Forum Proceedings: Carp management in Australia — state of knowledge

Melbourne, 19-20 June 2012

Edited by Wayne Fulton and Kylie Hall

Invasive Animals CRC

Australian Government
Murray–Darling Basin Authority

An Australian Government Initiative
CRC Australia

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Hosted by the Invasive Animals Cooperative Research Centre
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Front cover photo: Juvenile carp. Image: Inland Fisheries Service, Tasmania

Contents

Carp in Australia

Carp were first introduced to Australia more than 100 years ago. Several stains of carp, originating from both Europe and Asia can now be recognised from wild populations. Carp are now widely established throughout the Murray-Darling Basin and can also be found in all states and territories except the Northern Territory. Carp are very common in parts of this range in Australia and are considered to be one of our major pest fish species.

Carp are known as a generalist species because they tolerate a wide range of conditions and habitats. However, they usually prefer slow-moving rivers or lakes with soft vegetated sediments. Their tolerance of a wide range of habitats means that they are less affected by habitat disturbance than many native species. They normally live in a preferred temperature range of around 15–32°C, but are able to survive in a wide range of temperatures, including ice-covered lakes (at about 2°C) and much warmer ponds (up to about 40°C). Carp are able to tolerate poor quality water with low oxygen levels, and water that is slightly salty. In Australia, carp are generally rare at high altitude and uncommon in clear, fast-flowing streams. Juvenile carp are usually found strongly associated with aquatic plants in marsh areas or river backwaters for the first year of their life.

Carp feed by sucking soft sediment from the substrate into their mouths, where food items are separated and retained and the sediments are ejected. This habit often leads to a suspension of sediment in the water where carp are feeding. This feeding method also means that carp prefer areas with soft sediment, such as slow river pools and backwaters or lakes and ponds. This feeding habit is likely the cause of their main environmental impacts.

Many of the claims regarding carp's environmental effects are difficult to confirm because of the lack of information on waterway health before their introduction. For many waterways the decline in habitat quality took place before the presence of carp — due to activities such as catchment clearing, removal of bankside vegetation, de-snagging, stream channelisation, pesticide use and overfishing of native species. However, when a species makes up more than 80% of the biomass at some sites, as has been recorded for carp in Australia, it is difficult to believe that their environmental impact will not be significant.

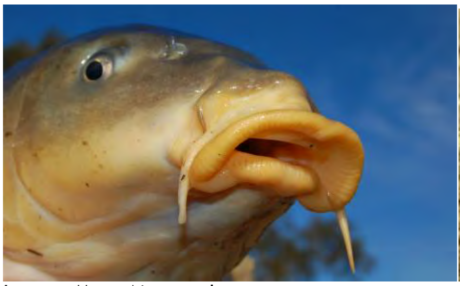

Image: Marc Ainsworth

Image: 'Fresh Fishing - the carp' *(www.freshfishing.co.uk)*

Ed note: Throughout this document the term carp, when used in a general context, refers to *Cyprinus carpio* L. and its various subspecies. In Australia this species is known by a variety of common names such as European carp, common carp and koi carp. A European/Asian subspecies (*C. carpio carpio*) and an east Asian subspecies (*C. carpio haematopterus*) are now generally recognised although some papers in this proceedings may refer to other sub-species. Also note that the title of the article in the Program at pps 7-8 may differ from the final written title as received from the author/s. The presenter at the Forum was the person listed in the Program.

Introduction to the Carp Forum

Heleena Bamford

Murray Darling Basin Authority

On behalf of the Murray-Darling Basin Authority, I would like to welcome you to three days of all things carp.

Most Australians rate carp right up there with cane toads and cockroaches; loved by some hated by most; prolific, pesty and not very pretty. The love-hate relationship between Australians and carp is an interesting study in contradiction. On one hand many of our actions favour carp greatly. We brought carp into Australia, established them in our rivers and then created some really perfect conditions for carp to breed and flourish. On the other hand carp are also hated by many and seen as the great villain in our rivers. They are often blamed for everything that is wrong with rivers and there is a very strong desire to get rid of them.

One would good thing that does come out of that intense dislike is a quest for more knowledge about the ‘enemy’. Carp could actually be considered one of the most studied freshwater fish in Australia. This is crucial however, as only through knowledge, research and testing are we going to be able to find practical solutions to the problems caused by carp.

For the past seven years the Invasive animals Cooperative Research Centre has undertaken a pretty extensive programme of carp research. At the same time many other organisations have also achieved significant advances in our knowledge and management of carp. We have come a long way. We do know a lot more about carp than we did 10 or even five years ago. However, it is still important that we continue to seek new and innovative solutions to deal with carp.

In the meantime, we still also have to deal with the problem that we have in front of us, right here, right now. And we have to do this with the tools and knowledge that we have available to us here and now as well. On-ground carp control efforts are important and it is imperative that the experience gained from these attempts is shared.

New knowledge is important. But new knowledge has no value unless it is shared, tested and recorded. So this forum is an important part of that cycle. So once again I would like to welcome you to the carp forum. I hope you'll find the next few days interesting, informative and a little bit inspiring.

Forum program

DAY 1 **Tuesday 19th June, 2012**

Time	Speaker	Organisation	Talk title
8.35-8.45	Bamford, Heleena	MDBA	Welcome to forum
8.45-9.00	Fulton, Wayne	IA CRC	Introduction and summary
Biology and impacts			
9.00-9.30	Koehn, John	DSE Victoria	The biology, ecology and vulnerabilities of carp
9.30-9.50	Gilligan, Dean	NSW DPI	The impacts of carp: Destructive ecosystem engineer or aquatic whipping boy?
9.50-10.10	Bamford, Heleena	MDBA	History of management and control of carp in Australia
Prevention, detection and planning			
10.10-10.30	Fulton, Wayne	IA CRC	Planning a pest fish management program
10.30-10.50	**Morning tea**		
10.50-11.10	Krug, Brigid	NSW DPI	Carp management in New South Wales
11.10-11.30	Clunie, Pam	DSE Victoria	Towards national emergency response arrangements for freshwater fish incursions in Australia
11.30-11.50	Acevedo, Silvana	DSE Victoria	Decision support tool for the mngt of freshwater fish incursions in Aust
11.50-12.10	Chadderton, Lindsay	The Nature Conservancy USA	Application of environmental DNA detection methods in mngt of aquatic invasive species
12.10-12.30	General Discussion		
12.30-1.15	**Lunch**		
Carp management case study			
1.15-2.00	Wisniewski, Chris Diggle, John	Inland Fisheries Service, Tas	The biology, management, control and eradication of carp populations in Tasmania
Control options — Containment, Regulators, Carp Traps and Screens			
2.00-2.20	Beesley, Leah	DSE Victoria	Minimising carp recruitment during environmental water delivery into wetlands in the southern M-D Basin
2.20-2.40	Hillyard, Karl	Dept for Water, SA	Improving the effectiveness of carp screens and guidelines to inform carp management options at wetland inlets
2.40-3.00	Conallin, Anthony (Rex)	Murray CMA	Carp trapping — modernising an age-old technique to control an invasive pest
3.00-3.20	**Afternoon tea**		
Control options — Fishing			
3.20-3.40	Bell, Keith	K & C Bell Global	Commercial carp harvesting
3.40-4.00	Norris, Andrew	Queensland DAFF	The role of fishing competitions in carp management
4.00-4.20	Jackson, Peter	Consultant	Challenges with the euthanasia and disposal of carp and potential ways forward
4.20-4.40	Brown, Paul	DPI Victoria	CARPSIM: Modelling the outcomes of fishing, water draw-downs, and biological carp control actions at a catchment scale
4.40-5.00	Collins, Christopher	VRFish	Carp from a recreational angler's perspective
5.00-5.30	General Discussion		

