

# CONTROLLING CARP

*exploring the options for Australia*

Jane Roberts  
and  
Richard Tilzey



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exploring the options for Australia

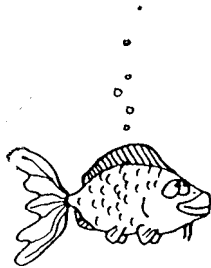
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# Preface

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Carp *Cyprinus carpio* L. is only one of twenty freshwater fish introduced to Australia which are now naturalised in our river and lake systems. Out of 43 fish species recorded from the Murray-Darling Basin, eleven are introduced (Cadwallader and Lawrence 1990).

Carp have been in Australia for over a century. Their present distribution is the result of rapid expansion following the comparatively recent (post-1960) introduction of a German strain. Carp are now present in every State except the Northern Territory and their distribution continues to expand at an alarming rate. Many translocations were almost certainly by irresponsible recreational fishers and, if this practice continues, it is only a matter of time before carp occur throughout Australia's freshwater systems.

Extensive surveys of aquatic habitats in the Murray-Darling Basin (including many headwaters which do not contain carp) were done by NSW and Victorian fisheries agencies in 1994-95. These showed that carp are now over 80% of total fish biomass in the entire Basin, and as much as 96% for some river stretches.

A national approach to addressing the carp problem has so far been lacking. It is fair to ask why, given Australia's strong commitment to scientific control of introduced terrestrial species such as the

rabbit, so little has been done on introduced aquatic species, other than some aquatic and floodplain weeds. The answers are not clear, with no single reason being convincing on its own. One reason, possibly, is that it is only recently that Australia has begun to value inland rivers and wetlands for their intrinsic ecological and multi-use values, rather than merely as a water supply. Another might be that river and wetland ecology is a comparatively young science in Australia.

Then there is the sheer size of the problem. Although the places where carp are found extend across many major catchments and several State jurisdictions, control activities have been local or, at best, regional. Victoria instigated control measures in the early 1960s in an unsuccessful attempt to contain the spread of an imported German carp strain, but have done little since. Tasmania successfully eliminated about 20 small populations in the 1970s, but carp were re-introduced some 20 years later. In essence, State authorities have only attempted direct control measures in isolated (mainly lentic) habitats. Addressing entire river systems has been seen as both impractical and expensive.

A further reason for the lack of concerted effort is that it is still unclear if carp are indeed the sole cause of the many river degradation problems as claimed by

many people. That a problem exists must be demonstrated before control actions are justified. Recent research supports claims that carp are adversely affecting aquatic habitats by increasing turbidity and uprooting certain species of water plants. Intuitively, if carp constitute over 90% of the total fish biomass, as in some parts of the Basin, then there must be some impact on aquatic fauna. Sadly, direct and indirect interactions between carp and native fauna remain poorly understood. Obviously broad-scale, quantitative assessment of the damage caused by carp requires further research.

Thus, although carp have been an issue of increasing importance within the Murray-Darling Basin since the late 1960s, it is still not clear what management options are available for controlling carp abundance. This is hardly surprising. Good management requires a certain level of knowledge about the issue to be addressed. Carp, although globally well-known as an aquaculture species, have been rarely studied in the wild. The population dynamics of wild carp in Australia are poorly understood. The current paucity of basic information on age structure and growth rates makes it difficult to relate carp abundance to environmental factors.

The apparent indifference of government to what is perceived to be a major problem by inland communities has aroused much dissatisfaction. The 'villain' aspect of carp is easy to identify. Carp are very conspicuous in the rivers and wetlands of the Murray-Darling Basin and are widely loathed and resented by people

associated with these waters. Carp are seen as causing extensive habitat and water quality degradation and the disappearance of native fish, and consequently are the subject of much emotion and debate. They are 'everywhere' (ie in virtually all waters within the Basin), so 'why isn't the government doing something about it?' This increasing public concern about carp led the Murray Darling Association to take a leading role in forming the National Carp Task Force in January 1996 to lobby for national government action on carp control.

In reality, research on the impacts of carp has been under way in recent years, albeit in somewhat fragmented fashion. Much of this research, some of which is still continuing, has been supported by both the Commonwealth and the states through the Natural Resources Management Strategy administered by the Murray-Darling Basin Commission.

This workshop was part of NRMS project (R558) commissioned to CSIRO Land and Water (formerly CSIRO Division of Water Resources) by the MDBC. Workshop costs were shared with the Fisheries and Aquaculture Branch of the Commonwealth Department of Primary Industries and Energy through its Fishcare program. The workshop had three objectives:

- \* To outline recent research and current thinking about carp ecology and impact in Australia;
- \* To review control options for carp;
- \* To identify realistic research and management directions regarding control.

The workshop began with an open forum which summarised and discussed carp research in progress. Particular emphasis was placed on the impacts of carp. This forum was facilitated by Professor Alistar Robertson, Charles Sturt University, Wagga Wagga and Dr Peter Fairweather, CSIRO Land and Water, Griffith. The forum built on the recent review by King (1995), bringing it up to date but not substantially changing her findings.

This document presents the core of the workshop, namely the prepared papers and the discussions and debates that followed most of the presentations.

The opening paper summarises what is known of carp in New Zealand where there is a policy of legislative containment, but no active control program. The second discusses vertebrate pest management principles and stresses the need to define the problem and to develop stringent management objectives and performance criteria.

The remaining seven papers address possible control options: environmental rehabilitation, the use of chemicals, physical removal, biological control using the Spring Viraemia of Carp Virus, immuno-contraception, and molecular approaches. A key feature of the two papers on physical removal is that they stress that harvesting carp will not necessarily result in a reduction in biomass, if populations are controlled by density-dependent factors. Indeed, the case study of the removal of an exotic predatory fish from English waters (paradoxically, to

enhance native cyprinid fisheries) demonstrates this.

In closing, it should be noted that after largely being ignored for two decades carp are now firmly on the national agenda. National government groups such as the Standing Committees on Agriculture and Resource Management, and on Fisheries and Aquaculture, are now considering the carp issue. These and other government agencies have agreed to create a Carp Control Co-ordinating Group to develop a national carp research and management plan and report to all government committees concerned with carp. Doubtless, one of the many tasks for this Group will be to consider the potential of some of the control options discussed here.

*Jane Roberts*  
*Richard Tilzey*  
July 1997

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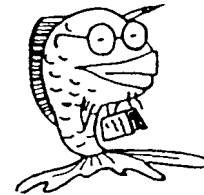
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# A brief history of carp in New Zealand

*R.M. McDowall*

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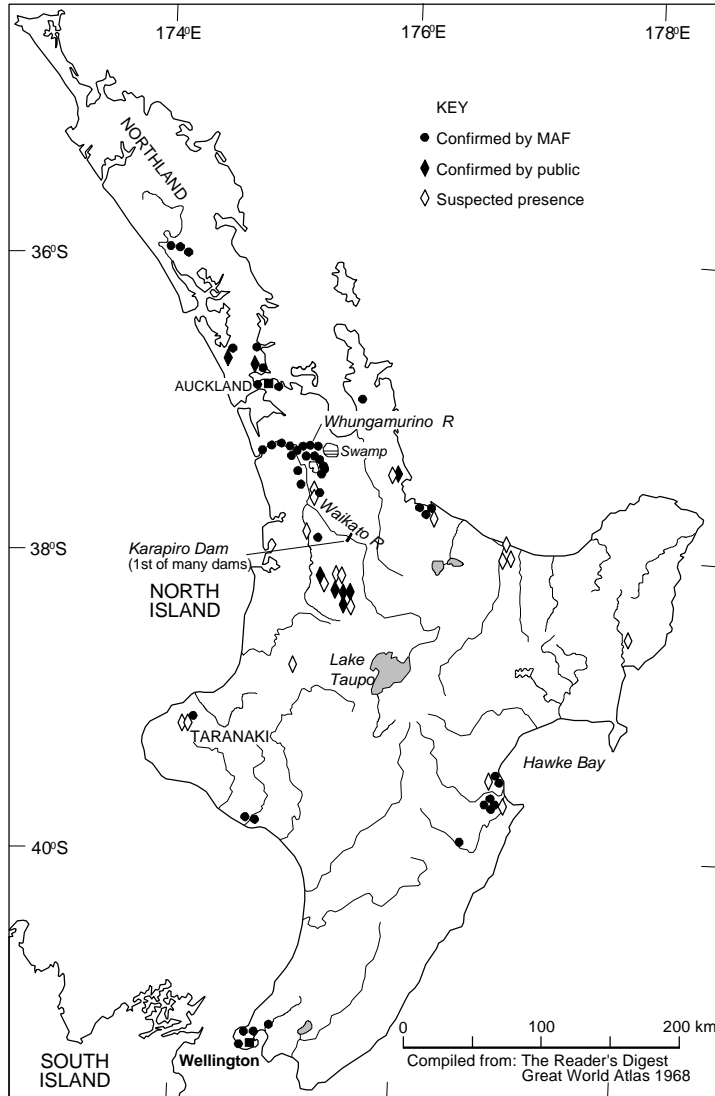
## **Historical perspective**

The European carp, *Cyprinus carpio*, may have been amongst the first fish species introduced to New Zealand, although the vagueness of some old accounts makes identification uncertain (Thomson 1922, McDowall 1990). The earliest reports of carp may actually have referred to goldfish, *Carassius auratus*. What is clear is that there were no European carp in New Zealand waters through the first half of the 20th century, though feral goldfish were quite widespread.

Given the broad habitat tolerances of carp, and the fact that almost everything else introduced into New Zealand proliferated and became a pest (McDowall 1994), 19th century accounts of carp in New Zealand waters may be doubted and were more probably goldfish.

During the 1960s, and since, there were occasional carp importations, probably mistakenly included amongst consignments of goldfish brought into New Zealand. Possibly carp were deliberately included in consignments as a means of importing a fish that would be refused entry if its identity was known. Occasional reports of carp occurrence resulted in any carp found being seized and destroyed. Dating from the 1960s, there was concern about the potential impacts of carp and New Zealand moved to avoid accidental or cryptic introductions by generally banning importations of any cold water fishes except under special permit, using provisions within the Animals Act 1967. European carp, including koi, were also amongst a suite of species eventually declared noxious in a 1980 amendment of the Freshwater Fisheries Regulations 1951 (the so-called 'Noxious Fish Regulations', amendment no. 16). This prohibited anyone from being in possession of the fish in New Zealand, alive or dead.

However, by the early 1980s, koi carp, an ornamental and selectively bred variety of European carp, had arrived in New Zealand, and had become patchily though quite widely distributed in captivity. This is the only variety of European carp present in New Zealand waters. When the noxious fish regulations were gazetted, New Zealand officials made a fundamental administrative blunder in allowing those people who already had koi in captivity to keep them under special permit, and it was not long before carp began to be found in natural habitats. This error was partly a result of the bureaucrats responsible not really knowing what koi were. In addition, there was a misconception that koi, being an ornamental variety, were likely to be rather fragile, and unlikely to proliferate and pose a threat to our aquatic environment.



**Figure 1.1** North Island of New Zealand showing distribution of koi carp (compiled by Steve Pullan, Ministry of Fisheries, Auckland).

When feral populations of koi were discovered in confined habitats, such as small farm ponds, efforts were made to eradicate them using poisons or explosives (McDowall 1990). However, in the early 1980s a population was discovered in the Whangamarino Swamp, an extensive lowland wetland with direct connections to the Waikato River, and before long they were reported to be widespread in the lower Waikato River system (Chisnall 1989, Pullan 1986). Habitats in the lower Waikato River clearly suited the fish. Over the following decade they proliferated and grew very rapidly, especially in the Whangamarino Swamp. Carp control in this body of water has not been regarded as a viable option for diverse reasons, including its large size (7290 hectares), multiple ownership (only part of the area is under government reservation as a Stewardship area) and the threat of any likely control measures to other life in the swamp (Cromarty 1996). Carp are now present there in very large numbers. Though they have spread beyond the swamp, they appear less abundant there.

The initial government response was to try to effect containment, but this was a dangerous tactic primarily because of the presence in New Zealand of individuals with overseas experience in coarse fishing, who viewed carp as a valued potential angling species. These individuals have been responsible for introduction of a variety of coarse fish species and/or their dispersion around the country's waterways; these include rudd, *Scardinius erythrophthalmus*, orfe, *Leuciscus idus*, brown bullhead catfish, *Ameiurus nebulosus*, as well as carp (McDowall 1990). Despite the best expressions of intent by the leaders of coarse fishing clubs, these species have gradually widened their ranges (Figure 1.1). For example, brown bullhead have even appeared in Lake Taupo, New Zealand's most valued trout fishery, though it is not known whether this was a deliberate action or accidental. The New Zealand experience has thus been that in spite of the assurances of some people, others cannot be trusted to respond to pleas for responsible action, but are more concerned about meeting their own selfish, short-term, angling objectives than they are with environmental responsibility and long-term effects. This applies to carp,

which have been liberated in several of the lower hydro-lakes of the Waikato River (A. J. Roxburgh, Department of Conservation, Hamilton, pers. comm.).

## **Present Situation**

Carp are still only sporadically present around the North Island of New Zealand, especially in the lower Waikato, and mostly as a result of natural spread from the Whangamarino Swamp. However, they are also known in several places in Northland, Taranaki and Hawkes Bay, mostly in wetlands, and may be even more widespread than present data indicate. They have the potential to live almost anywhere in New Zealand's warm to cool temperate environment (Hanchet 1990), and continued spread is likely unless the attitudes of a few environmental hooligans can be modified. Being highly durable fish, there is also potential for their spread amongst the wet fyke nets of eel fishers, in the same way as has been alleged for the recent spread of brown bullhead (McDowall 1990).

Other than in a few isolated instances, no explicit actions have been taken to control koi in New Zealand waters. They are caught by commercial eel fishers in the lower Waikato who have in the past had something of a dilemma when catching them. Possession either alive or dead was an offence, but so was returning them to the water alive or leaving them dead on the river bank. A limited number of special permits was issued to allow those catching carp to market them, in the hope that development of markets result in higher exploitation rates. Commercial exploitation has been partly successful, with one fisherman taking up to 100 kg of carp per fyke net per night, and selling the flesh as bait to commercial and recreational sea fishers (A. J. Roxburgh, Department of Conservation, Hamilton, pers. comm.) However, there has been a concern that placing any value on the fish will inevitably result in increased demand and further dispersion of the fish.

**Table 1.1** Recommendations from Hanchet (1990)

<b>Management</b>	<b>Research</b>
1 Identification of valuable water bodies and determining their potential to be at risk from carp	1 Obtaining basic biological information on the species in New Zealand
2 Clarification of the distribution of the species	2 Clarification of the genetic provenance of our carp populations
3 Monitoring of water bodies with carp present for fish abundance and resulting vegetation damage	3 Use of modelling to predict the potential range of the species
4 Assessment of the commercial potential of carp flesh.	4 Determination of vulnerable vegetation
	5 Monitoring of carp stocks in specified valuable and vulnerable waters
	6 Experimental control in suitable waters
	7 Assessment of the potential for control by commercial exploitation or other means
	8 Determination of the effects on other 'coarse fishes' such as perch and tench

Carp grow rapidly in New Zealand waters, reaching 165–280 mm in only 190 days (Hanchet, 1990), and reach a large size; fish 8–10 kg in weight have been recorded, with anecdotal reports of fish to 18 kg. These large fish provide a valued quarry for a growing number of coarse fish anglers. At times, large numbers of carp can be observed in the shallows around Whangamarino Swamp and this attracts bow hunters who chase the fish through the wetland.

## **Policy Issues**

When it became known that carp were well-established in the lower Waikato, a Koi Working Group was established involving representatives from the Ministry of Agriculture and Fisheries, the Department of Conservation, the Waikato Regional Council and the Auckland/Waikato Fish and Game Council. Their objective was to develop policy recommendations for management of problems related to the presence of the species. Pullan (1986) reported acceptance of a recommendation by this working group that there would be monitoring of carp populations in the lower Waikato using gill nets in vulnerable or occupied habitats in the system. However, this monitoring never took place.

The Department of Conservation commissioned a review of the potential effects of carp in New Zealand waters (Hanchet 1990); the report also made recommendations for both future management and research (summarised in Table 1.1). Few of these recommendations have been acted upon and, at the moment, there is a policy of legislative containment. Otherwise, apart from the provision of opportunity for limited commercial harvest (by special permit), there is no active management or investigation of the biology, distribution or abundance of carp in New Zealand.

Always there is the dilemma that legislation will be flouted and that should the fish acquire value to interest groups there will be a demand for wider dispersion and better access to the resource. There is presently no explicit evidence that carp are ecologically harmful to aquatic systems, but nor has there been any explicit attempt to evaluate their impacts. Carp are only one of several exotic species whose range is increasing and that are regarded with some concern; others include brown bullhead and rudd. At present, carp problems do not rank sufficiently highly to attract significant investment of effort. Brown bullhead in Lake Taupo, for instance, are of greater concern and have higher priority for research funding (Barnes 1996).

Compared with the more pro-active Australian situation, that in New Zealand could be regarded as passive, reluctant, acceptance of the species with the constant (largely unspoken) hope that there will not be massive impacts on ecosystems nor substantial wider dispersion of the species. This attitude undoubtedly reflects a perception that New Zealand possesses many fewer suitable water types for carp to proliferate in (most of our river systems are probably too gravel-bedded and fast-flowing) compared with Australia, plus a need carefully to set priorities for the limited available funding for freshwater fisheries research and management.

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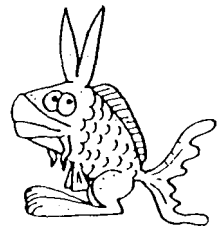
# Pest management principles for European carp

*Mary Bomford and Richard Tilzey*

# 2

## **Introduction**

In its simplest form, best practice pest management involves the following process: defining the problem; developing a management plan; implementation; monitoring and evaluation. This paper addresses what this process may involve for managing problems caused by European carp.



## **Defining the Problem**

The first question that needs to be asked is what are the perceived impacts of carp and what resources are affected? King (1995) lists the types of damage that may be caused by carp (Table 2.1).

When defining the problem, one also needs to ask what scientific evidence there is to quantify or rank these impacts. King (1995) reviewed this evidence and found that carp are probably not responsible for some types of damage that have been attributed to them. This includes declines in macro-invertebrate or native fish populations. For other perceived impacts there is not always reliable data, so it is not possible to determine whether these types of damage are significant or not.

In addition to knowing the cost and types of damage caused by carp, there is also a need to know who owns or is responsible for managing the resources being damaged. Estimating the cost of damage is a priority because it allows us to decide how much is reasonable to spend on control. Knowing who is being affected is important because then damage control costs can be shared in an equitable way.

Table 2.1 Ecological damage attributed to carp (after King 1995)

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<b>Types of water resources thought to be damaged by carp</b>
increased water turbidity and siltation
decreased macrophyte biomass and diversity
increased water nutrient loads
increased algal concentrations
reduced native fish numbers and diversity
decreased macro-invertebrate numbers and diversity
erosion of stream banks

---

Finally other factors which may contribute to the types of damage that are being attributed to carp need to be defined. This is an essential step if an integrated management plan for reducing the damage is to be developed. For example, King (1995) considers that physical damage caused by carp is difficult to separate from the contribution made by other environmental problems such as river regulation, cattle grazing and widespread vegetation removal. Also, drought/flood cycles and fishing effort may affect native fish abundance more than carp density does. So all these factors need to be taken into account if the goal is to reduce these types of damage.

## **Developing a Management Plan**

### ***Objective***

A rational objective of pest control will nearly always be to reduce or prevent the damage caused by a pest in the most cost-effective and environmentally safe manner. There is a need to be more specific though, and define objective in terms of measurable outcomes; that is, an objective states what is intended to achieve and by when.

### ***Management Options***

Once an objective has been set, the next step in developing a management plan is to select the management option (Table 2.2) that is most appropriate for the problem. This may differ for different regions and types of damage. Successful eradication (Option 1) offers perpetual freedom from the pest, its harmful effects and the high costs of sustained control. Eradication is defined in this context as the complete and permanent removal of all carp populations in a defined area by a time-limited campaign. 'Time limited' is important in this definition — eradication over a hundred years is really sustained control.

If eradication is to be attempted, then the set of six feasibility criteria developed by Bomford and O'Brien (1995) needs to be considered. Eradication can be achieved only when all six of these criteria (see Box)

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## Eradication Criteria

All must be met before eradication is an option

### **1 Rate of removal exceeds rate of increase at all population densities**

This criterion sounds simple and obvious, but in practice, it is an extremely stringent requirement for two main reasons. Firstly, carp populations, in common with other fish species, have high natural rates of population increase under certain conditions (Thresher 1997). Secondly, as density declines, it can take progressively more time and expense to locate and remove individual animals.

In many cases, the most difficult part of an eradication campaign will be just when eradication is nearly achieved (Figure 1), when it is extremely difficult and expensive to find and remove the few remaining fish. There must be a motive and resources to continue removing carp at these low densities, when numbers caught and damage inflicted are extremely low.

### **2 Immigration is zero**

This criterion can only be met in closed water systems where there is no chance of a natural re-invasion or of accidental or intentional (illegal) re-release. It may be possible in some places to use exclusion netting to seal a water system against re-invasion.

### **3 All carp must be at risk**

The removal techniques must eradicate all reproductive carp or fertile eggs to effectively prevent further breeding. Eradication would fail, for example, if trap or net shyness was inherited or learnt, or if fish developed genetic resistance to a poison or to a bio-control agent, because a subset of the population would not be at risk.

### **4 Population can be monitored at all densities**

If carp or their eggs cannot be detected at low densities, there is no means of measuring if control efforts are still causing the population to decline, and no means of determining if eradication is achieved. This technical requirement may be very difficult to meet.

### **5 Discounted cost-benefit analysis favours eradication over control**

Intuitively, one might think the value of perpetual freedom from a pest is very high, but market discount rates have a major impact on the current value of eradication. In cost-benefit discounting, the aim is to estimate the present value of future costs and benefits. This process greatly changes the economics of conducting eradication because all the costs are up front, whereas most of the benefits accrue in the longer term. There is, however, considerable debate about the selection of appropriate discount rates, particularly when non-market values such as conservation are being considered.

### **6 Suitable socio-political environment**

Even when technical and economic criteria are met, social and political factors play an overriding role in determining the prospects for successful eradication. The benefits of eradication as an alternative to continuing control must be convincing, mainly because of the high costs of eradication, but also because of community attitudes. People, such as some recreational 'coarse' fishers who traditionally favour carp, might resist or sabotage eradication attempts.

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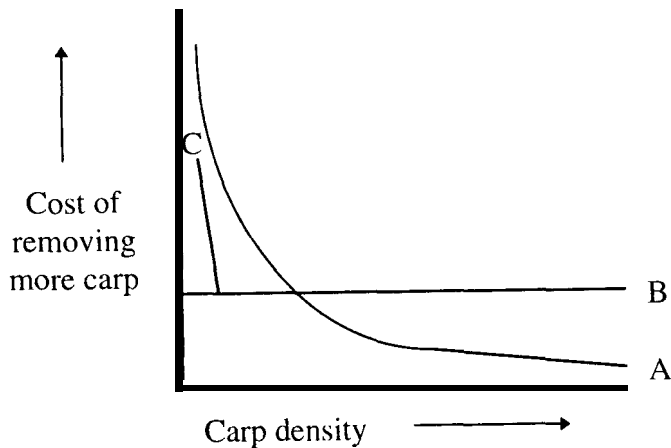
can be answered affirmatively. A single negative is sufficient to make eradication unachievable or impractical.

