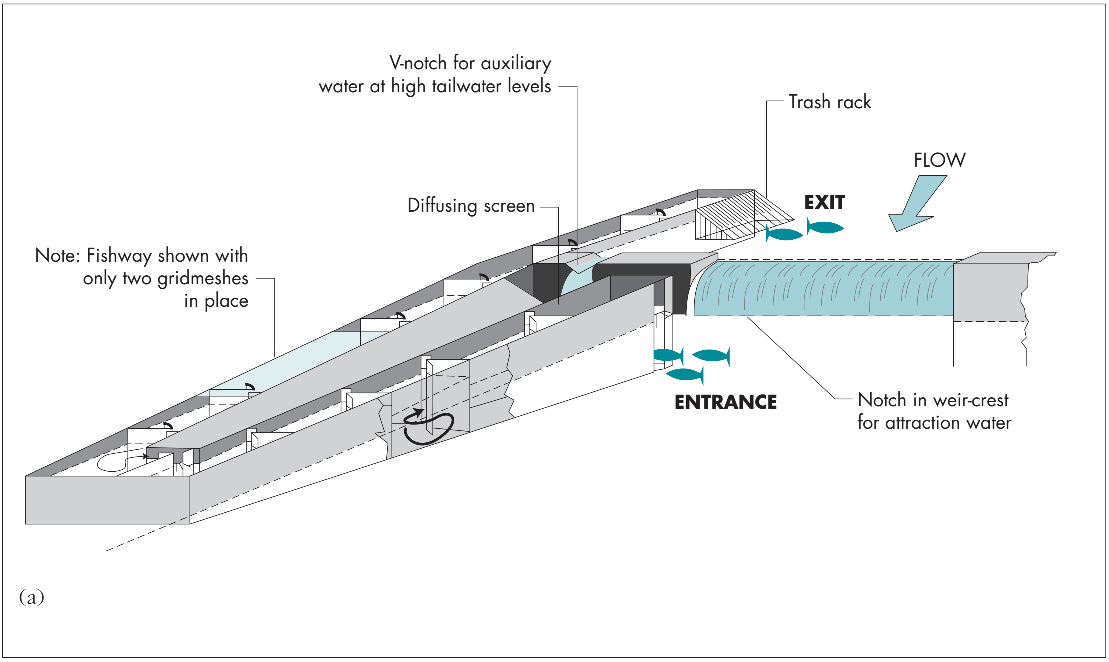
Rock-ramp fishways are less sophisticated designs that can be used on low weirs less than one metre high. They mimic natural stream riffles and consist of a 1:20 sloping rock ramp that has a series of rock ridges interspersed with pools (Figure 20). Each ridge has a number of slots through which the water drops to the next pool. Fish ascend through the slots, resting in the pools before attempting the next step up the ramp. The cost for a rock-ramp fishway varies depending on the availability of suitable rock.

High dams, such as Hume Weir, are too high for the preceding fishway designs. Alternative methods exist, such as fish locks, fish elevators (Clay 1995) and fish pumps (Marsden et al. 1997). Although fish pumps have not been used in Australia, a fish elevator has been installed on Yarrawonga Weir on the Murray River and is currently undergoing testing. Fish transport has also been conducted at the Yarrawonga site, removing fish from the entrance to the fishway, transporting them by truck and releasing them upstream of weir to avoid their being drawn into a power station inlet (C. Lay, NSW Fisheries, pers. comm. 1999).

'Fishways may reduce the impacts of carp by allowing native species increased access to habitats where their numbers have declined.'

Fishways may reduce the impacts of carp by allowing native species increased access to habitats where their numbers have declined. Movement is an essential part of life for all native fish species, whether it be in the form of daily feeding movements over relatively short distances, or long distance breeding migrations. Mallen-Cooper et al. (1995) reported large numbers of fish, including carp, moving through the vertical-slot fishway at Torrumbarry. Enhanced native fish populations may reduce the competitive advantage that carp have in many habitats, and provide increased predation pressure (Section 3.5.2).

Fishways also allow dispersal of carp to colonise new habitats. However, the ability of carp to negotiate fishways can be turned



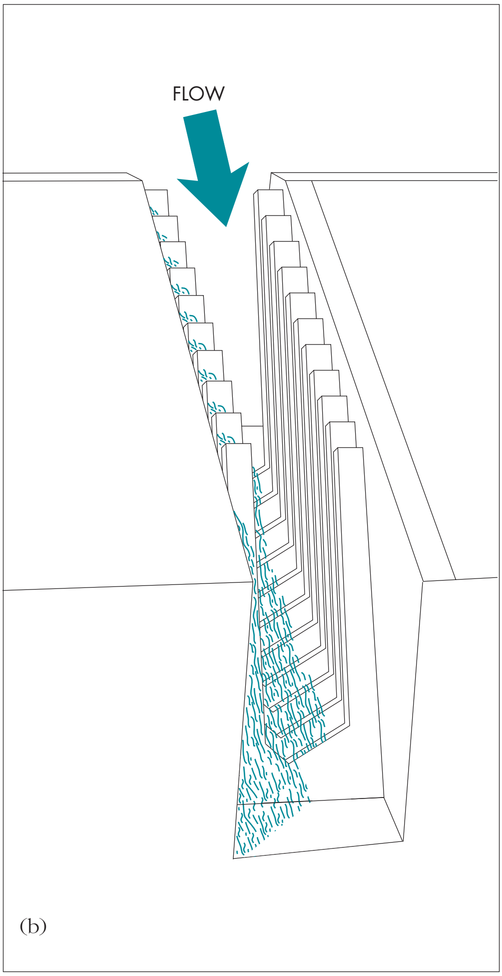
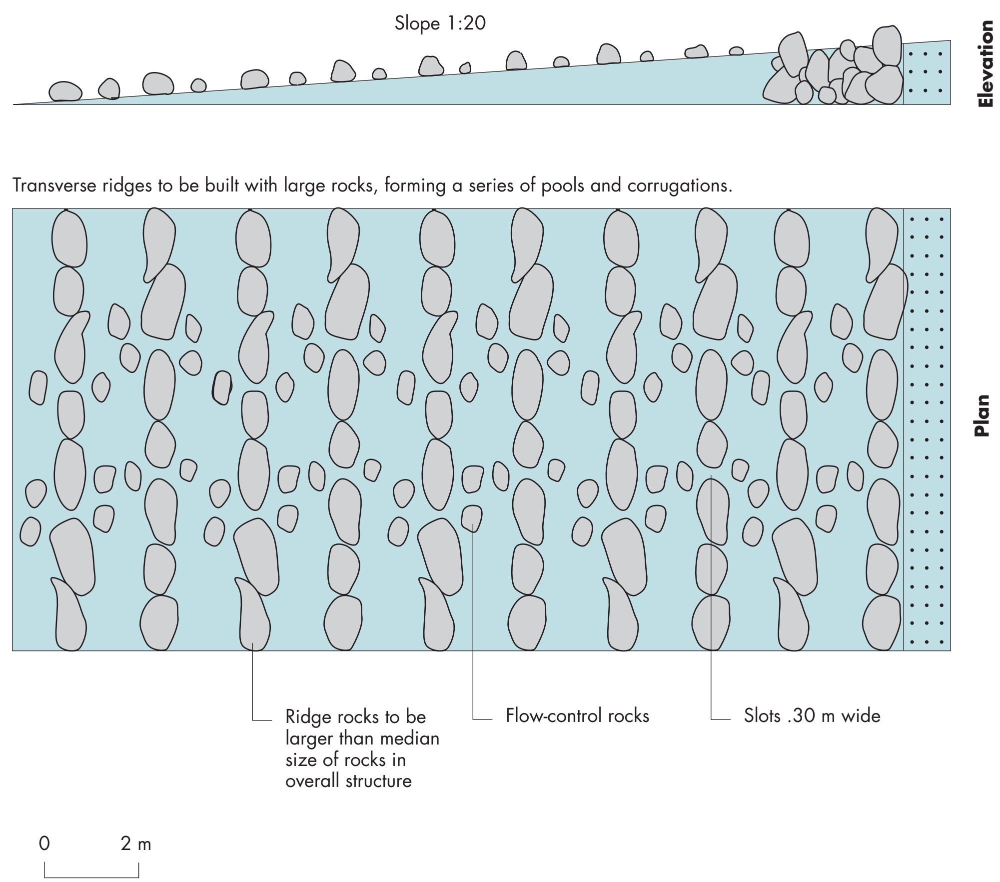


Figure 20: Diagram of (a) vertical slot,
(b) Denil and
(c) rock-ramp fishways.



(c)

to their disadvantage. By installing traps at the top of fishways, carp reaching the top of the fishway can be removed and destroyed while native fish are returned to the water. This process can be automated by installing electronic fishway monitors that distinguish between carp and native species. A suitable monitoring and image analysis system is currently being developed (B. Owen, University of Melbourne, Victoria, pers. comm. 1998), but more development is required to produce a working prototype.

7.4.2 Flow management

Rivers in the Murray–Darling system with the most variable hydrological regimes have the most diverse fish communities, containing a more even balance of species than rivers with relatively stable flows (Gehrke et al. 1995). The higher diversity in hydrologically variable rivers means that fish communities are more constant over time than in hydrologically stable rivers where changes in abundance of a few species can cause relatively large variations in community composition over time. Regulating river flows to provide water for agriculture and rural communities reduces the natural variability in flow regimes. Variable flows create a diversity of habitats that in turn are able to support a greater diversity of fish species than simpler habitats. By implementing environmental flow regimes that restore elements of the timing, frequency and variability of natural flow events, the dominance of carp in fish communities is likely to be reduced (Gehrke 1997b; Harris 1997). Many regulated rivers carry unnaturally high, stable flows during irrigation seasons which allow carp to enter floodplain nursery habitats to breed. By increasing flow variability, carp access to floodplain nursery habitats can be restricted, simultaneously reducing the impacts of carp on these habitats and potentially reducing survival of juvenile carp. River flow objectives currently being implemented in New South Wales rivers (Environment Protection Authority 1997) with a partial goal of reducing carp numbers include:

- protecting water levels in natural river pools and floodplain wetlands during periods of no flow
- protecting natural low-flows
- protecting or restoring a proportion of freshes (small to intermediate flows) and high-flows
- maintaining or restoring the natural inundation patterns and distribution of floodwaters supporting natural wetland and floodplain ecosystems
- mimicking the natural frequency, duration and seasonal nature of drying periods in naturally temporary streams
- maintaining or mimicking natural flow variability in all streams
- maintaining the rates of rise and fall of river heights within natural bounds
- maintaining groundwater within natural levels
- minimising the impact of instream structures
- minimising downstream water quality impacts of storage releases
- ensuring management of river flows provides the necessary means to address contingent environmental and water quality events.

7.5 Cost of contr ol

Purely hypothetical costs of complete carp removal in irrigation channels in the Murrumbidgee Irrigation Area (MIA) have been estimated for four alternative methods (Roberts and Ebner 1997). Applying the chemical acrolein during the irrigation season would cost $13.8 million, assuming that approval could be obtained to use acrolein for this purpose. Carp removal using rotenone outside the irrigation season was estimated to cost $1.4 million. Estimated costs using boat electrofishing were at least $1.9 million during the irrigation season, or at least $0.2 million outside the irrigation season. A similar hypothetical analysis for carp control in wetland habitats estimated water draw-down would be highly effective and cost $102 000 over ten years, whereas physical removal using nets would be less effective and cost $75 000 over ten years (Roberts and Ebner 1997). Of these removal methods, only chemical poisoning would be likely to ensure complete removal of carp from a given area. These two assessments made many assumptions because appropriate data were not available. This means that the actual costs incurred in practice may differ widely from estimated costs, but the estimates provide a reasonable indication of the likely cost difference between methods. The areas involved in these analyses in the MIA were relatively small so that the total costs would be much higher if these methods were to be applied across all carp habitats in large river systems such as the Murray–Darling Basin, or the Hawkesbury–Nepean.

Harris and Gehrke (1997) estimated the staff costs for field sampling in the New South Wales Rivers Survey at $215 per staff member per day. This covered salary, on-costs and government travel allowances. This figure contains considerable savings obtained by using summer students and volunteers to reduce the time contribution of salaried staff. The full cost in 1999 of a three-person electrofishing crew working to catch carp for a five-day working week was $5400. Vehicle lease and fuel costs may range between $500 and $800 per week. Full-sized electrofishing boats can cost between $40 000 and $90 000, although this cost can be spread over the working life of the boat. Maintaining an electrofishing boat in safe working order is also a significant cost that could average $100 per week for the working life of the vessel. The NSW Rivers Survey caught approximately 50% of carp larger than 100 millimetres from a 0.24 hectare section of the Bogan River near Bourke in New South Wales by repeatedly fishing over five days. The cost of electrofishing to reduce carp from other habitats can be estimated from this information and will be influenced by the amount of volunteer labour available, the need for qualified electrofishing crew, and whether a boat is purchased or leased.

'Carp eradication attempted in Victoria cost over $1 million and was unsuccessful.'

Many of the high-technology methods described in Section 7.3 are currently being developed for other pest animal species. Although further development is needed to apply these techniques to carp, there could be considerable savings from the success of work already under way.

Carp eradication was attempted in Victoria in 1962 by poisoning 1300 small dams. The exercise required 200 working days and $50 000 (Victorian Fisheries 1991a), equivalent to over $1 million at current values, and was unsuccessful. The cost of removing carp from small water bodies can be quite low, costing as little as a few thousand dollars for a single attempt. This expenditure may be justified in isolated habitats where recolonisation can be prevented. But the cost of effective control will escalate as the size of the habitat and the probability of reinvasion increase.

8. Strategic management at the local and regional level

Summary

This Chapter outlines the process for planning and implementing strategic management of carp at local, regional and national levels. The four components of the strategic approach to carp management are: defining the problem, developing a management plan, implementing the plan, and monitoring and evaluating results.

The first step in developing a management strategy is to define the problem. This means determining the nature and scope of the management concern (for example, loss of water quality or aquatic vegetation). A number of factors in addition to the presence of carp can contribute to observed problems, including human interference, habitat type, local influences on water flow and quality and other fish species present. The problems caused by carp may affect many natural resources. Therefore the management of carp as a pest species is a natural resource management issue which extends well beyond the realm of traditional fisheries management.

The second step is to develop a management plan. This must include clear objectives set in terms of the economic and/or conservation outcomes being sought. These management objectives should include interim and long-term goals. Developing the plan will involve an assessment of the most appropriate control technique(s) and strategy and setting the priorities for management. Best results in pest management are often achieved with a combination of techniques rather than relying on a single technique. Options for carp management include: prevention of further spread, local, small-scale poisoning or removal, exclusion, habitat rehabilitation to enhance native fish species, commercial or recreational removal, and wide-scale control options which may include new technologies. In developing a management plan, one or more of these options need to be selected that will best meet the management objectives. Measurable performance indicators then need to be defined which can be used to measure progress against the management objectives.

The third step, implementation, is dependent on an integrated approach for success. Although much of the responsibility will rest with a range of government agencies, cooperation and ownership must also be undertaken with other stakeholders and community groups. Ownership of carp management must ultimately reside with many agencies and groups, not just those with fisheries interests.

The fourth and key step is monitoring and evaluation. This should occur at different levels throughout implementation and on completion of actions. The efficiency of the operation needs to be monitored to ensure that the management plan is executed in the most cost effective manner. Monitoring will help identify inefficiencies so the management strategy can be continually refined. In addition, the effectiveness of the program in achieving the objectives needs to be monitored so that either the program objectives or the management strategy can be modified if necessary, in the light of further knowledge and experience. This may mean modifying the objectives, if they are unrealistic, or adding new objectives. Effectiveness is determined by evaluating achievements and outcomes against the performance indicators included in the management plan. Different techniques may have different success rates under different circumstances. Economic frameworks are needed to assist in the assessment of the relative cost and value of alternative strategies. Such frameworks require: the definition of the economic problem, data on the relative costs of different carp control strategies, and an understanding of why the actions of individual management agencies may not lead to optimal levels of carp control and how management may be improved.

This chapter includes three case studies: 'carp in a confined wetland area', 'rehabilitation of a small stream', and a 'national approach to carp management'.

8.1 Intr oduction

The preceding chapters have described current knowledge concerning carp (*Cyprinus carpio*) in order to develop general principles and strategies for best practice management of carp. The four components of the strategic management approach which can be applied to carp management have been previously outlined by Braysher (1993) (Figure 1) and consist of:

- defining the problem (Section 8.2)
- developing a management plan (Section 8.3)
- implementing the plan (Section 8.4)
- monitoring and evaluating progress (Section 8.5).

The challenge for managers and other stakeholders is to use the information in the preceding chapters, together with the process outlined in this chapter, to develop a strategic management plan to address the damage caused by carp.

Much of the carp management undertaken to date can be described as 'crisis management' which has been undertaken with little or no forward planning, when the problem becomes to big too ignore. This type of unplanned management should be avoided because it usually has little long-term effect and it is expensive to conduct recurring crisis management. It must be replaced by a more coordinated and strategic approach which will be more effective in terms of both costs and achievements.

Strategic management can only be undertaken following the formulation of careful plans after assessment of available options (Section 8.3). Strategic management is required where it is clear that carp damage will require continuing management and involves integrating control options into water body and habitat management to achieve specific reductions in damage.

This chapter explains how to use available information and processes to develop an appropriate strategic approach at national, regional and local levels. It describes the application of such processes in three case studies: one relating to the removal of carp from wetlands, another concerning the rehabilitation of a small stream, and the third a national approach to carp management.

8.2 Define the pr oblem

Chapters 3 and 5 set out the initial steps in defining the problems caused by carp. Chapter 4 outlines public concerns – which will assist in determining who the stakeholders are that 'own' a carp problem. Chapter 7 details techniques for measuring impacts.

The impacts of carp on industry and the environment have not been fully evaluated and costings are not available (Chapter 5). This is an area in urgent need of research (Section 10.4). The main problems attributed to carp are declines in water quality, declines in aquatic plants and invertebrates, declines in recreational fishing and more doubtfully, declines in native fish populations and stream bank erosion (Sections 5.2 and 5.3). Because the scientific evidence for these impacts is often not robust, it is important that problems attributed to carp are clearly defined at the start of a management program, so that performance measures can be put in place and fully evaluated to determine if the program succeeds in reducing the problem (Sections 8.3.4 and 8.5).