DAY 2 Wednesday 20th June, 2012

Time	Speaker	Organisation	Talk title
Control options – Use of poisons			
9.00-9.30	West, David	DoC, NZ	Freshwater toxins: The New Zealand experience
Control options – Predation			
9.30-9.45	Doyle, Katherine	IA CRC (PhD)	Can native predatory fishes control invasive carp in *SE* Australia?
Control options – Attractants/Repellents			
9.45-10.00	Patil, Jawahar	University of Tasmania	Two and a half tales of deception – integrated use of odour-donor and sterile Judas fish for carp control
10.00-10.15	Elkins, Aaron	IA CRC (PhD)	Environmental attractants: Isolation and identification
10.15-10.30	Thwaites, Leigh	SARDI	Carp acoustics: Attractants and repellents
10.30-10.50	Morning tea		
Future options			
10.50-11.10	Chadderton, Lindsay	The Nature Conservancy USA	Promising new developments in the containment and control of aquatic invasive species – some Asian Carp Control Strategy Framework initiatives
11.10-11.40	McColl, Kenneth	CSIRO	Koi herpesvirus: its potential as a biological control agent for carp in Australia – an Invasive Animals Cooperative Research Centre (IA CRC) project
11.40-12.10	Thresher, Ron	CSIRO	Daughterless technology: A recipe for eradicating carp in Australia
12.10-12.30	General Discussion		
12.30-1.15	Lunch		
1.15-1.30	Asmus, Martin	NSW DPI	Identifying significant hotspots of carp recruitment offers opportunities for the control of carp populations
1.30-1.45	Ling, Nick	University of Waikato, NZ	Get out, stay out! Restoring a small New Zealand floodplain lake: removal and exclusion of carp
1.45-2.00	Daniel, Adam	University of Waikato, NZ	How not to mess up a carp telemetry project
2.00-2.15	Crook, David	Charles Sturt University	Identifying key recruitment sources of carp using otolith chemistry analysis
Education and extension			
2.15-2.30	Hall, Kylie	IA CRC	Overview of the Invasive Animals Cooperative Research Centre Freshwater Program pest fish research extension activities
2.30-2.45	Wells, Adrian	Murray-Darling Association	Carp outreach, engagement and extension: Past, present and future
2.45-3.00	Afternoon tea		
Discussion and forward planning			
3.00-5.00	General Discussion		

The Invasive Animals Cooperative Research Centre Freshwater Program – Carp

Wayne Fulton[1]

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(wayne.fulton@invasiveanimals.com)

Background

The initial focus of the Invasive Animals Cooperative Research Centre's Freshwater Program was to develop an Integrated Pest Fish Management Plan for the Murray Darling Basin.

The IA CRC first Operational Plan for July 2005 stated;

"*The main focus of the Freshwater Program is the control of high profile invasive fish in the MDB … the overarching goal of the Program is an integrated pest fish management strategy for the MDB. This will involve developing and testing of applied technologies aimed at sustainable control of priority pest fish species, layered within an integrated strategic plan specifically for the Murray-Darling Basin.*"

To address these requirements it was decided to look at the requirements of such a plan and try and address some of the knowledge gaps. There are a number of elements that need to be considered in developing such a plan. These would include the following;

- Prevention/Detection
- Control options/techniques
- Target species information
- Support framework
- Education/Community engagement

The majority of projects focussed on carp as this was the main interest of the major funder (Murray Darling Basin Authority MDBA) However, some projects were generic in nature and could be applied or easily adapted to other species. Subsequent to the commencement of the initial round of projects, the MDBA changed its own focus to look at developing its own invasive species plan internally. This changed some of the later emphasis within the Freshwater Program and also the focus of the final outputs

The overall program included the following projects, some of which had a number of elements within them and some of which took a different direction to that originally envisaged at the outset;

Prevention/Detection

- Generic rapid response plan for new pest fish invasions.

Support framework

- Mapping of pathways for implementation of control options.
- Decision support framework for pest fish incursions

Control options/techniques

- Development of 'daughterless' technology for carp control.
- Koi Herpes Virus assessment.
- Biocide evaluation.
- Development of sensory attractants for pest fish control.
- Carp trapping technologies – Lake Bonney evaluation trial
- Acoustic attractants for carp

Target species information

- Carp reproduction hotspots in the Murray-Darling Basin.
- Carp movement and migration within the Murray-Darling Basin.
- Carp population dynamics – population modelling.
- Carp vulnerability synthesis report
- Tilapia population status and population dynamics.
- Development of genetic detection method for Tilapia (eDNA)

Education/Community engagement

- Community education and engagement.
- Pest fish education and management package

Other Programs

There were also projects that focussed on carp within two other IA CRC Programs (Education and Uptake). These included 5 PhD projects;

- Population genetics of carp in the MDB
- Identifying and isolating natural environmental attractants for common carp control
- Regulation and manipulation of sex in the carp *Cyprinus carpio* (L) - Eploring RNAi and microRNA pathways
- Impact of increased predator presence through stocking on carp populations and the implications for management
- Sex differentiation and determination in the carp *Cyprinus carpio*.

Also 3 demonstration sites;

- Carp control in the Logan Albert Catchment
- Identifying and implementing targeted carp control options for the Lower Lachlan Catchment
- Carp control in lakes Crescent and Sorell, Tasmania

This Forum gives us the opportunity to extend the results of these studies and present what they mean for management of carp. We also wanted to invite others to present the results of their work as well so that we can put together the latest options for carp management in Australia

The biology, ecology and vulnerabilities of carp

John Koehn[1]

[1]Arthur Rylah Institute, Department of Sustainability and Environment, 123 Brown Street, Heidelberg, 3084, Victoria, Australia (john.koehn@dse.vic.gov.au)

Key messages

Carp have become the most abundant large freshwater fishes in south-east Australia, now distributed over an area of more than one million square kilometres. Its invasion in Australia illustrates how quickly an introduced fish species can spread and dominate fish communities. Given their historical spread, dispersal mechanisms and ecological requirements, the range expansion of carp across most of the remainder of Australia has been predicted. In order to manage this pest species, it is important to review its biology and ecology.

Carp exhibit all of the traits predicted for a successful invasive fish species and clearly differ from native fishes in their biology, behaviour, resource use and population dynamics. These traits and the degradation of aquatic habitats and native freshwater fish populations have given this species an advantage over native species. Assessment of the ecological conditions that they encountered provides important context for their management (using Pest Management Principles). Carp are a species with high environmental tolerances and climate matching predicts that almost all Australian waters appear to be climatically suitable. Their behavioural traits do, however, provide some vulnerabilities that have and are being explored for control eg feeding, schooling and jumping.