These six criteria determine whether eradication is technically feasible and preferable to sustained control. It is also necessary to consider the chance of failure. Eradication is a risky business, and a failed eradication attempt is very expensive.

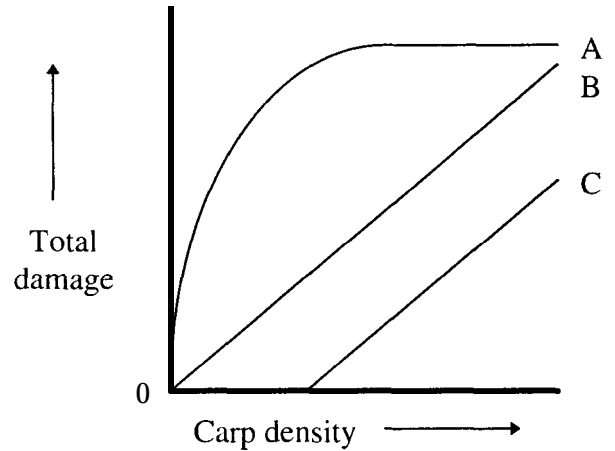
If these six criteria are applied to carp, national eradication is clearly not feasible now. Eradication may be feasible and economically sensible in some small and closed water bodies. Where eradication is not possible or desirable, one of the alternative management options listed (Table 2.2) needs to be considered.

Table 2.2 Management options for carp

	<b>Option</b>	<b>Outline of option</b>
1	Eradication	The complete removal of all carp from an area by a time-limited campaign
2	Strategic, one-off control	Such as release of a biocontrol agent that controls in perpetuity
3	Strategic, sustained control	Reduce carp to low numbers and keep them there
4	Strategic, targeted control	Only implement control when conditions indicate it is desirable – perhaps when there is reason to think numbers are about to increase or damage is about to occur
5	Crisis management	Control reactively, with no forward planning, when the problem becomes too big to ignore
6	Do nothing	Sometimes the costs of control exceed the benefits and cutting losses may be the best strategy



**Figure 2.1** Relationship between carp density and cost of removal.



**Figure 2.2** Relationship between carp density and level of damage.

Hypothetical relationships between carp density and control costs are shown in Fig. 2.1. Line A represents a scenario in which catch or kill rate is density-dependent, so the cost of removing additional carp increases sharply as density declines. Line B represents a scenario where costs are density-independent, for example, poisoning a body of water. If a few individuals are missed in a poisoning campaign, getting the last few (line C) may cost far more than removing the first 99%.

It is necessary to know the relationship between carp density and damage levels, so a target carp density can be set which will meet resource protection goals.

A hypothetical set of relationships between carp density and levels of damage is shown (Figure 2.2). Line A represents a case where carp are

preying on, or otherwise damaging, a native species of high conservation value. In this hypothetical case, even if carp numbers are reduced by 70%, the remaining carp will seek out and continue to damage the native species at the previous level. So reducing carp density by 70% would have no benefit. Not until carp numbers are reduced by about 90% does a significant increase in density of the native species occur.

Line B represents a case where carp damage is directly proportional to carp density. If, for example, each individual carp is responsible for stirring up a fairly constant amount of bottom sediment, then sediment loads will be reasonably proportional to carp density. Clearly this line will eventually flatten off at some maximum possible water sediment loading.

Line C represents a scenario where carp need to be over some threshold density before they start causing a problem. For example, there may be some threshold density of carp before they start to inflict damage on macrophyte beds. At lower densities they might largely restrict their diet to zooplankton, algae and insects.

It is necessary to select a management option from Table 2.2 that will reduce carp to a density where damage levels are socially and economically acceptable, and maintain them there.

### ***Management Strategy***

**A** management strategy describes the techniques which will be used to control carp and when and how they will be applied. There are a range of techniques that are available or that might be considered in the future for carp control. These include: poisoning; habitat modification (including restoring healthy ecosystems); exclusion netting; trapping and removal (possibly using commercial or recreational fishing); encouraging native predators (possibly by re-stocking species such as Murray cod or golden perch); chemical repellants; fertility control; biological control (including diseases and bio-vectored immuno-contraception).

When considering which technique to use, or which combination of techniques, it is essential to remember the type of damage reduction being targeted. For example, in a Victorian study in the late 1970s Hume *et al.* (1983) found that carp vary their diet with age. Juveniles feed mainly on algae and zooplankton, medium-sized carp feed on insects and detritus, and large carp eat all these items plus macrophytes. If a selected control technique changed the age structure of the population, it could cause a change in diet which might be undesirable.

### ***Social and legal issues***

When control techniques are assessed, it is necessary not only to consider the issue of whether they work and how much they cost, but also social and legal issues. Conservation and animal welfare groups are increasingly taking an interest in fisheries issues. For example, with poisons, the risks to non-target species need to be considered. It is likely to be extremely difficult to develop a carp-specific poison, and therefore non-target species may get poisoned if they are exposed. Regulatory authorities need to ensure that poisons are safe for non-target species and do not persist on land, in water, or in agricultural products. It is essential that Australia maintains its 'clean, green image' for exported agricultural products. For these reasons, the use of poisons can be dangerous and should be avoided in many circumstances. The use of piscicides such as rotenone for scientific sampling purposes is currently rigorously controlled by state fisheries agencies.

Humaneness, that is preventing pain and suffering, is difficult to measure, but animal welfare agencies consider that it is desirable to make a balanced evaluation of the benefits of using a poison against the cost in terms of suffering inflicted on the target animals and in comparison with alternative control options.



### ***Integrated pest management***

An integrated pest management strategy should be the goal. All available control techniques need to be compared for efficacy, cost-effectiveness, safety and overall acceptability. Successful pest control usually requires multiple approaches, combining different techniques to achieve optimal effectiveness.

If there is good information on the cost of carp damage and on the cost and effectiveness of control techniques, it should be straightforward to work out which techniques to use, and how much to spend on them to maximise the benefits of control relative to the costs. Unfortunately, good information is not always available on either costs of damage or on the effectiveness of control techniques. Better information is needed to improve management and have best practice. Ideally carp control needs to be implemented at a number of sites, and the damage at these sites compared with damage levels at matched sites where there has been no carp control. Large-scale, replicated experiments which cover a range of seasonal conditions and carp densities are desirable, because control strategies that work in one place or time may not be equally effective elsewhere. The adaptive experimental management approach described by Walters and Holling (1990) can be a valuable tool.

### ***Management units***

Experiments can also be used to yield information needed for another important aspect of management planning — determining the right size of management units. Carp are highly mobile, so it is important to control them over reasonably large areas, or many of the benefits of control can be lost through re-invasion.

### ***Stakeholder involvement***

All stakeholders and managers need to agree on what the problem is and what they are going to do to solve it. If some managers select crisis management, others decide to do nothing and still others attempt to

practise strategic, targeted control, all in the one catchment, this will give totally ineffective carp management. Without an understanding and commitment to owning the problem and its proposed solution by all managers of a water system, it is likely that the best management plans will fail, no matter how good the available control techniques are. Therefore it is important that all people with an interest in the problem and its solutions are involved in the planning process right from the start.

### ***Performance criteria***

Performance criteria need to measure changes to damage levels, not measure control effort or carp density. For example, the performance criteria that water nutrient and turbidity levels will be reduced to specified average and maximum levels by a specified date might be selected.

Performance criteria will not only let managers know if they are achieving our objective, they will also let managers know if they are failing. If control measures are not succeeding it will be necessary to change the strategy, or accept that it has ceased to be worthwhile to continue spending money on the failed strategy. One needs to remember that killing lots of carp, while it may give a sense of doing something about the problem, may not actually lead to damage control. Unfortunately, in the past, there has been a lot of money lost on pest control strategies in Australia that were ineffective. For example, money spent on poisoning mice after mouse plagues have erupted usually does little to reduce crop damage levels, and such poisoning may lead to environmental pollution with residues and pose unacceptable risks to non-target species. If managers used performance criteria effectively, they could ensure that money is only spent where and when it will be effective for reducing damage caused by pest animals.

## **Implementation**

Best practice management requires a strong emphasis on developing a strategy that includes all stakeholders and managers working together to implement a control strategy that meets their combined needs. In addition, control often needs to be conducted over reasonably large areas to reduce problems of carp re-invading. It is therefore essential that land/water managers co-operate with one another to implement control programs.

## **Monitoring and Evaluation**

This paper has emphasised the need for measuring both the damage caused by carp and the effectiveness of control techniques to reduce this damage, and the importance of these measurements being evaluated against performance criteria. Although many land and water managers and government agencies recognise that this is necessary, in practice implementing control is usually given a far higher priority than monitoring and evaluation. This is false economy. Without monitoring and evaluation, a lot of money may be wasted on ineffective campaigns. The same errors can be repeated in the future. Therefore, monitoring and evaluation are an essential part of best practice, particularly if it is incorporated into the adaptive experimental management approach espoused by Walters and Holling (1990). This will allow managers to move towards more efficient, effective and safer carp management.

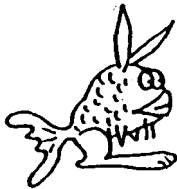
## **Conclusion**

The best practice carp management framework we have presented in this paper, allows managers to identify knowledge gaps and to ensure that available knowledge is put to best use for making those management decisions which are most likely to deliver cost-effective carp control. It also allows managers to gain more knowledge and improve management in the process.

It is important that managers keep the goal of cost-effective damage control in mind when considering the control options and techniques discussed during this workshop, so that they are focused on what reduction in carp density is needed to achieve this goal.

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# Environmental rehabilitation and carp control

*John H. Harris*

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## **Introduction**

Australians have two general kinds of opportunities available to control the pest fish, carp. The most obvious of these are the control methods involving direct assaults on carp populations. These assaults can be through direct population depletion by fishing, restricting recruitment or various other strategies.

Carp can also be directly assaulted by applying biological control methods; and by regulating the human activities which spread these fish into new areas. These 'direct assault' methods are dealt with by others elsewhere in these proceedings.

The second general kind of opportunity for carp control, which I will discuss here, is a restoration of the ecological processes in our aquatic systems to impose a form of indirect control. Such a control method would apply theory on the regulation of biotic communities, especially the ecology of 'weed' and invasive species. It would also make extensive use of many aspects of knowledge on the ecology of Australian aquatic biota, particularly those aspects dealing with the effects of human disturbance of aquatic systems. It would be based on the idea that restoring some of the resistance and resilience of natural ecosystems, interfered with by human development, will limit the success of carp.

Clearly, work to control carp indirectly by restoring ecological processes would closely parallel the programs of aquatic environmental rehabilitation which are already being implemented or proposed in Australian river systems, but which pursue a more general goal of environmental restoration. For either of these two goals, the activities can be grouped under five headings: catchment management, flow allocation, pollution abatement, habitat reconstruction and restoration of connectivity. Perhaps, given the increasing evidence of environmental degradation attributable to carp (Hume *et al.* 1983, Fletcher *et al.* 1985, Nannestad 1994, Roberts *et al.* 1995, King 1995, Broster 1995, Robertson *et al.* 1996) and the national concern which has led to this Carp Control Workshop, it would be most appropriate simply to list carp control as the sixth of these major headings for aquatic environmental rehabilitation.

### **Factors favouring carp**

In seeking means to control carp, it is essential to ask: 'What factors are responsible for their success?' The great adaptive capacity of carp (Scott

and Crossman 1975, Crivelli 1981) and its popularity in aquaculture have led to its status as the world's most widely distributed freshwater fish (Brumley 1996). Innate attributes contributing to its very broad potential niche and high adaptability include fecundity, rapid growth, longevity, tolerance of a broad range of water-quality conditions, capacity for rapid dispersal and a highly flexible omnivorous diet. This success as a coloniser has been emphatically demonstrated by the carp's rapid and extensive invasion of Australian waterways (Shearer and Mulley 1978, Hume *et al.* 1983, Olsen 1995, Brumley 1996).

It is accepted that many of Australia's freshwater systems have been extensively disturbed (eg Williams 1980, De Dekker and Williams 1986, CSIRO 1992). Environmental disturbance favours the establishment of new species (Tilzey 1980, Courtenay and Staufer 1984, Courtenay and Robins 1989, Arthington *et al.* 1990), and multiple forms of disturbance have been imposed on Australian waterways. They include the disruption of flow regimes, interference with lateral and longitudinal connectivity, pollution of various sorts, disturbance of habitat structure through poor catchment management, and the reduced frequency of natural environmental stressors such as floods and droughts. These disturbances, and particular ways in which they are likely to have favoured carp, are discussed in the next section.

Reduced species diversity implies that niche expansion is likely among successful colonisers, as new opportunities become available for colonisers to exploit food resources and habitat space. The declining diversity and abundance of Australian native fish species and increasing fragmentation of their distribution at large and small spatial scales mean there are more opportunities for new species because of reduced probabilities that competition and predation will act to prevent their establishment.

The intermediate disturbance hypothesis (Connell 1978) suggests that in non-equilibrium communities frequent disturbance tends to reduce species diversity. A test of this hypothesis in relation to riverine fish communities

in New South Wales is in progress through a large-scale survey (NSW Fisheries, in preparation), but there is already abundant evidence that fish species diversity is falling in Australian river systems, including the increasing proportion of the fauna on threatened-species lists (Wager and Jackson 1993), the decline of commercial fisheries (Cadwallader 1978, Pollard *et al.* 1980, Rowland 1989), and changing freshwater fish communities (Lake 1971, Lawrence 1989, Cadwallader and Lawrence 1990, Gehrke *et al.* 1995, Gehrke and Harris 1996).

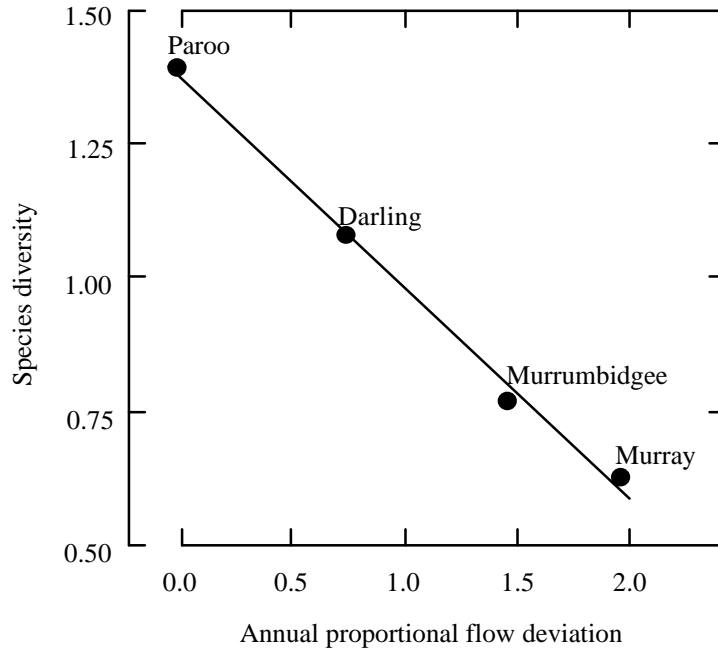
## **Environmental disturbances favouring carp**

### ***Disruption of Flow Regimes***

Studies by Gehrke *et al.* (1995) in four catchments of the Murray-Darling Basin showed how interference with the flow regime of increasingly regulated catchments was associated with lowered species diversity and higher relative abundance of carp (Figure 3.1), and they suggest ecological mechanisms. Changes in the character of Australian streamflow regimes – especially hydrologic variability and flow volumes – through water extraction, suppression of flooding, inversion of seasonal patterns, and stabilisation of flows for irrigation, together with the ecosystem problems arising from these changes, have been the focus of intense scrutiny (eg Teoh 1989, AWWA 1994, PMSEC 1996).

While many aspects of this broad group of hydrological changes have been implicated in declining native fish populations, it is the tendency to regulate irrigation flows to produce consistent, stable conditions which may most directly favour carp. Mallen-Cooper *et al.* (1995) found that carp catches in the middle reaches of the Murray River were greatest under stable flow conditions. Field observations (eg NSW Rivers Survey, NSW Fisheries, in preparation) show the strong tendency for carp to occupy slow-flowing habitats in river backwaters and floodplain wetlands, in preference to the faster-flowing, turbulent areas.





**Figure 3.1** Association between fish species diversity (Shannon's H) and a measure of river regulation, the annual proportional flow deviation, in four catchments of the Murray–Darling river system (from Gehrke *et al.* 1995).

Diverse communities experience cycles punctuated by natural 're-setting' disturbance mechanisms (Connell 1978), in aquatic environments these stressors are floods and droughts (Meffe 1984, Lake 1985, Thoms *et al.* 1996). The cycles are marked by periods of relative stability in which there are progressive increases in the abundance of common species, especially those with generalised feeding strategies and the higher-level predators. Uncommon and highly specialised species tend to decline during these times. Severe droughts or floods disrupt this period of stability, and the community composition and structure are re-set by the extensive mortality and interrupted recruitment which result, especially among the common species. These periodic disturbances enable re-establishment of

Flow management in Australian river systems has tended to protect against severe drought, and to suppress all but the most severe floods. Thus the re-setting mechanisms of both droughts and floods have been reduced, and the process sustaining aquatic community diversity is threatened, paradoxically, by a human disturbance of the system which diminishes natural disturbances.

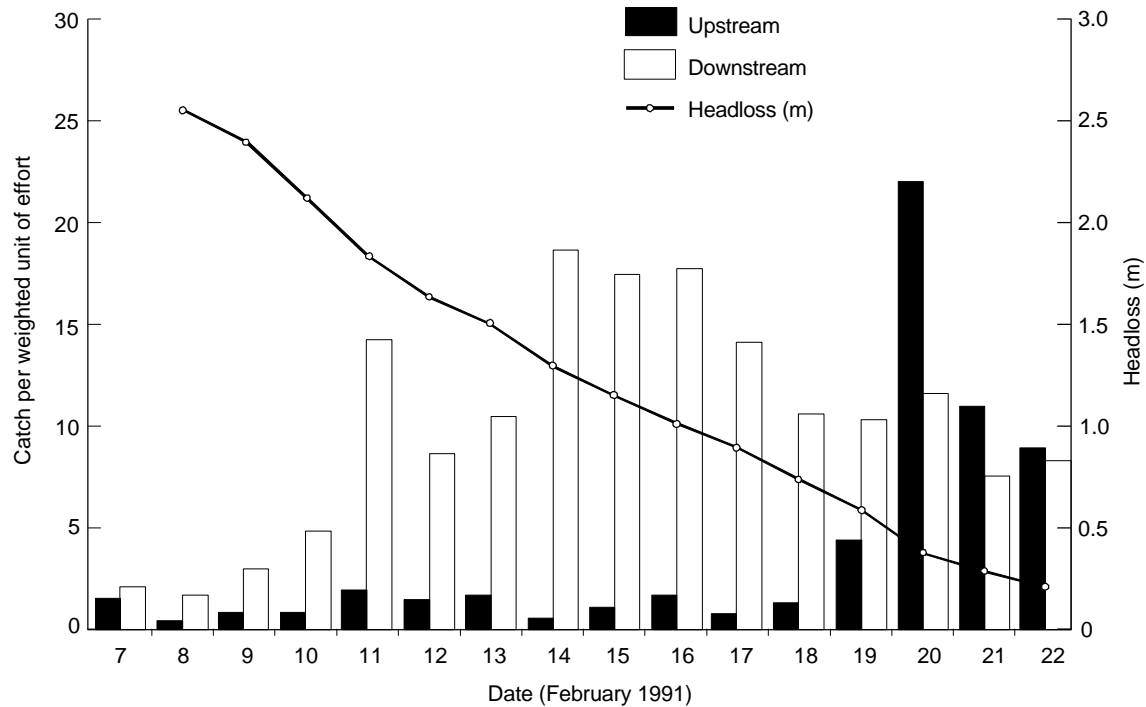
Environmental flow regimes are needed which restore seasonal and shorter term variability, which restore an adequate proportion of droughts and floods, and which provide adequate water volumes for riverine ecological processes.

### ***Interference with Connectivity***

Longitudinal connections, between the upstream and downstream reaches of river channels, and lateral connections between the channel and its floodplain wetlands, have frequently been interrupted by river management (Harris and Mallen-Cooper 1994, Thoms *et al.* 1996). Exceptionally high rates of water storage in Australia's dry and unpredictable climate have resulted in large numbers of dams and weirs which obstruct migration pathways; for example, there are over 3,000 such barriers on streams in New South Wales (Harris *et al.*, in press). Lateral connectivity has been interfered with by the suppression of flooding and by construction of levees, block-banks and other devices to modify floodplain flows.

Flow management also plays an important role in maintaining connectivity. Fish passage can be achieved, albeit irregularly and briefly, at the abundant low-level weirs in inland rivers by managing high flows so as to achieve 'drown-out' conditions (Figure 3.2).

Decreasing headloss (ie vertical discontinuity of the water surface upstream and downstream) as the weir drowned out over a 16-day period



**Figure 3.2** Sampling results during down-out flows at Bourke Weir, Darling River, in the rising stages of the February 1991 flood.

is related to the relative population density of golden perch upstream and downstream, as indicated by standardised catches. When headloss fell to 0.3–0.5 m, on 19–20 February 1991, the fish congregated below the weir were able to migrate upstream, with marked changes in population density (after Harris *et al.* 1992).

Interference with connectivity favours carp because its seasonal and habitat requirements for spawning are less demanding than those of many native species (Brumley 1996), so that more habitats represent useable areas for recruitment. Carp’s success in habitats where connectivity has

been reduced may also merely reflect increased carp recruitment in response to local declines in native fish. Certainly, such impacts on native fish communities through lost connectivity, often reaching local extinction, have been documented in many areas (Harris and Mallen-Cooper 1994).