Mapping plays an important role in defining the problem and developing a management plan. At the broadest scale (Figure 2) maps can be drafted to show the current and potential range of carp to help inform plans to reduce the spread of carp at the national level.

At a regional level, maps can assist in determining priority areas for different levels of carp management which may range from local eradication to preventing spread to no management. The maps can divide regions/catchments into different management units depending on their economic, recreational and conservation value. These maps can also highlight factors such as the density of carp and logistics such as access which will have implications for the management option chosen. The Carp Control Coordinating Group (Section 6.2.2) has developed a guide to setting priorities for carp management.

Maps can range from topographic maps or aerial photographs with overlays to interactive computerised Geographic Information Systems. A series of maps showing carp distribution and abundance over time may indicate changes associated with land, water and carp management and provide a basis for evaluating and modifying a management program.

'Mapping plays an important role in defining the problem and developing a management plan.'

Carp impact (or impact potential), distribution and abundance should be mapped at scales relevant to the required size of management operations – irrespective of jurisdictional boundaries such as catchment and local and State/Territory government boundaries.

8.3 Develop a management plan

There are four components to a management plan:

Define management objectives — Objectives are a statement of the planned achievements, defined in terms of desired outcomes — usually conservation or economic benefits. Objectives state what will be achieved, where and by when.

Select management options — The management option is selected that will most effectively and efficiently meet the management objectives. The options include: precautionary management, eradication, sustained management, targeted management, one-off management, and no management.

Develop management strategy — This defines the actions that will be undertaken — who will do what, when, how and where. It describes how the selected management options will be integrated and implemented to achieve the management objectives.

Define performance indicators — This is a list of measurable factors which will be used to determine if the management objectives are met once the management strategy is implemented.

8.3.1 Define objectives

The objective of pest control is to reduce or prevent the damage caused by the pest using the most cost-effective and safest methods possible, while maintaining long-term management goals. The objectives should be defined in terms of outcomes which can be measured. That is, what will be achieved where and by when.

Examples of the types of objectives which may be set for carp management could include:

- increase diversity and density of wetland plant areas and fish habitats in a defined area by 40% over the next three years
- limit the distribution of carp into new areas at the edge of their range
- improve water quality by reducing turbidity by 10 Nephelometric Turbidity Units (NTU) per year over the next two years in a defined area or river reach
- increase to a defined level the numbers and/or distribution of native fish in a defined catchment area or river reach
- increase numbers of carp removed by 200% through commercial and recreational fishing over the next two years in a defined area or river reach
- eradicate carp from defined areas, for example, irrigation channels (for economic reasons) or areas with threatened native fish (for conservation reasons) by a definite date
- eradicate newly introduced carp from defined areas by a defined date to prevent them entering a river system or spreading
- eradicate newly introduced carp from a river to protect a population of threatened native fish species and their habitat by a defined date.

The carp control objectives need to be achievable and have outcomes that can be measured independently from the other factors (for example, other fish species) that may affect the indicators (for example, water turbidity) in a disturbed catchment. The objectives of carp control need to be integrated with other management plans (for example, regional water plans) and national and regional strategies (for example, the *National Strategy for the Conservation of Australia's Biological Diversity* (Commonwealth of Australia 1996) and The Algal Management Strategy (Murray–Darling Basin Ministerial Council 1994)).

Generally, objectives for carp populations should be set in terms of the desired density of adult carp which is likely to achieve the desired reduction in impact. In some places, such as wetland nursery habitats, the density of juvenile carp may be more appropriate. In more complex scenarios, a combined measure of the number of juveniles in relation to the number of adult carp may give a clearer picture of the status of the carp population. Objectives should not be limited to carp populations, but must include targets for the impacts of carp. These may include, but are not limited to, public perceptions of carp population trends, the amount of aquatic vegetation, water quality objectives or angling catches.

'Objectives should not be limited to carp populations, but must include targets for the impacts of carp.'

Objectives may include public perceptions of carp population trends if negative public perceptions of high carp numbers is seen to be a problem in its own right. It may take many years to reduce impacts to acceptable levels. In these cases, it is necessary to set a series of interim objectives which may include, but not be limited to, initial reductions in carp numbers.

Community groups and local government authorities may need to seek advice from government agencies on how to set performance objectives. The level of reduction in carp numbers achieved with each control treatment is likely to vary between different habitats, and even between years because of different climatic conditions. The size of the habitat covered by the control program, and the resources available to control carp, will also have a large influence on the number of treatments required to achieve meaningful control.

The objectives established may refer to progressively increasing the number of habitats that have been treated, such as wetlands, farm dams, irrigation channels or council ponds, and could include establishment of strategies to prevent recolonisation by carp.

8.3.2 Select management options

Management of carp falls into two main categories: reactive and strategic. Reactive management can also be categorised into: one-off, where a single control activity is conducted in response to a specific problem; and continual, where control is conducted on a continual basis, usually because no long-term strategy to reduce impact has been planned. Strategic management options are usually better planned with more careful definition of the problem and consideration of objectives and options.

Once an objective is set, a management option can be selected. In selecting a management option, it is important to match it to the desired objective and to be realistic in terms of the available resources and technical feasibility. This is particularly important for carp, as many of the possible control options outlined in Chapter 7 are not currently available. The construction of a 'decision matrix' may be a useful aid for evaluating which options are most appropriate (Step 7 in Appendix A).

The following seven strategic management options available for carp management have been modified from Bomford and Tilzey (1997).

Box 7: Risk management principles

The 'precautionary principle', agreed to by Australia under Principle 15 of the *Rio Declaration on Environment and Development* (Intergovernmental Agreement on the Environment 1992), provides two main ways to deal with uncertainty and risk involved with managing biological systems to maintain biodiversity:

- When contemplating decisions that will affect the environment, the precautionary principle involves careful evaluation of management options to avoid, wherever practicable, serious or irreversible damage to the environment, and an assessment of the risk associated with various options.
- When there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

The National Strategy for the Conservation of Australia's Biological Diversity (Commonwealth of Australia 1996) applies the precautionary principle and the following risk management principle:

'The causes of a significant reduction or loss of biodiversity must be anticipated, attacked at source, or prevented.'

Carp could contribute to such losses.

Prevention is better than cure. Protecting ecosystems is far more cost effective than attempting rehabilitation once the damage is done. Some such changes can never be rectified. Emphasis must, therefore, be given to preventing carp spreading into new areas.

Precautionary management

Precautionary management can use the above principles to reduce risk to ecosystems. As carp have not yet spread across their potential range, an important management option is to prevent their spread. The spread of carp throughout Australia is continuing, dramatically illustrated by their recent introduction and establishment in Tasmania (Section 6.3.5).

'Preventing futher spread of carp into new catchments and regions of Australia must be an over-riding priority for carp management.'

It is important that carp do not expand their range into other areas of Australia where they do not currently occur, particularly into areas of high commercial or conservation value. Precautionary management may therefore be applied to habitats where carp are suspected to occur and where there is a risk they might spread to higher value habitats. Alternatively, precautionary management may be directed at containing known populations to prevent their spread.

Pathways by which carp can spread include: intentional release, accidental release, release through ignorance, flooding, and transport of fish and eggs by wildlife. Management options need to be developed to block each of these pathways to prevent further spread. The potential mechanisms of each pathway and potential management options are given in Table 14.

Preventing further spread of carp into new catchments and regions of Australia must be an over-riding priority for carp management. Prevention of such an expansion in range is both desirable and feasible through approaches which may include:

- Vigilance by the public, water authorities and resource managers, as well as strategic monitoring of fish populations

Table 14: Key pathways which can allow expansion of the range of carp in Australia.

Pathway	Potential mechanisms	Proposed actions
Intentional release	Deliberate transfer to establish new populations for use as bait, to develop new angling populations, or for ornamental value	Legislation, education, monitoring and notification of new locations
Accidental release	Use as bait in ignorance of the law, misidentification of carp for goldfish, contamination of fish stockings	Education on the potential effects, correct identification, improved hatchery controls, education and quality control measures within hatcheries
Release through ignorance	Use as bait in ignorance of the law, release of fish into storm water or sewage, misidentification of carp for goldfish	Education on the potential effects, correct identification
Flooding	Natural movement into wetlands, or above barriers	Use of barriers
Transport by wildlife	Carried by birds, foxes	Nil
Transport of eggs	Carried on the feet or feathers of birds	Nil

in critical areas, to detect and eradicate new outbreaks as soon as possible.

- The use of anglers and development of a 'spot a carp' campaign in critical areas would maximize public participation. As was the case in Tasmania, it is likely that invasions of carp into new areas will be first noticed by the general public. A national phone hotline or internet site (for example www.sunfish.org.au/recfish/NCTF/Carpdatabase.htm) may be a useful reporting mechanism. This could also be used to provide public information. A rapid management response depends on new outbreaks being immediately reported to relevant agencies and these agencies having the necessary resources and expertise to implement pre-planned strategic actions.

- A national, coordinated community education program to emphasise the importance of this issue and risks to the environment. This should use a variety of methods (including signs, posters, website, telephone information line, media stories, paid advertisements, angler press) and consider both accidental and intentional spread. In particular, additional efforts should be targeted to groups who are more likely to cause spread such as coarse anglers and anglers who may wish to use carp as bait.

- Legislation and regulations need to be consistent and penalties may need to be reviewed to highlight the importance of the issue. Compliance staff, particularly outside the existing range of carp, need to be informed of the importance of this issue.

- Existing barriers may be assisting the spread of carp. Fishways may be operated in ways to favour native fish movements but not carp (for example, by modifying attraction flows). In some instances, the erection of barriers may be an option to prevent further spread, although native fish movements need to be considered.

National Eradication

Eradication is the complete removal of all carp from a defined area by a time-limited campaign. National eradication has not been achieved for any widespread vertebrate pest species on mainland Australia (Bomford and O'Brien 1995). Despite numerous large-scale attempts, no eradication campaign against any well established, introduced vertebrate pest has been successful on any continent (Caughley 1977; Macdonald et al. 1989; Usher 1989; Bomford and O'Brien 1995). Eradication of carp from Australia is not possible at present. This option should be maintained as a longer term goal which might be achieved if new technologies become available, although biotechnological techniques are more likely to assist managers to reduce carp numbers and maintain them at lower densities rather than enable them to attain national carp eradication.

Local eradication

Successful local eradication of small pest populations has occurred, including for carp (Section 6.3). Before eradication is attempted all six of the criteria outlined by Bomford and O'Brien (1995) should be met:

1. *Rate of removal exceeds the rate of increase at all population densities* — If the removal rate is less than the rate of replacement at any population density, then eradication cannot be achieved. Populations subjected to control usually compensate with higher survival rates because of increased availability of resources (Caughley 1977, 1985; Caughley and Krebs 1983). As density declines, it progressively becomes more difficult and expensive to locate and remove individuals. Hence removal rates tend to decline at low population levels and if the removal rate declines to less than the rate of population increase, then populations will not decline further.

2. *Immigration rate is zero* — If animals can migrate into the eradication area, eradication will be unachievable or transient. Eradication of carp can most easily be met in isolated water bodies. Further introductions can occur, however, through a range of means such as floods, anglers or birds. Barriers such as screens across rivers or lake entrances may prevent migration of adult carp, but are unlikely to be successful for small juvenile fish that can pass through spaces in the screen.

3. *All carp must be at risk* — Removal techniques need not take all animals in the one attempt, but all reproductively and potentially reproductive members of the population, that is, adults, juveniles and eggs, must ultimately be removed for eradication to be achievable.

4. *Populations can be monitored at all densities* — If animals cannot be detected at low densities, there is no way to measure the success of the eradication program. As carp inhabit a wide range of (often turbid) aquatic habitats they are not easily observed or caught at low densities.

5. *Discounted cost–benefit analysis favours eradication over control* — There are few quantitative measurements for agricultural or environmental damage caused by terrestrial pests, making cost–benefit analysis difficult. There are no such data for carp. Eradication usually requires a large initial outlay, but if successful, there are no further costs and benefits accumulate indefinitely. Even if eradication would be more cost effective than sustained control, the benefits should still be weighed against the alternatives. Sustained control may be more cost effective than a one-off successful eradication. The chance of the failure of an eradication attempt and the cost of potential reintroduction also need to be taken into account.

6. *Suitable socio–political environment* — Even when technical and economic criteria can be met, social and political factors can play an overriding role in determining

the prospects of successful eradication. Strong support from the wider community is needed before eradication should be attempted. In particular there would need to be support for the cost of the program and the control techniques used (for example, there may be considerable resistance to the use of poisons or introduction of viruses). Eradication may also be opposed by industries based around the use of the pest involved and this must be considered in the encouragement of commercial carp harvesting.

'The potential reintroduction of carp into waters from which they have been eradicated remains a problem which is difficult to address.'

An affirmative response to all of these criteria is required before eradication should be attempted. A negative against any of the first three criteria will make eradication unachievable, and a negative against any of the last three criteria will make eradication impractical. Applying these six criteria to carp shows that national eradication is not currently possible nor likely to be in the forseeable future. Eradication of carp may be achievable in smaller, isolated waterbodies, such as farm dams, but not in most river systems. The potential reintroduction of carp into waters from which they have been eradicated remains a problem which is difficult to address.

Sustained management

Sustained management involves an initial widespread campaign to reduce populations to low levels, followed by maintenance control to prevent population recovery. Before adopting this approach, resources must be allocated to ensure that control is maintained into the future. An example of this may include an initial large-scale harvesting operation followed by regular, continued harvesting.

Commercial carp harvesting is being undertaken only on a relatively small scale in Australia (Section 5.4), but is currently increasing and being encouraged by some government agencies (Section 6.3). Commercial harvesting is likely to be economically viable only in restricted areas. The sustainability of the industry has not been assessed and further markets, products and export opportunities need to be explored (Section 5.4). As outlined in Section 7.3.1, commercial harvesting is likely to have little impact on carp populations in the long term but may reduce local populations to minimise damage as a short-term strategy. Consideration needs to be given to the impact a more effective control measure would have on an established carp harvesting industry, for example, the impact of a carp biological control agent should one be developed. 'Sunset clauses' should be part of any government assistance towards developing commercial fisheries as a short-term control measure, giving notification that the fishery will end if more effective carp control techniques are successfully developed.

Targeted management

Targeted management is used when the control effort is targeted to manage carp damage at a particular time, possibly when the population is most susceptible to control. The key to this strategy is to monitor the population to enable actions to be undertaken at the most appropriate time. An example of this may be poisoning a lake during low water levels (see Sanger and Koehn 1997) or before the spawning season.

One-off management

One-off management involves a single action to achieve a long-term or permanent reduction of carp damage to an acceptable level. An example of this may be the release of an effective biological control agent, if one becomes available for carp, or building an exclusion barrier. Future biotechnologies may enable managers to achieve and maintain higher levels of carp control at lower costs. The unavailability of biocontrol options is currently a major impediment to widespread reduction of carp numbers in Australia.

No management

In some situations, the costs of control exceed the benefits and no carp control may be the most cost-effective option. In some smaller, isolated waterbodies of no significant commercial or conservation value, there may be little value gained from carp control actions. No management has largely been the management option undertaken for carp to date, allowing carp to increase in both range and abundance as a pest species (Chapters 2 and 6).

8.3.3 Develop a management strategy

Having determined the most appropriate strategic management option from the seven alternatives listed in Section 8.3.2, the next step is to integrate the chosen management techniques from Section 7.3 into a management strategy.

This section covers some of the issues that need to be taken into account in developing a management strategy, including:

- value of adaptive experimental management
- experimental design
- availability of resources to adequately implement the options
- priority setting
- environmental, social and legal acceptability of the management strategy and actions
- decision analysis framework
- size and location of the management unit including water type and local conditions
- contexts of local, regional and national approaches.

The management strategy defines the actions that will be undertaken to achieve the management objectives. It sets out the techniques to be used and when, where and how they will be used. Control techniques need to be compared for effectiveness, cost-efficiency, safety, and acceptability. A combination of control techniques may be needed to achieve optimal effectiveness. Management strategies at the national level must also include options to develop new control techniques.

Adaptive experimental management

Strategic management is based on the concept of adaptive management, in which the management plan is flexible, responding to measured changes in economic, environmental and pest circumstances (Walters 1986). In passive-adaptive management (Walters and Holling 1990) a single strategy is selected, implemented, monitored and evaluated, and adapted according to the success or otherwise of the strategy. The active-adaptive approach puts up a number of alternative strategies which are all implemented, monitored and evaluated, and adapted according to which strategy is best (Walters and Holling 1990). The latter technique is more experimental and requires standardisation of monitoring and effort across strategies, replication of strategies and, ideally, nil-treatment areas where no control strategy is imposed. The challenge for those responsible for carp management is to use the information in the preceding chapters and the processes described in this chapter to develop a strategic management plan to address the damage caused by carp.

Experimental design *(Adapted from Olsen 1998 and Underwood 1990)*

Well designed experiments are often the only way to increase our knowledge of a pest species and to evaluate the effectiveness of management techniques. Good experimental design will help ensure that results are sufficiently conclusive to make recommendations for further management.

At the simplest level, management actions should involve some degree of monitoring and evaluation so that management can be progressively improved over time (in accordance with Figure 1). If the resources allow, and the situation is appropriate, more information can be obtained by comparing different management strategies or a single management strategy against a non-treatment 'control'.

Well designed experiments must follow a logical procedure such as that outlined in the steps given in the following two examples:

Example 1 — the possible effect of carp on macrophytes

Step 1 — Observation: Observing a pattern or departure from a natural pattern — for example, different biomass of macrophytes associated with different biomass of carp.

Step 2 — Theory: A theory arising from the above — and one which is often tested (Section 5.3) — is that low macrophyte biomass is associated with high carp biomass. Note that this makes no judgement about the reasons for this or causal links; it is simply a theory based on observed or predicted (for example, based on diet studies) patterns. If the pattern is proven, further testing would be required to determine why high levels of carp are associated with low levels of macrophytes (see Step 6).