Introduction

Carp (*Cyprinus carpio*), originally native to Eastern Europe and central Asia, are one of the most successful invasive freshwater fish in the world, now occurring in parts of Europe, Asia, Africa, North Central and South America, Australia and Oceania (Lever 1996, FAO 2002). Carp have become the most abundant large freshwater fish in south-east Australia and while, to date, they have only invaded a small portion of the Australian continent, (about 1 million of 7.6 million km^2) there is the potential for future invasion of many large river systems. Given their historical spread, dispersal mechanisms and ecological requirements, indeed, the expansion of carp across most of the remainder of Australia has been predicted (Koehn 2004). Hence, it is important to review its biology and ecology. This paper examines the biological characteristics of carp as an invasive species; compares carp to native species; assesses the environmental conditions that have allowed them to flourish; and considers how these attributes can be used to manage them.

Background

Carp were first introduced to Australia on several occasions from the mid-1800s (Koehn et al 2000), with three different strains being recognised (Shearer and Mulley 1978). Carp populations remained relatively contained until the introduction of the 'Boolara' strain to Gippsland in Victoria in the 1960s (Koehn et al 2000). This strain was translocated to farm dams and then spread rapidly throughout south-east Australia, particularly the Murray-Darling Basin. Carp have achieved biomasses as high as 3144 kg/ha and densities of up to 1000 individuals/ha (Harris and Gehrke 1997) and caused much public concern. This has led to the recognition of carp as a serious vertebrate pest in Australia (Braysher and Barrett 2000; Carp Control Coordinating Group 2000a,b; Koehn et al 2000, Koehn and Mackenzie 2004).

Carp biology

Carp exhibit all of the traits predicted for a successful invasive fish species (Table 1) — that is why they are in the International Union for the Conservation of Nature's top ten worst invasive fish. They have a well-documented successful invasion history with wide distribution and abundance, wide environmental tolerances, rapid growth, high reproductive capacity, broad diet, are gregarious, possess natural mechanisms of dispersal, are associated with human activity and have relatively high genetic variability, early sexual maturity and short generation times. Their specialist feeding mechanism of sieving through the substrate allows them take advantage of potentially under-utilised resources, including detritus at a base level of the food chain. Detritus is likely to be abundant, especially given that true detritivorous fish are lacking from most Australian freshwater fish communities (Cadwallader and Backhouse 1983, Pusey et al 2004).

The ability to modify habitats and ecosystems is a trait of many successful invasive species; including carp. Carp have been shown to destroy aquatic vegetation (Roberts et al 1995) and change the composition of invertebrate communities (Robertson et al 1997) and increase turbidity (King et al 1997), thus reducing photosynthetic production and visibility for visually feeding fish. Detrital carbon, rather than passing up through subsequent trophic levels of macroinvertebrates and smaller fish may become 'locked' away from the trophic chain for their lifetime (up to 50+ years) (Koehn 2004).

Table 1. Attributes of carp as an invasive species (from Koehn 2004; see original paper for references).

Attribute	*Details*
Invasion history, wide distribution and abundance	Introduced and successfully established throughout Europe, Asia, Africa, North America, South and Central America, Australia, New Zealand, Papua New Guinea and some islands of Oceania
Wide environmental tolerances	High environmental tolerances with: temperature tolerance 2–40.6°C, salinity up to about 14 parts per thousand (0.4 seawater salinity) and pHs 5–10.5, oxygen levels as low as 7% saturation and generally occur in most types of freshwater habitat
High genetic variability	Three genetic strains in Australia
Early sexual maturity	Males at 1 year, females at 2 years
Short generation time	2-4 years
Rapid growth	Hatching of eggs is rapid (two days at 25°C) and newly hatched carp grow very rapidly
High reproductive capacity	They are highly fecund broadcast spawners with egg counts as high as 2 million per female
Broad diet	Omnivore/detritivore
Gregariousness	Schooling species
Possessing natural mechanisms of dispersal	Mobile species with fish moving between schools. Dispersal can also occur with the downstream drift of larvae. Rates of transfer can be affected by conditions such as flooding
Commensal with human activity	Bred as an ornamental and aquaculture species, used as bait and sought by some anglers

Comparison to native species

When their biological traits are compared to native species, carp clearly differ in their behaviour, resource use and population dynamics. An example of this is given for the Murray-Darling Basin in Figure 1 (see Koehn 2004 for species comparisons in other regions).

- Maximum size
- Depth position
- Behaviour
- Diet
- Feeding
- Fecundity
- Env. Tolerances
- Habitat specificity
- Habitat range
- Movement
- Dispersal
- Growth
- Physical toughness
- Adaptability
- Competitiveness

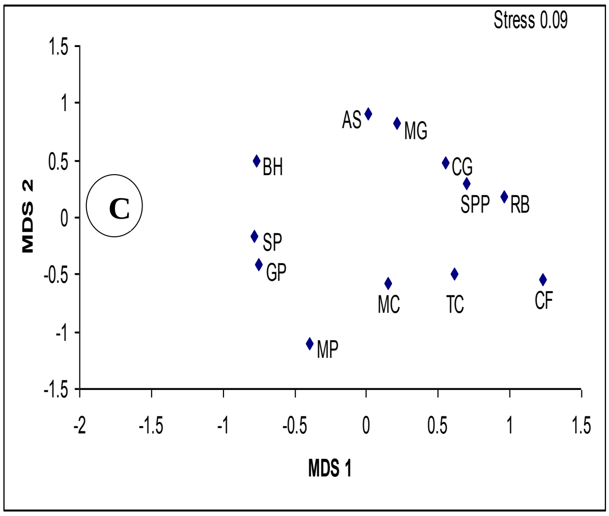

Figure 1. The similarities between carp (C) and native freshwater fish species of the Murray-Darling Basin (species names and codes are in Table 2) based on non-metric multi-dimensional scaling of attributes listed (left) for each species.

Table 2. Native fish species and their codes used for the carp-native species comparisons undertaken for the Murray-Darling Basin (refer to Figure 1).

Common name	*Scientific name*	*Species code*
River blackfish	Gadopsis marmoratus	RB
Mountain galaxias	Galaxias olidus	MG
Murray cod	Maccullochella peelii	MC
Trout cod	Maccullochella macquariensis	TC
Golden perch	Macquaria ambigua	GP
Macquarie perch	Macquaria australasica	MP
Silver perch	Bidyanus bidyanus	SP
Southern pygmy perch	Nannoperca australis	SPP
Australian smelt	Retropinna semoni	AS
Freshwater catfish	Tandanus tandanus	FC
Bony herring	Nematalosa erebi	BH
Carp gudgeons	Hypseleotris spp.	CGS

These traits, together with degradation of Australian aquatic habitats and native fish populations, have given this species a relative advantage over native species. This includes a lower spawning temperature (15–28.2°C) (Koehn et al 2000), hence earlier spawning times (Koehn and O'Connor 1990) and earlier access to resources than many native species. Carp can also take advantage of spawning areas downstream of water storages that release hypolimnetic water at temperatures too cold to permit the spawning of native species (Koehn 2001). Hatching of carp eggs is rapid (two days at 25°C) and larval growth is very rapid, enabling them to quickly escape predation pressure. An assessment of the potential impacts of the existing environmental threats to carp and native species in the Murray–Darling Basin showed that carp were much less likely to be detrimentally affected than native species (Koehn 2004).