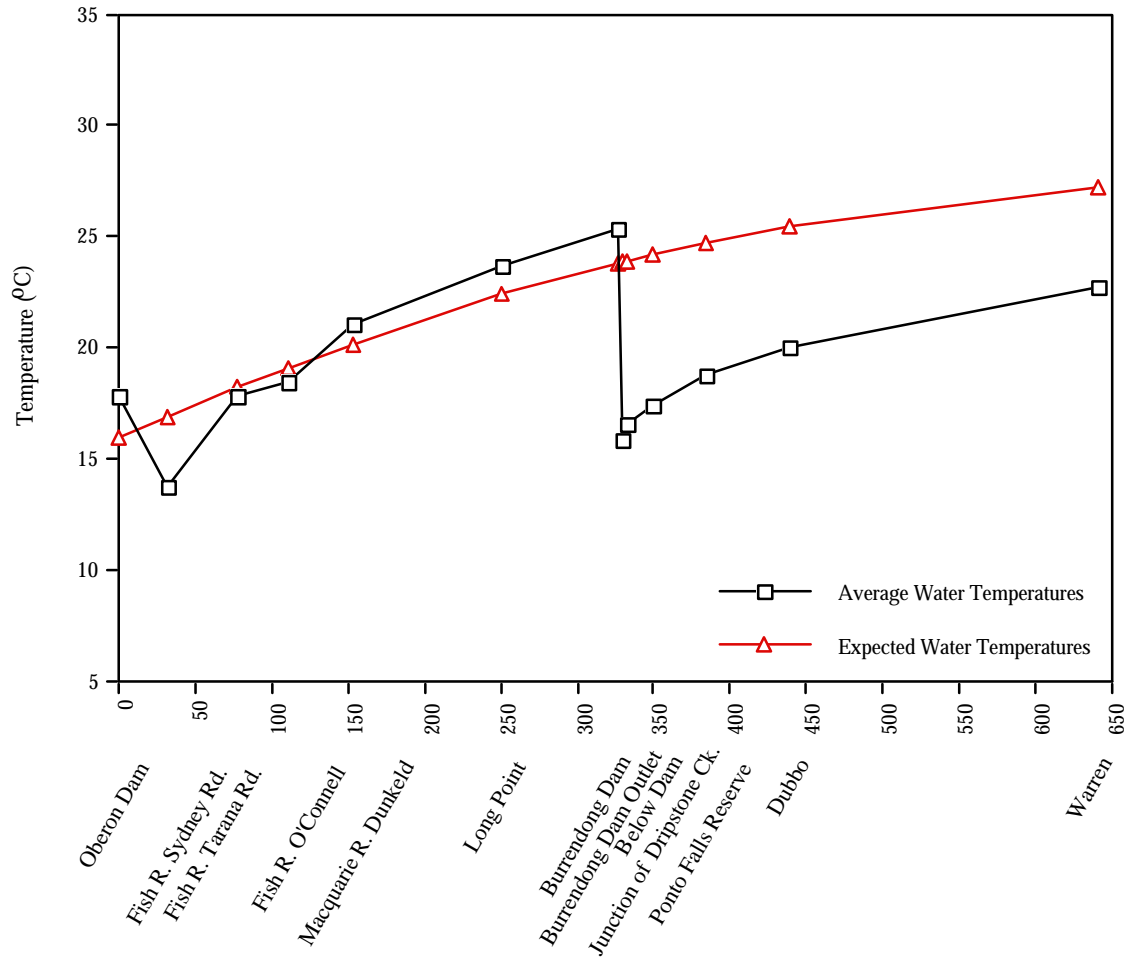
Furthermore, carp themselves have often been able to overcome migration barriers that obstruct some native fish, partly through their strong migratory behaviour (Mallen-Cooper *et al.* 1995), and partly through human transport to new waters (Broster 1995), a deplorable practice which is urgently in need of control through better regulation and public education. Many more new fishways are needed, and new techniques to provide effective passage at reduced cost must continue to be developed.

### ***Pollution***

Carp are a tolerant species, and show greater ability to exploit polluted habitats than some native species (Hume *et al.* 1983). Pollard *et al.* (1994), for example, showed high relative abundance of carp in eutrophic reaches of the Hawkesbury River system, and carp repeatedly dominate the fish in fish kills following large-scale contamination of inland rivers with toxic agricultural pesticides, suggesting they may regularly recolonise polluted sites and tolerate low toxicant levels.

Major parts of the Murray–Darling Basin’s system of large river channels are affected by coldwater pollution through irrigation discharges from the bottom of stratified storages (Figure 3.3, Harris and Erskine, unpublished data). Only the alien salmonid species have so far been found to thrive in

**Figure 3.3** (opposite) Cold water pollution of the Macquarie River, New South Wales, downstream of Burrendong Dam. A longitudinal profile of surface water temperatures was measured at 13 stations down the valley, then repeated on the following day. The averaged data show a 10-degree suppression of river temperatures below the dam and a continuing discrepancy from expected temperatures which persisted past the town of Warren, over 300 km downstream (Harris and Erskine, unpublished data).



Macquarie River System sites (km downstream)

these chilled conditions, and the physiology and behaviour of native fish appears to have been affected so that they are rare in such waters. Even carp, judging from the fact that their populations below irrigation dams are almost entirely composed of large adults, seem unable to reproduce in the cold, regulated water. But they are often numerous in these reaches, suggesting that carp populations are maintained by migration from downstream, and that low temperatures do not prevent these adult fish exploiting these altered reaches of rivers.

Great advances in river restoration can be made by building multi-level off-takes and other systems to reverse the present cold-water pollution in the many extensive river-reaches affected by irrigation storages.

### ***Disturbed Habitat Structure***

It is difficult to imagine how carp populations could benefit directly from changes such as siltation, loss of riparian and aquatic vegetation, removal of snags, or channel instability with widening and shallowing. But all these changes are believed to adversely affect many native species, thus creating opportunities for fish like carp which have sufficiently broad habitat tolerances to take advantage of such degraded habitats. Projects to control erosion and siltation, to replace snags in rivers, to fence-off riparian zones from grazing, and to accelerate the other aspects of remedial catchment management can all contribute greatly to restoring stream habitats and native communities.

### **Conclusion**

The components of a comprehensive, integrated program of restoration for Australian river systems all have potential to help control carp populations. Restoration should emphasise catchment management, flow allocation, pollution abatement, habitat reconstruction and restoration of connectivity. Each of these components is already the subject of various restoration efforts, but overall co-ordination and integration are lacking

and funding has so far been limited, fragmented and uncertain. A much greater level of long-term commitment is urgently needed.

In some cases, such as restoring key elements of natural flooding and drought patterns, or breaking down the artificial stabilisation of small-scale flow variability, river restoration can impact carp directly. But the greatest benefits are likely to result from rehabilitating native biotic communities to exert greater competition and predation pressures on carp. Projects to provide environmental flows in regulated rivers and to build new fishways, to control the various kinds of pollution and to restore aquatic habitat structure can all contribute to carp control. Perhaps, since the aims and methods are so congruent, carp control should simply be listed as another of the main objectives driving a comprehensive effort by the Australian community to restore our freshwater systems.

Might environmental restoration alone be sufficient to control carp populations at an acceptable level? This seems uncertain, and a lot of time would be needed to find the answer. Restoration cannot occur overnight. Furthermore, carp have substantial ability to alter aquatic habitats, which can offset or confound restoration efforts. No, an integrated program of carp control is needed. This program would integrate a specific, direct assault on carp populations with the restoration of ecological processes to provide complementary indirect control. The program could then serve as part of a major restoration of Australian wetlands and river systems.

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## **Discussion: Environmental Rehabilitation**

THERMAL POLLUTION by bottom release from impoundments was discussed at length. Whereas it was known that such cold water releases adversely affect native fish, adult carp are able to cope with these conditions. It was noted that these temperature will impact on the breeding of carp and native fish alike. Billabongs and irrigation ditches possibly act as off-stream carp refugia from cold water releases, as is the case in the Mitta Mitta River below Dartmouth Dam.

Installation of multi-level off-takes in dams is a feasible method of fixing this problem, but would be costly. There was general agreement that the potential benefits from installing multi-level off-takes needed careful definition before instigating construction. In the absence of other forms of native fish rehabilitation, increasing river temperatures between impoundments might further favour carp, as they are now the dominant fish present in most such MDB waters.

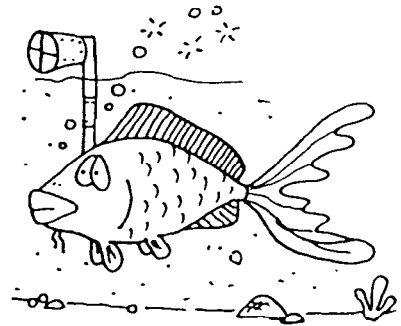
A key question that could not be answered was: are carp displacing native species or are they filling the gap left by decline/dispersal of native populations? Surveys had found carp:native fish ratios to be greater in regulated than in non-regulated rivers, but the causes for this had not been quantified. A possible link between carp and eutrophication was disputed, but the author John Harris noted that observations on the Hawkesbury River had seen carp occupy eutrophic waters (downstream of a sewage treatment plant) while native predators such as Australian bass had reduced abundance. It was agreed that there is little empirical information on how native fauna and carp interact, and there is a need for better knowledge of how environmental factors influence carp abundance.

There was general agreement that the environmental factors addressed in the paper need to be rehabilitated in an integrated strategic program. Research is needed to link specific mechanisms to the broad, overall situation. Environmental rehabilitation measures should favour native fauna, possibly to

the detriment of carp through such mechanisms as increased predation, but applied in isolation they will not fix the carp problem. It was agreed that direct carp control measures had to be part of an integrated strategy. How to adequately assess the success of rehabilitation measures needs considering. The most appropriate areas to begin rehabilitation experiments also need to be determined.

In conclusion, the rapporteur noted that at this juncture it was not known that a return to a pristine environment alone would completely control carp. The question of how to restore riverine habitats had only been discussed in relation to water temperature and stream-flow but there were several other major factors involved.

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# Use of chemicals for carp control

*Andrew C. Sanger and John D. Koehn*

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## 4

### **Four management options**

The use of chemicals to poison fish is a relatively straightforward technical exercise, but one which requires careful decision making and logistical planning. The use of chemicals to control carp must be examined in the context of the desired outcomes and processes which need to be undertaken. Chemicals which kill carp are available for use when the circumstances can be justified. The difficulty is to determine those circumstances.

Although a variety of chemicals such as rotenone, toxaphene and antimycin have been used in attempted eradication of freshwater fish species in North America, very few have been successful (Rinne and Turner 1991). Large-scale exercises have been conducted on both flowing and standing waters. The application of chemicals in these two aquatic environments, which are quite different, requires different approaches (see Experiences section, below).

Braysher (1993) provides a useful framework for planning and evaluating vertebrate pest management programs. The framework has five steps: Problem definition, in this case what damage is attributable to carp? Definition of objectives, which is to set criteria for management performance and failure; Identification and evaluation of management options; Implementation of management; Monitoring management impact.

Given that carp are a problem, and that criteria for management can be set (eg pre-determined level of population control, some level of recovery in degraded environments, some proportion of a catchment kept free of carp), then management options can be considered. The use of chemicals should be only one of the technical options.

Braysher (1993) recognises six possible management options: eradication; one-off control; sustained control; sporadic control; commercial harvesting and hunting; no control. Chemicals are worth considering for the first four of these.

### ***Eradication***

Chemicals are probably the only means presently available for eradicating carp from parts of their range. Bomford and O'Brien (1995) recommend (Table 4.1) six criteria which must all be met when deciding whether attempting eradication is worthwhile. Chemicals will achieve (1) and (3) and are particularly relevant to (5) and (6) as their use is controversial, so

Table 4.1 Criteria for deciding on eradication

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**Criteria for deciding on eradication (from Bomford and O'Brien 1995)**

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- 1 Pest must be killed at a faster rate than being replaced
  - 2 Immigration must be zero
  - 3 All individuals in population must be at risk
  - 4 Must be feasible to monitor populations at low densities
  - 5 Social-political environment must be favourable
  - 6 Discounted cost-benefit analysis must favour eradication over control
- 

may not gain support, and as they are expensive to purchase and use, and managing collateral damage is also expensive.

Carp were eradicated from Tasmania with rotenone in the 1970s. About 20 dams were successfully poisoned, and fortunately the carp had not escaped into any natural river systems prior to the poisoning. This demonstrates that eradication is possible, and is worthwhile when the problem is contained and detected at an early stage. As a result, Tasmania gained 20 years of freedom from carp (Maroney 1996).

However, poisoning may not always be so effective. In 1961–2, extensive and large-scale poisoning was conducted to eradicate carp from dams in south Gippsland, Victoria and a total of 1300 dams were poisoned with Limil, Santabrite or rotenone. These attempts were deemed successful from follow-up surveys in the following year. But poisoning of the Yallourn storage dam in the La Trobe river system was not successful and carp were found in the river in 1965 (Victorian Fisheries, undated).

The recent rediscovery of carp in Tasmania (Brown 1996) demonstrates that even in the face of the widespread public perception that carp are a

pest, it is very difficult to control the movement of the species; in effect, it is impossible to guarantee zero immigration.

### ***One-off Control***

Chemicals are not appropriate for one-off control because in most cases pest populations recover to pre-control levels unless eradicated.

### ***Sustained Control***

The use of lampricides in the Great Lakes region of North America to keep larval lamprey numbers to an acceptable level is an example of sustained control using chemicals. In this case the costs of control are vastly outweighed by the benefits: in 1988, \$7.5 million was spent on lamprey control to protect a fishery worth \$2–4 billion (Jude and Leach 1993).

### ***Sporadic Control***

There has not been a great deal of benefit achieved with this approach, although it is still used routinely in the USA and elsewhere to rehabilitate important recreational fisheries for a period. This is because pest species tend to recolonise quickly, so the benefits are transitory. Several large-scale examples from the US such as the Lake Delavan and Strawberry Reservoir (see below) restorations are notable examples

In summary, chemicals are probably useful when eradication is warranted but not particularly useful for one-off control. They can be useful in certain circumstances for sustained control and although widely used for sporadic control such applications are of doubtful long-term effectiveness.

## **Background**

Chemicals have been used to manage vertebrate and invertebrate pests for decades. The use of poisons is such an obvious and direct method of reducing pest numbers that it is often one of the first methods considered for control.



The benefits of the control of pests with chemicals in agriculture and human health applications are well known. Modern agriculture relies on the suppression of pests with chemicals (herbicides, fungicides, insecticides, vertebrate pesticides) and the quest for increased productivity and higher quality agricultural produce means that new chemicals are constantly under development to provide farmers with defences against pests. Similarly, for human health problems the use of chemicals to control disease organisms and their vectors is accepted as normal practice and being constantly refined

Chemicals have also been used to control pests for environmental, recreational and aesthetic reasons. In most cases chemicals developed for agricultural use have been adapted for use in these other areas. There has been less specialised development of chemicals for use in these areas, probably because the economic (food production) or human health imperatives have not been there to drive the process.

In the aquatic environment there have been some highly successful chemical control programs for various pests. The impetus for development of these control programs has also generally been for economic or human health reasons. Aquatic weed control is widely practised. The control of mollusc and insect vectors or hosts of disease organisms is also standard practice (eg in the Murray Valley to control mosquitoes which transmit arboviruses causing Murray Valley encephalitis).

The best example of control of a significant fish pest has been the development of the lampricides to control larval lamprey numbers in the Great Lakes, as mentioned earlier. In this case there was a significant commercial fishery which was affected, and an international effort was mounted to combat the problem (Jude and Leach 1995).

The scale of the research effort which went into examining the sea lamprey problem is notable in our current deliberations on carp control. The USA and Canadian governments both contributed to this effort, and

a massive study ended up identifying a compound which was highly toxic to lamprey larvae at concentrations which did not affect other aquatic life severely.

## **Issues of Specific Relevance to Australia**

### ***Carp Distribution***

The distribution of carp in Australia limits currently available chemical control methods to special case uses rather than the broad scale. Carp are presently found in all States and territories except the Northern Territory (Brown 1996). The fact that most of the distribution is in major catchments, in particular the Murray–Darling system, in which there are many hundreds of kilometres of connected waterways without major barriers to dispersal, precludes the use of chemicals. It is simply not worth the cost and the collateral damage.

There are, however, some examples of chemical control of carp in Australia which, clearly, have achieved their objectives: The eradication of carp from Tasmania in the 1970s and from the Cooper Creek drainage in South Australia was recently attempted (Hall 1988, Coombs 1996). It is assumed that these have been cost-effective but no studies have been published.

Examples of other species targeted with chemicals are: eradication of *Gambusia* from Tasmania using rotenone in the early 1990s; an attempted eradication of redfin perch from the Great Lake catchment in Tasmania in 1996; brown and rainbow trout from the headwaters of small streams in Victoria as part of the recovery plan for an endangered galaxiid (Raadik *et al* in prep). The *Gambusia* population was detected at an early stage, when still confined to a farm dam; the perch may have escaped into Great Lake from the farm dam in which they were discovered before being poisoned.

In these examples, eradication with chemicals was acceptable for several reasons, which mostly correlate with the criteria of Bomford and O'Brien (1995): high conservation values being protected or restored so that costs are outweighed by benefits; contained distribution of pest species; low probability of immigration or recolonisation; high probability of successful eradication; generally strong public and political support.

### ***Carp Biology***

*Environmental tolerance* Carp are a hardy species with particularly strong tolerances to poor environmental conditions (Brown 1996). No carp-specific piscicide is yet available (Marking 1992). In the absence of a carp-specific piscicide, the use of chemicals carries a high potential for unacceptable levels of collateral damage as carp are currently widely dispersed throughout high quality and degraded environments.

An example of this is that rotenone has been considered for eradicating carp from Lakes Sorell and Crescent in Tasmania. Rotenone is a broad spectrum piscicide that is toxic to most fish over the range at which it is toxic to carp. Lake Sorell and Crescent have a small population of carp as well as massive populations of an endemic galaxiid, found only in those two lakes, as well as short-finned eels which form the basis of a small but lucrative commercial fishery, and populations of brown and rainbow trout which form the basis of an extremely important recreational fishery. Rotenone to eradicate carp would kill these other fish species as well as many aquatic invertebrates, some of high conservation value.

The cost-benefit analysis in this case is difficult because of the many uncertainties surrounding the impact of carp on systems such as these (large natural lakes), the potential impact of their wider spread in Tasmania, the technical difficulties and uncertainties surrounding restoration of the lakes following poisoning of the carp (especially the re-introduction and population build-up of the galaxiid), the other uses to which the lakes are put, including irrigation supply, which limit options

for water management, and the relative inexperience of Australian fisheries managers in conducting such large-scale carp eradication programs

*Life history* No specific life-cycle stage has yet been identified for carp which is accessible and vulnerable, and hence an appropriate target for chemical control. The habitat of larval carp is unknown but assumed to be similar to that of adults. Eggs are laid on vegetation in shallow water, but they are probably no more vulnerable than the adults, and achieving a significant level of control by targeting eggs may not be realistic unless the level of recruitment to the adult population is strongly linked to the number of eggs produced. At this stage little is known of factors controlling recruitment in carp.

*Habitat preferences* Carp occur in marginal habitats of lakes and rivers, hence are difficult to eradicate from habitats with complex structures.

## **Chemical Assessment**

### ***Available Products***

Only a few products are available, of which the best known is rotenone. Each product has advantages and disadvantages (Table 4.2). There are other chemicals, insecticides and herbicides, known to be toxic to fish, but unfortunately most are also toxic to aquatic invertebrates and some are toxic to higher vertebrates. Several natural products used in subsistence fisheries offer prospects for further research. These are generally plant extract with a piscicidal effect similar to rotenone.

## **Prospects for Use**

### ***Availability***

Rotenone control of carp and other species of fish is a current management tool. It is effective in some circumstances. By pooling knowledge and

Table 4.2 Assessment of four chemicals for use as piscicides

### 1. ROTENONE

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Feasible now</li> <li>• Available in a range of preparations including raw product (unprocessed ground root of several tropical plants), as derris dust (an agricultural preparation), as a liquid, and as synergised liquid preparations</li> <li>• Not persistent</li> <li>• Can be neutralised by strong oxidants</li> <li>• Breaks down into harmless by-products</li> <li>• Very low mammalian toxicity, so relatively safe to use</li> <li>• Approved for use as a piscicide in some states</li> </ul>	<ul style="list-style-type: none"> <li>• Non-selective piscicide; hence collateral damage potentially high, particularly if susceptible taxa of high conservation value present</li> <li>• Expensive for large-scale applications. Preliminary estimates suggest millions of dollars for Lakes Sorrell and Crescent in Tasmania</li> <li>• Availability limited because derived from plants harvested in wild in Central and South America; large-scale applications would impact world supply and product price</li> <li>• Not approved for use as piscicide in some states</li> </ul>

### 2. ENDOSULFAN

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Highly toxic to carp</li> </ul>	<ul style="list-style-type: none"> <li>• Persistent, accumulates in environment</li> <li>• Non-selective</li> <li>• Not registered as piscicide</li> </ul>

Table 4.2 Assessment of four chemicals for use as piscicides (continued)

### 3. ANTIMYCIN

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Technically feasible, already demonstrated in USA</li> <li>• Registered as piscicide in USA</li> <li>• Commercial applications have been available</li> <li>• Toxicity varies with species giving potential to be selective for carp</li> <li>• Not persistent</li> <li>• No harmful break-down products and no long-term impact on environment</li> </ul>	<ul style="list-style-type: none"> <li>• Currently unavailable in commercial preparations or quantities</li> <li>• May be de-registered in USA in future</li> <li>• Not registered for use in Australia</li> <li>• Toxicity to Australian native fish unknown</li> <li>• Cost unknown but expected to be high; unless Australian or Asian manufacturer gains license to produce (small market makes this unlikely).</li> </ul>

### 4. ACROLEIN

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Expected to be cost-effective. Low concentrations known to be toxic to carp.</li> <li>• Commercial quantities available</li> </ul>	<ul style="list-style-type: none"> <li>• Highly toxic to mammals, therefore dangerous to use</li> <li>• Toxicity to native fish unknown</li> <li>• Potential for undesirable herbicidal effects in high conservation areas</li> <li>• Not registered as piscicide in Australia</li> </ul>

experience between practitioners it should be possible to develop a 'best practice' which would facilitate routine use as a fish management tool.

Continuing research into other applications is offering new products such as the new fish management baits being developed in North America (Prentiss Inc., New York) and alternative preparations (eg the liquid formulation used by Department of Natural Resources and Environment, Victoria). Products other than rotenone are not ready for use in Australia at present.

The use of acrolein, endosulfan and other agricultural chemicals as piscicides is not generally sanctioned by regulatory authorities at present. The time and cost of obtaining approval to use these chemicals in this way may not be economic for chemical manufacturers or government agencies (Marking 1992).

Antimycin, which has shown promise as an alternative to rotenone in the USA is not available in commercial preparations in Australia at present. The patent holder for this product does not envisage registration in the USA in the near future because of the costs involved, and does not have a production agreement with any major chemical manufacturer.

## **Externalities**

### ***Regulatory Concerns***

The agency responsible for fisheries management does not usually have responsibility for environmental regulation, consequentially some form of externally reviewed assessment process is required before the use of chemicals is allowed. The advantage of this procedure is that fisheries agencies must justify their use of chemicals in the environment in the same way as other government agencies and the public. The disadvantage is that the response time to critical situations may be slowed down; potentially controllable situations may become lost causes.

### ***Environmental Effects***

The environmental effects of all control methodologies, including chemical use, should be assessed using a cost-benefit analysis. This is particularly important due to the persistence of some chemicals in the environment, for example DDT. Non-target effects can be wide-ranging and significant. The lampricide TFM is probably the only example of a selective fish poison which achieves its objectives without serious non-target effects.

### ***Cost-benefit Analysis***

Eradication of a pest from a high conservation habitat is a one-off control but unless there is unanimous community support, the risk of deliberate reintroduction is significant. For a pest such as carp it is evident that there is widespread but not unanimous support, and deliberate introductions are known (Pierce 1996). Hence the probability of immigration (deliberate re-introduction) never reaches zero and attempts at eradication are difficult to justify.

### ***Public Relations***

The use of poisons has the potential to attract adverse media attention particularly if there are large kills of non-target organisms. Management of the logistical problems such as the disposal of tonnes of dead fish must be handled with care and every effort made to have the support of interest groups and allay public concern.

## **Experiences with Standing Water**

### ***Small-scale Applications of Rotenone in Farm Dams***

Applications of this type are fairly straightforward. Typically the dam is treated during a period of no discharge or spill, so that downstream effects are eliminated. Provided there are no source populations upstream, the treatment should be totally effective in the long term although there is no defence against deliberate re-introduction.



Some special preparations may be needed. For example, a farm dam with a nuisance population of redfin perch was partly drained in order to minimise the amount of poison required and to guard against accidental discharge of poisoned water (Sanger 1996). Under cool conditions (<12°C) rotenone is less effective but with lower sunlight levels will remain toxic for long periods, weeks or even months, making detoxification necessary even when there is no discharge.

A number of logistical issues and actions must be considered when planning: an accurate estimate of dam volume; calculations of desired concentration of toxicant preferably backed by on-site bioassays to account for variability in product performance under different water conditions; detoxification and clean-up requirements; draw down the dam if possible to reduce the quantity of toxicant used; all relevant government agencies (state and local) notified and necessary environmental approvals obtained; staff trained and OHS considerations integrated into proposal.