Step 3 — Hypothesis: During the building of a hypothesis, specific predictions are made from competing theories. Most hypotheses are constructed in the positive form that makes a prediction that there will be a difference between treatments. For example, 'Where carp biomass is high, there will be a reduced biomass of macrophytes'.

Step 4 — Null hypothesis: Before the hypothesis can be tested statistically, it is usually restated in the negative form, called a null hypothesis, which usually states that there will be no difference between treatments. For example, 'There will be no difference in the biomass of macrophytes at different carp biomass.'

Step 5 — Test or experiment: The above null hypothesis could be tested by comparing macrophyte communities in similar bodies of water with different carp densities. Alternatively, carp numbers could be manipulated within an experimental design which will also allow the effectiveness of different control options to be tested.

Ideally, the null hypothesis should be tested with a concurrent comparison of similar habitats with different carp densities. However it is clearly difficult to achieve a range of carp densities within a connected water body, short of netting off large sections of habitat (although some experiments have used carp exclusion cages to monitor the recovery of macrophytes). Because a range of carp densities are not always possible to achieve at comparable sites, studies (Section 8.6.1; Pilby Creek, Box 9) may simply monitor changes at a single site following manipulation of carp numbers.

The most conclusive results will be obtained by direct comparisons between similar sites where the only differences are the control options, resultant carp numbers and the responses of assumed links such as post-management macrophyte biomass. If there are inherent differences between management sites such as different riparian vegetation, water flow and quality, sediment composition, composition of flora and fauna and pre-management macrophyte biomass, the results will be confounded and a direct comparison of results is not valid.

Important elements of experimental design include: use of non-treatment 'controls'; replication of treatments and non-treatment controls across a number of sites; random allocation of treatments and non-treatment controls to sites; standardised data collection across sites and over time; methods to avoid, overcome or account for confounding effects; and the use of appropriate statistical analysis to increase the power of the conclusions and avoid the incorrect acceptance or rejection of null hypotheses.

Step 6 — Support or reject the null hypothesis: The hypothesis is either upheld or rejected depending on whether the null hypothesis is supported by the analysis of the data collected. The next step is to refine the original theory to establish more direct causal links between management options, carp numbers and resultant impact. Theories that could explain the lack of macrophytes at high carp levels are that 'carp at high densities graze and uproot macrophytes faster than they can recover' and/or 'high densities of carp suck up large amounts of sediments resulting in siltation of aquatic vegetation and increased water turbidity which reduces light penetration required for photosynthesis'. The second theory is more complex than the first because there are a number of assumed causal links and a number of experiments would have to be conducted to determine whether carp are the main cause of siltation and turbidity, and whether these factors are the main reason for macrophyte decline.

Example 2 — the possible effect of carp, livestock access and bank vegetation on stream bank slumping.

Step 1 — Observation: Observing a pattern or departure from a natural pattern — for example, undercutting and slumping were observed to occur in streams where carp were present. Other factors that were also associated with bank slumping were clearing of bankside vegetation and stock access.

Step 2 — Theory: Stream bank slumping may be caused by carp, stock access and/or clearing of bankside vegetation.

Step 3 — Hypothesis: During the building of a hypothesis, specific predictions are made from competing theories. Most hypotheses are constructed in the positive form that makes a prediction that there will be a difference between treatments. For example, if carp are controlled, stock are excluded and/or vegetation on banks is intact stream bed slumping will not occur, but it will occur if carp are not controlled, stock have access or if there is no riparian vegetation.

Step 4 — Null hypothesis: Before the hypothesis can be tested statistically, it is usually restated in the negative form, called a null hypothesis, which usually states that there will be no difference between treatments. For example, 'carp control, stock access and/or stream bank vegetation will not affect stream bank slumping'.

Step 5 — Experiment: This is a 3-factor experiment: carp (C), stock access (S), no riparian vegetation (V) — alone or in combination are hypothesised to cause stream bank slumping. A factorial experimental design to test these factors in combination is required to determine whether there are any interactions between them. Hence stream bank slumping is assessed under the following combinations of treatments:

- carp densities high (+C), stock access (+S), no riparian vegetation (+V) which is the treatment combination which has all factors set to cause slumping
- carp densities high (+C), stock access (+S), riparian vegetation intact (-V)
- carp densities high (+C), no stock access (-S), no riparian vegetation (+V)
- carp densities high (+C), no stock access (-S), riparian vegetation intact (-V)
- carp densities low (-C), stock access (+S), no riparian vegetation (+V)
- carp densities low (-C), stock access (+S), riparian vegetation intact (-V)
- carp densities low (-C), no stock access (-S), no riparian vegetation (+V)
- carp densities low (-C), no stock access (-S), riparian vegetation intact (-V) which is the treatment combination where all potential slumping factors are absent.

Each of these treatment combinations would need to be replicated at more than one site so that the results obtained could be analysed statistically.

Step 6 — Support or reject the null hypothesis: The results would enable the null hypothesis to be accepted or rejected for each of the three factors tested alone and in combination.

Box 8: Economic Frameworks

Economic frameworks require:

- a definition of the economic problem
- data on the relative costs and benefits of different management options
- an understanding of why some individual actions may not lead to optimal levels of control
- an assessment of ways in which government actions might intervene to overcome market failure.

Managers can use economic frameworks to select the most appropriate management strategy for their circumstances. This can be done using the stepwise approach outlined in Appendix A. Ideally, managers could use this approach to optimise control effort, but often budgets are constrained by competing demands and less than optimal amounts are available. Managers have to allocate priorities to areas where control will be conducted. Priorities will depend on the goal of control, the method to be used and the relative threat and manageability of carp in the area. Complete information is almost always absent to support many of the decisions needed for this process and managers will often have to make 'best guess' estimates. This process will, however, give defensible decisions, especially if they are empirically tested by monitoring and evaluating the outcomes. Managers also need to estimate losses and potential future losses from environmental degradation caused by carp.

The effort applied to protect an agricultural or conservation resource will be influenced strongly by that resource's value and the discount rate applying to benefits that accrue from it. These factors influence vertebrate pest management (see Pearce et al. 1989; Ecologically Sustainable Development Working Groups 1991; Johnston 1991 for more detail).

Discount rates

Discount rate refers to the fact that people usually prefer to receive benefits as early as possible and to pay costs as late as possible. The weighting of present over future is known as discounting, and the rate at which the weight changes is the discount rate (Pearce et al. 1989). Calculating discount rates involves using the reverse equation to that used for calculating interest rates on invested money.

There is concern about the environmental implications of applying the market discount rate to production systems (Pearce et al. 1989; Ecologically Sustainable Development Working Groups 1991). The rate may be higher than society wants in order to protect desired benefits, such as protecting water resources and/or natural biodiversity. Governments may intervene to redress the balance between the objectives of the private landholder or water users and those of society, although this may not always achieve the desired result (Ecologically Sustainable Development Working Groups 1991). Often, sufficient knowledge of the true costs and benefits is not available, or the benefit may not be easily valued. The Ecologically Sustainable Development Working Groups (1991) report on sustainable agriculture urges caution on government intervention in this area.

Valuing benefits

Benefits that are normally subject to market forces, such as changes in productivity of a commercial fishery, are relatively easy to value in monetary terms, although as mentioned earlier, the impact of pests and the costs and benefits of control have usually been poorly quantified. Some benefits, however, are not normally marketed and hence are not readily assigned a monetary value. Examples include animal welfare and protecting native plants and animals, biological communities or landscapes. In the case of carp, changes to water quality, aquatic habitats or native endangered fish populations have not readily been assigned a monetary value. Conservation values such as intact wetlands or native fish populations have yet to be reliably priced. Where carp control is being considered, however, such values should be included in the cost–benefit analysis.

There is considerable debate on how to value these non-market resources or whether they should be valued other than in terms of their intrinsic value (Chisholm and Dumsday 1985). Some economists believe that useful techniques for valuing non-market resources will soon be available to assist decision makers. Current examples of these techniques include travel cost analysis (Pearce et al. 1989), Hedonic Pricing (Streeting 1990) and Contingent Valuation (Wilks 1990). They are based mainly on the concept of ascertaining what individuals are willing to pay to protect or improve the environment (Pearce et al. 1989). There is no assurance that all natural resources can be valued accurately before they are extinguished or irreversibly damaged (Pearce et al. 1989).

Developments in valuation techniques should be watched closely. In the meantime, funding agencies and researchers should ensure, where practicable, that studies of vertebrate pest damage quantify the damage of pests on ecological sustainability of production and other systems, so that decision makers can take all likely consequences into account.

Animal welfare organisations would also like the suffering caused by harvesting or control techniques to be factored in as a potential cost to the Australian community in vertebrate pest management decisions (Appendix A; Choquenot et al. 1996). As yet, this has not occurred for any pest species in Australia.

Economic frameworks of the type outlined in Appendix A also need to identify the different economic options and roles for national agencies, regional managers such as the Murray–Darling Basin Commission, State agencies, catchment authorities, local Shires and associations. In some cases there may be a need for the smaller, local authorities to be supported by larger, national groups. Such frameworks need to take into account both local and national considerations.

There is also a need for managers to estimate losses caused to other areas and industries should the ‘do nothing’ option be exercised. At the same time, the opportunity cost of controlling carp versus investing in improvements in other industries and alternative approaches to protect the environment need to be considered.

Economic frameworks also need to consider the benefits of carp which may increase with increasing variety, quantity and value of carp products.

Availability of resources to adequately implement the options

Economic frameworks can assist managers to assess the relative value of alternative control strategies for a pest problem and the relative benefits compared with other risks that must be managed.

Priority setting

A structured approach to setting priorities is essential to ensure that resources are well spent. A method for assigning priorities to areas for carp management is currently being undertaken by the Carp Control Coordinating Group (CCCG) (M. Braysher, Carp Control Coordinating Group, unpublished data, 2000). Important steps to achieving this include:

1. Dividing Australia into areas with and without carp.
2. Assessing the difficulty and expense of management for each area.
3. Identifying management areas where eradication is possible.
4. Separating other areas according to other major goals.
5. Ranking each management unit based on the threat from carp.
6. Determining the overall ranking which is reassessed after consideration is given to other secondary factors.

High priority should be given to identifying areas where carp do not yet occur and to developing and implementing management actions to prevent their introduction.

Ranking management units involves an assessment of the importance of such issues as biodiversity, water quality, cultural, tourism, and recreational values.

Environmental, social and legal issues

When selecting appropriate control techniques it is not sufficient to consider only whether they work and how much they cost. Environmental, social and legal implications also need to be considered as do indigenous cultures and animal welfare issues (Sections 4.5 and 4.6). Environmental effects, including impacts on non-target species, are important particularly when commercial harvesting, poisoning or biological control options are contemplated (Section 4.4). Opposition has been expressed toward many available or potential control techniques (Sections 4.3, 4.4 and 4.6), for example:

- a large-scale commercial carp harvesting industry, which may be seen as a substitute for more effective but costly management options, has the potential to be difficult to dismantle should more effective control techniques be developed
- concern about the impacts of commercial harvesting on non-target species
- concern about the impacts of poisons on non-target species
- the release of viral or genetically manipulated organisms is not viewed favourably by the general public and it is likely to be difficult to convince opponents of the safety of effective organisms because of perceived risks to public health and non-target species.

Decision analysis

Norton (1988) describes a series of questions that managers can ask to determine if proposed control measures are feasible and acceptable. Similar questions and answers are given for two carp control techniques in Table 15.

These questions and answers have identified several problems, including the:

- absence of biological control options that have been demonstrated to be safe and effective for reducing the damage caused by carp
- inability of harvesting to effectively reduce numbers in all areas

Table 15: Decision analysis table for considering factors affecting the acceptability of control measures for managing carp populations (questions after Norton 1988).

Questions	**Answers**	
Is the control measure:	**Harvesting**	**Biological control***
Technically possible?	Yes, in some areas	Not at present**
Practically feasible?	Yes, in some areas	Needs to be developed and tested
Biologically effective***?	Usually no	Possibly
Economically favourable?	Not cost-effective below a certain population density. Not at all in some areas	Yes
Environmentally acceptable?	Mostly, with safeguards	Yes, if target-specific
Politically acceptable?	Yes	?
Socially acceptable	Yes	?

* Biological control is any control technique which involves the release of live organisms, such as: viruses or bacteria to causes diseases, live vectors to spread immunocontraceptives or genetically modified carp with 'fatality' genes

** Predator stockings possible but not tested. Most other options are not developed at present

*** That is, the proposed control measure will reduce population size sufficiently to reduce damage levels

- problem of cost-effective harvesting
- uncertainty of future political and social acceptability of biological control agents, especially the use of viruses and genetically modified organisms.

Management units

Management units for carp control can be defined at any scale — national, State, regional or local. Given the mobility of carp and their ability to move throughout river systems, together with their propensity to be spread by other means (Section 2.1), reinvasion can occur quickly. Managers need to recognise that different plans will be implemented at different scales. Ecologically based management units need to be of sufficient size to be effective and avoid reinvasion but not so large as to be unmanageable and fail to function as a unit. The size of the management unit is likely to be determined by the size and type of the water body present. Examples of management units include: discrete water bodies such as dams, billabongs on a floodplain which have the ability to connect during high flows, and river reaches between barriers which prevent reinvasion.

Management units can also be based on socio-political boundaries, such as the boundaries of catchment management groups, regional authorities (for example, jurisdiction of a water management agency) or individual States, whose agencies may be responsible for many management actions. Management at the boundaries of these units should be coordinated to achieve meaningful outcomes on an ecological scale.

8.3.4 Define per for mance indicators

A final component of any management plan is setting a series of performance indicators. Performance indicators should be developed so that they reflect the objectives of the management strategy, are achievable and measurable. For example, an objective may be to increase the amount of aquatic vegetation in a wetland by 20% per year by removing carp and to prevent subsequent immigration by installing barriers. Two performance indicators are needed here to measure the:

- amount of aquatic vegetation each year
- number of carp inside the barriers.

Performance indicators demonstrate whether management objectives have been achieved. If success has not been achieved it may be necessary to change or modify the management strategy. Variability in environmental conditions influences fish populations and other ecosystem components and must be taken into consideration when setting and measuring performance indicators.

The primary aim of carp management should be to reduce to acceptable levels the damage they cause. Therefore the effectiveness of management actions can be measured against environmental variables such as density of aquatic plants or a measure of water quality.

Performance indicators should:

- use standardised measurement indices and procedures
- use methods which can be undertaken within the budget and skills available
- be monitored and evaluated on an appropriate scale (Section 8.5).

8.4 Implementation

Implementation of carp management is described in detail in Chapter 9. As most waters are controlled or managed by government rather than private agencies, management strategies must be undertaken by these agencies in conjunction with public bodies and community groups. The value of the group approach to pest management is that it fosters wider ownership of the problem. The group approach requires local community support based on an understanding of the damage carp cause and how it can be addressed, and fosters a strong sense of ownership of the management plan and management which addresses the concerns of all stakeholders.

8.5 Monitoring and evaluation

As described in Section 8.3.1, the key to the success of strategic management is the monitoring of clearly defined performance indicators and evaluating the results so that the efficiency and effectiveness of the program can be assessed. Evaluation of monitoring data enables refinement of the control strategy in relation to the objectives. Without monitoring and evaluation, a lot of money may be wasted on ineffective campaigns. Therefore monitoring and evaluation is an essential component of best practice to ensure that carp control is efficient, effective and safe. It is important to distinguish between efficiency (relating to operational objectives) and effectiveness (relating to performance objectives) as management can be efficient but not effective. For example, 75% of carp may be removed efficiently, and for little cost, but this strategy would be considered ineffective if the objective was to protect aquatic plants and: a) carp removal was not continued or other control measures were not undertaken to prevent subsequent population increases, or b) this level of population reduction was insufficient to reduce damage to aquatic plants.

Evaluation needs to:

- compare the results from different management actions and different sites
- assess changes to performance measures over time, including the longer term.

8.5.1 Operational monitoring

Operational monitoring aims to assess the efficiency of the operation in relation to what was undertaken, where and for what cost, with the aim of improving efficiency. This may be in the form of a description of operations and reporting the numbers or weight of carp removed or killed per unit effort. This information can usually be collected by the on-ground operators such as the organisers of fishing competitions, or from commercial harvesting records.

Monitoring carp populations (Sections 7.1) and the impacts of carp is an essential, integral and continuing part of a carp control program. The minimum monitoring necessary includes:

- monitoring carp density before a control operation
- monitoring again soon after the control operation
- periodic monitoring.

'Monitoring should begin before the management program is implemented.'

The frequency of monitoring should be determined by the way carp population data will be analysed. Powerful population modelling techniques have been developed in fisheries science for the purpose of analysing and predicting trends in fish populations over time (Hilborn and Walters 1992). These models should be used wherever possible to maximise the ability of monitoring to detect long-term changes in carp populations. Different types of models have different data requirements, making it imperative that the monitoring program collects the right data at the appropriate frequency. Repeat monitoring should at least be done in late summer to increase the chance of detecting whether spawning has been successful. In isolated habitats where complete eradication has been successful, ongoing monitoring is not required unless there is a risk of reintroduction.

Monitoring should begin before the management program is implemented. It is part of assessing the problem and is an integral part of planning a management program. The outcomes of monitoring provide the basis for many decisions on expenditure of effort and resources. Monitoring is also used to evaluate and if necessary adjust, redirect or abandon a program if the desired objectives are not being achieved. For this reason it is crucial that monitoring programs are well planned and executed. Monitoring programs should, where possible, be designed to:

- use indices of impact and abundance that are standardised to enable comparisons over time and among different habitat types
- monitor impacts of the management program on valued resources, such as fish habitats, aquatic vegetation or native fish species, as well as on carp abundance
- monitor before and soon after control operations, and then periodically
- use methods that are easy and rapid. A better assessment is given by many approximate assessments over many sites than by a few precise assessments over relatively few sites
- record information in a standardised format that allows changes in indices of impact and abundance to be compared over time. Most State and Territory fisheries agencies can provide suitable forms for recording this information
- assess carp abundance using indices that are long-lasting, such as catch-per-unit-effort, catches obtained over a relatively large number of sites, or changes in the observed distribution of carp. Catches of carp obtained from a single site are likely to vary greatly over time
- ensure that sampling is not biased by, for example, only sampling near bridge crossings or boat ramps where access is easy. Reliable sampling must be representative of all the carp habitats within the area of the control program
- make use of advice from professional freshwater ecologists and fish biologists.