Environmental conditions

Assessment of the ecological situation they encountered provides important context for their management and predictions of future spread. The carp invasion of south-eastern Australia occurred after there had been considerable damage to the aquatic environments present and severe reductions in native fish populations. Predation does not appear likely to be a limiting factor for adult carp in southern Australia where there are few large fish predators (Cadwallader and Backhouse 1983) and serious predation by birds is unlikely (Barker and Vestjens 1989a,b). At the time of carp introduction, most predatory native fish species had already suffered massive declines, hence, the rapid expansion of carp may have been assisted by a lack of predatory pressure (Koehn 2004). In any case, a highly fecund species such as carp may simply overwhelm predators with large numbers of juveniles, and are assisted by rapid juvenile growth rates that allow them to quickly reach a size that precludes their consumption by most predators.

Carp are a species with high environmental tolerances and climate matching predicts that most Australian waters appear to be climatically suitable for them to survive (Koehn 2004). Carp are already established in regions that encompass almost all climatic conditions in Australia. In south-east Australia, Driver et al (1997) found carp to occupy all types of habitats up to 500 m above sea level, though they were less common in clear, cool, swift-flowing waters. Koehn and Nicol (1998) showed carp to prefer slow flowing waters, including billabongs and backwaters compared to other large native species, such as Murray cod, Trout cod and Golden perch. Gehrke (1997) found increased carp numbers correlated with the amount of environmental disturbance, notably the degree of river regulation. The large number of dams and water storages in south east Australia also provide a vast array of still water habitats that favour carp (Koehn 2001).

Transfer pathways

Dispersal pathways and mechanisms are important factors assisting range expansion of invasive species (Ricciardi and Rasmussen 1998). Carp are a highly mobile species, so within catchments, migrations and downstream larval drift will be effective methods of dispersal (Koehn and Nicol 1998, Stuart et al 2001). Invasions of new catchments can effectively only occur through human intervention. Transfer of carp by anglers, either through accident or ignorance, or deliberately to establish new fishing grounds, has been recognised as a major source of invasion into new catchments both in Australia and New Zealand (McDowall 1997, Koehn et al 2000). Such actions have occurred despite the illegality of keeping, transport or release of carp in most states in Australia (Koehn et al 2000). The continued legal sale and distribution of ornamental 'koi-strain' carp in New South Wales has severe implications for carp dispersal in south-eastern Australia and it has been recommended that this legal status be changed (Georges and Cottingham 2002).

Transport vectors (Cohen and Carlton 1998), a depauperate biota and environmental disturbance (Ross 1991, Cohen and Carlton 1998) have all been suggested as reasons for accelerating invasion rates. All of these conditions are met in the Murray–Darling Basin and other regions of south-eastern Australia, providing the basis for the witnessed rapid expansion of carp.

Vulnerabilities

The current lack of realistic options for wide-spread carp control (see Roberts and Tilzey 1997) only highlights the need to use Pest Management Principles (Braysher 1993, Koehn et al 2000) and support actions of the National Carp Management Strategy (Braysher and Barrett 2000, Carp Control Coordinating Group 2000a,b) which include community support and emphasis on the prevention of future spread.

One of the potential control techniques for carp is the removal of adult fish by either commercial or recreational fishing. It has been suggested that fishing to levels of less than ten percent of original population abundance would be required to make any real impact on these fish populations (Thresher 1997). Given the remote nature and range of habitats that carp now occupy, commercial harvesting may only reduce populations of carp in certain localised areas and thus is unlikely to achieve wide-scale population reductions. Whilst the removal of carp by anglers has many benefits in terms of public education and community involvement in rivers, the impacts on populations are low (Michael Hutchison and Andrew Norris, Queensland DAFF, personal communication).

As a highly mobile, schooling species, carp can be susceptible to capture when moving. In particular, some of the behavioural mechanisms exhibited by carp have already been identified and exploited by the using of ‘jumping’ or ‘push’ traps (Stuart et al 2006, Thwaites et al 2010). Such traps have been installed for carp removal at fishways along the Murray River and on selected wetlands. As with any removal, however, assessment needs to be undertaken as to whether this can occur at the scales needed to effectively impact populations. It is unlikely that this will be achievable in the short term. Schooling and the use of radio-tagged ‘Judas’ carp has been used successfully to track and selectively remove schools of carp in Tasmanian lakes (Inland Fisheries Service 2008). The use of specific spawning habitats has be identified (Stuart and Jones 2006, Dean Gilligan, NSW DPI, personal communication) and targeting these habitats has been suggested as a potential means of control (Stuart et al 2001). Pertinent examples of this include the drying of wetlands after they become isolated. The unique feeding mechanism of sifting through substrates may also have potential for investigation.

Acknowledgments,

I wish to thank the many people with whom I have worked with and discussed carp over the years. This paper draws heavily on the contents of Koehn (2004).

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Questions

Q: What proportion of fish are large?

John: Depends on the status of the population, during the drought most of the fish were large. The growth rate of carp is very fast so after a couple of years they are outside the predation range of most fish, so the only time they are really vulnerable to predation is just after spawning.

The impacts of carp: Destructive ecosystem engineer or aquatic whipping boy?

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Carp are considered one of the world's eight most invasive fish species, are considered 'ecosystem engineers' and are considered one of the primary drivers of the degradation of aquatic ecosystems in many of the countries where they have been introduced. Poor conditions of a broad suite of aquatic ecosystem variables — from water quality to birds — have been attributed to the impacts of carp. However, for over two decades it has been questioned whether they represent 'villains' or 'victims'. At least thirty-nine studies have used manipulative experiments (either replicated enclosure/exclosure experiments, replicated pond experiments or unreplicated before-after assessments of carp eradication, control or exclusion) in an attempt to quantify the impact of carp on aquatic ecosystems. While a few of these studies have quantified an impact on one or more environmental variables, the results have been highly variable between studies. Correlative analysis of a five year data-set containing data on carp density and a broad range of environmental variables adds to this already extensive body of work. This new study contributes novel information collected from lotic waterways, and by partitioning the potential impacts of small juvenile and adult life stages. As per previous research, very few consistent negative impacts could be detected.

Based on the consensus of this large number of independent studies, it should be accepted as fact that carp might not be the ecological villains they are often portrayed to be. It is undeniable that because carp comprise such a large majority of fish biomass within river systems that they must have ecological consequences. The available scientific data suggests that their impacts are probably being masked by even more detrimental pressures acting on aquatic ecosystems.

[Abstract only provided]

Questions

Q: You mentioned the effect that increased numbers of carp had on native fish, what was the effect they had on other introduced fish like redfin?

Dean: There were very few redfin in the data set in the Lachlan so couldn't analyse it. For goldfish it was positive, conditions that are good for carp are also good for goldfish. There was no significant response for gambusia, although I can report an observation (by another person) in the Macquarie Marshes of carp herding and attacking gambusia.