### ***Large-scale Applications of Rotenone in Reservoirs***

Large scale rotenone treatments have been done worldwide, with the most notable examples coming from the USA. A recent review found that approximately 48% achieved their goal (Meronek *et al.* 1996).

The rotenone treatment of Strawberry Reservoir treatment in Utah is one of the largest carried out and has been documented on video (Anon., undated). The case is instructive as the scale of this treatment is similar to what would be required for Lakes Crescent and Sorell in Tasmania and for parts of the Murray-Darling Basin (see Box: Strawberry Reservoir, Utah USA).

### **Experiences with Flowing Water**

In 1962 a massive rotenone exercise was undertaken on the Green River which flows through Wyoming, Utah and Colorado USA, with the aim of eradicating non-game species prior to the construction of a dam so that

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## Strawberry Reservoir, Utah, USA

At the time of treatment, Strawberry Reservoir had a surface area of about 1800 ha. The reservoir stratifies in summer, and fish are confined to the epilimnion as a result of low oxygen levels below the thermocline. This meant approximately 160,000 ML of water needed treatment, plus some 250 km of tributary streams.

The planning period lasted over several years, with an intensive period during 1989 and 1990. Issues such as the world supply of rotenone affected the timing of the treatment, as the quantity needed (400 tonnes of powder) represented a significant proportion. The volatile political climate of the area where the raw product is sourced also delayed supply of the large quantities required.

Fisheries management actions initiated before treating with rotenone included changes to fishing regulations to allow harvest of as many sportfish as possible, relocation of valuable spawning fish to other lakes, and production of large numbers of hatchery-bred juveniles for restocking the lake after treatment.

Paid and volunteer personnel were involved with the treatments. Fifty staff worked for 20 days on the tributaries. Treating the lake required 260 staff plus additional volunteers (including the Utah National

Guard), and took 5 days. Machinery used included floating bridge barges which could be loaded with semi-trailer loads of rotenone, smaller punt-style barges which could handle about 250 kg of rotenone, and much smaller conventional vessels with fire pumping equipment which were used to spray the shallow margins of the lake with liquid rotenone.

Afterwards, no fish could be found living in the lake or tributaries and as such it was considered a success. Several out-flowing streams required detoxification for several days until rotenone in the lake had broken down sufficiently to be non-toxic.

Re-stocking the lake occurred within months of the treatment, and the stocked fish survived and grew well. However, the presence of undesirable pest fish immediately downstream of the reservoir represents a threat to the sport fishery, and a number of habitat management and hatchery based fisheries initiatives were planned in an attempt to give the desirable species a competitive edge over the pest species.

The total project required in excess of 1000 days of staff time excluding training and planning time. Combined with the cost of the rotenone and machinery hire or purchase, the total cost was in the order of millions of dollars.

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game species could be stocked and thrive. A total of 715 km of river and tributaries were poisoned using 75 drip feed stations, 81 350 L of rotenone, over 100 staff and 7800 kg of potassium permanganate as neutraliser. Despite extensive planning, some 'overkill' of fish occurred downstream and resulted in much public controversy about such management actions. By 1963 some of the species which had been 'eradicated' had already begun to recolonise (Holden 1991).

Two rotenone exercises have been done recently in flowing water by the Freshwater Ecology Division of Marine and Freshwater Resources Institute in Victoria: post-impoundment surveys of the Mitta Mitta River (Koehn *et al.* 1995) and trout eradication in many small headwater streams of the Upper Goulburn river system (Raadik *et al.* in prep). The Mitta Mitta River treatment was a large-scale exercise done in a river similar in size to many of those where carp eradication might be required. The Goulburn River exercise was a highly targeted exercise in which eradication of brown trout was essential to protect the endangered *Galaxias fuscus* as part of the national recovery plan for this species (Koehn and Raadik 1996, Raadik 1995). Although done under different conditions and for different purposes, combined these two examples illustrate many of the practical considerations involved (Tables 4.3 and 4.4).

Both were done under low flow conditions, using stop nets to collect fish which floated downstream. Fluorescein dye was mixed with the rotenone to provide visual evidence of mixing. Fish were collected from the site as seen and neutralisation (potassium permanganate) done at the end of the site. Rotenone was applied then neutralised in riffle sections to maximise mixing. As these cases presented different problems, different approaches and solutions were used.

## **Process**

Unlike most other forms of fish sampling, poisoning is of especial significance in terms of both public perception and the possibility of a kill

**Table 4.3** Details of rotenone-treated sites on two Victorian streams: the Mitta Mitta River and *G. fuscus* streams on the upper Goulburn River.

<b>River</b>	<b>Reason</b>	<b>Size</b>	<b>Maximum Depth</b>	<b>Site length</b>	<b>Dur- ation</b>	<b>Fish Biomass</b>
Mitta Mitta River (8 sites)	Surveys	50 m	8 m	130–380 m Total of 2.3 km	3 h	3.9–72 kg Total of 189 kg
<i>G. fuscus</i> streams (7 streams)	Brown trout eradication	2–5 m	1 m	2–8 km Total of 20 km	5–7d	Total of 25 kg

**Table 4.4** Logistic problems and solutions for rotenone sites on two Victorian streams: the Mitta Mitta River and *G. fuscus* streams on the upper Goulburn River.

<b>River</b>	<b>Problem</b>	<b>Solution</b>
Mitta Mitta River	Depth and size	Use of divers to distribute rotenone into pools and to collect fish Mixing was assisted by boats
	Fish disposal	Burial
	Willow leaves	Constant cleaning of stop net
<i>G. fuscus</i> streams	Length of stream	Conduct trial with fluorescein to determine flow times
	Lack of access	Walk down stream to apply rotenone Walk down stream to apply neutraliser
	Long delay	Have caged fish downstream to alert of any overkill
	Endangered species	Poison only below their lowest known distribution
	Re-invasion	Installation of in-stream barriers

beyond the sample area. Stringent logistical preparation is of the highest importance and cannot be underestimated. In Victoria, for example, the process follows these steps.

An Environment Protection Agency permit must be obtained before rotenone can be used. A licence is issued only on the signature of the Director. Permits are only issued for the eradication of exotic species or for the enhancement of endangered species. Permit requirements and conditions will vary from state to state. A measure of the 'public' aspect of doing a chemical treatment is the list of individuals and institutions to be notified: water-boards and water supply management; regional land and shire managers; general public; local media?; local police; research institutions (study sites present?); tourist operators and owners of fishing tours, golf course.

In addition to adhering to government policy regarding occupational and safety, there are many other actions which are wise but not obligatory:

- involve local agencies;
- advance notice should target angler groups;
- ensure adequate and ready availability of chemicals and ample supply of neutraliser, determine distribution of other species needing protection including species other than fish such as frogs and invertebrates;
- check all aspects of timing such as season of year, time required to complete job, check water temperature as below about 12°C rotenone is less effective and ensure water flow is low;
- in addition to equipment ensure adequate labour with more than enough people rather than less;
- anticipate where the mixing and neutralisation zones are to be located and practise methods;
- plan how to dispose of fish as this could easily blow out to be a major problem and cost;
- confirm how to access sites beside the river for full length of study site;
- plan for disaster, provide for an overkill;
- confirm the weather;
- check dosage;
- confirm condition then position of stop-nets



These points must all be taken into account into what is an overall risk-assessment/feasibility study as to whether the task should be

undertaken or not. There is an absolute need for stringent planning for any poisoning exercise.

### **Application**

The prospects for large-scale use of rotenone are limited. The current Tasmanian carp situation is one of the few large-scale application where fish toxicants are being seriously considered. However, the cost, the associated environmental risks, and the problems of ensuring a completely effective treatment and completely eliminating the risks of reintroduction mean it is unlikely to go ahead. Small-scale use of rotenone will probably continue because it is effective in small and controllable environments such as farm dams and small reservoirs, and reasonably cheap.

Novel uses of rotenone, such as fish management baits, require further testing. These may be species selective and so be a cost-effective means of reducing population numbers in certain situations.

The use of other poisons requires a great deal of development. A review of acrolein is merited: it has the great advantage of being cheap but the disadvantage of being highly toxic to mammals and its effects on native fish or desirable introduced fish are unknown.

### **Future Prospects**

Chemical control at present is relatively crude. What is needed to move beyond this stage is a selective poison that does not cause environmental harm, and that can be delivered in a cost-effective way to control carp numbers on a large scale. The development of TFM to control larval lamprey in the Great Lakes demonstrated that species-specificity is possible when enough effort is directed towards the problem. This would only be achieved if such a program was considered to be a better means of control than other methods.

## Acknowledgements

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## **Discussion:**

### **Use of Chemicals**

THE CHAIRPERSON NOTED that the use of chemicals was often a controversial issue with varying degrees of social acceptance, and the use of lampricides in the North American Great Lakes was one of several methods aimed at restoring the fisheries therein. The general observation was made that poisoning has been used successfully in several recreational fisheries, albeit at considerable expense, only for the problem species to be subsequently reintroduced by anglers. The chances of reintroduction have to be included



in risk analyses. It was noted that the physical removal of poisoned fish was usually impractical.

How to best apply chemicals generated much discussion. It was agreed that broad-spectrum applications were currently impractical because of cost and the potential to harm species other than carp. A carp-specific poison would need to be developed, but this may not prove feasible and involve considerable expense. However, chemical companies were increasingly tailoring their products. Were there ways of presenting poison so that it would only be taken up by carp? The possibility of using baits was discussed. Poisoning key sites could be a useful tool. Irrigation channels often act as carp reservoirs and because they are artificial habitats chemicals could be used there without the same level of concern about conservation values. Are there stages in the carp life-cycle when it is more vulnerable to poisoning? An example was given of controlling the spread of introduced Japanese kelp by targeting a particular life-cycle stage with herbicide. The possibility of exploiting seasonal carp behaviour, such as spawning, was also discussed.

The need to draw together all state regulations and protocols pertaining to piscicides was raised. In some states, such as NSW, the use of piscicides for scientific sampling purposes was extremely limited. There was general agreement that piscicides are a potentially useful tool, but should be part of a suite of control techniques. If translocated populations of carp are detected before they have had chance to disperse, the use of chemicals to eliminate them from localised habitats is probably the most effective method currently available.

In conclusion, the rapporteur noted that there were parallels between the use of chemicals to control blue-green algal blooms and their possible use on carp. In both cases a rational decision must be made as to the worth of using this method. The use of pesticides in agriculture typically requires cost-benefit analysis. At present there were both logistical and species-specific problems in the wide scale use of piscicides. Potential research areas included studying life-cycle and behavioural aspects which may make carp vulnerable to chemical control.

# Physical removal as an option for the control of feral carp populations

*Ronald E. Thresher*

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The physical removal of fish is, by far, the worlds most popular and, debatably, successful technique for managing fish populations. For the majority of fished stocks, those that inhabit the coastal or open oceans, physical removal via commercial and recreational fishing is, in fact, the only way the populations can usually be managed. For these reasons, there is a very large body of empirical and theoretical literature on the effects of fishing on fish population dynamics, and considerable expertise on the application of these principles to the sustainable management of fisheries.

## **Fundamental Principles of the Dynamics of Exploited Fish Stocks**

Populations are controlled by two broad classes of processes: density-dependent and density-independent. An example of the former is decreasing growth rate and increased mortality (= starvation) as density increases relative to a food supply, and an example of the latter is a winter kill during a cold spell, in which half the animals die irrespective of the absolute density. In practice, the distinction between the two processes often blurs: low daily ration due to high densities could lower resistance to cold, for example, thereby adding a density-dependent component to a nominally density independent process.

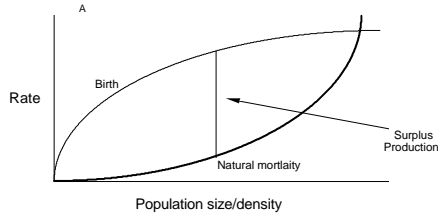
The basic cause of density dependent population regulation is the differing effects of population size on birth and death rates. In general, birth rates decline and death rates increase as densities increase. The population size where birth rate equals death rate is called the 'carrying capacity' of the environment, and in simple population models is the sole point of population stability (other than 0), to which densities return if the population is perturbed (eg fished or over-stocked). The rate of convergence depends on the resilience of the population, which is an expression of its reproductive potential relative to the magnitude of the disturbance. If reproductive rates change only slightly as a result of a decline in density, the return to equilibrium conditions is relatively slow and smooth, whereas if changes in density result in a huge increase in reproduction, populations typically oscillate back and forth across the equilibrium point and may go extinct at the trough of its oscillations.

The mathematics of the dynamics of exploited fish populations have been extensively developed, starting from very basic logistic growth models. Good texts on the subject include Lackey and Neilsen (1980), Cushing (1981) and, as an advanced text, Hilborn and Walters (1992). In its simplest form, however, fundamental stock dynamics can be expressed in two curves – a surplus production curve and the stock-recruitment relationship. A third variant on the theme, known as yield-per-recruit analysis, is very fish-production specific, and will not be considered here.

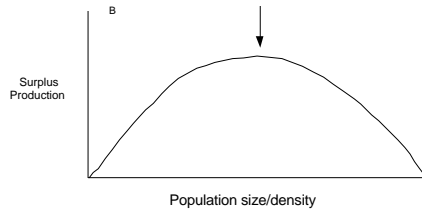
The surplus production curve (Figure 5.1a) is derived from the differing effects of density/stock size on birth and death rates. In theory, at any given density below carrying capacity, birth rate on average exceeds death rate (and so the population grows towards carrying capacity). The difference between the number of individuals added by birth and the number dying is referred to as 'surplus production', in the sense that that surplus can be removed without altering the density of the population (it just does not grow). Because the birth and death rates change non-linearly with density, a plot of surplus production against density is also curved, increasing as density increases from 0, then declining as the carrying capacity is approached (beyond which it goes negative) (Figure 5.1b).

The stock-recruitment relationship is an applied, specific application of the surplus production approach, which focuses on the numbers of new individuals ('the recruits') added to a population as a function of its size. The logic parallels that of the surplus production model. At small population sizes, on average relatively few recruits are added to the population due to the small number of breeding adults. The number of new recruits each spawning season increases more or less linearly as density increases (ie, as the number of breeding females increases), but only to a point.

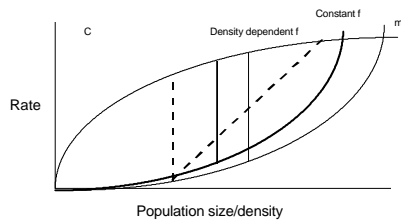
Eventually, density-dependent factors, such as food limitation and competition between juveniles for food, begin to have an increasingly large effect, so that at high densities the number of recruits is either constant (eg, there is only enough food to support a fixed number of juveniles, irrespective of how many eggs are shed) (Figure 5.2a) or begins to decline again, eventually going (in theory) to 0 (Figure 5.2b). The shape of the Ricker curve, or its variants, depends on specific population parameters (age at first maturity, fecundity, mortality schedules) and the nature and magnitude of density-dependence. Considerable work has been done to verify stock-recruitment relationships in field populations, with mixed results (see Cushing 1981). Most studies find an indication of a stock-



The effect of population size on birth and death rates. The difference between the two (vertical line) is defined as 'surplus production'

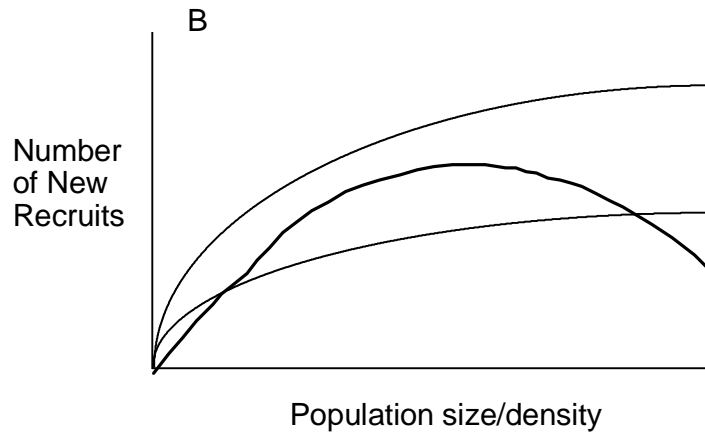
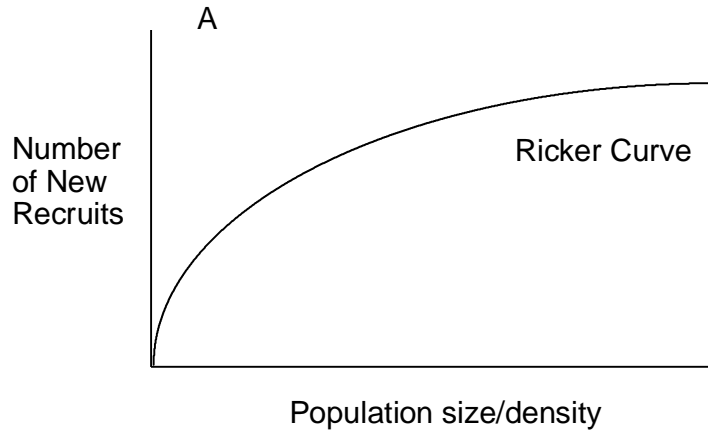


A plot of surplus production against population size. The population size at which surplus production peaks (arrow) is referred to as 'maximum sustainable yield' (MSY) and is a common target for fisheries managers



The effects of different harvesting strategies on MSY, given identical birth curves. Three harvest strategies are illustrated: no harvest ( $m$  = natural mortality), constant harvest effort, and effort that increases as population size increases

**Figure 5.1.** Fish populations. (a) The surplus production curve; (b) Effect of density-dependent factors; (c) Maximum sustainable yield.



**Figure 5.2.** (a) The basic stock–recruitment relationship, in which the number of new recruits increases to a constant level as the number of breeding adults increases. (b) Variants on the stock–recruitment curve that differ either in the rate of population increase with increasing density. In one case, recruitment declines at high population densities due to, for example, parental cannibalism on the new recruits.

recruitment relationship, but also huge variability about the expected line linking the two variables. This 'noise' is thought to result from the density-independent effects of environmental variability (eg good years versus bad years for juvenile growth) and errors in measuring the actual numbers of adults and recruits (Koslow 1992).

Modern fishery management techniques try to use these relationships, and their derivatives, to maximise the productivity of a fishery. Because surplus production is highest at moderate population sizes, the overall management objective is usually to harvest a stock with sufficient intensity as to shift the population towards the highest point of surplus production (often called the density of 'maximum sustainable yield') and/or highest recruitment. Exactly where this point lies depends in part on the fishing strategy used. In the crudest sense, fishing mortality adds to natural mortality, shifting the overall mortality line upwards and the point of maximum sustainable yield slightly downwards (Fig. 5.1c). However, if fishing mortality itself varies with stock size, the effect on both carrying capacity (in the sense of the population stability point) and the point of maximum yield can be very complex (Fig. 5.1c – dashed line).

In part because of this complexity, the exact target density is very debatable. Recent consensus suggests one of about 30-40% of 'virgin' (pre-fished) biomass as a reasonable general target. Management of a stock at this point, however, is confounded both by difficulties in managing fishers (about which a large 'science' has developed) and environmental variability. The smaller a stock, in general the less resilient it is to the effects of environmental factors and overfishing, such that reducing a stock towards a theoretical point of maximum sustained yield also increases the probability that, in the face of a series of bad recruitment years, it will go economically extinct. Note that economic and biological extinction are not the same thing, as in most fisheries (whales and high value fish such as bluefin tuna possibly being the exceptions), economic returns to the fishers decline at very low catch rates, so that at some point well above biological extinction fishing for the species stops. Biological extinction can occur,

however, when species at low density are caught as a by-catch in higher value fisheries, whereby the incentive to fish is maintained due to the value of the target species.

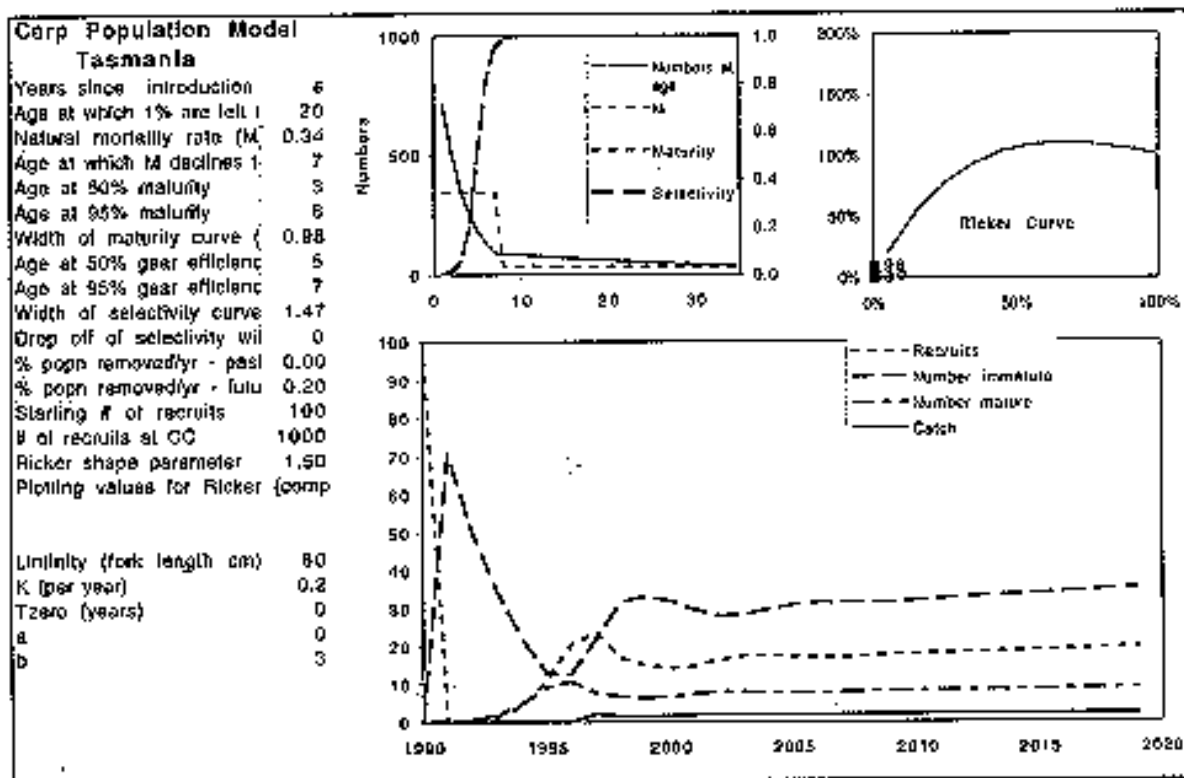
### **Application of these Principles to Carp Regulation**

I can find very little direct information on the population dynamics of wild carp. However, the basic effects of density on individual and population growth rates are well established for pond cultured carp (Alm 1959; Bninska 1991), and are indicated for wild populations by, for example, Backiel and Le Cren (1967).

In principle, carp populations have to be at one of three states: below carrying capacity and growing (though perhaps constrained by density-independent factors), at or near carrying capacity, or above carrying capacity (and hence declining). Recent introductions (eg Tasmania) are likely to be well below carrying capacity, whereas those in the Murray–Darling system appear to be close to, if not at carrying capacity. Simple population models (Figure 5.3) indicate that the dynamics of the two types of carp population (Tasmania and Murray–Darling), and the impacts of physical removal on them, are likely to be very different.