In contrast to other vertebrate pests, such as foxes and rabbits, where the impacts are often direct and observable, the impacts of carp are more likely to be indirect and not readily observable, requiring detailed analysis to detect whether any impact has actually occurred (Chapters 3, 4, 5), or whether the management program has been successful in reducing the level of impact.

'Interest groups can assist coordinating agencies in recording information on carp distributions and density estimates in a standard form.'

Assessment of impact may be laborious and time consuming unless simple measures can be used. The current state of knowledge on carp impacts is such that there are no widely applicable simple measures of impact. Part of the monitoring program should therefore include developing suitable measures for each situation, in consultation with experienced biologists and statisticians who are often employed by State fisheries agencies, to allow for greater standardisation and coordination at a later time.

Long-term information on carp impacts and abundance is essential for management programs because carp numbers can fluctuate widely from year to year. Problems caused by variation in carp numbers can only be overcome with long-term monitoring. Ideally, carp monitoring should be tied in with existing monitoring frameworks for water quality and other aquatic ecosystem indicators to avoid duplication and allow correlations to be drawn between habitat changes and carp density and population structure. Monitoring habitat quality of carp-free areas is also essential to allow a more quantitative assessment of the impact of carp where they become established in new areas. Catchment Management Committees, River Management Trusts, River Management Committees and regional interest groups can assist coordinating agencies in establishing and maintaining long-term monitoring programs, and in recording information on carp distributions and density estimates in a standard form. State fishery agencies can then integrate this information with biological surveys, commercial fishery statistics, results of angling competitions, fish kills and compliance reports. These assessments can then be coordinated among State agencies by a central agency or committee at a national level.

If monitoring data is held in a centralised database and is accessible to other users, the analytical tools and models needed to assess monitoring results in a consistent way can be made available to all groups involved in carp management. The advantages of a centralised system include all carp control groups having access to the results of other groups to compare results, while the central agency retains the ability to see which management approaches are the most successful or least effective.

In almost every instance, past assessments of carp have provided indications of impact or abundance, rather than exact measures. For this reason the importance of standardisation must be emphasised. Standardisation of assessments of carp abundance depends on the use of robust indices that reflect long-term trends in carp numbers.

8.5.2 Per for mance monitoring and evaluation

Performance monitoring aims to assess the effectiveness of a management plan in meeting its objectives (Section 8.3.1) by taking measurements of the defined performance indicators (Section 8.3.4) and evaluating these results. The carp management program is evaluated by comparing information acquired in the monitoring program against the pre-determined objectives.

'Carp control programs may take many years to achieve their full benefits.'

Some performance measures can be taken by on-ground managers but others involve complex ecological relationships and are better obtained by researchers. Performance monitoring usually requires a long-term perspective and some experimental and scientific rigour if results are able to be interpreted accurately (Sections 7.2 and 8.5.2). In some cases, models can be used to predict results which can then be used to evaluate results actually achieved. Both the model development and management actions can be continually improved as more data are collected.

The level of reduction in carp numbers achieved with each control treatment is likely to vary between different habitats and between years because of different climatic conditions. Also carp control programs may take many years to achieve their full benefits. Experience and caution are needed in interpreting short-term monitoring. Some impacts of carp may not respond to carp removal immediately, or may require specific flow events such as floods or droughts to 'reset' the system before the effectiveness of the program becomes apparent. It is relatively common for short-term monitoring to conclude, incorrectly, that no change has occurred in response to a management program. Hence monitoring programs need to be carefully designed to take account of site and seasonal variability, time lags and flow events when determining if a carp control program is achieving its defined objectives.

In most cases it will not be possible to assess a program by referring to experimental control areas without carp. Rather, a useful basis for comparison will be other areas where carp are not controlled or levels of damage recorded at the site before carp control started. Often assessments of the effectiveness of existing programs are based on uncertain or equivocal evidence. Evaluations will be more sound if data from designed monitoring programs running over several years are available.

To avoid the pitfalls of misinterpreting monitoring information, community groups and local government authorities are advised to seek advice from specialists in government agencies on how to design, conduct and evaluate performance monitoring programs. Carp population models and similar models of carp impacts have potential to be invaluable in interpreting monitoring results to judge whether targets are being met and in deciding whether further monitoring is required.

One crucial outcome from evaluation is an assessment of cost effectiveness of different management options. Many groups involved in carp control will not have the resources to test different methods. However, the cost effectiveness of different approaches can be determined at State and national levels by comparing local-scale management programs. To make this comparison, the total costs of carp control need to be measured, including both monetary costs and the contributions of time and equipment by participating groups. The cost of developing new control techniques are usually high and these costs also need to be included in cost–benefit analyses for carp control (Appendix A).

8.6 Case studies

8.6.1 Carp in a confined wetland area — Pilby Creek

Box 9: Best practice management of carp in a confined wetland area

Carp are perceived by many in the community to be a major cause of the decline of native aquatic vegetation and a reason for the decline in numbers of waterbirds. This case study is based on a wetland with carp present and efforts by a cooperative group to control carp populations and restore the wetland vegetation to more natural conditions. Pilby Creek is near Lock 6 on the Murray River, near Berri in South Australia. A project of restoration was initiated by the Renmark Berri Branch of the South Australian Field and Game Association and became a cooperative effort with the Murray–Darling Association and Riverland Fishermen's Association. Being public land, support was needed from the Department of Environment, Heritage and Aboriginal Affairs as the land managers and from South Australia Water as the water managers on behalf of the Murray–Darling Basin Commission.

Defining the problem

Pilby Creek wetland is an old billabong of approximately 17 hectares, and is considered to be an area of high value for native birds and fish. Carp moved into Pilby Creek during floods from nearby rivers. After carp numbers increased, the aquatic vegetation and water quality decreased, and this was thought to be the cause of a decline in native plant and bird species (Forbes 1995). There was public concern for natural conservation values, with carp being perceived to be the greatest cause of the decline in ecosystem health. Opportunities for duck shooting and an area free of carp for aesthetic values were important to the local community. The major limiting factors for the health of the ecosystem were water regulation and carp. Other factors such as nutrients, fishing, lack of riparian vegetation and cattle were not an issue.

Should it be possible to eradicate carp from the Pilby Creek billabong, a secondary problem of preventing carp from re-entering the wetland would need to be addressed.

Site description

The Pilby Creek Project is regarded as an experimental site to investigate the effects of carp removal. Artificial refilling of the wetland is made possible by the proximity to Lock 6 on the Murray River which allows water to enter via a channel above the wetland. In addition, draining is possible via Pilby Creek. The area is remote, fenced and locked from the general public, reducing the chance of public interference.

Objectives

The objectives of the Pilby Creek Project are to:

- enhance the ecology of the wetland adjoining Pilby Creek in the absence of carp
- restore the wetting and drying cycle of the wetland and prevent carp from returning on refilling
- restore the aquatic vegetation in the wetland for its conservation value
- increase the bird numbers visiting the wetland for their recreational hunting value which may also bring an economic gain to local businesses.

Economic gains will be minimal because the main objectives of the project are to protect and enhance conservation values, with increased tourism as a secondary benefit. The site work may also have value as an experimental model for carp control in other areas.

Management options

One-off management options to meet the above objectives by reducing carp numbers include:

- poisoning
- a single event of draining
- removal by commercial or recreational fishers.

Following the removal of carp by any of the above one-off control options, further one-off control options could then be used to prevent adult carp re-entering the wetland by installing a gate, screen or other exclusion devices. Preventing access by eggs and juvenile carp could be more difficult. Another option for sustained control would be to maintain artificial drying and wetting cycles. The wildlife and vegetation enhanced by these options, however, would need to be more important than the native fish habitat and nursery areas likely to be lost by preventing access by native fish.

Management strategy

The control options selected as being the most likely to succeed, operationally efficient and environmentally effective were drying the wetland to remove fish, followed by the installation of barriers to exclude adult fish. A team consisting of several stakeholder groups was engaged to drain the wetland, screen and refill it.

Implementation

As Pilby Creek wetland is a public waterbody, benefits of its management to meet conservation goals accrue to a wide range of people who may be able to contribute to the cost and effort. Costs include:

- capital work to drain the area
- establishing natural or artificial refilling
- erecting exclusion screens
- assessing any habitat changes.

The Pilby Creek Project began in 1989 with a plan and several funding bids prepared by volunteers and staff from the Murray–Darling Association and South Australian Department of Fisheries. Funding of $9470 was provided through the Natural Resources Management Strategy (NRMS) in 1992 to prepare a management plan. The partnership between community groups with financial support from government agencies is useful as it provides both financial support, community ownership and volunteer labour. A further $83 200 funding from NRMS was used to construct a control drain at one end and install screens to exclude fish at the other end. In 1993, the billabong was drained and commercial operators removed 1200 carp and 1000 native bony herring (*Nematalosa erebi*). Carp density before and after removal was not estimated. Before refilling, screens were placed across the intake to prevent recolonisation by carp.

A further $7200 was received in 1995 for ongoing management and monitoring and $3600 was received in 1997 from the Commonwealth Fish Care Program (Natural Heritage Trust) for monitoring. Total funding for this project over ten years totals $103 520 and has been assisted by in-kind support of agencies, volunteers and commercial fishers. Carp removal was sustained for five years but ongoing funds and volunteers are needed to maintain regular artificial draining and refilling to maintain the vitality of the wetland (Brock et al. 1994).

Defining performance indictors

There should be an evaluation of recovery from the original problem to assess the success or failure of the program. Water plants could be assessed as recovering by a measurable amount. This could involve measuring the number of plants of significant species or estimating the area covered by a plant community at a suitable time.

No photographic records or base-line data are available on the wetland condition prior to carp to evaluate the success of restoring the wetland by excluding carp (Roberts and Ebner 1997). These would have been useful to assess the effectiveness of any experimental restoration.

Monitoring and evaluation

Despite a lack of pre-treatment data, the performance of the experiment, in particular water quality and amount of vegetation, was observed by members of the community groups (Forbes 1995). Regeneration of native plants was also observed (Forbes 1995). However, full assessment and monitoring is needed to determine success. Volunteers continue to supervise draining and refilling of the wetland and observe changes in the wetland. The results from that year showed a reduction in turbidity, increases in abundance of ribbonweed (*Vallisneria* spp.) and increased density of other macrophytes and macroinvertebrates compared to the untreated site (Schiller 1996).

The use of community groups in urban wetland rehabilitation has been reviewed by Dance (1997), who concluded that local people are vital in determining whether positive or negative changes actually occur. Dance suggests that any lead agency should have long-term interactions with user groups to ensure that banks and vegetation are not trampled and that pest fish species are not reintroduced. Evaluation of periodic monitoring over the long term is required to determine if rehabilitation goals are being met. Long-term monitoring is still needed to ascertain whether the native vegetation continues to recover.

The results of this project are confounded because several management options (removal of carp, removal of native bony herring and alteration of hydrology) were all implemented simultaneously. Unfortunately, interpretation of the results is even further complicated by the lack of comparative data on the condition of the wetland before the management plan was implemented. It is therefore not possible to attribute changes in vegetation to carp removal alone because the effects of the other options cannot be isolated. This problem highlights the need for professional advice on management plans and designs for monitoring and evaluation before plans are implemented.

Other considerations

In developing similar agency or community group partnership projects the following issues may need to be considered:

- ability of the wetland to dry naturally or the need for artificial draining and refilling
- is the water body small enough to be contained to prevent the easy recolonisation by carp
- possibility of major floods which would reintroduce carp

- accessibility of the habitat to uninformed recreational fishers who might accidentally reintroduce carp
- accessibility of the habitat to commercial fishers and markets to assist in removal of carp
- skills of volunteer groups
- possibility of educational institutes, government agencies and community groups assisting in monitoring
- influence of other factors such as nutrient inputs, altered hydrology, lack of riparian vegetation, catchment clearing and the presence of cattle, all of which may have contributed to the original problem.

A decision to proceed with carp management will be strongly influenced by the natural conservation value of the proposed management unit. An estimate of the habitat value for native fish is particularly important if fish are to be excluded. The Pilby Creek Project includes a plan to eventually stock native fish. Field and Game Association groups see the Pilby Creek Project as a model for control of carp in wetlands that are valued for waterbirds and game birds (Section 4.9).

Other cases

Other groups have attempted similar programs but a cost–benefit analysis may be needed if evaluation of best management practice is to be undertaken.

The Geelong Field and Game Association drained Reedy Lake near Leopold in Victoria in 1996 and made a channel to the Barwon River. A water regulator and a fish screen were installed. The cost of $16 500 came from a community group. Regimes of drying and refilling can assist in carp control. Reedy Lake had been maintained with high water levels since the 1970s and carp had gradually increased in numbers and in the 1990s were damaging Phragmites and Typha beds. In 1997, 10 000 carp were killed in the drying lake (I. McLachlan, Secretary, Victorian Field and Game Association, pers. comm. 1998). After the lake was inundated again in June 1997 there was evidence of regrowth of plants. Current management focuses on maintaining low water levels to allow plants to regenerate and monitoring carp numbers. The project is considered a success by stakeholders who are represented on a Steering Committee which now manages the project (I. McLachlan, Secretary, Geelong Field and Game Association, Victoria, pers. comm. 1999).

In Gippsland in Victoria, the Bairnsdale Field and Game Association began a similar project in Macleods Morass, a large Ramsar-listed wetland near the town. The wetland naturally dried for the first time in possibly 80 years during the drought of 1996–97. A commercial operator with a seine net removed several tonnes of carp from a remaining waterhole. A screen was installed across the main channel to the Mitchell River with assistance from a number of community groups and a grant of $10 000 from the State government. A partnership began, with cooperative community funding through the Natural Heritage Trust of $39 000 for monitoring and assessment of this site and a seagrass area in Jones Bay, Gippsland Lakes. The project includes an experiment to assess the levels of damage with and without carp.

Enhanced wetland in an anabranch of Pilby Creek following carp removal and refilling three times. Source: A. Brumley, East Gippsland Institute of TAFE.

Aluminium screens to restrict carp movement into Macleods Morass. Source: A. Brumley, East Gippsland Institute of TAFE.

8.6.2 Rehabilitation of a small upland stream — Little Moe River

Box 10: Best practice management of a small upland stream

This case study is based on a small upland stream in Gippsland in Victoria, the Little Moe River, which contains a desirable native fish species as well as carp. The river is undergoing restoration to natural conditions, and the success of restoration is an example of a cooperative venture undertaken by the Settler's Creek Landcare Group, Waterwatch, the Catchment Management Authority and Freshwater Ecology in the Department of Natural Resources and Environment. Benefits of restoration have been recognised both to the stream reach being rehabilitated and to the habitat downstream through improvements in water quality. The removal of carp is seen as an important aspect of this restoration.

Defining the problem

The Little Moe River and its tributaries flow through land used primarily for dairy cattle grazing (see Figure 21). As a result of this intensive land use, extensive clearing of native vegetation including riparian zones, has occurred. This alteration of streamside vegetation, combined with the effects of unrestricted stock access to the stream banks and bed, has been largely responsible for the degradation of instream habitat within this region. This habitat deterioration has in turn led to the disappearance of a number of native fish species which were once abundant in this area. One such species is the river blackfish (*Gadopsis marmoratus*) which, according to anecdotal reports, was abundant in many of the waters within the region until about 40 years ago. River blackfish are an important species for both conservation and recreational fishing. Carp are perceived to have contributed to this decline through their effects on water quality and increased sediment disturbance.

Settling sediments fill pools and holes scoured in the river bed, decrease substrate variation and reduce useable habitat areas.

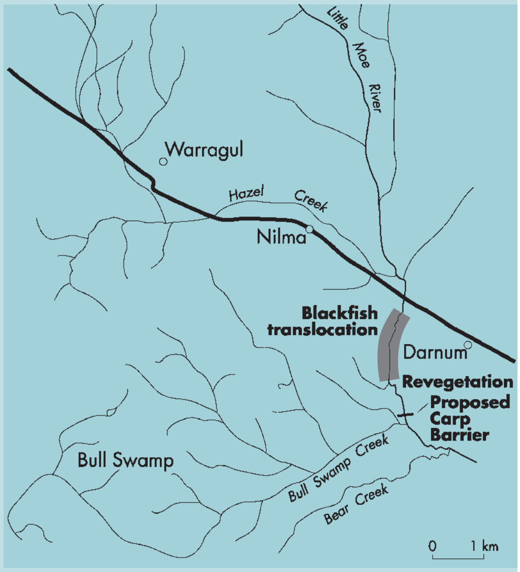


Figure 21: Little Moe River, Victoria, undergoing restoration to natural conditions.

Clogging of the substrate by fine sediment removes spaces between particles (gravel and cobbles) which are used as habitat by juvenile fish, small fish species and stream invertebrates. Eggs deposited in gravel substrates can be smothered by sediments. Species such as river blackfish lay adhesive eggs requiring clean sites for attachment and if these sites are covered by sediment, spawning may not be possible or may be unsuccessful (Koehn and O'Connor 1990b).

Despite general habitat deterioration caused by a range of factors, the removal of carp was considered to be important for restoring both water quality and the diversity of freshwater fauna.

Objectives

- to eradicate carp from a section of the Little Moe River
- to improve native fish habitats
- to improve populations of river blackfish.

Management options

One-off eradication from a confined area combined with sustained control to prevent recolonisation and some targeted habitat management.

Carp eradication — as many of the highly technical options for carp control are not yet available (Chapter 7), only physical control options are possible. As the stream is small, commercial eradication is not economically viable, recreational removal is unlikely to be sufficient and chemical poisoning was not deemed suitable because of the collateral damage it would cause to desirable species. Therefore, removal by electrofishing was considered the most suitable option. A downstream barrier was then installed to prevent recolonisation.