Q: In relation to the observation of carp attacking gambusia do you think that was an isolated observation or do you think we have underestimated the impact they can have?

Dean: No, I think it is a rare event and all the literature on diet analysis of carp shows that fish feature very rarely in carp diet. They are known to prey on fish eggs but few adult or juvenile fish are eaten by carp.

Q: Were you saying high biomasses of carp were associated with high biomasses of native fish, do you think that had much to do with the habitat that you were looking at.

Dean: Yes, almost certainly, but I think they are collinear because they are occupying the same types of habitat rather than a direct relationship that cod and carp are there together.

Q: I would suggest there is a danger in taking information from a series of reports and coming up with facts that are not supported by real results.

Dean: I agree that there is a real risk of accepting something that is read and passing it on as fact. For the reviews that I summarised, I checked back to the original sources. But I do question that they only chose some of the studies to summarise and not all of them.

History of management and control of carp in Australia

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Summary of the topic

Early attempts to manage carp in Australia typically involved direct control in isolated habitats, with chemicals usually being the method of choice. Addressing entire river systems was seen as both impractical and prohibitively expensive. Over the last twenty years a plethora of workshops, compendia, plans, research proposals and guides have resulted as well as a national strategy for carp control. There has also been an increasing appreciation of ecological principles, including integrated pest management, adaptive management and aquatic rehabilitation. But the on-ground application of these principles has been rarely practiced, and either confused, incomplete or overly ambitious.

Local catchment and natural resource management groups are increasingly interested in managing carp at the local scale and this has triggered the development of user-friendly, step-by-step guides that outline a structured but flexible methodology that can assist decision-making about carp management; this has led to the development of numerous regional control plans. Despite a significant increase in knowledge of carp ecology and advancements in control techniques, the species is still abundant and widespread. A selection of the more important and immediate actions to advance the battle against carp include:

- ensuring rapid response arrangements are in place
- taking an holistic approach to reduce carp damage as part of overall riverine rehabilitation; identifying all recruitment hotspots
- researching and trialing the best combination of current control methods
- ensuring that ‘environmental’ watering programs do not inadvertently detract from control efforts.

The first 150 years

Although they were present in the Murray-Darling Basin (MDB) in the 1960s, the initial explosion of carp numbers in the Basin was a direct result of widespread flooding in the mid-1970s. Victoria unsuccessfully tried to contain an imported German strain in the early 1960s. While the first releases of carp appear to have had limited impact, the release of the ‘Boolara’ strain in the 1960s led to a rapid expansion of carp distribution, especially in the Murray-Darling Basin. Outside of the Basin, Tasmania did eliminate about 20 small populations in the 1970s. Attempts to introduce carp into Western Australia between 1896 and 1907 were unsuccessful, however they did become established sometime later.

State authorities only attempted direct control in isolated (mainly still water or lentic) habitats; addressing entire river systems was seen as both impractical and too expensive. Chemicals were typically the method employed to rid small dams and drainages of carp. Also, the attitude towards carp was polarised — while some regarded them as vermin, others actively imported, kept and spread them, in particular the ornamental koi strain.

Commercial harvesting was also employed by various states at different times.

Adopting a more strategic approach — a national management strategy

In 2000, the *National Management Strategy for Carp Control* was published by the Murray-Darling Basin Commission (MDBC). Its goals were to:

- prevent the spread of carp; reduce impacts to acceptable levels
- devise environmentally and socially acceptable methods of control
- improve community understanding of carp impacts
- ensure efficient use of public resources.

This Strategy recognised and prescribed roles for the range of stakeholders interested in carp management — including land, water, fisheries, environment protection and nature conservation agencies; research and development organisations; catchment management groups; recreational anglers; rivercare/landcare groups; landholders; commercial fishers; conservation groups; researchers; local government and individuals.

The Strategy was agreed to by all participating governments, but no funding for implementation has ever been provided (although the Murray–Darling Basin Commission did give nearly $10 million to the Pest Animal Control and Invasive Animals Cooperative Research Centres for carp and other pest fish research over a ten year period). The estimated impact of carp in Australia has been conservatively put at nearly $16 million per year (although the basis behind such figures can be curious). In the 13 years since the Strategy was published, that amounts to $308 million worth of damage!

A research plan, *Future Directions for Research into Carp*, was also produced to focus carp research on the information needs of the National Strategy. Probably because the Plan was not meant to be prescriptive, it is largely still relevant.

To complement the initiatives of the Murray-Darling Basin Commission, the Bureau of Rural Sciences also produced *Managing the Impacts of Carp* in 2000. This document was one of a series based on pest management principles and contained encyclopedic knowledge on the biology, history, control options and principles of vertebrate pest management as applied to the species.

Carp management plans

While the *National Management Strategy for Carp Control* outlines the principles and broad approach to managing carp, it is of limited value to local groups wanting to develop and implement a local carp management plan. The Murray-Darling Basin Commission, recognising the importance of local groups, commissioned the development of a user-friendly, step-by-step guide for local carp management groups. *Ranking Areas for Action* outlines a structured but flexible methodology that can assist decision-making about carp management. The main elements of this approach are to:

- define the problem
- determine management units for aquatic systems and assess and rank their conservation and water quality status
- assess and rank the threat of carp in each of the units
- assess the likelihood that an effective program to manage carp damage can be implemented.

Plans have been developed for several regions including the Condamine (Dewfish), MacIntyre River (Queensland), Lower Murray (Katarapko), Upper Murrumbidgee (Australian Capital Territory) and Tahbilk (Goulburn River, Victoria). Encouragingly, several of these plans have been incorporated into the broader activities of the Murray–Darling Basin Authority's Native Fish Strategy (NFS) Demonstration Reaches.

PESTPLAN is an initiative of the University of Canberra and the Invasive Animals Cooperative Research Centre and complements *Ranking Areas for Action* by aiming to increase the capacity of pest managers to

apply best-practice pest management using current knowledge. World-first academic courses in Wildlife Management and Natural Resource Management (incorporating strategic pest management) are being developed by the University of Canberra.

The Lachlan River 'Carp Cleanup — River Revival' is an initiative of the Invasive Animals Cooperative Research Centre and has been operating since January 2007 to trial and showcase control technologies. Control tools have included William's carp separation cages to harvest carp migrating within the river channel; pheromone traps; and the use of the electronically tagged 'Judas' carp approach to maximise the commercial harvest and removal of carp from Lake Cargelligo.

The control of carp in two lakes in Tasmania commenced in 1995 and is still ongoing; the estimated cost of removing carp so far (to 2011) is $8 million. This is a rare example of sustained and integrated management, and also underlines the importance of prevention and containment as a control strategy.

State management strategies and the Native Fish Strategy

There have been several state-based carp control plans produced over the years. The two most current plans are in Queensland and New South Wales. *Control of Exotic Pest Fishes — An Operational Strategy for Queensland Freshwaters 2000–2005* was prepared in response to growing community concern regarding the effects of exotic fish species on native fishes and their habitats. This was later succeeded by *Control of Exotic Pest Fishes — An Operational Strategy for Queensland Freshwaters 2011–2016*. The New South Wales carp control plan outlines the most up-to-date information about the biology and impacts of carp and what is being done, or should be done, to stop further spread and control the size of populations, to better understand carp and to increase the understanding and involvement of the community. The final plan was released in November 2010.