The Tasmanian population is apparently still small. Hence, its growth will be constrained at the ‘near 0’ end of both the surplus production and stock-recruitment curves, due to limited parental biomass. Although per capita fecundity is high for carp, implying a potential for rapid population growth, in most systems juvenile mortality is also extremely high, so that huge rates of population growth are not typical for small ‘founder’ populations. However, as resources at this stage are likely to be relatively unlimited, carp growth rates and fecundity are likely to be near maximum, and the population can be expected to slide up the density scale along a traditional logistic curve (slow initial growth due to small biomass, then a period of very rapid growth, followed by a decline in growth rate as carrying capacity is approached). The key parameters in determining the





**Figure 5.3.** Screen dump of a simple fish-population model that predicts the trajectory of the population (bottom panel) as a result of a harvest strategy (top-left panel) and a stock–recruitment relationship (top-right panel). Parameters used to specify the model are given on the left. For the sake of simplicity, the effects of environmental factors on recruitment and mortality have not been incorporated into this model.

rate of growth are juvenile and adult mortality rates, as these have the greatest bearing on the rate at which parental biomass increases.

The Murray–Darling population, on the other hand, may also exhibit a low recruitment rates, but if so, it would be due mainly to high rates of juvenile mortality, depressed parental growth rates and depressed per capita fecundity – all presumably due to resource (most likely food) limitation. Depending on the nature of resource limitation, an equally likely pattern is for recruitment to be at some moderate level, held there relatively invariably (aside from density-independent factors, such as drought) due to a constraining effect of food availability on the number of juveniles that can survive to maturity. In such a system, per capita fecundity is depressed due to resource limitation, but population fecundity remains high, due to the high density of spawning individuals.

The theoretical effects of harvesting on these two systems differs correspondingly. Any harvesting of a Tasmanian-type population will slow the population growth rate by reducing parental biomass. The magnitude of the effect is directly proportional to the intensity of the fishing, both in terms of the magnitude of the catch and the extent to which all reproductive age classes are taken. Simulations indicate that very high catch rates can hold the biomass at low levels, given reasonable ‘guess-timates’ of the stock–recruitment relationship. If it is possible, holding the biomass at such low levels has two important consequences, other than delaying the onset of the rapid population growth phase. First, it obviously reduces the impacts of the species on the existing system. And second, it maximises prospects for biological extinction. The extinction rate of natural populations is most closely related to the size of the population, in terrestrial as well as aquatic systems (Elliott 1986, Stacey and Taper 1992).

As noted above, risk models based on population dynamic theory for marine stocks indicate the risk of population collapse due to adverse environmental conditions increases as population size decreases. Although

the putative longevity of carp (upwards of 40 years) suggests that the prospects for natural extinction of the Tasmanian population is slight, the sometimes inclement climate conditions in the Tasmanian highlands could result in high levels of density-independent mortality that, combined with an artificially maintained low population density, could result in a long period of low population densities.

Harvesting a Murray–Darling type population, however, is likely to have only a small effect on carp impacts or its reproductive potential. The surplus production and stock-recruitment models both indicate that if the population density is driven down by harvesting, the net effect will be to increase resources available to survivors and either no impact on net recruitment or, worse, a rapid increase in recruitment, growth rate, fecundity, etc., to the point where recovery to pre-fished conditions occurs rapidly (eg Smith *et al.* 1997). This appears to be the experience overseas, where heavily-fished carp populations rebound rapidly once the harvest program stops (McCrimmon 1968). Even fishing mature populations of carp to less than 40% of pre-fished biomass is likely to have a negligible effect on the medium- or long-term dynamics of the population, due to the likely logistic population growth curve. For physical removal to cause a shift to a relatively (but probably still temporary) stable alternative population density, the stock would have to be fished to a low enough level that it was pushed to the pre-log stage of population growth, when the population is limited by the number of available spawners. Where this point lies with carp is, apparently not known, but it is probably at something less than 10% of virgin biomass.

The extent to which harvesting Murray–Darling type populations reduces carp impacts on water quality and native biota is also not clear. Overseas experience seems to imply that such effects are negligible. The only reference I could find that indicated a notable improvement in water quality, recreational fishing, following a program of commercial carp removal is Cahoon (1953). In this example, water clarity improved from about 15 cm to more than 1 m, aquatic macrophytes reclaimed 30 000

acres of the lake and the recreational catch of sport fish increased by 75%, following 8 years of commercial fishing of a 30,000 hectare lake in the southern USA. During that period, more than 500 tonnes of carp were removed. Unfortunately, although the author attributes the improvement to carp removal (via seine nets), (1) the editor of the journal, in an unusual move, inserted a footnote into the paper commenting that this was unlikely to be the cause, based on experiences elsewhere; (2) the carp removal program occurred at the same time as recreational piscivores were aggressively stocked into the lake; (3) an annual program of major lake drawdown was maintained. Hence, even though the author asserted that physical carp removal was the primary cause of the lake's improved conditions, the evidence that this is so is far from conclusive, due to confounding effects of other manipulations of the lake's ecosystem that occurred at the same time.

Simulations indicate that the key parameters required to predict the impact of harvesting are the schedule of fishing induced mortality (across all age classes, constant percentage of population, density dependence, etc.) and the stock-recruitment relationship. Varying the rate at which the population increases at low population densities, for example, has a huge impact on both the natural rate of population increase and its resistance to fish-down by harvesting. Under most apparently reasonable scenarios, consistent harvesting of 10–20% of the adult population will result in a long-term decline of about 40–50% in the total adult population size. Predicting more precisely or accurately the impact of a harvest strategy requires much better information than currently available on recruitment variability and dynamics.

The effects of a physical removal program also depend on the frequency and magnitude of density-independent sources of mortality. As noted above, founder populations of many species often rapidly go locally extinct because they suffer short-term adverse environmental conditions, which the population is not yet strong enough to resist. In the simplest example,

if a population consisting of one male and one female suffers a 50% mortality due to cold weather, then the problem is solved. Even at slightly greater densities, a substantial depression in numbers could greatly reduce reproductive efficiency (depending on the behaviour of the species in question) and reduce the ability of the population to either increase or even maintain itself. Harvesting also typically reduces the number of year-classes present in a stock. There are numerous examples where one of the first effects of substantial fishing is to remove most of the older, larger fish from the population, concentrating the majority of the reproductive output in younger fish (eg Smith *et al.* 1997). Contracting an effective reproductive population from fish spanning a 15-year age-range to one spanning only 5 years changes the scale of the environmental variability required to depress the population. If fish potentially spawn annually for 15 years, then for the population to collapse, adverse conditions would also have to persist for 15 or more years; but if the population is truncated by fishing to only 5 reproductive years, then only 5 adverse years need to occur in a row for the population to have difficulty maintaining itself. Given chaotic behaviour in weather systems, the probability of 5 consecutive poor years is substantially greater than a run of 15 poor years.

### **Principal Conclusions**

Physical removal of carp kills carp, and physical removal of lots of carp kills lots of carp. The extent to which physical removal can help 'solve' the carp problem very much depends on the scale of the harvest effort and the dynamics of the population. In principle, it is relatively easy to construct accurate mathematical models of closed carp populations, and then assess analytically and through simulations the effect of different harvest regimes (size of harvests, selectivity patterns, seasonality, etc.) on population size, structure, impacts and viability. No such models exist, so far as I can tell, and at this point, their accuracy and precision would most likely be constrained by limited biological information on, for example, natural mortality schedules. Nonetheless, prior to embarking on a

program of sustained harvesting, development, evaluation and exploring various options through one of these models would seem to be a very high priority, in order to assess whether the effect of feral populations justifies the fishing effort expended and, possibly, the commercial expectations generated.

A strong recommendation must be that available data on population variability of carp in Australia be collated and analysed, in the context of age- or length-specific fisheries models, in order to extract all available information on the population dynamics of the species. Fisheries scientists are extremely good at 'mining' even relatively poor quality data for useful estimates of key population parameters. Even a coarse analysis of available information could fill many of the very evident gaps in our knowledge of carp population ecology, and provide strong indications of the impacts of physical removal, or any other management strategy (poisoning, biological control), on carp numbers.

Even without a well parameterised model, however, the available information on carp, combined with reasonable 'guesstimates' of their dynamics, suggest that physical removal, via commercial harvesting, recreational fishing or scientific harvesting, will in most instances have only a small-to-moderate impact on carp numbers. Heavy exploitation certainly has the potential for holding a population at a relatively low level (say, 50% of pre-fished biomass), but the control is likely to be effective only so long as the fishing pressure is maintained. Typically, as population densities decrease under the impact of harvesting, catch per unit effort also decreases, so that if physical removal is to be employed as a means of reducing densities, mechanisms would have to be in place to ensure that the harvest effort was maintained.

The heavy fishing pressure required to substantially affect carp stocks would also have to be evaluated for its own impacts on native biota. Extensive netting, for example, could put at severe risk populations of native fish species already driven to low densities by habitat degradation

Where physical removal, on a large enough scale, could have significant value from a control perspective is in situations where either population numbers are already low, as in newly invaded habitats, or where the population is suffering poor recruitment due to adverse environmental conditions. As indicated above, heavy fishing of marginal populations, focussing on the mature adults, could minimise the rate at which these populations grow, and increase the potential for natural extinction. Australia is well known for periods of extreme environmental conditions, with either drought or flood conditions often severe and persisting for several years. Carp are well known for being very responsive to this variability, with populations often dominated by few year-classes (Bninska 1991) Such environmental variability could well facilitate natural extinction of marginal populations, if they are kept small. A vigorous harvest program at the onset and during such periods of reproductive stress could also have a medium-term (5–10 year) impact on even large populations, even in the absence of continued fishing.

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## **Discussion:**

### **Physical removal**

THERE WAS CONSIDERABLE discussion about the lack of size-at-age data. Without such data, growth and mortality rates could not be estimated and fed into predictive models. Commencing collection of a time-series of these data should be given a high priority and the existing commercial fishery for carp was seen as a logical source. Because of the wide distribution of carp across different habitats, data-sets should be collected from each of the South Australian, Victorian and NSW commercial fisheries. NSW fishers now only have access to 5% of inland river systems and policy is to phase out commercial fishing.

It was not known how the existing commercial fishery was impacting on carp populations. Commercial catch data are not sufficiently detailed, although some fishers keep more elaborate records. In the fishery on the South Australian section of the River Murray, representation of carp in the commercial catch had fallen from 70% by weight to 40%, but improved Murray cod and golden perch recruitment was thought to have contributed to this decline. A closely monitored strategic fishing program within specific locations could be a useful tool to assess impact. If the commercial fishery is to be developed, fishers must be kept aware that the goal of a carp control program is eradication. Some NSW survey data suggested that carp recruitment was probably irregular in some areas, with apparent missing age classes. Ron Thresher stated that he expected environmental cycles, such as the El Nino Southern Oscillation, to cause changes in carp recruitment/



abundance, as is the case for several marine fish species. Freshwater systems have flood and drought cycles and are typically more variable than marine habitats.

The usefulness of single-species models was discussed. Length-based, surplus production models are useful, but aged-based models are preferable and cohort analysis should be the goal. Density-dependent parameters could be incorporated, as could density-independent environmental factors such as flow-rates, water temperatures, etc. However, there is very little information on other potentially important factors such as mortality from predators, variations in food supply, etc. Variations in carp abundance appear to occur comparatively frequently and can be used to assess a model's predictive power. At this juncture, there is certainly inadequate information for multi-species modelling.

In concluding, the rapporteur re-affirmed the need for good size-at-age and mortality data to develop effective models. Little was known about year class strengths and stock-recruitment relationships for carp, nor about the composition of the commercial catch. Basic biological and population studies were needed to assess carp behaviour, such as migration, and determine if there are discrete stocks. Effective models are one of the best tools to assess adaptive management measures.

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# Removal as an option for management of an introduced piscivorous fish — the zander

*Phillip A. Smith, Richard T. Leah and John W. Eaton*

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# 6



Zander (*Stizostedion lucioperca* L.), an alien piscivorous fish, has established itself in some United Kingdom (UK) waters (Maitland 1969, Smith *et al.* in press). This has not been regarded as advantageous because the majority of UK anglers prefer to catch native fish such as roach (*Rutilus rutilus* L.) and bream (*Abrama brama* L.) but not zander. Furthermore, the development of zander populations in some waters has been associated with the decline in abundance of native fish

(Klee 1981, Smith *et al.* 1994). As zander are piscivorous (Fickling 1985, Leah and Kell 1985), this alien predator has been perceived by anglers and some fishery managers as detrimental to the abundance of native fish. Consequently, fishery managers need to know the effect that zander-colonisation has on fish community structure and possible measures to reduce any impact.

### **Zander Biology and Introduction to the UK**

Zander are freshwater fish in the Percidae family (Collette *et al.* 1977). They may live up to 16 years, reach 20 kg in weight and 1.4 m in length and are the main open-water piscivorous fish in eutrophic waters in Europe (Kitchell *et al.* 1977). They have well-developed eyes which enhances visual feeding in these turbid waters (Ali *et al.* 1977). Their original distribution was limited to central and eastern Europe, but due to transplanted and natural propagation they are now widespread (Craig 1987). In most countries, zander are highly valued for eating and also as a recreational game fish (Willemsen 1983). Many populations are harvested commercially by fishermen and this exploitation has to be regulated to prevent overfishing.

Zander were initially brought into the UK as an ornamental fish in the nineteenth century and were restricted to isolated waterbodies (Maitland 1969). In 1963 they were introduced into the Great Ouse Relief Channel in an attempt to improve the fishery and a large population soon established in this and connected waters (Linfield and Rickards 1979). Populations of zander also developed in other catchments due to illegal transfer and they can now be found (Figure 6.1) in many waters including the Fenland drains, the Severn and Trent catchments, isolated still waters and sections of the East Midlands canal system (Maitland 1969, Linfield and Rickards 1979, Hickley 1986). There seems no reason why the species should not continue to spread via the interconnecting river and canal network of lowland England.

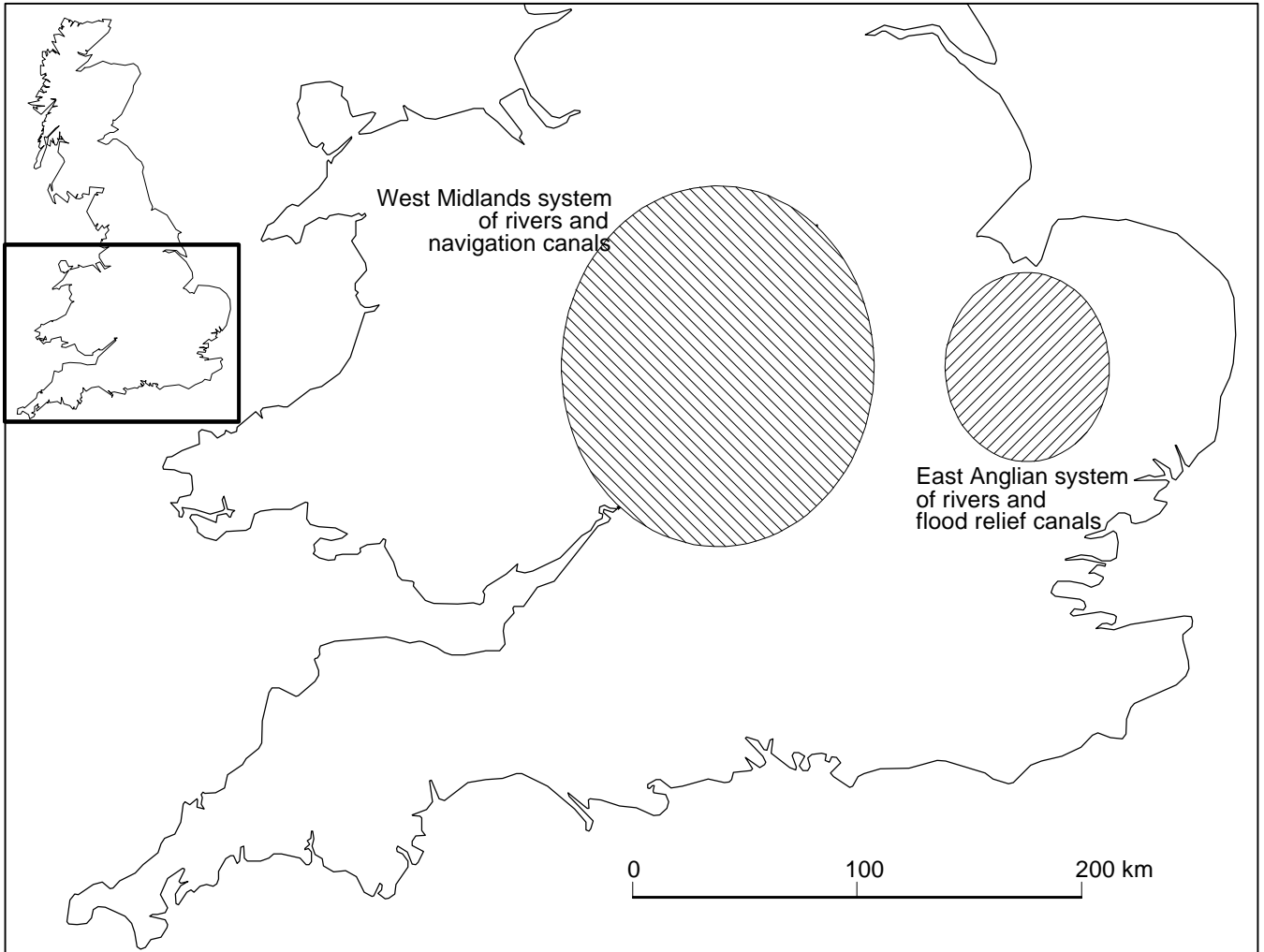


Figure 6.1 Location of the principal zander populations in the UK.

## **Recreational Catch and Release Fisheries Based on Native Fish in UK Canals**

The British canal system is a 2000-km interconnecting network of channels originally built for the transport of goods in the 18th and early 19th century. These waterways tend to be shallow (maximum depth 1.5 m) and narrow (width 10–15 m) and are nowadays used mainly for recreational boating, angling, water supply and nature conservation. The overriding factor influencing the ecology of these canals is the amount of boat traffic they carry (Murphy and Eaton 1983). Canals with little boat traffic have plant growth and clear water. As the amount of boat traffic increases, through a variety of mechanisms, the water clarity and amount of vegetation decreases. In heavily trafficked canals the water tends to be turbid, eutrophic, and, as there are few macrophytes, provides the ideal habitat for zander (Kitchell *et al.* 1977).

The fish community of these canals usually consists of a large number of fish such as roach and gudgeon (*Gobio gobio* L.) (Pygott *et al.* 1988). There are few piscivores, as the visually hunting pike (*Esox lucius* L.) and perch (*Perca fluviatilis* L.) usually occur in low numbers, presumably disadvantaged by the turbidity (Pygott *et al.* 1988, Staples 1992).

These heavily-trafficked canals are managed as recreational catch and release fisheries and are popular venues for anglers. Consequently the fishing rights are rented to angling clubs and fishery managers are concerned that the introduction of zander may reduce native fish stocks and decrease the value of the fishery.

## **Evidence for Impact of Zander on UK Fisheries**

The actual impact on an existing fish community following the introduction and establishment of piscivorous fish may be complex (Fickling and Lee 1983). A more detailed account of the ecological effects of introducing zander to the UK can be found in Smith *et al.* (in press). In theory, zander can reduce the numbers of other fish through a variety of

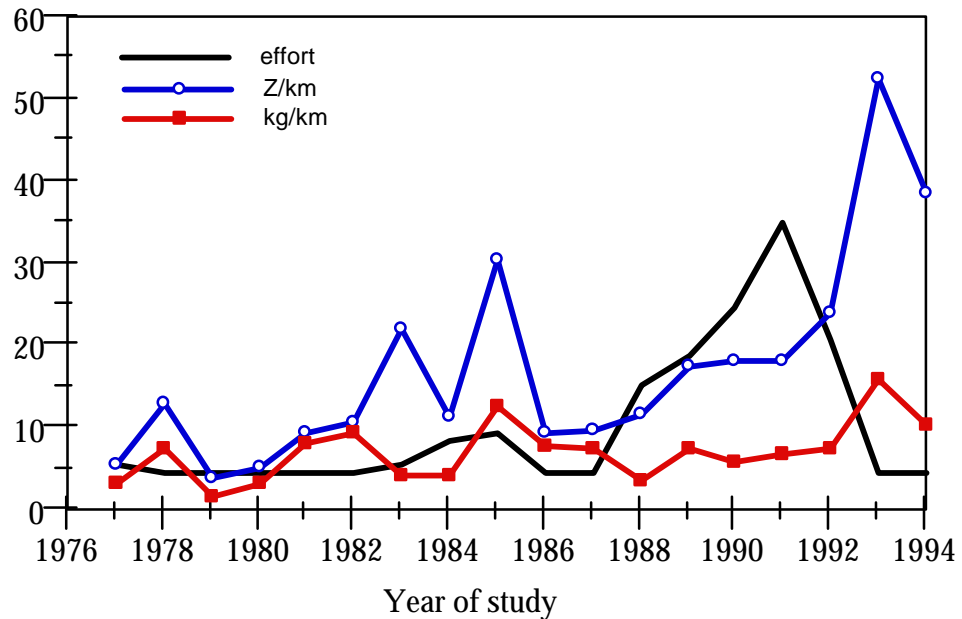
**Table 6.1** Literature published on the impact of zander on UK fisheries

<b>Author(s)</b>	<b>Content and conclusions</b>
Linfield and Rickards (1979)	Summarises introduction of zander to East Anglia and hypothetically discusses impact of zander
Klee (1981)	Summarises introduction and subsequent colonisation of connected waterbodies in East Anglia. Circumstantial evidence that zander reduce abundance of prey
Hickley and North (1983)	Describes the introduction of zander to the Severn Trent area. Report that zander have no impact on prey fish in Coombe Abbey Lake and in North Oxford Canal
Linfield (1982)	Using data presented by Klee (1981) suggests that in some of the East Anglian rivers there is a predator:prey imbalance and suggests predator culls or stocking to 'restore the balance'
Leah and Kell (1985)	Low biomass of prey fish in the East Anglian rivers cannot be solely attributed to the effects of predation by zander
Hickley (1986)	Management of zander may be possible in enclosed waters, but populations in rivers and canals would be more difficult to manage
Adams (1993)	Zander have not adversely affected roach populations in East Anglian rivers
Smith, Leah and Eaton (1994)	A zander-populated section of the North Oxford Canal contained a significantly lower biomass of fish than the adjacent uncolonised section
Smith, Leah, and Eaton (1996, in press).	

mechanisms (Wootton 1992). Direct predation may lead to a decrease in prey abundance (Benndorf 1990). Indirectly, prey may alter their behaviour in the presence of the predator and this could affect habitat utilisation and cause an increase in mortality (Diehl and Eklov 1995). However, the introduction of zander may not affect all fish equally (Popova 1978). Large fish will be less vulnerable to predation and spiny-finned (eg perch) or deep bodied fish (eg bream) may be less affected when compared with more easily caught fish such as roach or gudgeon.