Riparian revegetation — efforts (made primarily over the last ten years) by local Landcare groups to improve riparian vegetation and water quality have been significant. Extensive stretches of stream banks have been fenced, restricting the access by cattle to stream banks, and riparian vegetation has been planted over more than three kilometres of stream length. Fencing, in conjunction with natural and assisted revegetation, has led to improvement in both water quality and the quality of instream habitat.

Habitat improvement — it is important to improve the instream habitat for fish, especially river blackfish, by adding logs, branch piles and woody debris. Eventually, this will occur naturally from the re-established riparian vegetation zones as they mature.

Blackfish reintroduction — river blackfish are currently being reintroduced into this reach of the Little Moe River under a Fishcare and West Gippsland Catchment Management Authority project.

Management implementation

A small instream barrier was constructed to restrict the migration of carp upstream. This was similar to one used successfully in the Upper Goulburn River system to exclude trout (Salmonidae) from habitats supporting a small threatened native species (Raadik and Saddlier 1996). After the barrier was constructed, carp were removed from waters upstream using intensive portable backpack electrofishing techniques which selectively remove carp and allow river blackfish to be returned to the stream unharmed. Ninety-seven carp ranging in size from 67 grams to 5.9 kilograms were removed from 22 sites in the upper Moe River system. An additional 30 carp were removed during an electrofishing demonstration conducted for stakeholders. It is considered that as carp were in relatively low numbers, all carp were removed, but follow up surveys are planned to ensure this.

Performance indicators

It is expected that the above activities will result in:

- improved water quality through reduced turbidities in the Little Moe River and downstream
- improved habitat quality within the Little Moe River through reductions in areas sediment and increased areas of aquatic vegetation and woody debris
- increased diversity through increased number of species and abundance of native fish, aquatic flora and aquatic macroinvertebrates
- reduced carp numbers in the Little Moe river.

Water quality (including water temperature, pH and turbidity), aquatic vegetation and woody debris areas will be measured, sedimentation will be visually assessed and fish and aquatic macroinvertebrates

Monitoring and evaluation

Project success will be monitored through the Waterwatch program which operates throughout the Moe River system, involving the local Nilma and Darnum Primary School students. Through systematic recording of water quality in the Little Moe River and surrounding waters, the improvement of water quality will be monitored in both the short and long term. This will allow any changes in water quality to be identified following carp removal. Improvement in river blackfish abundance and fish habitats will be assessed through follow-up surveys within the creek system by Freshwater Ecology, Department of Natural Resources and Environment.

The specific benefits of carp removal alone cannot be assessed because three other management options were implemented at the same time.

8.6.3 National appr oach to carp management in Australia

Box 11: Best practice national carp management

This case study outlines a hypothetical best practice approach to a national strategy to carp management.

Defining the problem

As the range and abundance of carp has increased, so too has community concern over the ecological damage — both real and perceived — caused by carp. Although there is now evidence to show the types of ecological damage that carp are capable of causing (Section 5.3), the magnitude of their impacts compared with the impacts of river flow regulation, dams and weirs, clearing vegetation, nutrient enrichment and catchment disturbance, is far from clear. Nevertheless, many groups — particularly ecologists, conservationists, landholders and fishers — believe that there is enough scientific and anecdotal evidence that carp are causing environmental damage to justify expenditure on carp control.

Management plan

The Federal Government, through the CCCG, has developed a strategic and tactical approach to carp management in conjunction with both State and community activities. The rehabilitation of rivers, targeted research into the ecological understanding of the species and potential biotechnical control options are being funded. This approach is outlined in the following strategic management plan.

Management objectives for freshwater fish in Australia also include conservation of biodiversity, protection of threatened species, communities and populations, and protection, restoration and rehabilitation of aquatic habitats. Reducing the impacts of carp may contribute to these objectives.

Objectives

Even though costs of direct and indirect damage caused by carp have not been estimated, these are likely to be relatively large. Invoking the precautionary principle (Intergovernmental Agreement on the Environment 1992) dictates that action to reduce those impacts should be undertaken as soon as possible, allowing for a later assessment to refine the relative costs and benefits of carp management.

Specific objectives include:

- preventing further spread of carp
- research into the ecology of carp in Australia and the development of biotechnical control options
- rehabilitating Australian rivers to favour native fish species
- strategic control of carp in certain areas.

Management options

The wide distribution of carp in Australia requires adaptive experimental management using different options for different circumstances, implemented so that treatments and their effectiveness can be monitored and evaluated.

Management strategy

The management strategy will implement a coordinated, integrated, strategic national approach to carp management using a wide range of national, State and local agencies.

Implementation

Active monitoring of carp populations toward the edge of their current range was undertaken and the data were entered into a national database. These data, together with population data, were used to develop a predictive model to provide scenarios to manage range expansion. No practical methods for sustained carp control on a large-scale are currently available. Research into selected options for biological control was undertaken to provide long-term, effective control options. Complete eradication and effective, one-off control were undertaken in smaller isolated areas, especially in areas of new introductions. Sustained control and sporadic control were undertaken in selected areas, using commercial and recreational harvesting, poisoning, water level manipulations and improved river flows. Commercial licences restricted to certain areas were given for a limited 10-year period to be reviewed by a scientific panel after assessing their use following the development of other control options. Improvements in native fish populations and fish habitats were made through cooperative strategies with State agencies.

Performance indicators

Performance indicators need to be set for each objective across each management area.

Monitoring and evaluation

Any expansion of carp populations can be determined through fish population monitoring and reports from anglers. Testing of biotechnical control options will be used to evaluate the success of this research through field experiments. Rejuvenation of native fish populations is more difficult as a long term dataset may be needed to take account of natural variability. Regular base line monitoring of fish populations are required and surrogate variables such as improvements in available habitat, access to habitat and improvements in water quality may be used to measure the success of the strategies implemented. Monitoring and evaluation needs to be undertaken on a scientific basis through a combined effort of State agencies and community participants.

9. Implementation

Summary

This chapter focuses on the people and organisations involved with managing the damage caused by carp. These include: (1) those involved in carp management at the strategic and policy levels of government, (2) those who conduct strategic research to assist policy makers, to monitor existing populations or to develop control measures, and (3) a range of people, often working together, whose involvement is at the operating level of implementing and monitoring carp management decisions. These range from Commonwealth, State and Territory agency officers to regional and local community groups. As carp occur in public waters, cooperative approaches to their management are vital and should be encouraged at all levels.

Carp are widespread in public waters, especially in south-east Australia, so people involved in implementation of carp management are often responsible for protection of publicly owned natural resources. This contrasts with the management of most vertebrate terrestrial pests, where many animals occur on private land, and landholders may have either legislative requirements or gain personal economic benefits from control of the pest. Implementation of carp management is not solely the realm of government fisheries agencies but involves other agencies, regional catchment groups and a wide range of community groups. Aesthetic, conservation, cultural, recreational, commercial and animal welfare values all need to be taken into account in implementing carp management. This chapter addresses how public managers and public stakeholders can implement management options.

9.1 National level

At the National level there are two bodies which act to develop networks at the policy level, the National Carp Task Force (NCTF) (Section 6.2.1) and the Carp Control Coordinating Group (CCCG) (Section 6.2.2) (Figure 22). The NCTF was the first initiative for a national approach and has a role of networking and encouraging development of ideas for controlling carp (*Cyprinus carpio*) including commercial harvesting. The aim of this group was initially to lobby for government action on the carp problem, but its aim is now to provide information to both the community and managers and to coordinate other interested groups. The CCCG will link to the NCTF to coordinate activities and build upon current research outcomes to develop a national strategic approach. Both groups use funding from the Murray–Darling Basin Commission and Commonwealth Natural Heritage Trust (NHT). The NCTF is also supported and convened by the Murray–Darling Association. Membership of both groups includes research scientists and representatives from government agencies. The NCTF has community members and stakeholders from regional areas and those concerned with the damage caused by carp. The CCCG has representatives from fisheries agencies concerned with government policy. Both groups will be involved with implementing strategic direction of approaches to carp control.

9.2 Gover nment involvement

Through their role as legislators and as representatives of the wider community, government agencies are stakeholders in the management of pest species. As carp mostly occur in public waters, government agencies must have a greater responsibility and influence in carp management than they do for pest species that occur mainly on private land.

At the national level, the Commonwealth Government is involved in providing a coordinating role for carp control. This role has recently been taken on by the CCCG (Sections 6.2.2 and 9.1) which will help set national priorities for carp control. The

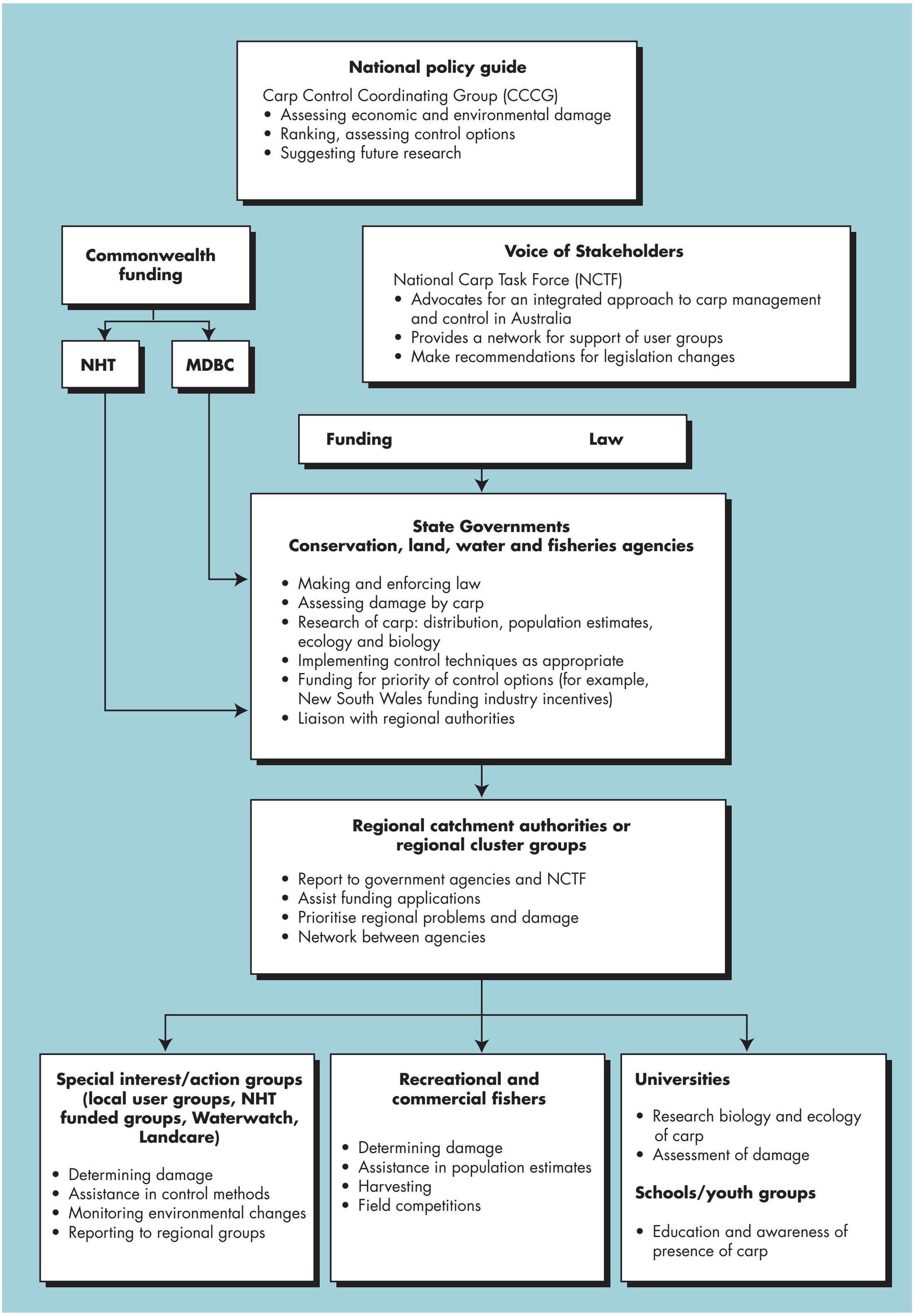


Figure 22: Flow diagram of strategic direction to carp control.

Commonwealth Government also has a role in environmental management and in funding carp research. Funding is currently possible from several potential Commonwealth sources:

- Fisheries Research and Development Corporation — which provides funding for commercial fisheries related research (Section 10.1)
- Bureau of Rural Sciences (BRS), through the National Feral Animal Control Program (NFACP) (under the NHT)
- Murray–Darling 2001 FishRehab Program (under the NHT) — which has a specific directive to provide funding for carp research relating to their control.

The Commonwealth Government is also responsible for legislation that provides import restrictions (Section 6.2) and strategies such as water reform that can affect fish populations including carp (Section 6.2).

'As carp mostly occur in public waters, government agencies must have a greater responsibility and influence in carp management than they do for pest species that occur mainly on private land.'

State and Territory governments, through their agencies, currently undertake most carp management and monitoring of carp populations (Sections 7.1 and 7.2). The role of State agencies is generally more active in management than Commonwealth agencies and this can vary between areas depending on control priorities and methods. State governments have legislation covering carp (Section 6.3; Table 13) and also have a role in extension and public education. Control efforts need to be coordinated nationally, even when they are implemented at State or regional levels.

The various management actions being undertaken by State agencies are outlined in Chapter 6. These activities range from minimal, to eradicating small, new introductions, to encouraging widespread commercial exploitation. In some States, carp harvesting is an integral component of managing native fish harvesting and conservation. There are many other management actions and strategies relating to the natural environment and waters which can affect carp populations. These may include implementing weir policies, wetland policies, floodplain and catchment management plans and water reform strategies.

9.3 The regional role of extension services and catchment management

Implementing a strategic approach to pest control usually involves a number of agencies or groups applying a range of control techniques. Any widespread control mechanism for carp is likely to involve new technologies and processes (Section 7.3) that may need to be explained and accepted by the wider public before they can be used. Traditionally, State and Territory extension services have been pivotal in assisting in the adoption of new technologies and processes. A better understanding of the problems that carp cause in aquatic habitats is needed to dispel some widespread misunderstandings. Different extension techniques may be needed for different control techniques and for different management goals and scale of operations — national, State or Territory, regional, district or local. As most wide-scale control programs will be implemented by government agencies, the role of extension officers is likely to be one of education within regions affected by the program.

9.4 Group formation

Because carp populations are widespread, it is important for interested community groups to interact to share information and experiences from different areas. Groups involved in identifying the problems caused by carp may also have the ability and desire to assist in the planning, implementation and evaluation of management strategies. Involving interested groups of people, with a range of skills and expertise in the planning process, encourages group ownership of management decisions and facilitates group participation in implementing the plan. Ideally, composite action groups are formed with a mixture of skills, including scientists, technicians, naturalists and local interest groups as well as managers. Additionally, there should be a flow of information between interest groups. For example, NCTF, formed from a range of stakeholders, was initiated by participants of workshops in 1994 and 1995 (Section 6.2.1). Scientists interested in conservation of native fish are included in the NCTF as well as lay people directly affected by the presence of carp in their environment. Commercial fishers formed a subcommittee of the NCTF to discuss techniques, codes of practice and markets. A workshop for commercial fishers was held in Victoria to assist in their operations, in developing markets and value-adding to carp products (G. Gooley, Marine and Freshwater Research Institute, Victoria, pers. comm. 1998).

'It is important for interested community groups to interact to share information and experiences from different areas.'

Public authorities and organisations with responsibility for managing public waters and water storages where carp occur need to be involved with carp control measures. These bodies usually have a legislative obligation to produce catchment management strategies and therefore are indirectly required to consider carp damage in their policy. Ideally there should be integration of strategies across States, shires, boards, government departments and authorities to form a coordinated approach for carp control within a region. Particular options such as those outlined in Section 8.3, could be implemented at local and catchment levels. In Victoria, Catchment Management Authorities consist of members representing landholders, river and catchment management. In New South Wales, the Total Catchment Management and River Management Committees function in a similar way. These groups may be responsible for interacting with local planning and State government planning processes, directing or guiding others to undertake projects and taking an active role in obtaining funding.

Broad community groups are concerned with possible carp damage as part of other water and habitat issues. These groups are either organised from individuals with the same interest (for example, Landcare groups) or are facilitated at the government level. They form locally and, as stakeholders in an area, contribute to decision making and assist actions. Various participants desire involvement in the initiation and implementation of carp management actions.

Groups such as Field and Game Associations, Field Naturalists, Native Fish Australia and local schools are concerned with constructive action in local situations and work together as volunteers. Other groups use government financial support to facilitate community volunteers who can be resourceful and take local ownership of a problem. A paid coordinator, with access to scientific information and with skills in communication within teams, ensures that carp and their impacts are addressed in a national context, but at a local scale, and with appropriate information and techniques.

In summary, each group has a particular reason for involvement in carp management and has different resources to implement action. Some possibilities are summarised in Table 16.

9.5 Facilitating ef fective gr oups

9.5.1 Partnerships

A unified approach to discussions on carp has occurred at the national level (Section 9.1) with the driving force being a desire to manage and control carp. Energy must now be directed to develop best practice options and to foster further partnerships for managing carp and other environmental problems (Section 8.4).

Table 16: The role of government agencies and community groups in implementing projects to manage carp impacts.