Exotic fish are only one of eight threats to native fish, and carp are one of eleven exotic species with wild populations in Australia. The *Native Fish Strategy*, released in 2004, recognises that improvements to native species populations will only happen if a range of measures are undertaken on a 'landscape' scale and over significant timeframes. Carp management activities must be integrated with broader programs for both native species recovery and overall improvement of river health. The *Native Fish Strategy* prescribes a range of actions for carp (and other pest fish) management.

So why are carp still here?

Key reasons for the resilience and persistence of carp are their biophysical attributes, eg fecundity, tolerance to temperature and low dissolved oxygen levels and wide range of habitat preferences. With current technologies available, it is not possible to eradicate carp in Australia. Also, not enough is known about the relationship between carp density and damage (ie how much reduction of carp numbers is enough?).

While there are various management tools available to deal with carp, and each has both advantages and disadvantages, no single method has led to successful eradication. While some biological control methods (eg daughterless technology and koi herpesvirus) have the potential to be extremely effective, they are both very expensive and risky to develop.

Most of the traditional control methods for exotic species involve direct population reduction. But as has happened time and again, employing only one technique just doesn't work. Also, the documentation of past eradication and control attempts has generally lacked detail, making it difficult to learn from past experience. Detailed objectives, description of site characteristics, the methodology used (including monitoring), resources required, costs, permits, public consultation and engagement, should all be documented to enable learning from each exercise. Also, a potential problem is that carp is now a primary component of the food chain — if millions of carp are removed at once (such as through a virus), what will the impact of tonnes of dead carp be on the water quality of a river, and the fauna that live in it?

Adequate monitoring is essential to assess the effectiveness of control. Monitoring of fish populations, whether native or non-native, is difficult, and there are many other factors operating in the system that need to be considered. What we also need to do is document any failed control efforts — these can tell us as much as those that appear to have worked.

Governments are adept at getting plans developed — and these are often invaluable documents — but they have a poor track record of implementing them (consider for example recovery plans for threatened species, or threat abatement plans for pests — How many species have ever come off an endangered species list? How many introduced pests have stopped being a pest?). This is a serious shortcoming which needs to be addressed by both state and commonwealth governments. Also, carp legislation is outdated, unenforced and sometimes contradictory!

The future — the Murray-Darling Basin alien fish plan

Preventing new species entering the Basin and establishing self-sustaining populations is a primary objective of this Plan. It is far more economical to prevent non-native species from being introduced in the first place — it costs about 100 times more to fix these problems than it does to prevent them. Preventing pest fish incursions through quarantine, legislation and education is the most cost-effective management approach.

Prevention strategies will not entirely eliminate the risk of new incursions occurring. We need to be prepared to rapidly respond to new incursions. This may include an eradication or containment exercise, assessing the response attempt and follow-up monitoring and site restoration. An Invasive Animals Cooperative Research Centre report, *Advancing Development of National Emergency Response Arrangements for Freshwater Fish Incursions*, details the progress towards national incursion responses. There is a need to focus effort on finding out where and how pest fish enter the system — this is called pathways analysis and is a critical factor in prevention.

Managing established pest fish is expensive and resources are limited so immediate actions should focus on reducing the negative impacts and identifying priority areas. The best results can be achieved by implementing coordinated and directed action at a Basin-wide scale.

Carp management is a shared responsibility and while some key stakeholders can be motivated and interested in controlling pest fish species, there is a need to increase their capacity for action. This could be done through activities such as training workshops, scenario testing, experiential learning and community-based research.

Recommendations for carp

There are many, many worthwhile avenues to pursue in the field of carp management, and they are well documented in some of the reports and strategies mentioned above. Therefore the following recommendations are just a selection of important and immediate things to do. Firstly, as previously mentioned, prevention and rapid response are critical.

The poor health of riverine systems is invariably caused by more than one process, and reducing the impacts of carp in a degraded catchment is unlikely by itself to restore that catchment to 'full health'. Rehabilitating Australia's rivers requires a balance between resource and environmental needs, not attempting to return the aquatic environment to a pristine or original state.

Carp reproduction does not occur uniformly throughout river systems, and a majority of carp larvae originate from a relatively small number of locations. The identification of 'hotspots' can add value to large-scale control programs by targeting adult fish migrating towards spawning areas, targeting spawning aggregations, excluding spawning adults from hotspots, and intercepting juveniles as they leave spawning areas.

Integrated pest management is a methodology that has been used widely in the control of terrestrial species, but has had limited use in riverine environments. It involves the application of a range of technologies applied simultaneously in order to achieve a predetermined objective. Management activities focus on reducing impact rather than simply reducing pest density. Ideally, the experimental design of the control program is such that an assessment can be made of the most effective method, or combination of methods, allowing for the methodology to be used and adapted for future control programs.

Applying pest management principles, there is a need to research the best combinations of control methods to use in different scenarios. These results should then be tested in a small number of 'demonstration sites' that are adequately resourced and have realistic timeframes.

The initial explosion of carp numbers in the Basin was a direct result of widespread flooding in the mid-1970s. In the same vein, there are real risks associated with environmental watering events. Agencies responsible for water delivery need to ensure that there are safeguards in place to prevent watering events from inadvertently creating dispersal pathways and nurseries for carp and other pest fish.

Acknowledgments

The input of Heleena Bamford (Murray–Darling Basin Authority), who provided useful comments on the draft is acknowledged.

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Questions

Q: Question is more about tilapia than carp and it is about your number 1 point…rapid response, because we feel it is not a matter of if but when tilapia get in to the northern MDB…what are the plans for response?

Heleena Probably not a question just for me, but this is one of the fundamental things we want in the basin alien fish plan, we want to be able to have systems and processes in place with communities and agencies defined. We also want to have draft management plans and testing scenarios, and if we can possibly get memorandums of understanding in place would be good. Trying to identify invasion pathways are also important because it enables us to target what are the likely areas tilapia might turn up in. If we do that we might be able to pre-plan for what we need to be aware of in particular areas. There are many things that can be done but it requires the will to do it and the money to do it and people working together to do it.

Planning a pest fish management program

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Background

Pest fish management in the past has mainly focused upon the pest itself, and eradication was usually the goal. However it is now well known that once a pest fish becomes established across a wide range, total eradication is unlikely with present control options. The fact that pest fish that were common around the 1900's are still widespread today is evidence of this. Because of this limitation the focus is changing to managing pest damage or impacts rather than concentrating just on reducing pest numbers.

The concept of 'pest fish' has also changed with time, and what may be a pest in some circumstances or places may be a valued resource in other situations. A pest fish is now usually considered to be a species that causes more harm than good to a human valued resource.

Management of pest fish is also now a more complex social, economic and environmental issue, with many aspects to consider in any control program. It is no longer an option to simply focus on the pest fish without considering the other consequences of any control actions. The important point is to look at the individual situation as each problem may require a different course of action such as protection of specific habitat perhaps at only a certain time of year. For a threatened species the only option may be to move that species. In other cases reduction in numbers of the pest fish may be the best option. It is also no longer enough to just have the technical options to control pest fish.