There has been little research in the UK on the impact that zander may exert on their prey (Table 6.1). The majority of studies have used historical introductions as unplanned experiments. Analyses have consisted of either before and after comparisons (Linfield 1982, Hickley and North 1983) or an examination of adjacent zander-colonised and zander-free sections of river or canal (Smith *et al.* 1994) or a combination of the two (Klee 1981). Any difference in fish community has been attributed to zander without real examination of alternative explanations. Some of these studies have resulted in contradictory conclusions. The East Anglian catchment provides a good example of this. Early work by Klee (1981) and Linfield (1982) suggested that zander were the cause of the low biomass of other fish in the catchment. Then Leah and Kell (1985) argued that the low biomass of fish in the same area could not be solely attributed to zander. Later Adams (1993) reviewed the 1980–1983 East Anglian data and concluded there was no evidence of zander having had an adverse impact on other fish.

Controlled introductions of piscivores into aquatic communities have been undertaken in Europe and America, but there the interactions have been greatly influenced by fluctuations in recruitment caused by stochastic meteorological and hydrological events. Therefore at present, the role of zander in structuring fish community composition in UK waters is not known and hence the impact of introducing this fish is also not known.



**Figure 6.2** Relationship between Catch Per Unit Effort (CPUE) for numbers (zander/km) and weight (kg/km) and total effort applied (km fished per year) for the North Oxford Canal 1977–1994.

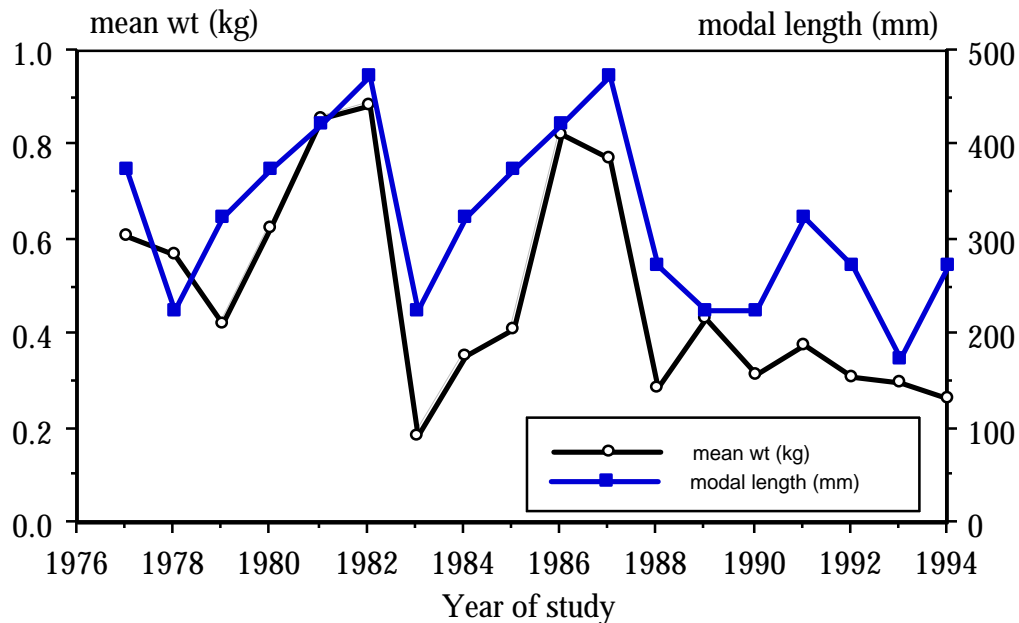
### **Removal as a Technique to Reduce Predation on Native Fish**

Zander were found in a section of the North Oxford Canal in 1976 and sections of this canal have been culled every year to monitor the zander population (Smith *et al.* 1996). The zander-populated section of the canal is 26.3 km long, 11 m wide and has a maximum depth of 1.5 m. It is one continuous body of water and fish are free to move along its length. Immigration and emigration are restricted by navigation locks at each end. During 1988–1992, in an attempt to decrease biomass and hence predation pressure believed to be exerted by zander population, culling intensity was increased. This was achieved by removing zander from a larger section of the canal and in some cases by removing zander twice

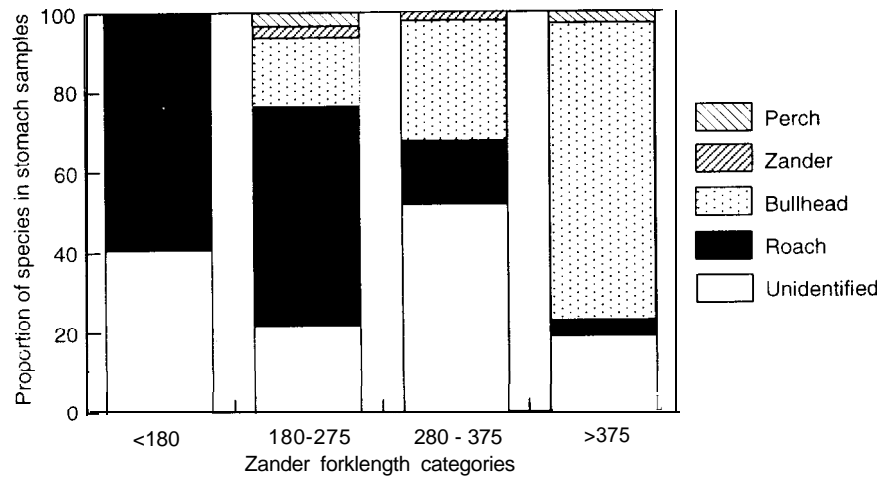


from the same section. In 1993 and 1994, the removal intensity decreased to pre-1988 levels. As exploitation may reduce the abundance of percids (Bagenal 1977, Reid and Momot 1985), analysis of this removal program provides an insight into the usefulness of culling as a technique to reduce the zander predation pressure on recreationally important native fish.

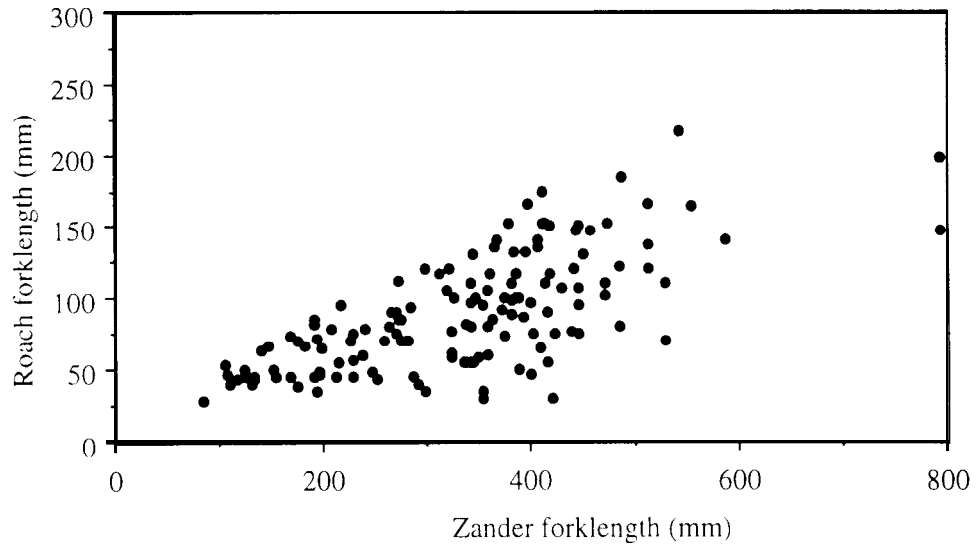
Removal was achieved using a boom-mounted electric fishing equipment (Hickley and Starkie 1985). This is a selective method which tends to preferentially catch larger fish, but does allow large areas to be covered. Data on the numbers, and size of zander caught were analysed in relation to the amount of effort used (Figure 6.2). The catch per unit effort (CPUE) provides an index of abundance, and as similar equipment was used throughout the study, numbers and density of zander can be monitored.



**Figure 6.3** The mean weight and modal length of zander caught from the North Oxford canal.



**Figure 6.4** The proportion of prey types found in the stomachs of 95 zander removed from the North Oxford canal.



**Figure 6.5** Relationship between the length of zander and the length of consumed roach, their principal prey.

At the low culling intensity (1977–1987), zander numbers generally increased but biomass fluctuated. As culling intensity increased (1988–1991), numbers increased but biomass did not. This suggests that culling at the higher level does not decrease the biomass of zander in this canal but exerts selection towards a population of more, but smaller individuals. This is in agreement with the suggestion by Hickley (1986) that zander populations in canals may be difficult to manage.

Calculation of mean weight and modal length of zander caught during the removal program (Figure 6.3) shows that during the period of low culling intensity (1977–1987), there were two dominant cohorts, each present for a period of 4–5 years. However, after the increase in removal intensity, no dominant cohorts were observed and the zander population consisted of many small fish. Because zander are cannibalistic (Figure 6.4) and because there are few avian or mammalian predators of zander, we suggest that at low removal intensities, the zander population was regulated by cannibalism (Smith *et al.* 1996).

As the removal intensity increased, large zander were selectively removed due to gear bias and this led to a reduction in cannibalism and relatively higher numbers of young zander survived.

Harvesting at these two levels altered the size structure, but not the biomass, of the zander population and this has implications for interaction with prey fish. Zander are clearly gape-limited predators as the length and species of prey consumed are dependent on the length of the zander (Figures 6.4 and 6.5). Small zander were found to consume roach whilst larger zander consumed mainly bullhead. This is important as the recreational canal fishery depends on roach and not bullhead. In this case, the removal program altered the size structure of the zander population, did not decrease zander biomass and may even have increased predation pressure on native cyprinids which are important for the fishery.

### **Removal as a Management Option for Zander-Populated Canals**

The establishment of zander populations in some canals has resulted in a number of problems for fishery managers. At present, the addition of

zander does not improve the fishery value of waters in the UK as anglers do not want to catch them. Furthermore, anglers claim that zander reduce the abundance of other fish and advocate removal programs.

A review of the UK literature found that the impact of zander is not known. Culling zander has been attempted but the evaluation of 18 years data of harvesting a canal population suggests that culling at a low level has little effect on population dynamics. Increasing culling intensity to the 1988–1991 level altered the population dynamics. It resulted in a decrease in the average size of the zander, but did not affect total biomass. However, as the size of prey eaten by zander is related to its size (Figure 6.5) this will have shifted predation pressure towards smaller prey. As the type of prey consumed also depends on the size of zander (Figure 6.4), a population of small zander would consume more cyprinids than a population of larger ones. Consequently, the reduction of the average size of zander by culling may have exacerbated its impact on native cyprinid fish. As cyprinids form the basis for the recreational fishery, culling zander may actually increase its impact.

### **Acknowledgements**

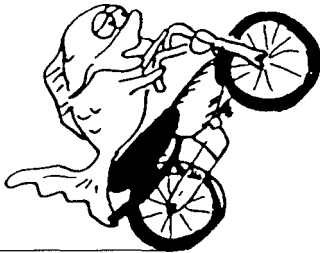
This work was completed whilst PAS was funded by British Waterways. The views presented here are those of the authors and not necessarily those of British Waterways. PAS would like to thank CSIRO for support to attend the workshop in Australia.

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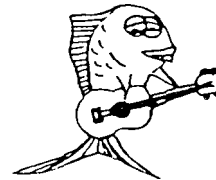
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# Spring Viraemia of Carp Virus (*Rhabdovirus carpio*): a biological control agent?

*Mark S. Crane and Bryan T. Eaton*

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## **Introduction**

Biological control of carp in Australia by an infectious agent such as an exotic virus was first mooted in the 1970s (Stephenson 1978) following discovery, isolation and identification of the Causative agent of spring viraemia of carp (SVC), an acute, haemorrhagic disease of farmed carp in Europe

(Fijan *et al.* 1971, Bachmann and Ahne 1973). At the Carp Forum held at Wagga Wagga, NSW in 1994 and the National Carp Summit held at Renmark in 1995, the possibility of using this virus known as spring viraemia of carp virus (SVCV or *Rhabdovirus carpio*) as a biological control agent for carp was discussed (Hindmarsh 1994, Crane 1995); prior to any further assessment, it was recommended (Crane 1995) that a feasibility study to determine the possibility of releasing SVCV as a biological control agent in Australia should be undertaken.

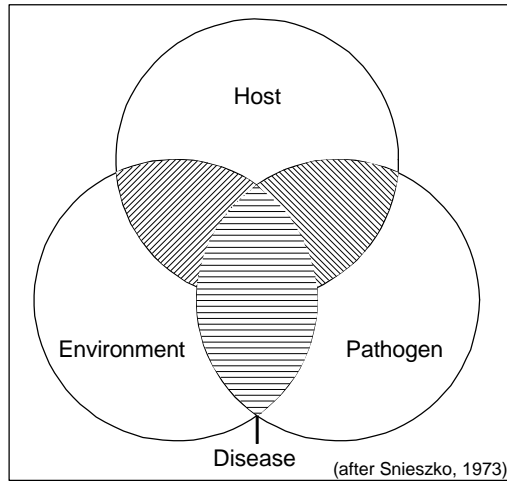
An important part of such a study is obtaining current knowledge on the epizootiology of the disease as it occurs in Europe and making an assessment of the implications in the Australian context. This report reviews briefly our current understanding of the epizootiology of fish diseases in general and of SVCV specifically, provides a brief introduction to the structure, classification and replication of SVCV and discusses the possibility of genetic manipulation of the virus to alter its efficacy as a biological control agent. Other issues, such as legislation, socio-economic impact, animal welfare, associated with the possible use of SVCV as a biological control agent have been discussed previously (Crane 1995).

## **Fish Pathogens and Disease**

Outbreaks of infectious disease in aquatic animals are usually the result of a complex interaction of a number of factors. Although the presence of an infectious agent is necessary to cause disease, fish may harbour an infection, whether viral, bacterial or parasitic, but not show clinical signs or adverse affects, ie no disease, unless other influencing factors are introduced.

These other factors may be host- or environment-based and, as illustrated by Snieszko (1973; Figure 7.1), play important roles in the development of infectious disease. For example, covert infections with *Aeromonas salmonicida* in farmed salmonids can remain undetected without clinical signs until adverse environmental conditions, such as poor water quality or excessive handling, cause stress to the fish thus lowering their disease-resistance and triggering a disease outbreak (McCarthy 1977). Indeed, in





**Figure 7.1** The factors and their interaction affecting infectious disease development in fish and other aquatic animals (after Snieszko 1973).

recent years, the importance of environmental factors in fish disease outbreaks has been emphasised (Snieszko 1981, Anderson 1990).

In many instances, aquatic animals are farmed in the presence of infectious agents and control of environmental factors is essential to limit the incidence of disease and thus reduce the negative economic impact. Many infectious agents of fish must be considered facultative pathogens (Jeney and Jeney 1995); ie, an infection involving these agents does not necessarily result in disease and, indeed, may remain as a covert infection indefinitely.

## **Spring Viraemia of Carp**

### ***The Virus***

The viral aetiology of spring viraemia of carp (SVC) was proven in 1971 when Fijan isolated the causative agent in cell culture and successfully transmitted the disease to carp (Fijan *et al.* 1971). Morphological and biochemical properties of the virus were consistent with those of a rhabdovirus, and the name *Rhabdovirus carpio* was suggested. As with

other virus names which tend to specify the diseases they cause, the name 'spring viraemia of carp virus' (SVCV) is used more commonly. Previously, the disease had been called 'infectious dropsy of carp' (IDC) the aetiology of which was unknown due, in part, to the occurrence of both an acute, ascitic condition and a chronic, ulcerative form. It is now known that the acute form (SVC) is caused by *R. carpio* and the chronic disease (now known as 'carp erythrodermatitis') is caused by a sub-species of the bacterium *Aeromonas salmonicida* (Bootsma *et al.* 1977).

Rhabdoviruses infect arthropods, fish, mammals, plants and reptiles. They are grouped into five genera, three of which (*Vesiculovirus*, *Ephemerovirus* and *Lyssavirus*) infect animals. *Vesiculovirus* genus members exhibit various degrees of serological cross-reactivity and genetic similarities. One serogroup contains vesicular stomatitis virus (VSV), the rhabdovirus prototype, and approximately 20 ungrouped viruses. SVCV is an ungrouped member of the *Vesiculovirus* genus (Dietzschold *et al.* 1996, Wagner and Rose 1996).

A number of antigenically distinct rhabdoviruses have been isolated from fish, including SVCV, infectious haematopoietic necrosis virus (IHNV), viral haemorrhagic septicaemia virus (VHSV) and pike fry rhabdovirus (PFR) (McAllister 1979). All these viruses are considered exotic to Australia. However, given the putative European origin of carp in Australia, it is not impossible that SVCV may already be present in this country. IHNV and VHSV are members of the *Lyssavirus* genus and are pathogens of salmonids. PFR is a member of the *Vesiculovirus* genus and it has been suggested that SVCV and PFR be regarded as two serotypes of the same virus (Jorgensen *et al.* 1989).

Rhabdoviruses typically are bullet shaped. SVCV is approximately 160 nm in length and 70 nm in diameter (McAllister 1979). The virus is composed of a single stranded RNA genome and multiple copies of five proteins designated G (glycoprotein), N (nucleocapsid protein), P (phosphoprotein), M (matrix protein) and L (RNA-dependant RNA polymerase) (Wagner and

Rose, 1996). Although the size of SVCV RNA has not been determined accurately, rhabdovirus genomes are relatively small, in the 11-15 kilobase range (Dietzschold *et al.* 1996). Rhabdovirus genomic RNA cannot be translated directly into protein. Such viral RNAs are described as having negative polarity, in contrast to the positive polarity of messenger RNA and the genome of viruses such as poliovirus which can be translated into protein.

The outer surface of rhabdoviruses is covered with spikes composed of the G protein. Inside the virus the RNA genome is tightly encased by the N protein and associated with two minor proteins P and L. The M protein is believed to act as a bridge between the coiled ribonucleoprotein (RNP) core and viral membrane.

SVCV replicates in a variety of mammalian, piscine, avian and reptilian cell lines (Bachmann and Ahne, 1974, de Kinkelin *et al.* 1974, Clark and Soriani 1974, Hill *et al.* 1975, Roy 1981). This wide *in vitro* host cell range does not reflect a capacity of the virus to naturally infect diverse host species. The complex processes of natural infection and the limited number of ways in which a virus can actually enter a prospective host animal appear to limit the SVCV host range to, in the main, cyprinids (Table 7.1). The virus replicates *in vitro* at temperatures of 4 to 32°C with an optimum, which depends on the cell line, between 20 and 25°C. Maximum yields of virus are obtained in cells of cyprinid origin (Bachmann and Ahne 1974).

### ***The Disease***

SVC is enzootic in all countries of Europe (except UK), where carp are farmed. It is rarely observed, if at all, in wild carp populations and is considered a disease of farmed carp which are reared under intensive conditions of aquaculture. The disease affects carp of all ages and occurs in spring and early summer when water temperatures are on the rise. The clinical signs which are typical of any systemic infection include ascites, surface haemorrhages, dark skin colouration, exophthalmia, pale gills (due

to anaemia), abnormal swimming movements and depressed respiratory rate. Mortalities can be as high as 100% or as low as 5% but are usually in the 20–40% range. Presumptive diagnosis can be made based on described features (see Wolf 1988 for review), and confirmed by virus isolation in cell culture with subsequent serological identification or by immunodetection of viral antigens in fish tissue (Faisal and Ahne 1984, Rodak *et al.* 1993).

**Table 7.1 Known Host Range for Spring Viraemia of Carp Virus**

<b>Fish Species</b>		
Common carp	<i>Cyprinus carpio</i>	(Cyprinidae)
Silver carp	<i>Aristichthys molitrix</i>	(Cyprinidae)
Bighead carp	<i>Hypophthalmichthys nobilis</i>	(Cyprinidae)
Crucian carp	<i>Carassius carassius</i>	(Cyprinidae)
Grass carp	<i>Ctenopharyngodon idella</i>	(Cyprinidae)
Tench	<i>Tinca tinca</i>	(Cyprinidae)
Goldfish	<i>Carassius auratus</i>	(Cyprinidae)
Northern pike	<i>Esox lucius</i>	(Esocidae)
Guppy	<i>Lebistes reticulatus</i> = <i>Poecilia reticulata</i>	(Poeciliidae)
Sheatfish	<i>Silurus glanis</i>	(Siluridae)

In recent years, modifications in management practices have reduced the impact of the disease in continental Europe and, although the virus remains present, the disease has a low prevalence and is of little concern to the aquaculture industry. However, in the UK, carp are imported from continental Europe for sport fishing and SVC which is not enzootic in UK remains a major concern in that country. Introductions of the virus with imported carp (introduced as a sport fish for angling purposes) have resulted in major disease outbreaks in farm ponds and lakes sometimes with up to 95% associated mortalities. A major effort is required to contain and eradicate the disease to ensure that it is not introduced into open waters where it could affect native, wild or farmed cyprinids (Anon 1989).

With regard to the host range, it is noteworthy that the name spring viraemia of carp is misleading. It is generally accepted, if not proven yet, that most if not all cyprinid species are likely to be affected to a lesser or greater degree. In addition, some non-cyprinid fish species such as the silurid sheatfish, *Silurus glanis* (Fijan *et al.* 1984), the poeciliid guppy, *Lebistes reticulatus* (Bachmann and Ahne 1974) and the esocid pike, *Esox lucius* (de Kinkelin *et al.* 1973, Jorgensen *et al.* 1989) are also susceptible to infection and succumb to disease (Table 7.1). As further investigations continue, the proven range of fish species, cyprinid and non-cyprinid susceptible to infection by SVCV will probably increase. A further demonstration of the broad host range for this virus is its ability to infect the insect *Drosophila melanogaster* (Bussereau *et al.* 1975).

### **Carp Farming in Europe: Impact of SVC**

In most European countries where carp are farmed there are no self-sustaining carp populations in the wild. The summers are too short and too cool for ambient water temperatures in rivers to reach the threshold required to trigger natural spawning. Those carp that do inhabit the rivers are likely to be escapees from carp farms or live in artificially heated waters (eg near power plants).

The natural habitat of carp, meaning those places where carp thrive, are bodies of freshwater with water temperatures in the range of 18–22°C and where there is good grass and plant growth to provide ideal spawning grounds, for example, flooded areas with shallow water. Thus, in Europe, specific management practices are used which address the cool winter temperatures. In spring, artificial spawning is often practised and, following egg incubation, hatched fry are placed in ‘nursery ponds’ until they are old enough to be transferred to earthen grow-out ponds which are normally 0.7–1.0 m deep. Both natural and artificial feed are used and by the end of the first growing season, that is in autumn, the carp are 30–50 grams in weight. To protect them from the cold temperatures and ice of winter the carp are transferred to deeper over-wintering ponds where they

hibernate; their metabolic rate is reduced, they show little activity and feeding stops (at temperatures below 5°C).

At the onset of the next spring, the carp are returned to the grow-out ponds for the warmer seasons. The carp grow to approximately 500 g in this second season and the process is repeated a third time until they are ready for harvest in the autumn of the third year when they reach approximately 1.5 kg. Following harvest, the fish are maintained in concrete ponds with little or no feeding ('depuration') and it is during this period that the carp lose their 'muddy' taste prior to sale.

It is important to understand the basics of carp farming because it is the intensive farming conditions which, in part, determine the severity of an outbreak of SVC. Following winter hibernation, the carp have depleted energy reserves and are in weak or poor condition. Moreover, it is known that the optimum temperature range for carp occurs above 18°C. Thus, during the spring period when temperatures range between 10–15°C, carp physiology, although functioning, is not at its optimum and biochemical reactions (enzymatic processes such as antibody production) are out of balance. It is also at these temperatures (above 10°C) that SVCV replicates within the host. Thus if the spring is long and cool with a temperature range of 10–15°C the virus has a good opportunity to multiply while the immune response of the carp is suppressed and delayed (Ahne 1986); its immune response is only fully effective at temperatures greater than 15°C. Thus in years with relatively long, cool springs mortality due to SVC will be higher than average. In years with short springs when the temperature rises to above 15°C quickly, virus replication is limited by the carp immune response and incidence of disease and mortality are low.