Group	Problems the group aim to address in relation to perceived damage by carp or coordination of control methods	Role of the group in managing carp impacts	Source of funds
National			
Bureau of Rural Sciences	Impact of carp as a vertebrate pest.	Develop integrated, strategic approaches to manage the impacts of carp.	National Feral Animal Control Program under the Natural Heritage Trust.
Carp Control Coordinating Group	Need for a national management strategy on carp control.	Provide coordinating information for carp control to be used as advice by State agencies.	NHT (1998 for three years) via the Murray–Darling 2001 FishRehab Program.
Murray–Darling Basin Commission	Impacts of carp on water quality in aquatic habitats and irrigation areas; decrease in water quality and native fish populations.	Environmental rehabilitation and management; carp research and their control.	NHT Strategic Investigations and Education Program.
Fisheries Research and Development Corporation	Impacts of carp on other fisheries; need to investigate commercial opportunities of carp.	Provide funds for research.	Government and Industry
State			
Government departments such as Conservation, Land, Fisheries, Natural Resources (see Chapter 6)	Loss of native fish and aquatic plants; increase in turbidity and decrease in water quality; loss of riparian vegetation; deterioration of natural habitat and water quality; biodiversity conservation.	Enact, implement and enforce the keeping, movement, fishing and other uses of carp; extension.	State
Regional Catchment Authorities	Loss of native fish and aquatic plants; increase in turbidity and decrease in water quality; loss of riparian vegetation; deterioration of natural habitat and water quality; biodiversity conservation	Integrated catchment management, policy and direction.	State government and local rates

Group	Problems the group aim to address in relation to perceived damage by carp or coordination of control methods	Role of the group in managing carp impacts	Source of funds
Water and Irrigation Authorities	Erosion in channels; increase in turbidity; increase in nutrients; vegetation loss.	Manage allocation of water resources for irrigation agricultural use; control of carp.	State government and local rates
Local shires	Decrease in water quality; decline in business and tourism; lack of businesses to utilise carp.	Planning and regional economic development.	State government and local rates
Community action groups, for example, Waterwatch	Decrease in water quality; lack of awareness of presence of carp.	Empowering local people to be concerned and involved in their aquatic environment.	Volunteer, State and national (Natural Heritage Trust).
Special interest groups, for example, Field and Game, Field Naturalists	Loss of aquatic vegetation; decrease in water quality; decline in habitat for water birds.	Undertaking special projects, for example, protecting and enhancing waterbird habitats.	Projects and ongoing action; volunteers and funds for special projects.
Schools	Awareness of presence of an introduced species and its impacts.	Education on all environmental issues that affect aquatic habitats; use of an integrated curriculum.	State governments
Recreational anglers	Loss of native fish; loss of habitat for native fish.	Action such as competitions; education; possibility of carp as an angling species.	Local volunteers; group fees, for example, Native Fish Australia; State, for example, Victorian Recreational Fishing Peak Body.
Commercial fishers (associations and State councils)	Decline in native fish; lack of markets for carp.	Commercial use of native and introduced fish.	Self employed; industry enhancement for some operators in New South Wales.

A development plan was funded under the National Fish Care Program. It proposed a unique cluster approach for the Western Murray region of north-west Victoria and southern New South Wales (Heslop et al. 1998). A group formed from a diversity of regional operators and government support agencies would be more active than a simple network. Such an integrated network would be better able to achieve both the reduction of carp numbers and the enhancement of native fish populations. The partners and stakeholders, of up to 260 individuals, would link and would be likely to benefit from the regional development (Heslop et al. 1998). Further funding would be needed to have a central project officer as an ongoing facilitator.

9.5.2 Social principles of participation and facilitation

One of the greatest benefits of education and community group awareness is gaining public involvement in the management process so that they are better informed and can actively contribute. Empowering participants is part of best practice management. Empowerment of both the community and water managers to undertake carp management is essential for its success. This type of involvement begins in school science education by developing an approach to discovery, followed by more investigative inquiry where student involvement is paramount (Trowbridge et al. 1981). The process of inquiry identifies a problem, formulates hypotheses, designs investigative approaches and tests ideas.

Involvement in environmental actions is likely to lead to a lasting education and has been encouraged in science education (Malcolm 1989). A problem-solving exercise within the secondary school biology curriculum led to a carp barrier being erected to a wetland near Glossop High School in the Murray Riverland (Schultz 1998). This investigation and its outcomes drew on existing knowledge on carp management and the support of senior school staff.

Government departments have extension services in many fields where information is communicated through pamphlets, talks and field days. A more active approach with greater involvement is even more likely to change attitudes (Easton 1998). An example of this approach is a carp project in northern New South Wales where participants were encouraged to take part in fishing competitions, carp tasting and the production of a recipe book (Easton and Elder 1997).

'The ownership of carp as a regional or local problem should lead to local solutions.'

Active participation has been used in community groups and by a range of government agencies. This process was initially demonstrated on a large scale by the Landcare Program which empowered an attitude change and consequent action (Campbell 1990). This model has been adopted by the Waterwatch Program, a national community-based water quality monitoring program which encourages community groups to develop action plans. The carp catching day in Waterweek (October 1998) by Waterwatch Victoria followed the example in New South Wales (Easton 1998) and could encourage best practice carp management in future local projects (R. O'Kane, Waterwatch Victoria and Department of Natural Resources and Environment, pers. comm. 1998). A key aspect of Waterwatch is also to develop successful partnerships between volunteers and local agencies (Rixon 1998).

The ownership of carp as a regional or local problem should lead to local solutions. Groups can be useful for effective implementation of best practice carp management. Using the social principles of team building, groups can:

- implement changes in attitudes towards carp
- take ownership of problems in local public waters
- implement programs with volunteer energy

- investigate other factors relating to conditions of local aquatic habitats and catchments

- encourage other changes in catchment practices

- be part of a coordinated approach at a regional level

- gather data to monitor results of programs to be used for evaluation.

If the level of networking from national groups to regional areas is encouraged there will be a successful transfer of educational and scientific material to be applied in a local context. Ownership of the local problem could lead to local investigations using best practice carp management.

10. Deficiencies in knowledge and practice

Summary

A number of deficiencies in knowledge which may affect the management of carp in Australia have been identified. The biology and ecology of carp in Australian environments are not well understood and the effect of carp on the environment and native species has not been quantified. A lack of objective, quantitative data on the impacts of carp on industries and on the environment poses major problems for determining priorities for carp control. Reliable measures of economic and environmental costs will allow evaluation of the efficacy of different control techniques and of appropriate expenditure on control, research, management and development programs. This would also allow control efforts to be targeted to areas of greatest need or benefit.

More information is required on the factors that affect carp populations in Australia and how changes in conditions may be used to the best advantage in carp management efforts. There are few data on the structure and dynamics of carp populations. Standardised indices of abundance need to be developed. Such information is vital to the successful implementation of many control techniques.

There are no reliable data on the cost of controlling carp in the different types of habitats in which they occur or the costs of using the different control methods. The costs and benefits of different management strategies need to be compared to determine their cost effectiveness.

Significant knowledge gaps exist in some of the possible technical methods for carp control. This is particularly apparent in the area of biological controls, which may offer some of the most promising options for long-term and large-scale control. Further evaluation and development of these options is needed. Understanding population dynamics of carp and having the ability to model them is essential for predicting future outbreaks and the potential effects of wider scale control options.

Most carp management is currently undertaken by fisheries agencies, who have little experience and training in vertebrate pest control, and there is little coordination between States or with other agencies. Adoption of the national guidelines will involve some changes at all levels of management: National, State, regional and local, both within government agencies and other stakeholder groups.

10.1 Intr oduction

The recent resurgence of interest in the damage caused by carp (*Cyprinus carpio*) and in carp control has highlighted the limited current level of knowledge of carp in Australian environments. Whilst many actions and knowledge gaps are listed in this chapter, some of these are of greater importance than others, and priorities must be given to those areas which can do the most to limit damage caused by carp in Australia. This chapter examines deficiencies in both knowledge and practice.

Universities, fisheries and natural resource agencies, regional institutes and other groups in Australia have conducted research on carp since the 1960s. There has been an emphasis on identifying impacts of carp, although some research has been directed at control measures (Chapters 5 and 7). Deficiencies in research are listed in Sections 10.2 to 10.5. Several groups have undertaken a coordinating role to direct carp research. CSIRO and the Murray–Darling Basin Commission supported a range of carp research projects from 1992–96 and also linked their results with other groups (Roberts and Tilzey 1997; Roberts and Ebner 1997). The Cooperative Research Centre for Freshwater Ecology (CRCFE) has undertaken research through its members: NSW Fisheries, University of Canberra and the Murray–Darling Freshwater Research Centre. The CRCFE also undertook an analysis of future directions of research (K. Davis, unpublished report 1997) and will implement future research projects that are pertinent to a strategic approach to carp management.

Future research into carp management may also be funded under the Fisheries Research and Development Corporation (FRDC) although this will only involve the commercial harvesting aspects of carp management. Prior to implementing new FRDC projects, a strategic approach was developed at a workshop attended by a range of stakeholders related to fisheries industries (commercial and recreational), scientists and managers. A report identified deficiencies in research and how FRDC could best support commercial research and monitoring projects (G. Newman, Chairperson FRDC Workshop, unpublished report 1998). Areas for future work included:

- evaluating techniques for carp harvesting and control
- information on carp distribution and biology for population modelling to evaluate a carp fishery and to implement control measures
- estimating and modelling commercial yields in carp populations subject to varying environmental conditions
- exploring cost-effective methods for exploiting smaller populations if a carp fishery is to develop
- studies on value adding and market research to increase the benefits from harvesting a resource that has an inherently low value
- estimating non-commercial benefits of carp control including enhancing native fish populations. This may ultimately have commercial benefits if native species can be restored to support increased harvesting.

All carp harvesting activities need to be supported by targeted research. In particular, research is required to:

- identify efficient fishing techniques which limit by-catch of native species
- assess the efficiency of different carp harvesting methods
- assess the value of harvesting for providing long-term population control
- determine when carp densities are low enough to reduce damage to acceptable levels.

Research into methods to measure and manage carp numbers and their impacts and summaries of research currently being undertaken are discussed in Chapter 7.

The Carp Control Coordinating Group (CCCG) is developing a document, *Future Directions for Research into Carp*, which will provide a holistic overview of carp research directions and should prompt more strategic, coordinated research activity.

A Centre for the Analysis and Management of Biological Invasions has recently been formed to incorporate the biological, geographic, economic and information services to improve the research base for managing biological invasions. This venture can bring greater cohesion to a multidisciplinary approach to manage invasive species across different ecosystems, for a range of species, including carp (Professor P.S. Lake, Cooperative Research Centre for Freshwater Ecology, Victoria, pers. comm. 1999).

There is a need for greater education and extension and coordination of carp management (Section 10.6). There needs to be greater consistency between States with regard to carp management policy - several States are currently reviewing their regulations and strategies (Chapter 6). There also needs to be prioritisation (Section 8.3.3) of carp management, including further spread, at the national, State and regional level. The general community has a valuable role to play in early detection of new carp incursions, carp removal, habitat management and monitoring of habitat condition.

10.2 Populations, distribution and abundance

10.2.1 Future spread

Deficiency

It is likely that carp can tolerate the conditions of most Australian aquatic habitats. The recent discovery of carp in Tasmania and their establishment in Papua New Guinea indicate that carp are still spreading. The highest risk mechanisms, areas for future spread and the potential impacts of such spread need to be identified. Predicting the risks of carp spreading and the damage that may occur, can be used to focus efforts and set priorities to prevent or control further spread into areas of greatest risk of harm.

Developments required

An assessment is required of the risks of carp spreading into other catchments within Australia and likely impacts should such spread occur. This assessment should include the mechanisms that exist to spread carp into different habitats through both deliberate and accidental means. The risks of introductions by coarse and live bait anglers deserve particular attention. The areas where such spread could have the most harmful consequences also need to be identified.

10.2.2 Long-term data sets and models on factors affecting abundance

Deficiency

There are inadequate quantitative long-term data on carp population dynamics, growth rates, densities, distribution, abundance and the factors affecting them. These aspects of carp biology are likely to vary between different climatic regions in ways that may influence decisions on control methods. Carp control is a long-term exercise requiring high quality data over a sufficient time scale to develop reliable and sophisticated population models to evaluate likely outcomes of different management strategies. Key impediments to obtaining such data have been the lack of monitoring of carp populations, a lack of validated methods for determining population age structures, and limited understanding of reproductive strategies.

Developments required

Agencies and funding bodies with responsibility for carp management need to agree to support long-term data collection on carp and to devise methods for doing so that do not require excessive resources. Of particular importance is collecting data on factors affecting the age structure of carp populations so that key times and conditions for recruitment can be identified. This includes long-term age-based data sets of carp populations from different regions of Australia which will allow state-of-the-art models to be developed for carp populations, their impact, and their responses to management. Development and use of such models will enable both research and control efforts to be focussed in areas where reducing the damage caused by carp is likely to be achievable. These data need to be used to develop carp population models that can be used to evaluate the potential effects of different management strategies and techniques. Such models need to be expandable to account for possible differences in fecundity, spawning conditions, growth rates and population dynamics in different climates because it is unlikely that carp populations around Australia all behave in the same way as those in the Murray–Darling Basin.

10.2.3 Carp biology in Australia

Deficiency

More information on the basic biology of carp in Australia including behaviour, reproduction, feeding, migration, social interactions, and other ecological details is needed for targeting, refining and focussing management options more effectively. For example, it is not known whether carp actually spawn in flowing water in main river channels in Australia. Other deficiencies include aspects of carp reproductive and digestive physiology that could provide targets for new control methods.

Developments required

Research is needed to address these information deficiencies. One obvious need is to determine the spawning requirements for carp in Australian aquatic habitats. Targeted studies are needed to identify possible weaknesses that could be attacked by new control methods.

10.3 Economic impacts

10.3.1 Impacts on fisheries and other industries

Deficiency

The impacts of carp on native fisheries (both commercial and recreational) and other industries are not well understood and hence it is difficult to assign priorities to carp management actions to minimise impacts. Knowing the costs and impacts on fisheries and other industries will allow for control techniques to be focused in areas where damage can be minimised cost effectively.

Developments required

Knowledge of the density–damage relationships of carp and their impacts and cost to fisheries and other industries (Section 5.2), particularly impacts on:

- individual fisheries, especially those identified by commercial fishers to be of high priority
- water turbidity
- irrigation pumps and channel banks.

10.3.2 Carp as a resource

Deficiency

There has been little development of markets and products for use of carp in Australia. Information on the resource value of carp will allow better decisions to be made on carp control based on cost-benefit assessments.

Developments required

An assessment of the total market value for existing carp products is required. There is a need for an economic assessment of export markets and potential value-added products for which carp can be used so the potential increase for carp markets both in Australia and overseas can be estimated. Marketing assistance may follow this evaluation. The risk that further development of carp harvesting as a commercial industry or for recreational fishing could inhibit the future control of carp through claims for loss of income and compensation also needs to be evaluated. Options for managing this risk need to be investigated including the feasibility of incorporating ‘sunset clauses’ into permits for the recreational or commercial use of carp.

10.4 Environmental impacts

10.4.1 Identifying environmental impacts

Deficiency

The environmental impacts of carp in Australia are largely unknown. In particular, little is known about the interactions between carp and native fish species, density–damage relationships between carp and environmental variables (for example, water quality) or the effects of carp on most aquatic habitats. An understanding of the interactions of carp with the environment and native aquatic species is necessary so that management options can be focussed to reduce harm to acceptable levels in areas with the highest environmental values. This will allow the type and location of impacts of carp to be estimated and will assist strategies to reduce them. Understanding of carp impacts will enable better assessments of the risks posed by carp expanding into new habitats. Knowledge of the damage carp cause and density–damage relationships will allow the most cost-effective management options to be determined and will help allocate priorities to minimise damage to areas of greatest importance.

Developments required

Scientifically validated studies of the impacts of carp on a wide range of environmental variables are required, particularly to:

- quantify interactions between carp and native fish communities and species
- quantify changes that carp cause to other animal communities, such as zooplankton, macroinvertebrates, amphibians, reptiles and birds
- quantify the damage that carp cause to a range of aquatic habitats in Australia (for example wetlands)
- determine the levels to which carp need to be reduced to reduce environmental damage to acceptable levels
- determine the degree of recovery which is possible by controlling carp and its significance with respect to other degrading factors
- assess the economics of environmental damage caused by carp.

10.4.2 Measuring impacts and recovery

Deficiency

The problems of measuring the impacts of carp and the techniques to do so are discussed in Section 7.1. There is a particular need to quantify environmental impacts and be able to make reliable predictions on different scales across the distribution of carp in Australia. A better understanding of impacts and recovery is needed to enable realistic management objectives to be developed and monitoring programs to be designed that measure appropriate performance indicators are also required.

Developments required

Controlled, replicated experiments that test the impact of carp over a range of environmental variables and measure the recovery of ecosystems following carp reduction or eradication.

10.5 Population control techniques

10.5.1 Information to determine the feasibility of control options

Deficiency

There is often insufficient information to determine whether carp eradication and/or damage reduction is an achievable objective in different habitats in Australia. The six feasibility criteria developed by Bomford and O'Brien (1995) for successful pest eradication are outlined in Section 8.3.2. Choquenot and Parkes (in press) have examined models for setting thresholds for pest control effort in relation to target pest densities and levels of resource damage. There are often inadequate data to make reliable assessments on the resource protection benefits of carp control or the feasibility of carp eradication.

Developments required

In areas where carp control is to be undertaken, balanced, reliable data on the criteria that will determine whether the control program objectives can be met need to be collected and evaluated.

10.5.2 Environmental rehabilitation

Deficiency

There is evidence that aquatic ecosystems close to their natural condition, and which have intact native fish communities, are able to limit increases in carp populations. However, the reverse situation, that rehabilitation of degraded ecosystems can reduce established carp populations, has not been tested. Many ecologists and conservationists consider environmental rehabilitation is likely to offer benefits for carp control (Section 4.4). Rehabilitation research is needed to determine whether this approach has potential as an option for carp management.

Developments required

Rehabilitation sites should be established where environmental attributes that make conditions less favourable for carp, and which are likely to enhance native fish numbers, can be experimentally manipulated. Carp populations and natural biota need to be monitored to measure responses to rehabilitation and the efficiency of reducing carp impacts. Realistic time frames must be considered for this option.

10.5.3 Envir onmental manipulation (drainage, water level fluctuations)

Deficiency

It is likely that environmental manipulations, such as changes to water levels and environmental flows, can be used to control carp but this approach has not been evaluated on a large scale. The impacts of such environmental manipulations on other species have also not been evaluated.