Sustainable resource use

Pest fish management is only one component of sustainable resource use. There are many other uses and users of our water resources and we need to consider a whole of system approach. If we want to restore freshwater fish populations; removing pest fish is only part of the solution. Figure 1 (reproduced from Murray-Darling Basin Commission 2004) provides an illustration of how the various factors that impact on freshwater fish habitat can have a cumulative effect on native fish populations.

It is often said that carp for example are a symptom of degraded river systems caused through poor catchment management practices. It is true that carp are quite at home in degraded rivers, but that is because they are a very adaptable species, not because they prefer these systems. They can live just as well in pristine rivers.

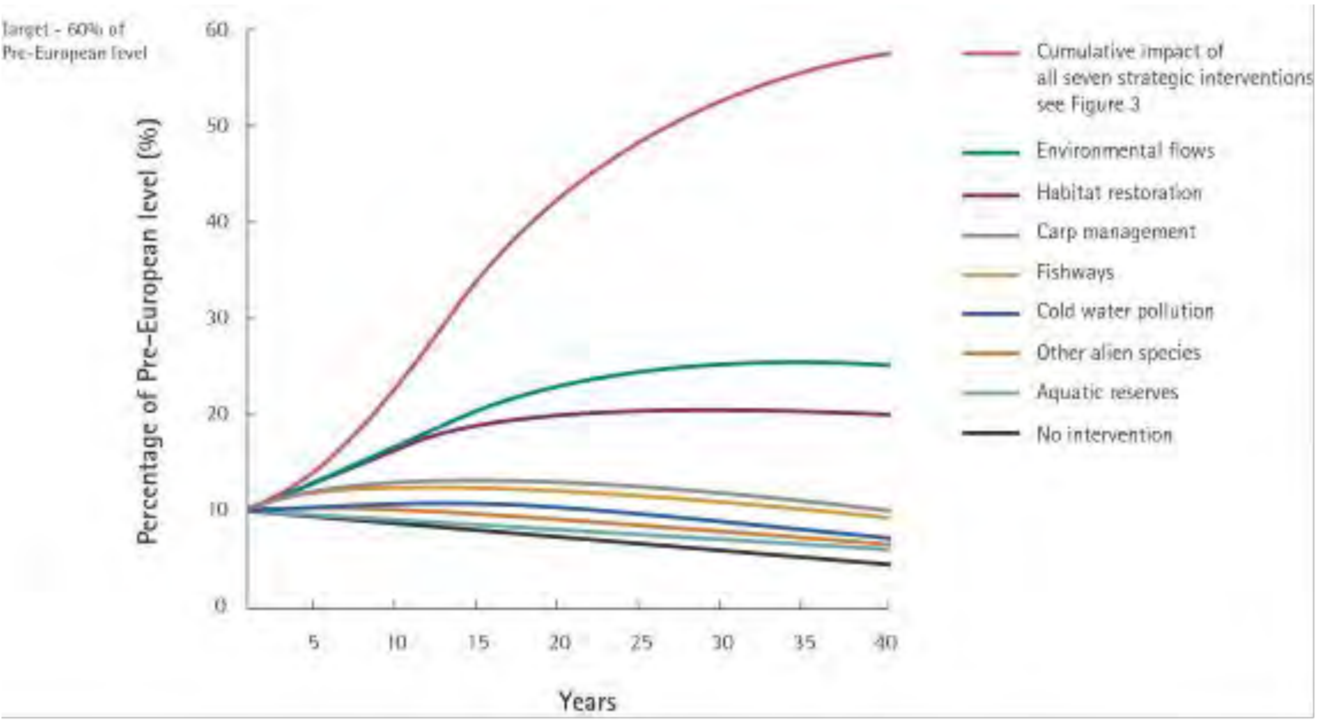

Figure 1. Illustration of how the various factors that impact on freshwater fish habitat can have a cumulative effect on native fish populations. (Reproduced from the Murray-Darling Basin Commission Native Fish Strategy 2003-2013)

Develop a Plan

To tackle a pest fish problem requires an organised strategy and any management program will benefit from a strategic approach. Planning is essential, but what is required is an operational plan which is about actions rather than regional or state plans which are usually primarily frameworks.

A 10 point approach to developing a plan is described below with the key points being:

1. **Define the problem**
2. **Identify and engage key stakeholders**
3. **Identify and prioritise key management units**
4. **Determine management objectives and measurable goals**
5. **Identify and evaluate management options and conduct a risk/benefit analysis**
6. **Develop a detailed management action plan**
7. **Implement the management plan**
8. **Monitor and evaluate outcomes**
9. **Implement adaptive management**
10. **Report and share outcomes**

1. Define the problem

- Is it a pest fish problem at all?
    - Pest fish are present, but are they really the problem?
- Could it be habitat degradation from other sources?
- Could it be not enough water at the right time?
- Could it be movement barriers?

In other words, make sure that it is the presence of pest fish that is causing the problems to the resource that you are concerned about.

2. Identify and engage key stakeholders

- Who else is going to have an interest in what you may want to do?
- Identify what concerns they may have.

This type of information will be critical in determining what can and can't be done. It is also critical to have a champion/s to drive the process.

3. Identify and prioritise key management units

For example, if you are thinking of tackling carp, you will need to do so on a scale that can be managed and across an area that will not be readily re-colonised from connected un-treated areas. The range of the species you are concerned about may be too big to influence. Perhaps for another species the task is not quite as big or its distribution may not be continuous and isolated populations can be tackled separately. Choose management units that are practical.

4. Determine management objectives and measurable goals

This is a key step that is rarely considered up front and it is also where reality often sets in.

- What do you want to achieve?
- What does success look like?
- Can you realistically achieve your chosen goal?
- How can you measure progress towards this goal?

A population estimate or a measure of existing impact may be required so that change can be assessed in the future.

5. Identify and evaluate management options and conduct a risk/benefit analysis

- Determine what management options to use.

With your management goals in mind, determine how it can be done. At this point you may need to reconsider the goal if it is found to be unachievable. If the objective is clear, then consider the options that are available and suitable. Take some advice on development of an integrated management program (see PestSmart Fact Sheet on Integrated Pest Fish Management). In practice, most pest fish management programs will work better if a number of methods are combined, so look at integrating a number of methods rather than just relying on one.

- Evaluate the risks and the benefits of the control options

This is relatively straight forward for an agricultural enterprise, but far more difficult when evaluating environmental issues or recreational fisheries risks and benefits. The control options may put other species at risk with only minimal chance of controlling the pest fish. This would not be an acceptable option. In other cases some impact on other species may be necessary to control a pest that is causing widespread damage.

6. Develop a detailed management action plan

Document the intended process for your own benefit and for others. It may also help to highlight gaps or problems and also critical points in the process.

7. Implement the management plan

This is where many pest fish management programs actually start. They go directly to the control options without prior planning. Actual removal, if that is to be part of the strategy, could still be some time off. If the planning process recommends particular actions, then processes such as approvals and permits and notifications and equipment procurements etc should be done at this point. After the initial planning has been done, then proceed to the field component.