Thus, integrating results from research and on-farm experience has provided a better understanding of the interaction between the virus, environment and the host and, in recent years, aquaculture management practices have been modified accordingly to reduce the impact of disease.

Carp are provided increased feed just prior to winter so that their energy reserves are high for the over-wintering period. This measure is particularly important in years with warm winters when the carp may be more active in the milder temperatures during over-wintering but when there is no natural food to support this increased activity. Clearly, at the onset of spring, carp which are in better condition will be less susceptible to disease.

In addition to increased feeding before hibernation, carp are also subjected to anti-parasitic treatments to remove external parasites which can affect fish condition and also act as vectors for SVCV (Ahne 1985).

Handling stress is also an important factor and can precipitate a disease outbreak. Relocation from the over-wintering ponds to grow-out ponds should be undertaken with as little stress as possible to the fish. Timing of the relocation (leaving the fish undisturbed in the deeper, cooler ponds for as long as possible) so that the spring period is as short as possible, even though this means shortening the growing season, can assist in reducing the impact of the virus. Because these and other changes in aquaculture management, SVC has had little impact on carp farming in Europe over the last 10 years.

The situation is different in the UK where SVC is not enzootic. Here, the fish populations are immunologically naïve, that is, they have had no previous exposure to the virus and immunity has not developed. In addition, in contrast to other European countries, spring temperatures are characterised by relatively large fluctuations, eg from 10°C to 20°C and back to 10°C, in only a few days. These conditions are very stressful for fish and, in the absence of any immunity, introduction of the virus (with imported fish) usually triggers very severe outbreaks of SVC with high mortality rates (up to 95%).

### **The Australian Environment: Implications for SVC**

In summary, outbreaks of an infectious disease of fish are dependent on the presence of the causative agent, the occurrence of adverse

environmental conditions and the presence of susceptible hosts (Snieszko 1973). In Europe, prior to 1990, severe outbreaks of SVC occurred during relatively long, cool springs and were more severe when fish were in poor condition due to over-wintering problems and/or suffering from excessive handling stress. Moreover, increased mortalities occurred when there were secondary bacterial infections which were also quite common. Under these cool (10–15°C) conditions, the virus replicated within the host free from any constraints imposed by the host's immune response (suppressed at lower ambient temperatures) and large numbers of virus were shed into the water where transmission was enhanced by the relatively high stocking densities used in carp farming. It is interesting to note that the decrease in stocking densities in recent years may also have been a contributing factor in the reduction in SVC prevalence.

In some areas of south-eastern Australia, carp constitute up to 90% of the fish biomass in some inland river systems (Gehrke *et al.* 1995) and little is known about their disease status or the presence of infectious agents. Although Australian carp appear to represent a naive population with no previous exposure to SVCV, and therefore highly susceptible to infection (Stephenson 1978), carp in Australian waterways do not appear to be in poor condition and environmental stresses seem to be low. It is questionable whether environmental conditions in Australia would be conducive to disease outbreaks, should SVCV be introduced, for the following reasons. The fish are not confined to a restricted area (compared with the intensive farming conditions used in Europe) and therefore are free to seek favourable environmental conditions with respect to stocking density, water quality, water temperature, food source etc. On mainland Australia, carp are not subjected to severe winters, spring-time is relatively short and summers are long and hot.

While these reasons appear valid, prior to any decision on the use of SVCV as a biological control agent for carp in Australia, a review of the host and environmental factors specific to Australia and pertinent to the disease is needed. For example, what are the ambient water temperatures during the year in the Murray-Darling Basin? Do carp undergo periods of



significant stress such as at the time of spawning, or are there areas of poor water quality that would increase the susceptibility of carp to disease? Are Australian carp SVCV-free with no previous exposure to the virus? Is the density of carp in Australian rivers sufficient to permit efficient virus transmission?

## **Properties of SVCV as a Biological Control Agent**

There are a number of pivotal questions about the virus which will determine its effectiveness as a control agent.

- (1) Can the virus survive under Australian water temperature conditions?
- (2) Is the virus virulent for Australian carp? (Efficacy).
- (3) Is the virus specific for carp or cyprinids? (Safety).

Should SVCV fail to demonstrate the necessary heat resistance, specificity or virulence at a suitable level, recent advances in molecular biology raise the possibility that a variant may be genetically engineered to do so.

## **Made-to-Order Viruses**

There are two ways in which the biological properties of a population of viruses such as SVCV can be altered.

### ***Selection of Viruses with Desired Properties from Natural Populations***

RNA viruses exist as genetically heterogeneous populations and the name 'quasi-species' has been applied to such populations (Eigen 1993).

Individual viruses in a quasi-species may differ slightly, say by a few nucleotides, from other members in the population. Nucleotide changes or mutations are introduced during replication of the viral RNA and the progeny of a single RNA virus may rapidly become genetically heterogeneous over time. While most mutations are silent and do not result in amino acid change, others lead to alterations in the amino acid sequence of virus-encoded proteins. Some alterations may reduce the fitness of the virus to replicate, others are 'neutral' and do not affect the

capacity of the virus to survive in the environment within which it is replicating. The importance of this genetic heterogeneity lies in the fact that should the environment (temperature, appearance of antibody etc.) change, there may be variant viruses in the population which are better suited to the new conditions and proceed to successfully compete with and out grow other viruses in the quasi-species. Variant viruses then proceed to create a new quasi-species in the altered environment. Thus it is possible to select viruses with desired properties by altering the conditions under which viruses replicate.

### ***Genetically-Engineered Viruses with Specific Properties***

Until recently, procedures to genetically engineer negative strand RNA viruses have lagged behind those for positive strand RNA viruses. In the latter case, development of experimental manipulations was made relatively simple by the fact that the RNA is infectious and capable of initiating infection when introduced into cells. DNA copies of viral RNA could therefore be altered by standard genetic engineering techniques, converted back into RNA and introduced into cells to yield genetically altered virus. In contrast, the genome of negative strand RNA viruses is not infectious unless complexed with N, P and L proteins. Only in the RNP form can negative strand RNA be transcribed into mRNAs for viral proteins or copied to give full length RNA for the synthesis of new genomic RNA (Conzelmann 1996). In recent years, techniques have been developed which permit the synthesis of RNP inside cells. Thus negative strand RNA could be converted into DNA, modified by genetic engineering, incorporated into RNP and in that form initiate virus infection. Techniques are available therefore to genetically alter SVCV in the search for viruses with desired properties.

A frequent result of growing viruses in cultured cells is that, although they continue to replicate in their natural host, they do not display the virulence that characterised the virus prior to adaption to tissue culture. Fortunately, passage of SVCV in cultured cells *in vitro* does not reduce

virulence for carp. This not only makes it easier to maintain stocks of virulent viruses but also permits genetic manipulation of virulent virus, a process which requires virus growth in tissue culture.

### **Can SVCV survive under Australian Water and Temperature Conditions?**

There are few data on the effect of temperature on SVCV stability in water. A number of strains of SVCV of varying virulence could be imported from Europe into microbiologically-secure facilities and their ability to survive at a range of water temperatures determined. If the virus is rapidly inactivated at Australian water temperatures, a 'heat resistant' variant may be selected from the quasi-species population by, for example, passage of SVCV in permissive cells at temperatures above 25°C. Alternatively, the virus may be exposed to elevated temperatures prior to growth in cells at 25°C or higher.

### **Is the Virus Virulent for Australian Carp?**

As alluded to, the use of SVCV as a biological control agent for common carp has been suggested previously (Stevenson 1978). Indeed, as part of a Victorian State Carp Program funded by the Ministry of Conservation, fish from nine species, including carp, were sent to the Fish Diseases Laboratory, Ministry of Agriculture, Fisheries and Food, UK where they were tested for susceptibility to SVCV (Hume *et al.* 1983). Although the virus appeared specific for carp, these studies did not indicate that SVCV could be used as a biological control agent; not only were small numbers of fish used but also it was recognised that virus-susceptibility of vertebrate fish species is only part of the issue and the research program was discontinued.

Since then our knowledge of the virus, the disease and of carp in Australia has increased but further research is still required. For example, SVCV of varying virulence characteristics have been isolated in Europe (Ahne 1979). It will be necessary to determine and compare the effect of these

different isolates on the several varieties of Australian carp. This will be most readily achieved under laboratory conditions although it is recognised that it is not possible to reproduce in an artificial environment the complex and varied conditions under which carp live. However, there is no other way available to readily ascertain if SVCV is virulent and to determine the influence of temperature, fish age and stocking density of SVCV infection (albeit under defined conditions).

The virulence of heat-resistant or modified virus should also be determined experimentally. Such experiments will reveal which strain of SVCV causes the greatest mortality in Australian carp and the temperature and fish density conditions which maximise virulence, at least under laboratory conditions. The results will indicate the likelihood of the virus being able to exhibit a virulent phenotype under natural conditions.

### **Is SVCV specific for Carp or Cyprinids?**

It is of paramount importance to determine whether SVCV is able to infect Australian native fish and introduced species other than carp. The initial species to be tested experimentally for susceptibility should be determined on the basis of their representing a particular piscine genus or family and the relative proximity of the ecological niche occupied by the target piscine or amphibian species to that of carp. SVCV replication in target species exposed to the virus should be determined, not by the appearance of clinical signs which is an unreliable criterion of infection, but by polymerase chain reaction (PCR)-based detection of viral RNA in blood and organs such as liver, spleen and kidney and/or by virus isolation in cell culture (Faisal and Ahne 1984).

### **Molecular Approaches to Virus Modification**

Natural or laboratory-selected isolates of SVCV may manifest reduced virulence for Australian carp. Genetic engineering offers the possibility of increasing the virulence to a level similar to that observed in disease outbreaks in UK. An appreciation of genetic factors governing SVCV virulence may be obtained by comparing the nucleotide sequence of

virulent and avirulent European isolates. Not all nucleotide sequence differences observed between virulent and avirulent viruses may be associated with virulence and, if a number of isolates of varying virulence are examined, it is likely that several virulence markers may be identified. Proof that a particular sequence contributes to virulence can be obtained if insertion of that sequence into an avirulent virus results in an increase in pathogenicity. Similarly, it may be possible to reduce the immunogenicity of the virus so that even in an immunocompetent host the virus does not stimulate an effective immune response.

European data indicate that SVCV displays a host preference for cyprinids. However, if experimental infection of target Australian species provides evidence of a wider host range, it may be possible to modify the SVCV G protein and abrogate its capacity to infect non-cyprinids. G protein is responsible for binding virus to a receptor molecule on the surface of host cells and the specificity of the interaction between particular sites on the G protein and cell receptor controls the host range of the virus. The exquisite host cell specificity shown by some viruses is often due to the presence of a receptor molecule which is found only on the surface of a small number of cell types. A number of techniques are currently available to determine precisely the region of viral proteins responsible for cell binding.

There are two explanations for the ability of viruses to infect cells from different species. First, susceptible cells may contain the same or a closely related receptor molecule. In this instance, the virus may bind to the receptor via the same or different sites on the G protein. Second, the virus may bind to different receptor molecules on different cell types. In the latter case, it is likely that the G protein contains a number of different binding domains. In situations where separate regions of G protein are required for entry into different cell types, it may be possible to delete the

appropriate region from the G gene of SVCV and render the virus incapable of entering non-cyprinid cells.

## **Discussion**

In Europe, where SVC is enzootic, aquaculture management practices have been modified to reduce the impact of the disease in farmed carp. These modifications have been so successful that in the past ten years while the virus remains enzootic the low prevalence of the disease has had little impact on carp farming. Even prior to this time, while severe outbreaks caused significant economic impact, the occurrence and severity of disease outbreaks were unpredictable. For example, in 1986 on one farm in Saxony, Germany, mortalities due to SVC varied between 5% and 65% between individual ponds on that single farm. The precise reasons for this variation, presumably due to the complex interactions between the infectious agent, its host and the environment (Snieszko 1973, 1981), are not known. Thus, in Australia too, the host and environmental factors which would influence the severity of an outbreak of SVC, should it be introduced, are largely unknown.

In addition, the properties of the virus may also indicate that in an unmodified form it is unsuitable as a biological control agent. As discussed, the virus has a broad host range. Are there species of native Australian fish or other aquatic animal which are susceptible to infection with SVCV? Could the SVC virus adapt to new hosts? Moreover, SVCV is a facultative pathogen dependent on adverse environmental conditions to cause disease. For effective biological control, it is desirable that the pathogen should be not only host-specific and genetically stable but also so highly virulent and contagious that disease outbreaks are guaranteed under any condition. In spite of these cautionary comments, recent advances in molecular biology offer the possibility that SVCV may be genetically altered to provide a pathogen with the high virulence, restricted host specificity and low immunogenicity appropriate to an effective biological control agent. The development of a genetically modified SVCV should proceed following

public consultation and have the support of the community and approval from the Genetic Manipulation Advisory Committee.

Finally, it should be noted that SVCV is an OIE List B agent and spring viraemia of carp a notifiable disease. The release of SVCV would therefore render Australia an 'infected' country and this could have serious trade implications for exports of ornamental fish but would have to be considered in the context of the putative beneficial effects of SVCV brought about by a significant decrease in the Australian carp population.

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## **Discussion: Application of Viruses**

SEVERAL QUESTIONS CENTRED on the influences of carp population density and water temperature on the effectiveness of SVCV. High population densities favour effective transmission of the virus, but much would depend upon the condition of the fish. Stressed fish are more susceptible to infection. Carp densities in Australia are both variable and largely unknown, but fish are usually free to roam unlike those held in comparatively high densities in European culture ponds. SVCV can persist in the environment for several months at low temperatures but breaks down rapidly in warm habitats.

Modes of SVCV transfer were discussed. Within a water body there is horizontal spread via fish urine and faeces. Between water bodies, fish-eating birds could probably effect natural transfer. Whereas SVCV is only known from Europe, its apparent absence from SE Asia may be due to no targeted attempts to identify it. Similarly, in Australia it is not known if SVCV has been accidentally introduced previously. If the virus has mutated here it is hard to say how detectable it would be, but researchers could look for antibodies. Mark Crane thought it unlikely that the different strains of carp in Australia would have significant differences in susceptibility to SVCV. All age groups are susceptible but not all infected fish die, leading to proportionately greater immunity in older age classes. There is no evidence of inherited immunity.

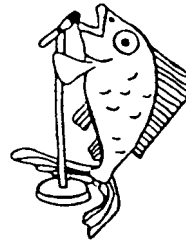
Could SVCV be altered to meet the Biological Control Act requirements for specificity? This is possibly not a problem here as there are no cyprinids native to Australia and a high likelihood that natives are not vulnerable. Within the past few years, techniques have been developed to genetically engineer viruses such as SVCV. Thus, if the virus does infect non-cyprinids, the problem of making it carp-specific could probably be overcome given time and resourcing. The AAHL facilities could be used to examine European strains of SVCV within Australia. If SVCV was released in its natural form, there would probably be problems with international trade (in fish) as it is a notifiable disease.

The rapporteur concluded by noting that SVCV was rarely seen in wild carp in Europe and it caused a wide range of mortality rates when it did occur. There

were considerable doubts about its ability to persist in Australian habitats. European information could be used to model likely outcomes of introducing SVCV. Stocking rates of infected fish and population densities of wild fish are important issues and there is a need to make the most of the first release.

Can the virus be successfully introduced? Although RNA viruses are known to be genetically labile, many RNA viruses remain uniquely adapted to a particular host species. SVCV has a relatively broad host range and extensive testing of native, non-cyprinid fish is required. The virus may already be here. A conservative approach is needed. The ability to genetically engineer RNA viruses offers opportunities to limit virus adaptation to new hosts. A 10-year, or more, development program may be needed to satisfy regulatory authorities, particularly the genetic manipulation advisory committee if the virus is genetically altered, and convince the public.

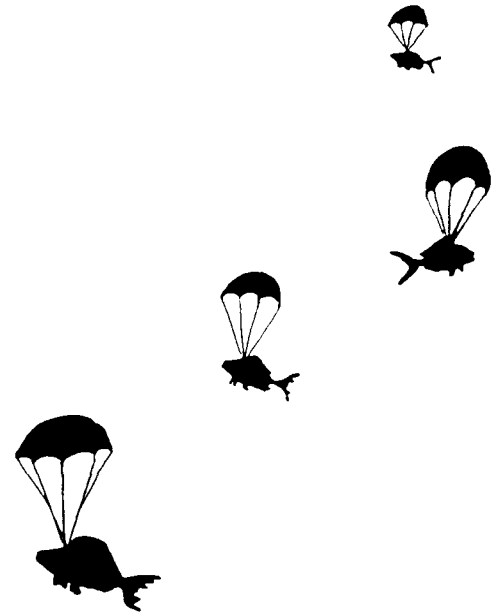
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# Immuno-contraceptive control for carp

*Lyn A. Hinds and Roger P. Pech*

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## **Introduction**

Throughout the world many vertebrate and invertebrate species have been intentionally or unintentionally introduced into environments not originally occupied by them, have adapted successfully, and have come to be considered pests. For Australia, a classical example is the introduction of the European rabbit, *Oryctolagus cuniculus*, and the European red fox, *Vulpes vulpes*.

The impact of these species on the fauna and flora has been well documented, as are the current management techniques (Williams *et al.* 1995, Saunders *et al.* 1995). Most of these techniques use mortality agents which may not be acceptably humane, are not species specific, and can be expensive to apply. In the short term such methods may be effective because they reduce the numbers of the pest and the damage they cause. However, in time, populations re-establish and, unless the mortality method is repeated frequently, the problems recur. If the fertility of a pest species could be impaired by an appropriate agent, together with increasing mortality, then the potential for recovery of the population would be lower. Recently, the CRC Vertebrate Biocontrol Centre formulated an approach which aims to reduce fertility to a level which would prevent population growth (Tyndale-Biscoe 1994, 1995). For the rabbit and wild mouse, the approach involves delivery of a gene expressing an essential species-specific reproductive protein in a species-specific virus, such that, when the host is infected by the recombinant virus, its immune system raises antibodies to the same proteins in its reproductive tract, blocking reproduction. Thus, if the animal does not die from the viral infection it will be rendered infertile (Tyndale-Biscoe 1994, 1995). This approach is under development with some very promising results for a laboratory mouse model. For the fox, no specific fox virus has been isolated and the approach is oral delivery of the sterilising agent expressed by recombinant bacteria in a bait (Bradley 1994). Clearly, the aim is to produce a species-specific effect which will have a significant impact on the pest species without any effects on non-target species.

This approach is high risk, in terms of achieving a practical outcome, requiring a multi-disciplinary research team to focus on all levels of the problem (molecular biology, immunology, virology, reproductive biology, field ecology and population modelling) and long term funding.

The European carp, *Cyprinus carpio*, also introduced in the mid 1800s, is present in many of the river systems of Australia, including the waterways of the Murray–Darling Basin. It is widely viewed as a major pest – ‘the

underwater rabbit' – although its impact on the river systems and their flora and fauna has not been demonstrated unequivocally. Is fertility control feasible for carp?

Outlined below are some of the issues which must be considered before such an approach could be adopted. We consider the relevant attributes of immuno-contraception, the potential methods for compromising the fertility of carp and the options for delivery systems. One possible dissemination method is to use a genetically engineered pathogen but there is limited epidemiological information to assess the potential for this mode of delivery. With present information on carp population biology, a preliminary assessment of the efficacy of fertility control may be feasible. The data requirements for a predictive model are discussed in terms of general ecological theory and with reference to recent published models from overseas.

### ***Attributes of Immuno-contraception as a Management Technique for Carp***

Any immuno-contraceptive agent should demonstrate several essential characteristics before it can be considered acceptable for the management of a particular pest. In this instance, the target reproductive protein (or antigen) must be specific to carp, that is, show no cross-reaction with non-target species. The immuno-contraceptive antigen must induce and sustain an effective immune response which affects fertility to a level which reduces the abundance of carp to below damage-related thresholds.

If the antigen is delivered using a pathogen or other vector, the delivery system should also be specific to carp and there should be limited opportunities for evolution of host resistance to the antigen or the vector.

Further, the delivery of the antigen should be technically straightforward, cost-effective and humane, and should reach a large proportion of the target population. A self-disseminating delivery system could meet these prerequisites, although this is likely to require the release of genetically

modified organisms (GMOs) into the environment (and into a source of food for humans). For alternative non-disseminating systems where the antigen may be delivered in a bait, it is essential that no toxic chemical residues be released into a food source for humans and the environment generally.

### **Candidate Reproductive Antigens**

Carp are highly fecund, with females producing >1 million eggs during spawning; under ideal conditions more than 90% of these eggs are fertilised and more than 80% hatch. Survivorship of fry is also high under such conditions. The life span of carp in Australian waters is reputed to be up to 20 years.

Primary sites in the reproductive system which may be targeted to impair fertility include the development of the gametes and the function of the gonads. In particular it may be possible to target primary germ cells and disrupt normal sperm or oocyte development (gametogenesis). In the testis, disruption of the maturation of sperm within the male reproductive tract could be feasible. In the ovary, it may also be possible to disrupt final maturation stages of the oocyte, including egg investments and development of the micropyle, as vitellogenesis (yolk formation) proceeds. Vitellogenin synthesis in the liver and/or uptake by the follicles in the ovary could be impaired at several different stages.

At another level, the hormonal feedback loop of the hypothalamic–pituitary–gonadal axis could be perturbed by inhibiting the release of gonadotrophin-releasing hormone from the hypothalamus or of the gonadotrophins from the pituitary. This would interfere with the normal steroid synthesis patterns essential for the normal function of the gonad and for maturation of the gametes. Such an approach, however, is not ideal because these hormonal pathways are not species specific.

The potential outcomes of any reduction in the efficiency of the process of gametogenesis could be fewer eggs (ovulation blocked) and/or sperm, eggs

and/or sperm with impaired function (fertilisation blocked; adhesion of eggs to substrate impaired; embryos non-viable), or an altered sex ratio of offspring in favour of males.

If the fertility of the carp cannot be reduced to a level where the abundance of carp is at or below an acceptable level, an alternative or additional method may involve affecting the viability of the growing hatchlings. This could be achieved by disrupting critical growth and developmental processes under the control of other hormones, such as growth hormone and/or thyroid hormone.

### **Potential Delivery Methods**

Several delivery methods for an immuno-contraceptive antigen can be proposed. These include baits which contain only the antigen or baits that include non-disseminating pathogens which have been genetically engineered to carry the gene for the antigen. Baits would need to be designed to match the feeding behaviour of carp (for example, buoyancy-adjusted microcapsules) to ensure ingestion by non-target species did not occur.

The use of species-specific self-disseminating pathogens (viruses, bacteria, parasites) which have been genetically engineered to invoke the immuno-contraceptive response are considered the ideal delivery system. At this stage no self-disseminating pathogens specific to carp are readily identifiable, although *Rhabdovirus carpio* has been suggested as a candidate biological control agent (Brown 1996, see Crane and Eaton). Potentially, an engineered pathogen may be able to combine the advantages of lethal and fertility control. However any system which requires the release of GMOs into the environment raises ethical and safety concerns in the national and international community (Tyndale-Biscoe 1995). The risks and benefits of any such release would need to be assessed.