Developments required

Effects on carp populations of manipulations, such as increasing or decreasing water levels or total drainage, need to be monitored and evaluated. The cost of this approach, in terms of native flora, fauna and habitat characteristics needs to be assessed simultaneously.

10.5.4 Biomanipulation

Deficiency

Predation on carp, especially young fish, by native piscivorous species such as Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*) has been recognised by fish ecologists (Section 7.3.6) as a potential carp management option. No scientific trials have been conducted in Australia to determine the level of carp control afforded by manipulating food chains.

Developments required

Experiments using different densities of native predator species need to be conducted in enclosed waters to assess the impact on different carp population densities and changes in carp numbers and habitat conditions over time. The size and effectiveness of fish stocked and the time required to establish effective predator populations also need to be assessed.

Many biomanipulation approaches can be combined with conventional control methods to get the most benefit. For example, large numbers of carp are removed by conventional means and then predators are stocked to keep the remnant carp population under control. The effectiveness of these treatment combinations of conventional and new technologies needs to be evaluated.

10.5.5 Chemicals

Deficiency

There is currently no method of chemical control that is specific to carp. In addition, currently available chemicals are either in limited supply or too expensive for large-scale application. Improved delivery methods and chemical specificity will increase the feasibility of using chemicals as a carp management option with fewer environmental risks and reduced costs.

Developments required

Improved delivery methods for existing poisons may reduce the quantity and cost of product needed to treat a specified area. Refined delivery methods may make non-specific poisons more specific to carp. One example is the delivery of rotenone in a flavoured pellet bait which attracts carp only. Other poisons may be developed that kill carp without harming native species. All new delivery methods and new poisons will require extensive testing.

10.5.6 Biological control using viruses

Deficiency

To assess the potential use of viral control agents, such as Spring Viraemia Carp Virus (SVCV), it is important to understand methods of application, limitations and risks. There is little information on the behaviour of fish viral agents, including their transmission between individuals. The effects of SVCV on Australian carp populations under Australian conditions are not known. Key questions which need to be answered in regard to SVCV in Australia have been outlined by Crane and Eaton (1997) (Section 7.3.5). If biological control using viral agents is technically feasible, and socially and economically acceptable, it could provide sustained carp control at relatively low cost.

Developments required

Research is needed to determine the potential for SVCV or other viral agents to control carp under Australian conditions and the potential risks for non-target species. The social perception of viral control, and international trade implications, will also need to be addressed before viral control can be attempted.

10.5.7 Control using molecular approaches (chromosomal manipulation, gender manipulation, inducible fatality genes)

Deficiency

Molecular approaches may provide opportunities for cost-effective, wide-scale carp control, but there is a need for further development and testing. Many of these requirements have been outlined by Grewe (1997; Section 7.3.8).

Developments required

The feasibility of developing molecular approaches for wide-scale carp control in Australian conditions needs to be investigated.

10.5.8 Effects of multiple controls

Deficiency

The benefits of pest control can theoretically be multiplied by simultaneously applying more than one form of control (Section 7.3). However, limitations in development of individual control methods has largely prevented evaluation of multiple control options that may offer increased effectiveness with potential cost savings.

Developments required

Experiments and field trials are needed to test combinations of control techniques at an appropriate scale. Examples might include commercial harvesting of adults from a river reach combined with poisoning off-channel wetlands to remove juveniles or poisoning a lake followed by predator stockings.

10.5.9 Exclusion barriers

Deficiency

Barriers in the form of 'fish screens' have been used to exclude carp but their success has not been determined. Screens may prevent the movement of larger fish, but eggs, larvae and juvenile fish may easily pass through. Further options to improve screen design could be investigated. The effectiveness of acoustic and electric barriers in excluding carp has not been tested. Fish barriers have potential as cost-effective, environmentally friendly methods of carp management to assist one-off or sustained management applications.

Developments required

Testing of physical and acoustic and electrical barriers for all sizes of carp is needed.

10.5.10 Carp harvesting

Deficiency

Environmentally friendly and efficient methods of carp harvesting in a range of habitats are needed.

Developments required

Targeted research into by-catch, environmental damage, efficiency and effectiveness of carp harvesting techniques in providing long-term reductions to reduce damage to acceptable levels.

10.6 Management

10.6.1 A coordinated, national education campaign

Deficiency

The general public and community groups interested in carp control are not well-informed about current developments in carp control techniques and management, with the result that local efforts lack coordination. Improved understanding by the public of the biology of carp, possible management techniques and the value of coordinated management based on best practice principles, pest management principles and participation of all stakeholders, will engender support for carp control activities.

Developments required

A national, coordinated communication and education strategy and campaign aimed at improving the knowledge of all stakeholders and the general public of carp and their impacts.

10.6.2 Effectiveness of current management

Deficiency

There is a lack of reliable information on the effectiveness of current carp management because of inadequate monitoring and evaluation. Proper monitoring and evaluation of the effectiveness of control techniques will enable improved methods and approaches to be developed so that the effectiveness of carp management in Australia can be continually improved. Monitoring and evaluation will also allow cost savings by discontinuing inefficient or ineffective methods.

Developments required

Operational monitoring, to assess the efficiency of the operation, performance monitoring, to assess the effectiveness of the management plan, and evaluation need to be integral components of all carp control programs. As part of this, simple standardised monitoring methods need to be developed and promoted to allow better comparison of results over time and between regions. This will enable managers to assess whether they are achieving carp damage-control objectives efficiently.

10.6.3 Management zones

Deficiency

Most current carp management is undertaken by State and regional agencies (mainly fisheries agencies) with little coordination between States or agencies. A coordinated system of management zones will allow more efficient strategic planning, better risk assessment and systematic implementation and evaluation of management programs to control damage caused by carp.

Developments required

The feasibility of establishing carp management zones which do not coincide with local shire or State boundaries needs to be evaluated. For example, a zone system based on existing classifications of river drainage divisions, catchments, and sub-catchments may allow resources to be coordinated more efficiently. National coordination to develop management zones, under the umbrella of CCCG, may assist this.

10.6.4 Coordinated information systems

Deficiency

Most carp research and management is undertaken by agencies, institutions and community groups with limited exchange of information between groups. With increasing efforts in carp research and management, there is a need for centralised records of work in progress and results achieved to assist with adaptive management, adoption of new techniques and a decreased risk of unnecessary duplication of effort.

Developments required

A central database which records details of all carp-related research and management projects, with supporting documents, is needed to facilitate coordination at a national level, and communication at local operational levels. Easy access, for example via the internet (as with the current carp distribution database www.sunfish.org.au/recfish/NCTF/Carpdatabase.htm), with a simple Geographic Information System-based user interface is needed to allow easy updates and dissemination of information. Established groups such as CCCG and the National Carp Task Force are in a good position to be involved in this objective.

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Appendix A

Economic strategies for carp management

(Bomford and workshop participants 1995)

Water managers who wish to determine the optimal economic strategy for managing a problem caused by carp (*Cyprinus carpio*) could use the stepwise approach outlined in this appendix. We recognise that often the information necessary to complete the steps is lacking. Nonetheless, the exercise of attempting to go through the process, recording the assumptions and making best guess estimates, may prove a useful aid to decision making for carp management.

STEP 1: *Identify desired outcomes and estimate a dollar value for each of these*

Where outcomes are measurable commodities, such as a reduction in water quality to a specified level, this should be reasonably easy. Where outcomes are difficult to measure or intangible, such as reductions in numbers of anglers because of large carp numbers, water managers may be obliged to estimate how much they consider is an acceptable amount to spend to achieve that outcome.

STEP 2: *List all control options and how much they would cost to implement*

Control options can be different techniques, combinations of techniques, or different levels or frequencies of application of techniques (Chapter 7). It is important that the options for control are expressed as activities that a manager can select either to do or not to do.

STEP 3: *Estimate the relationship between carp density and damage for each resource damaged by carp (see Figure 23, Section 5.4.4)*

For example, if carp are reduced by 50%, how much will this improve water quality. There may be interactions between pest density and other management practices which need to be taken into account. For example, the improvement in water quality caused by reducing carp densities by a certain amount may vary in different habitats.

STEP 4: *Estimate the effectiveness of each control option*

How much will a given effort using a particular control option reduce pest density?

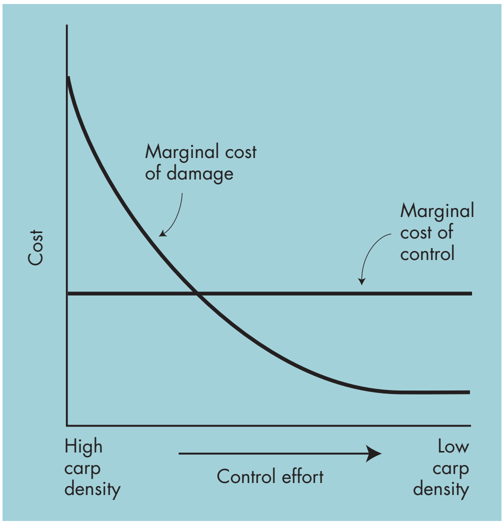
STEP 5: *Use the information from Steps 1–4 to estimate costs and benefits of implementing each control option, including options which combine more than one technique*

Costs will be those associated with implementing control options, and may include costs of monitoring carp and planning. Benefits will be the value of the reduction in damage to resources (that is the value placed on desired outcomes listed under Step 1). Different carp management options will generate different cost–benefit relationships.

Estimates of benefits and costs can be discounted back to net present values (usually using a discount rate equivalent to the interest rate on financing of the control operation). This will reduce the value of costs and benefits accruing in the distant future relative to those accruing in the near future.

STEP 6: *Carry out a marginal analysis (Figure 23) (A1)*

Plot both the incremental marginal change in the cost of carp control and the incremental change in the cost of damage caused by carp against the level of carp control contemplated. Where the two lines cross is theoretically the optimal level of pest control (Hone 1994). Further increases in control activity do not cause commensurate reductions in damage, so at higher levels of control beyond



Figur e 23 (A1): A marginal analysis as described in Step 6 (units on the x-axis are level of control effort not carp density). A marginal analysis is an analysis of the relative shift in cost and benefit values that occur as incremental changes are made in the level of pest control effort.

this point, costs will exceed savings in reduced damage.

The problem for carp managers is that because they often do not have good information on the damage–density relationship it is hard to estimate the optimal control point. Further, even if they can make a good guess, it is not usually practical with most control techniques to simply cut off control efforts at some pre-determined carp density. It is preferable to have a range of control options ranked along the x-axis, with their associated cost and benefit values for implementation, so a manager can select which option is optimal. For example, number of removal runs by electrofishing could be put along the x-axis.

STEP 7: *Construct a table listing all the control options and their associated costs and benefits (this is called a pay-off matrix)*

Managers may wish to construct different matrices for different conditions, such as different removal rates, seasonal conditions or water quality values. Managers will also need to consider time-scales when constructing these matrices — what time span is covered and how will this affect costs and benefits?

These matrices can then be used to select the option(s) which best meet the manager's desired outcome. If the manager is risk-averse, the best options will be those that bring in reasonable returns under all conditions. If the manager's priority is to maximise profit, the preferred options will be those that are likely to give the highest returns on investment, despite the risk of having no returns or even a loss.

Pay-off matrices can also be used by water managers to compare returns on investment in carp control with returns on using the money for some other purpose, such as increased water treatment.

Steps 1–7 complete the basic model. The model can be made more accurate by adding additional features. Incorporation of such features will make it more complex, but including at least some of them may be necessary to make the model accurate enough to be useful. Some additional features that might be worth including are:

- social benefits in Step 1, such as increased biodiversity and threatened species protection, better water quality, increased angling opportunities, and retaining rural tourism
- risk management for potential spread of diseases by carp to native species
- effects of government intervention on costs (in Step 2) such as tax incentives or direct assistance with implementing carp control
- commercial harvest of carp as an alternative control could be included as an option in Step 2
- indirect effects of pest control, for example, the effects of carp control on Murray cod numbers could be included as an interaction in Step 3

- the form in which benefits come may be significant to the manager (Step 5). For example, it may be more attractive to remove carp commercially than to address more damaging and expensive environmental problems.

Much of the information needed to follow the steps outlined above is not available. Appropriate levels of control required to reduce some of the environmental damage caused by carp cannot be determined because the cost of the damage is intangible. While some techniques are available which attempt to quantify such intangible effects (Braysher 1993) these are complex and expensive to use and of limited reliability. Despite these problems, the steps outlined above, especially Steps 1–5, enable managers to assess the most appropriate actions to achieve the desired reduction in damage

Abbreviations and Acronyms

ACF	Australian Conservation Foundation
AFCAA	Australian Federation of Coarse Anglers Association
AFFA	Agriculture, Fisheries and Forestry – Australia
ANZECC	Australia and New Zealand Environment and Consultative Committee
AQIS	Australian Quarantine and Inspection Service
ARSFC	Australian Recreational and Sport Fishing Confederation
ASFB	Australian Society for Fish Biology
AusRivAS	Australian River Assessment Scheme
BACI	Before-After-Control-Impact
BRS	Bureau of Rural Sciences
CALM WA	Conservation and Land Management, Western Australia
CAMBI	Centre for the Analysis and Management of Biological Invasions
CARP	Carp Assessment and Reduction Program
CCC	Community Consultative Committee
CCCG	Carp Control Coordinating Group
CIT	Canberra Institute of Technology
CMAs	Catchment Management Authorities
CPIS	Carp Production Incentive Scheme
CPUE	Catch-Per-Unit-Effort
CRC	Cooperative Research Centre
CRCFE	Cooperative Research Centre for Freshwater Ecology
DPI	Department of Primary Industries
EA	Environment Australia
EFSC	Exotic Fishes Sub-Committee of ASFB
ESD	Ecologically Sustainable Development
FRDC	Fisheries Research and Development Corporation
FWAA	Far West Anglers Association
GIS	Geographic Information Systems
IFC	Inland Fisheries Commission
IFG	Inducible Fatality Gene
ISG	Inducible Sterility Gene
LWRRDC	Land and Water Resources Research and Development Corporation
MCFFA	Ministerial Council on Forestry, Fisheries and Aquaculture
MDA	Murray–Darling Association
MDBC	Murray–Darling Basin Commission
MIA	Murrumbidgee Irrigation Area
NCTF	National Carp Task Force
NFA	Native Fish Australia
NFACP	National Feral Animal Control Program
NHT	Natural Heritage Trust
NMSCC	National Management Strategy for Carp Control
NRMS	Natural Resource Management Strategy

NTU	Nephelometric Turbidity Units
PIRSA	Primary Industries and Resources South Australia
QAP	Quality Assurance Program
QFMA	Queensland Fisheries Management Authority
RAA	Recreational Anglers Association
Ramsar	See Glossary
RecFish	Formerly Australian Recreational and Sport Fishing Confederation.
SAFGA	South Australian Field and Game Association
SARDI	South Australian Research and Development Institute
SCARM	Standing Committee on Agriculture and Resource Management
Sp.	Abbreviation for an unnamed species
Spp.	More than one species of the genus
SVCV	Spring Viraemia of Carp Virus
VRFish	Victorian Recreational Fishing Peak Body
VPC	Vertebrate Pests Committee

Glossary

Acclimation: The process of allowing animals to become accustomed to experimental conditions, usually in an artifical environment such as aquaria where temperature, lighting or water quality are artificially maintained.

Acclimatisation: The process by which animals become accustomed to a change in natural environmental conditions, such as occurs when fish are transferred from one river system to another, or as a result of seasonal climatic changes.

ad hoc: Impromptu or unplanned, refers to management of problems reactively without reference to a strategic plan.

Adipose fin: Small, fleshy rayless fin on the posterior dorsal surface of 'primitive' fish like salmonids.

Algae: Single-celled, colonial or filamentous aquatic plants, distinct from vascular plants.

Alluvial plain: An area of fairly flat land where a river has deposited silt.

Anabranch: Branch of a river which leaves the main channel and may rejoin further downstream.

Aquacultur e: The farming of fish or other aquatic organisms under artificial conditions.

Attached algae: Algae which are attached to objects such as rocks, sediments or other plants.

Barbels: Fleshy, sensory protrusions around the mouth of carp and some other fish. Commonly referred to incorrectly as 'whiskers'.

Basin: An area in which the ground level dips from all directions towards a common central point. A river basin is the area drained by a river and its tributaries.

Benthic: Living on or in the bottom of a water body, bottom living.

Benthivor ous: Animals that feed on the animals from the benthos.

Benthos: Animals living on or in the sediment at the bottom of a water body.

Billabong: Typically ox-bow lakes which are cut off from river channels, but also refers to other naturally-occurring floodplain waterbodies.

Biofilm: The thin film of biological material, such as bacteria and algae, that grows on submerged surfaces.

Biological contr ol: The use of living organisms to control pests or diseases. This may involve the release of a natural or genetically modified organism.

Biomass: The weight of living material. The total weight of all organisms in a particular habitat or area.

Biota: All living organisms, usually used for all the living organisms in a place (for example, the Australian biota).

Biotic: A descriptor of the living components of ecosystems, (for example, a biotic response is the response of all or some living things to a change in some other part of an ecosystem).

Bloom: Rapid, temporary increase in the population of aquatic photosynthetic microorganisms (for example, phytoplankton or cyanobacteria) to the extent that the water becomes discoloured and, if the microorganisms are toxin producers, unfit for drinking.

Brackish: Water with a salinity greater than fresh water but less than sea water, usually found in estuaries.

Car nivor e: An animal that mainly eats animals.

Catchment: The area from which a river, stream, lake or other body of water receives its water.

Catadr omous: Describes fish that migrate from fresh water as adults to spawn at sea (for example, eels).

Ceratopogonidae: Biting midges, larvae of which are found in freshwater habitats.

Channel: The part of a stream or river confined between banks, or a deeper passage through a lake or harbour.

Chir onomids: Midges, larvae called blood worms, found in aquatic environments.

Clay: A fine particle of sediment. Finer than sand.

Coarse fishing: A recreational sport that arose in England and Europe as a 'gentleman's pursuit', where cyprinids including roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*), chub (*Leuciscus cephalus*) and dace (*Leuciscus leuciscus*) are caught and released.