Clearly there are many factors which may limit the effectiveness of any biological control agent. In this instance, the immuno-contraceptive agent



and the delivery system will need to function in a reasonably wide range of environmental conditions (eg, water temperature, pH, dissolved oxygen, salinity). The selection of a disseminating pathogen as a vector would require one which is species-specific, or at least did not affect native and commercial fish species in Australia. It would be necessary that the pathogen did not affect marine organisms, otherwise containment within Australia could not be guaranteed.

If the effect on fertility is not permanent then the frequency of application of the control would be influenced by such factors as the duration of infertility and the frequency of spawning.

## **Modelling**

Given the lack of information on ecological processes determining the distribution and dynamics of carp populations in Australia, these core data must be collected. Recent epidemiological modelling for marine and freshwater systems is very limited. Morand (1995) developed epidemiological models for fish pathogens, and Grenfell *et al.* (1992) constructed a model for phocine distemper virus in seals but this was based on contact rates at haul-out sites.

A basic model for a micro-parasite (viruses and bacteria) would require estimates of case mortality, duration of latent and infectious periods, duration of immunity (if any), presence or absence of a carrier state, and the transmission rate. The transmission rate is a key parameter which is usually least understood and poorly quantified, but it can be estimated indirectly.

Models for macro-parasites (eg, cestodes) are invariably more complex (see for example, Morand 1995). Consequently, epidemiological models are likely to have little quantitative data to predict patterns of disease, threshold host densities and impacts on carp population dynamics.

## Population Dynamics and Management

The dynamics of carp populations depend on regulatory processes, that is, those which act in a density-dependent way (Sinclair 1989). Without density-dependence, carp populations would either increase without limit or decline to extinction. For most fish species, it is assumed that juvenile mortality is density-dependent (Sinclair 1989) and adult mortality is density-independent (Charnov 1986). The outcome of any control technique will depend on the life stage that is targeted and how this interacts with regulatory processes.



The review of carp biology by Brown (1996) suggests several regulatory mechanisms might apply for carp populations in Australia. Growth is variable and depends on the availability of food, with temperature setting a density-independent threshold. Maturation is correspondingly variable and appears to depend on males and females attaining size thresholds. Egg production is also size-dependent. There is little information on causes of mortality although the observation that only large carp are found in dried-up waterways suggests size-dependent mortality may apply.

A model constructed by Jensen (1993) for walleye (*Stizostedion vitreum*) in Lake Erie includes all the above features and gives some indication of how fertility control might apply to carp in Australia. Food-limited growth, with maturation and egg-production dependent on size, are density-dependent processes which will result in the rate of increase declining to zero at carrying capacity. The approach to carrying capacity may be monotonic or the population may cycle around an equilibrium level if there are lags induced by any of these processes. For example, a low mortality rate for mature fish generates cycles whereas high mortality for this age class results in a rapid adjustment to equilibrium and no cycles.

In a more variable environment, a stable equilibrium or cycles around a carrying capacity, may never be observed, but the same density-dependent

processes will govern the population dynamics. In Jensen's (1993) model, variation in egg survival generated limited variation in population size. The addition of independent variation in larval survival resulted in substantial variation in population size. When size-dependent mortality was imposed, there was little fluctuation in population abundance regardless of variation in either egg or larval survival. However, with this last constraint the model's results were considered by Jensen (1993) not to correspond to observations of natural populations. Two important points emerge. Firstly, density-dependence tends to damp out the effects of changing egg or larval survival. Secondly, size-dependent mortality which favours large fish would almost completely negate any effects of egg or larval survival on the variation and mean abundance of the adult population.

The effect of fertility control is similar to a reduction in egg or larval survival. If carp populations are regulated by similar processes as the walleye, then Jensen's (1993) model predicts that any reduction in the level of fertility will not produce a commensurate reduction in carp abundance. This does not rule out immuno-contraception as a potential control technique. It just means that higher than expected levels of infertility may be required to have any useful effect. Similar caveats will apply to lethal control methods (Sinclair and Pech 1996).

Other trophic interactions may enhance the value of fertility control. Food availability will be affected by competitors and mortality can be increased through predation by fish, birds and humans. The observation by Brown (1996) that an increased abundance of carp has not resulted in more predatory fish tends to suggest that carp may be secondary prey. If this is true then predation should be capable of driving low density carp populations to extinction. However once carp populations exceed a particular threshold density, predation will have no regulatory effect (Pech *et al.* 1995). The pattern in Australia of a limited initial spread followed by a dramatic increase in the abundance of carp (Brown 1996) appears

consistent with predator-prey models where carp are secondary prey.

The value of fertility control for the management of carp depends partly on the technique's effectiveness at reducing the abundance of carp and partly on the level of control which is required. Development of effective fertility control techniques will need a multi-disciplinary research effort in molecular biology, reproductive physiology and ecology, as well as an understanding by managers of the threshold density below which carp cease to be a significant cause of damage to the biotic and abiotic environment.

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## **Discussion:**

### **Immuno-contraceptive control**

THE EFFECTIVENESS OF IMMUNO-CONTRACEPTIVE techniques as a control tool for highly fecund animals such as fish was queried. Fish typically have mortalities >99% in the first year of life and mortality is often density-dependent. Thus the progeny of a small proportion of the spawning population may have the potential to maintain recruitment if a significant increase in juvenile survival occurs. Marine studies suggest a 50% reduction in fecundity has virtually no effect on population size. Research is needed to assess if density-dependence and compensatory processes are important factors in carp recruitment. Carp are not usually piscivorous, but they do eat their eggs. Competition for food may be significant. Inter-specific competition is poorly understood and if fewer young are produced, predators may switch away from carp. It is unclear if juvenile mortality is driven by predation or environmental processes. The need for information on carp biology and population dynamics was again stressed.

Species-specific aspects generated much discussion. Whereas most genetic manipulations were highly specific, they had not yet been tested in fish. If baits were used as a vector, how could they be made carp specific? Would carp/goldfish hybrids be vulnerable? Would carp develop an immune

response? There was insufficient information to adequately answer these questions. The spatial problems in effectively delivering the agent within the carp's distribution range were debated. A gradual application running over at least 10 years was probably needed, but modelling was required to more accurately determine the time-span. Strategically targeting key recruitment sources and events would probably be the most effective method. Hence, there was a need to better understand the carp's reproductive dynamics and behaviour. If successful recruitment years can be predicted, this would improve delivery efficiency. Carp normally spawn in spring and there is evidence for a second spawning in early autumn, with water temperature probably being an important stimulus. It is unclear if they pair-off or are group spawners, although the latter has been observed. Under flood conditions, carp often spawn well away from the river channel.

The rapporteur noted that these techniques had currently only been used with mammal pests and not fish species. Whereas fish did not attract the same humane issues as mammals, this may not be so in the near future. Ideally, a carp-specific antigen and vector are desirable, but cyprinid-specific may be sufficient in Australia. Obtaining better population dynamics information was a major issue in determining the potential of immuno-contraceptive techniques and the proportion of the population that should be targeted.

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# Potential of molecular approaches for the environmentally benign management of carp

*Peter Grewe*

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## **Introduction**

Advances in molecular biology mean there are now a number of different molecular approaches for control, and possible eradication, of pest populations. Ones relevant to carp *Cyprinus carpio* L. in Australia include chromosomal manipulation, gender manipulation (via hormones and transgenic methods) and the introduction of inducible fatality genes via transgenic methods. These methods can be briefly summarised as follows.

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*chapter NINE*

### ***Ploidy / Chromosome Manipulation***

Manipulation of ploidy levels, for example triploidy induction, can be achieved by blocking extrusion of the polar body. This method is primarily used to induce sterility in production line fish (Cassani and Caton 1995; Allen *et al.* 1996).

### ***Controlling Sex Composition of Populations***

Single sex or homozygous populations can be achieved by treating gametes prior to fertilisation under controlled (laboratory) conditions. Gynogenesis is achieved by fertilising eggs with sperm that have been UV irradiated. This results in all-female lines through blocking the polar body extrusion (heterozygous gynogen) or the first cell division (homozygous gynogen). Androgenesis is achieved by using gamma-irradiated eggs which results in blockage of first cell division and produces homozygous male and female lines. These manipulations are useful for rapid production of pure and inbred lines (Nagy *et al.* 1984, Nagy 1987, May and Grewe 1993). The advantages of producing monosex lines of fish include faster growth rates of female carp while male fish mature more quickly but at smaller sizes.

### ***Hormonal Treatment***

Treatment with the male hormone, testosterone, can produce all male fish, some of which are chromosomally female (XX) but function as fertile males. These functional males can be crossed with normal XX females to produce 100% female lines. Again if faster growth rates are required, production line fish which are 100% female would have an advantage over a mixed sex group of fish (for review of treatments see: Grewe, 1996).

### ***Transgenic Manipulation***

Genes which do not normally occur in a target species but which have specific effects can be inserted deliberately. Examples of this are the incorporation of rainbow trout growth hormone into coho salmon, and the inclusion of human sex determining gene into XX mice to produce functional male mice (Koopman *et al.* 1991).



According to a recent evaluation (Grewe 1996) of these four, only the inducible fatality gene (IFG) offers any real prospect for long-term control or even eradication of carp. In relation to the other methods, this report stated that:

Chromosomal methodologies appear to offer only short term control of carp populations. Altering sex ratios can also produce short-term benefits; however, population models indicate that using this approach XX females persist in the population, although at reduced absolute numbers, so that eradication is not possible. Consequently, neither chromosomal nor gender manipulation strategies appear to constitute a means of locally eradicating carp, though the techniques may still be useful as a means of augmenting other approaches.

Reasons for considering IFG over other approaches were mainly related to its long-term application and its potential for 100% security, if correctly implemented (Grewe 1996). Species-specificity and the impossibility of developing immunity, which are both positive reasons for using an IFG approach, are in fact common to all genetic manipulation approaches. Because technical aspects of the IFG approach are given already (Grewe 1996), this paper concentrates on general aspects of IFG as an approach.

Note that all forms of control relying on genetic manipulation are required to meet certain ethical and/or legal standards. However, these are not considered further here.

## **Overview of the Inducible Fatality Gene (IFG) Approach**

The IFG approach has distinct stages or steps. These are: identification and selection of appropriate genetic material for transfer, which must include the fatality gene and a reporter gene (see below); incorporation of this genetic material into the individual genome; delivery of genetic material at a population scale; monitoring the spread of IFG through natural populations via the reporter gene; pulling the trigger to activate the fatality gene once pre-determined levels of introgression have been met. Each of these presents its own technical, and logistical, challenges.

The complete sequence from first to last step has not yet been implemented full-scale to control a problem species. As each step is critical to eventual success of the control method, some of the technical considerations are outlined below.

### ***Finding a Fatality Gene***

One possibility is ricin, a protein found in the seed coats *Ricinus communis*, the castor oil plant (Olsnes and Pihl 1982). Ricin is highly toxic to eukaryotic cells and acts by interrupting protein synthesis. Interest in the potential use of this protein stems from the fact that it consists of two chains, alpha and beta. The alpha chain is cytotoxic and will cause death to the cell in which it is produced.

The potential for using ricin in biological control would thus comprise the alpha chain linked to a promoter in a transgenic construct. Once activated, however, the gene would kill the cells in which it occurred. One benefit of this would be that, even if ingested, the dormant stage would not be fatal to other organisms due to the lack of activity.

### ***Finding a Mechanism to Control and Regulate Expression of the Transgene***

A number of promoters are known for use in regulating gene expression in fish, including in carp:  $\beta$ -actin promoter, anti-freeze protein promoter, and metal inducible metallothionein promoters.

Metallothioneine is a good example of a promoter used in transgenic manipulations of carp. It works through simple dietary supplements, with the gene producing low molecular weight proteins which bind heavy metals such as zinc, cadmium, and copper. This promoter activates a gene in the presence of these heavy metals such as zinc which can be deliberately introduced as a dietary supplement. Its use, therefore, as a promoter gene is limited to those environments with an already low concentration of zinc. Other fish eating the same feed would not be affected as they do not have the transgene.

### ***Getting the Transgene Construct into the Genome***

Getting the transgene construction into the carp genome then effectively spreading it through the fish population is a three-stage process.

The first stage is getting it into the carp genome; this can make use of standard manipulation techniques such as micro-injection, electroporation, Baeckonization and biolistics. Although described as standard, their usefulness, success and applicability for a pest control program is not assured: for example, micro-injection is time-consuming and more of an experimental technique; retro-viral infection cannot at this stage be guaranteed as species-specific. Refinement of existing techniques, most probably biolistics, would be required for large-scale production. Other refinements that are needed are to experimentally determine what are the optimal quantities of DNA to be used.

The second and third stages are logistic and implementation challenges which include the creation of a hatchery population that is homozygous for the transgene followed by the stocking of these fish into the wild. Setting realistic numbers for each of these means investigating the interplay between number of modified carp introduced, breeding rate, movement, and requires sufficient knowledge of carp number and dynamics to develop a simple but realistic model. For example, Grewe (1996) used a simple spreadsheet model to explore introgression rates in a hypothetical closed system with a modest carrying capacity of 100 000 carp. Initial stocking rate and size/age of fish stocked were shown to be the most critical factors: 'Achieving adult populations that are 50% transgenic requires many more than 50 generations at stocking rates less than 1% but only 1–2 generations at stocking rate of 20%' (Figure 1 in Grewe 1996).

### ***Monitor and Trigger the Transgene***

This requires monitoring the spread between-populations and abundance within-populations of transgenic fish as indicated by the reporter gene. Then, when the pre-determined target introgression levels have been reached, whether 40% or 60% or 90%, there will be a logistical exercise of

activating the fatality gene, followed by whatever mopping-up exercises may be necessary.

### **Information Gaps**

The outline above relies on assumptions and reveals how little of the necessary information is available for properly assessing both the impact and effectiveness of the IFG approach. Other basic biological variables are also required which relate to modeling and to genetic diversity; these are critical for fisheries management agencies wanting to determine impacts of any proposed actions (Table 9.1). Only a few of these are known already. Modelling ones are self-explanatory; with genetic diversity, the critical issue is: are the carp effectively one population within the Murray–Darling Basin; is this a single interbreeding population; if not, then how similar are the sub-populations in terms of migration and movement into new areas?

In addition to these knowledge gaps on carp in Australia, there are four main technical challenges to overcome:

- Availability of brood females for experimental embryos
- Promoter/Transgene Construct (inducibility) requires development
- Delivery System for effector molecule
- Rate of introgression.

As regards the last, rate of introgression, first-pass estimates suggest that the system at present appears to require up to 28 generations for 100% introgression (Grewe 1996) which is quite long. Methodologies which could be implemented to expedite this rate are:

- implanting multiple copies of the transgene in the carp genome
- exploiting the shooting phenomenon observed in carp (Andrew Sanger, pers. comm.). Essentially this would entail stocking large fish which should then exhibit exponential growth rates compared with fish of equal age.

**Table 9.1** Information gaps for two areas critical for assessing potential for genetic modification for controlling carp

<b>Information Gaps</b>	
Modelling	<ul style="list-style-type: none"> <li>– carrying capacity</li> <li>– processes related to density dependent / independent effects on mortality and fecundity</li> <li>– age class structure</li> <li>– growth rates</li> </ul>
Genetic Diversity	<ul style="list-style-type: none"> <li>– number of reproductively isolated strains</li> <li>– distribution of genetic strains and their behaviour</li> <li>– degree to which strains hybridise naturally</li> <li>– rates of gene flow between strains</li> </ul>

- examine different stocking strategies to improve survival of implanted fish
- improve husbandry skills to enhance growth rates in the hatchery (ie, use growth hormone in the food to increase growth).

## **Management Implications and Recommendations**

Integrating a genetic weakness into wild populations via the stocking of transgenically modified fish containing an inducible fatality gene (IFG) appears to be a viable, if perhaps long-term strategy for the environmentally benign control, and perhaps eradication of the carp from Australian waters. Development of a broodstock of fish containing the IFG appears to be technically feasible given the current state of molecular biology. Refinement of an optimal inducible promoter and development of an efficient delivery vector for the effector molecule are components of a successful system that require development. These are not trivial tasks, but they appear to be quite achievable, given the current state of technology. Development of an IFG system for carp could be done in 3–5 years. Integration into the wild population would then depend on ecological variables and the efficiency of stocking strategies.

The long-term nature of developing and then integrating the transgene into a wild population prior to induction is perhaps less immediately appealing than currently applied methods, such as application of toxicants and physical removal, which produce rapid and highly visible results. However, such methods often have highly undesirable side-effects on other components of the ecosystem, and very often do not constitute a long-term solution. As well, a variety of techniques can potentially be used to accelerate the development and optimization of some components of an IFG-based approach. For example, there are well-established husbandry techniques for carp that could be used to substantially reduce the time taken for fixation of the IFG in brood stock, such as reducing age at sexual maturity, shifting sex ratios to, potentially, all male broods, and increasing the size at stocking of transgenic fish relative to wild fish. Optimization of grow-out techniques is also likely to minimize developmental and stocking costs.

Time to full integration into the wild population could also be reduced by incorporating several IFG constructs in different chromosomal locations. Stocking a fish that has 10 unlinked homozygous chromosome locations of the IFG would be as effective as stocking 10 fish, each with a single IFG construct. To an extent, creation of multiple carriers of the IFG is highly likely in any case during the initial development of the transfected fish, as the probability of integrating the construct in the exact same chromosome location in all individuals is very low. Inter-breeding of the transgenic brood fish would effectively achieve offspring with multiple copies, thereby accelerating incorporation into the wild target population relative to the rates suggested (Grewe 1996).

More realistic estimates of basic ecological and biological variables for carp than those used in the model would also streamline any stocking program and maximize IFG introgression. Variables such as carrying capacity of various age classes, timing of spawning, fecundity, age class structure, and mortality schedules will facilitate accurate modeling as well as assist with determining the feasibility of any stocking strategy.

## Acknowledgements

Brad Evans assisted with review and summary of pertinent literature examining methods for genetic manipulation of carp. Michael Fietz provided suggestions and invaluable discussions. Bob Ward and Ron Thresher provided editorial input on the initial drafts of the technical report.

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## **Discussion: Genetic Manipulation**

IT WAS NOTED that this technique has not been used with fish and there were many critical questions requiring research. It was initially conceived as a method to control escapees from aquaculture establishments. At present, there are too many variables to accurately predict a time-span for development.

The logistics of employing this technique were discussed. As there are many millions of carp in the wild, quite large releases of transgenic fish would be needed to achieve the desired flow-on through the population(s). Large-scale (>10<sup>6</sup>) hatchery production of carp is feasible at reasonable cost. A focussed stocking strategy targeting specific areas should probably be used, rather than attempting wide-scale releases.

The question of ecological timing was noted. There were probable benefits in targeting poor recruitment years. Possible problems with the reduced fitness of hatchery fish as against wild fish were discussed, as it was obviously desirable to have transgenic fish surviving and spawning over as long a time as possible.

Possible promoters were discussed and baits could be used as an alternative to wide-spread substances in solution. It was agreed that whereas the method requires two delivery processes, this had some advantages, the most notable being that because of the trigger system, this technique would not be genetically selected against. Localised targeting could also take place. A reporter gene could be used to determine the level of gene flow into the wild population and the point at which to use the promoter. Reporter genes also had potential usefulness in estimating some population parameters, such as biomass and mortality.

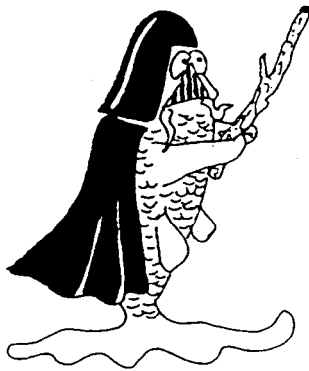
What would happen to predators eating 'toxic' carp? The substance is trapped in carp (ricin) and will not transfer to other animals. Discussion on public acceptance noted that considerable public education would be needed to gain acceptance; first, to justify stocking a perceived pest as a



control measure and second, to ease fears about genetic engineering. The logistic implications of possible massive carp kills also need consideration.

The chairperson noted that there were several technical hurdles to be overcome and research cost predictions were required. There would also be public relations issues to contend with, including the release of genetically modified fish and the impact of massive, widespread fish kills. The need for carp population structure knowledge is fundamental to this and other methodologies and successful development may be several years away and even longer for implementation. With all control measures, an integrated approach is required.

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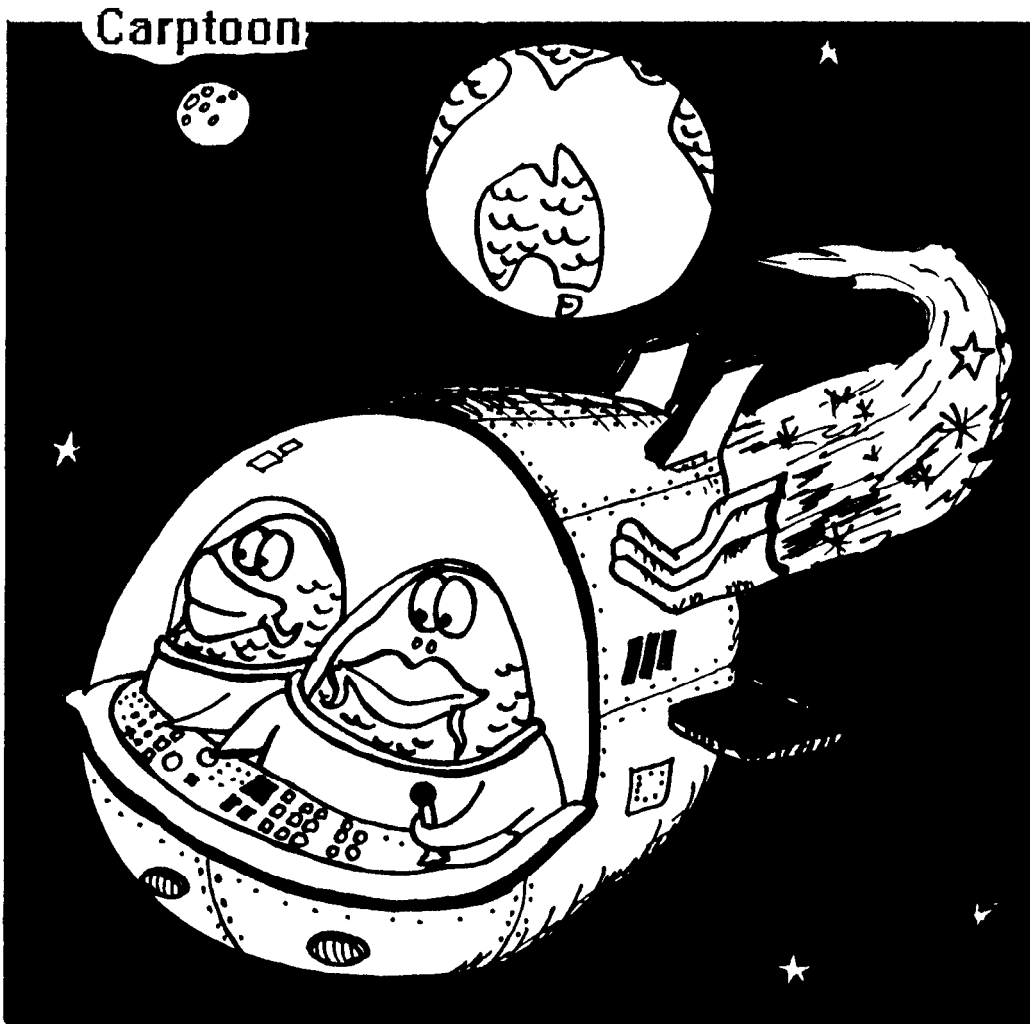
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