Coastal types: There are three main kinds of coast in Victoria. These are dominated by: cliffs; (sand barriers) beaches and dunes; and marshes, tidal banks and mangrove swamps.

Cobble: Substrate particles with a diameter of 64 millimetres to 256 millimetres.

Coleopterans: Beetles.

Community: All organisms inhabiting a common environment and interacting with one another.

Cyanobacteria: Bluegreen algae.

Cyprinidae: The taxonomic family including carp (*Cyprinus carpio*) and other species such as goldfish (*Carrasisus auratus*), roach (*Rutilus rutilis*), and tench (*Tinca tinca*).

Dam: A wall or other structure holding water back.

Decomposers: Organisms (for example, bacteria and fungi) in an ecosystem which convert dead organic material into simple compounds that primary producers can utilise.

Delta: A deposit, usually fan shaped, of large amounts of silt at the mouth of a river.

Demersal: Living on or near the bottom of the ocean.

Detritus: Organic debris from decomposing material.

Detritivor e: A consumer organism that directly consumes dead organisms and the cast-off parts and organic wastes of organisms (for example, vulture, jackal, earthworm, termite, millipede, ant, and crab).

Dischar ge: Flow of a river, usually measured in megalitres per day.

Discount rate: The rate used to calculate the present value of future benefits or costs. Discount rates are calculated using the reverse equation to that used to calculate interest rates on invested money (that is, the interest rate is negative).

Ecologically Sustainable Development (ESD): 1992 Brundtland Report by the World Commission on Environmental and Development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'.

Ecology: The study of the interactions of organisms with their physical environment and with one and other, including results of such interactions.

Ecosystem: A term used to encompass all the organisms (biotic) in a community together with the associated physical environment (abiotic) factors with which they interact (for example, a rockpool ecosystem, a forest ecosystem, a wetland ecosystem).

Emergent vegetation: Vegetation growing or protruding above the water surface.

Endemic: Used to describe a species that is naturally restricted to a particular region (although it may be able to establish in another region if introduced).

Ephemeral: A term used for organisms with short life cycles, usually adapted to making rapid use of favourable environmental conditions.

Epifauna: Fauna associated with the substrate surface.

Erosion: The act or process of eroding, especially the wearing away of the land surface by sun, wind, water, frost or ice.

Estuary: The section of a river near its mouth where river flow meets tidal currents, and where fresh water becomes saline.

Eutrophication: An increase in the nutrient content of a body of water, occurring either naturally or as a result of human activities. Eutrophication leads to a rapid increase (bloom) in growth of algae.

Euryhaline: Able to live in a wide range of water salinities.

Exploitation competition: Competition between species where one suppresses another's rate of increase by prior consumptive use of a limiting resource. For example, carp competing with native fish for food.

Feral: The description given to animal species that are normally domesticated (for example, cats, goats, pigs, horses, camels and goldfish) but which have reverted to a wild state.

Fish passage: Ability for fish to move unimpeded up and down the river system.

Fishway: A structure which provides fish passage past an obstruction in a stream.

Flocculate: The aggregation of particles.

Fluvial: Of, or produced by, a river.

Food chain: Pathway of energy.

Food web: The linking and inter-linking of many food chains as may be found in a complex ecosystem with several trophic levels (for example, lake, eucalypt forest).

Fork length: One of the ways to measure the length of fish with forked tails, from the tip of the snout to the inside angle of the fork.

Form: Particular observable characteristic of variant of a particular individual. The phenotypic expression of the genetic makeup. Carp can have a mirror or fully scaled form. It is possible to have different forms within the same strain.

Gastropods: Molluscs including snails and limpets.

Genotype: Genetic makeup of an individual.

Gravel: Substrate particles with a diameter range of 2 millimetres to 16 millimetres.

Groundwater: Water that is found beneath the surface of the ground, usually in porous rock known as an aquifer.

Habitat: The place normally occupied by a particular organism group or population of species (for example, nesting habitat, freshwater habitat).

Hemipterans: 'True bugs' such as backswimmers and water boatmen.

Herbivore: An organism that eats plants or other photosynthetic organisms to obtain its food.

Hybrid: Individual resulting from interbreeding of two species, for example, carp and goldfish. A hybrid needs to be infertile for the two parents to be regarded as two species.

Hydrology: The study of water on, or under, land.

Indigenous: Native, although not necessarily restricted, to an area.

Index of abundance: An indicator of relative number or density of a species which has a mathematical relationship (usually linear) to absolute numbers or density.

Infaunal: Fauna living in the substrate.

Inorganic: Not forming part of the substance of living bodies.

Interference competition: Competition between species where one suppresses another's rate of increase by interfering with its ability to procure or use a limiting resource, or where one species limits another's use of a limiting resource, not by prior consumptive use, but through preventing access (for example, through behavioural aggression and exclusion). For example, carp competing with native fish for habitat space such as spawning sites.

Invertebrate: An animal without a backbone (for example, worms, insects, amoebae).

In-stream-use: Ways of using water which do not require it to be removed from the river or wetland system.

Ledgering: Method of catching carp used by coarse anglers.

Lentic: Still water systems (for example, billabongs, lakes, wetlands).

Leptoceridae: Caddis flies which live in cases.

Lotic: Flowing water systems (for example, rivers).

Marginal analysis: An analysis of the relative shift in cost and benefit values that occur as incremental changes are made in the level of pest control effort.

Market failure: Occurs when resources are not allocated efficiently through the use of the market, that is, when the costs and benefits to society are not equated by the natural market forces of supply and demand (for example, unsustainable use of natural resources or development of social inequities).

Market value: When commodity prices set by natural supply and demand have undesirable social or environmental consequences (for example, unsustainable use of natural resources or development of social inequities).

Macroinvertebrate: An animal without a backbone (for example, worms, insects) visible to the naked eye.

Macrophyte: Large aquatic plant.

Microcrustacean: Very small, mainly aquatic, gill-breathing organisms with antennae, jointed legs and hard surface skeleton.

Oligochaetes: Aquatic worms.

Omnivore: An organism at the consumer level that obtains its food energy from both plants and animals (for example, humans, feral pigs, carp).

Organism: Any living thing, animal, bacterium or plant, whether one-celled or many celled.

Parasite: An organism attached to another causing the host harm.

Peduncle: The caudal peduncle is the narrow part of a fish's body at the base of the tail.

pH: A measurement to indicate the level of acidity or alkalinity of a solution where pH 1 is highly acidic, pH 7 is neutral and pH 14 is highly alkaline.

Phenotype: Appearance of an organism depending on the genotype and environment.

Phytoplankton: Free-floating, single-celled or colonial algae.

Piscivore: An animal that feeds on fish.

Plankton: Free-floating, mostly microscopic, aquatic organisms — can be divided into phytoplankton and zooplankton.

Pock mark: Small depression in bottom sediments caused by carp feeding activity

Population: A group of animals of a particular species occupying an area where they are subject to the same broad environmental or management conditions.

Potable: Drinkable (water).

Precipitation: The process by which water falls from the atmosphere, as rain, hail, sleet, snow or dew.

Predator: An organism that captures and feeds off another organism.

Primary salinity: An accumulation of soluble salts in soil and water (salinisation) which occurs through natural processes.

Race: Genetically distinct populations of a geographic region. Species that are now geographically isolated and not able to interbreed with another race, for example, Chinese and European carp.

Ramsar: Convention on Wetlands of International Importance, held 30 January–3 February 1971 in Ramsar, Iran.

Recharge: The replacement of groundwater (for example, the recharging of aquifers) by rain or other forms of precipitation.

Redfin: An Australian common name for European perch (*Perca fluviatilis*)

Reservoir: A place for storing water or the water which is stored.

Rhabdovirus: The group of rod-shaped viruses that includes the Spring Viraemia of Carp Virus.

Riffle: Relatively shallow, fast-flowing section of a stream where the water surface is roughened and not smooth.

Riparian: Of or on the river bank.

River: A large permanent stream flow of water in a natural channel with banks, which flows into the sea, or a lake.

Saline: Of or containing salt.

Salinity: The concentration of various salts dissolved in a volume of water.

Salmonids: Trout and salmon species.

Salt water intrusion: The movement of saline water into an aquifer.

Silt: An earthy deposit laid down by a river, lake, or other water body, which is finer than sand but coarser than clay.

Spawn: In aquatic animals, to produce or deposit eggs and sperm.

Species: Group of interbreeding individuals not breeding with another such group and which has the characteristics which distinguish it from other groups.

Stock: Term used in natural resource management as the group of individuals of a species that can be managed as one unit. The number of stocks of a species depends on movement and breeding within the populations.

Strain: A genetically distinct group of individuals which may occur in a range of populations. They have a particular proportion of alleles and may be referred to as a halotype if genetic analyses are performed. They show little genetic variation and may be a result of a breeding line.

Stratum: A horizontal layer of any material, especially a layer of sedimentary rock, usually one of several parallel layers (plural is strata).

Str eam: A small river. First-order streams have no tributaries, second-order streams are formed by the confluence (flowing together of two streams) of two first-order streams, third-order streams from the confluence of two second-order streams, etc.

Substrate: The solid bottom of a water body to which an animal may be attached, on which it moves about or with which it is otherwise associated.

Surimi: Reconstituted fish flesh.

Swamp: An area of soft, permanently or intermittently wet ground, often with coarse grasses or reeds. Also called a marsh or wetland.

Taxon: A unit of biological classification, such as species, genus or class; a group of organisms sharing common characteristics (plural taxa).

Taxonomy: The science of classification of animals and plants.

Teleosts: The large group of fish that have a skeleton composed, at least in part, of bone.

Total length: A standard measurement of fish length from the tip of the snout to the tip of the tail. Most commonly used for species with non-forked tails.

Transect: An imaginary line drawn through an ecosystem in order to help ecologists sample and describe a biological community.

Tr ophic level: The level of the food chain from which organisms obtain their energy. Herbivores represent one level as plant eaters. Carnivores represent another level as animal eaters.

Trichopterans: Caddis flies.

Turbid: Not clear or transparent — water muddy with suspended silt or sediment.

Turbidity: A measure of the amount of suspended solids (usually fine clay or silt particles) in water and thus of the degree of scattering or absorption of light in the water; level of cloudiness in the water.

Upwelling: The vertical movement of water from the bottom of a lake or ocean to the surface. Upwellings often bring nutrient-rich water to the surface and cause localised zones of high productivity.

Watershed: : A boundary between areas drained by different river systems.

Waterbody: Any water habitat, ocean, lake, steam, wetland.

Water table: The top level of water in the ground that occupies spaces in rock or soil and lies above a layer of impermeable (non-porous) rock.

Weir: A barrier across a watercourse which may be submerged by rising water levels. Usually lower in height and built on smaller rivers than a dam.

Wetland: Any habitat that is permanently or intermittently covered by fresh water or saline water to a depth of up to 6 metres at low tide. Includes permanent rivers, intermittent streams, floodplains, lakes, billabongs, marshes, swamps and springs.

Zooplankton: The animal constituent of the plankton, small floating herbivores that feed on phytoplankton; a collective term for non-photosynthetic plankton.

Zostera: Generic name for eelgrass or long sea grass; grows in estuaries and bays.

Scientific names

Fish

Atlantic salmon *Salmo salar*

Australian bass *Macquaria novemaculeata*

Australian grayling *Prototroctes maraena*

Australian smelt *Retropinna semoni*

Barramundi *Lates calcarifer*

Basses Percichthyidae

Big-headed carp *Aristichthys nobilis*

Black bream *Acanthorpagrus butcheri*

Black carp *Mylopharyngodon piceus*

Bony herring *Nematalosa erebi*

Bream *Albamis brama*

Brown trout *Salmo trutta*

Carp (includes mirror, leather, king, scaled and European carp) *Cyprinus carpio*

Checkon *Pelecus cultratus*

Chub *Leuciscus cephalus*

Cods Percichthyidae

Colarado squawfish *Ptychocheilus lucius*

Congolli *Pseudaphritis urvilli*

Crucian carp *Carassius carassius*

Dace *Leuciscus leuciscus*

Darling river hardyhead *Craterocephalus amniculus*

Dwarf galaxias *Galaxiella pusilla*

Eels Anguillidae

Estuary perch *Macquaria colonorum*

European barbel *Barbus barbus*

Fat-headed minnows *Pimephales promelas*

Flathead gudgeon *Philypnodon grandiceps*

Fork-tailed catfish *Arius graeffei*

Freshwater catfish *Tandanus tandanus*

Gambusia *Gambusia holbrooki*

Galaxiids Galaxiidae

Gemfish *Rexea solandri*

Golden galaxias *Galaxias auratus*

Golden perch *Macquaria ambigua*

Goldfish *Carassius auratus*

Grass carp *Ctenopharyngodon idella*

Grunters Haemulonidae

Gudgeons Eleotridae

Guppies *Poecilia reticulata*

Hardyheads Atherinidae

Jungle perch *Kuhlia rupestri*

Long-finned eel *Anguilla reinhardtii*

Macquarie perch *Macquaria australasica*

Mangrove jack *Lutjanus argentimaculatus*

Minnows Galaxiidae

Mountain galaxias *Galaxias olidus*

Mud carp *Cirrhinus molitorella*

Mullets Mugilidae

Murray cod *Maccullochella peelii peelii*

Murray galaxias *Galaxias rostratus*

Murray hardyhead *Craterocephalus fluviatilis*

Non-parasitic lamprey *Mordacia praecox*

Northern cod *Gadus morhua*

Ox-eye herring *Megalops cypdnoides*

Oxelyan pygmy perch *Nannoperca oxleyana*

Perchlets Kuhliidae

Pike *Esox lucius*

Prussian carp *Carassius carassius*

Rainbrow trout *Oncorhynchus mykiss*

Rainbowfish Melanotaeniidae

Redfin perch *Perca fluviatilis*

Redtail black 'shark' *Puntius* spp.

River blackfish *Gadopsis marmoratus*

Roach *Rutilus rutilus*

Rosy barb *Puntius conchonius*

Rudd *Scardinius erythrophthalmus*

Saratoga *Scleropages leichardti*

Shiners *Notropis* spp.

Short-finned eel *Anguilla australis*

Silver carp *Hypophthalmichthys molitrix*

Silver perch *Bidyanus bidyanus*

Southern bluefin tuna *Thunnus maccoyii*

Southern purple spotted gudgeon *Mogurnda adspersa*

Southern pygmy perch *Nannoperca australis*

Spangled perch *Leiopotherapon unicolor*

Sword tails *Xiphophorus helleri*

Tench *Tinca tinca*

Tilapia *Oreochromis* spp.

Trout cod *Maccullochella macquariensis*

Variegated pygmy perch *Nannoperca variegata*

Western carp gudgeon *Hypseleotris klunzingeri*

White bream *Blicca bjoerkna*

Yarra pygmy perch *Nannoperca obscura*

Mammal

Water rats *Hydromys chrysogaster*

Birds

Cormorants Pelecanidae

Pelican *Pelicanus conspicillatus*

Reptiles

Estaurine crocodile *Crocodylus porosus*

Freshwater crocodile *Crocodylus johnstoni*

Invertebrates

Daphnia *Daphnia* spp.

Midges Chironomidae

Yabbies *Cherax destructor*

Plants

Attached algae *Chara* sp.

Bluegreen algae *Cyanobacteria*

Common water milfoil *Myriophyllum papillosum*

Derris root *Derris* spp.

Filamentous algae *Spirogyra* sp.

Juncus *Juncus* spp.

Plant-like algae *Chara* sp.

Phragmites *Phragmites australis*

Pondweed *Potomogeton* spp.

Poplars *Populus* spp.

Ribbonweed *Vallisneria* sp.

River red gum *Eucalyptus camaldulensis*

Soft-stemmed pondweed *Potamogeton pectinatus*

Typha *Typha* spp.

Willows *Salix* spp.

Agents causing diseases

Anchor worm (crustacean) *Lernaea cyprinacea*

Asian fish tapeworm *Bothriocephalus acheilognathi*

Blood fluke (digenea) *Sanguinicola inermis*

Carnation-head tapeworm (cestode) *Caryophyllaeus laticeps*

Cheilodonelliasis (protozoa) *Cheilodonella cyprini, Cheilodonella hexastichus*

Cottonwool fungus *Saprolegnia*

Disease caused by (protozoa) *Apiosoma piscicola*

Disease caused by (protozoa) *Ichthyobodo necator*

Disease caused by (monogenea) *Gyrodactylus* sp.

Disease caused by (protozoa) *Myxosoma dujadini, Myxosoma encephalica*

Disease caused by (digenea) *Neodiplostomum perlatum*

Emphysematous putrefaction (bacteria) *Edwardsiella tarda*

Enteritis (protozoa) *Eimeria cyprini, Eimeria subepithelialis*

External gill parasite (monogenea) *Dactylogyrus anchoratus, Dactylogyrus vastator*

Gill rot (fungus) *Branchiomyces sanguini*

Goldfish ulcer disease (bacteria) *Aeromonas salmonicida*

Gut flukes (digenea) *Allocreadium isosporum, Allocreadium carporum*

Kidney disease (protozoa) *Sphaerospora cyprini*

Spring Viraemia of Carp Virus *Rhabdovirus carpio*

Tissue parasite (protozoa) *Myxobolus muelleri*

Trichodiniasis (protozoa) *Trichodinella* sp., *Trichodina domerguei*

Weakness disease (protozoa) *Cryptobia cyprini*

Whitespot (protozoa) *Ichthyophthirius multifilis*

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Z

Introduced carp dominate fish communities throughout many waterways in south-eastern Australia. They also occur in Western Australia and Tasmania and have the potential to spread through many more of Australia's water systems. Carp could eventually become widespread throughout the country.

Carp are known to damage aquatic plants and increase water turbidity but their impacts on native fish species are not yet clear. Carp are also a commercial and recreational fishing resource.

Managing the Impacts of Carp provides a comprehensive review of the history of carp in Australia, their biology, the damage they cause and community attitudes to these problems and their solutions.

Key strategies for successful carp management are recommended by the authors who are scientific experts in carp management. These strategies are illustrated by case studies.

Managing the Impacts of Carp is an essential guide for policy makers, land and water managers, carp fishers and all others interested in carp management.