8. Monitor and evaluate outcomes

- Has the process worked?
- Has the original objective been achieved?
- Is progress being made?

It will be difficult to evaluate progress if you have not initially established what you want to achieve or a way to measure it.

9. Implement adaptive management

This is the feedback step. Progress towards the goal has been assessed, now what do we need to change (if anything) to achieve our objective. Do we change methods; introduce new methods; change timing or location of controls; get more resources etc. Alternatively do we need to revisit our objectives or other planning steps.

10. Report and share outcomes

This may save others a lot of trouble in the future

- Document the plan.
- Document what was done.
- Document the results including what worked and what did not work.
- Make the results available to others.

It is not claimed that this process will solve all problems in all circumstances. What it may do is save time and money. Not all steps may be necessary in each and every case and the order may need to be changed to suit the circumstances in some cases. In some cases, species or site specific steps may need to be added.

Key messages

- The aim of pest management is to reduce damage
- Understanding the problem is vital
- Setting achievable objectives is essential
- 10 steps to developing a management plan are presented
- You must monitor and then modify the program (if necessary)
- Seek help when required (earlier is better than later)

There are many sources of information available on individual state and federal government department websites as well as the PestSmart material on www.feral.org.au

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Questions

Q: Could you give us a recommendation on the best way to disseminate this information, you guys have done an extremely good job on your website, what has been the most effective means of getting information out?

Wayne: The best way to get information out is a good question and we have chosen to take a number of paths because I don't think there is any one best way. Often it is a matter of "horses for courses". For example our recent roadshows primarily targeted landowners and this was for the larger pests that are often managed on an individual property basis. These fora we are trying to focus on fisheries managers although not a lot have attended. You simply have to use multiple methods depending on the circumstances.

Carp management in New South Wales

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Summary

Carp are an introduced freshwater pest fish now widespread throughout most of New South Wales, particularly in the Murray–Darling Basin and the river systems of the mid-New South Wales coast and tablelands. In many areas they dominate the fish biomass at the expense of native species. Recent research and anecdotal reports indicate that carp numbers are increasing as a result of favourable conditions following the 2011 flooding events. Their range is also purportedly expanding to include an increasing number of coastal catchments, particularly on the New South Wales north coast.

Carp are listed as a Class 3 noxious fish in New South Wales — recognition of the fact that they are an established pest species in New South Wales. This listing does permit their sale and possession. Carp are an inland commercial fisheries species and the koi strain of carp are a popular ornamental fish in New South Wales. Despite being permitted for possession and sale in New South Wales, the Government discourages further spread of carp through education and awareness-raising activities.

New South Wales Department of Primary Industries has developed a Carp Control Policy and Carp Control Plan which outline the legal methods for carp control in New South Wales.

Management of carp

New South Wales Department of Primary Industries implements various regulatory, advisory and collaborative mechanisms to manage carp in New South Wales.

Ornamental fish breeders who have 10,000 litres of water (or more) and sell fish, including ornamental koi carp, require an aquaculture permit, and it is illegal to use live carp as bait. A variety of ornamental and noxious fish advisory materials have been developed by the Department of Primary Industries and are widely distributed. These publications promote the responsible keeping of ornamental fish, and encourage recreational fishers to humanely dispatch and utilise or dispose of pest fish appropriately. Due to the diverse cultural groups interested in ornamental fish, some publications have been translated into popular community languages to target non-English speaking stakeholder groups. To raise awareness of noxious fish and the prevention of pest fish, Department of Primary Industries staff attend relevant events, such as the Australian Koi Society Pet and Garden Show in Sydney, and work collaboratively with key stakeholders on the New South Wales Ornamental Fish Working Group, which has representatives from industry and hobby sectors.

The commercial Inland Restricted Fishery in New South Wales is another activity managed by the Department of Primary Industries that provides a mechanism for removal of carp; however this is generally a low value market which is sensitive to volume and has high operating and transport costs.

Protection and restoration of aquatic habitats can help to tip the balance in favour of native fish and away from introduced pests such as carp and the Department of Primary Industries is involved in several aquatic habitat rehabilitation projects. Carp control technology such as carp separation cages, may be installed in specific areas where all required feasibility criteria are met. In addition, the department is engaged in current and emerging carp research and initiatives and is a partner in the Invasive Animals Cooperative Research Centre, collaborating on novel technology such as koi herpesvirus.

Constraints

Constraints to effective carp management in New South Wales include the large geographic area affected; the connectivity of many waterways; the lack of effective broad-scale control or eradication options; and limited resources in regards to both funding and staff. A risk-based and coordinated approach is therefore important to ensure the limited resources are used to maximum effect to increase the success of control programs.

Carp Control Policy and Control Plan

The Department of Primary Industries receives a large number of queries from the general public and local agencies regarding available options for carp control. In 2009 the Department of Primary Industries developed a Carp Control Policy to ensure consistent and accurate advice is provided to stakeholder groups regarding legal carp control methods in New South Wales. The Policy was developed in response to a large proportion of public enquiries that demonstrated unrealistic expectations and a general lack of understanding in regards to the limitations of pest fish control.

The Policy provides information about the circumstances for which the Department of Primary Industries will consider supporting carp control, including where:

- a new population is discovered in previously carp-free catchments or sub-catchments
- there are compelling environmental reasons for attempting eradication of new populations
- eradication is feasible
- resources are available.

A New South Wales Carp Control Plan was developed to align with the Carp Control Policy in November 2010. The Carp Control Plan aims to provide a framework for carp management by outlining what is already being done and outlining the actions that are considered feasible and might be most valuable in terms of stopping further spread, controlling the size of populations, to better understand the biology, population dynamics and environmental impacts of carp and to increase the understanding and involvement of stakeholders and the community.

Carp control planning in New South Wales

Control methods supported by the Department of Primary Industries Carp Control Policy include:

- legal recreational fishing methods, including public fishing events
- harvesting by Inland Restricted Fishery commercial fishers
- consideration of (depending on characteristics of target area and available resources)
    - installation of carp separation cages on fishways or wetland regulators
    - wetland management (including exclusion screens)
    - draining and drying of private water bodies
    - control methods in conjunction with stocking of native fish.

Although public fishing events are likely to have minimal impact on carp populations, these events provide an opportunity to raise public awareness on a range of aquatic issues including the importance of native fish, protection and restoration of aquatic habitat, and prevention of pest fish introduction and spread.

Before implementing carp control activities in New South Wales, natural resource managers must consider:

- the feasibility of control methods depending on the characteristics of target area, the aims of the control work and resources available
- harvesting by Inland Restricted Fishery commercial fishers
- appropriate permits/approvals as required
- humane means to euthanase and utilise or appropriately dispose of captured carp (Note: harvested carp cannot be sold, unless taken by a commercial fisher from the Inland Restricted Fishery).

The Carp Policy does not support:

- illegal methods
- use of fishing equipment in non-compliance with the regulations
- use of fish specific poisons, such as rotenone (except under direct supervision of New South Wales Department of Primary Industry officers and in accordance with the Australian Pesticides and Veterinary Medicines Authority permit conditions)
- use of other chemicals, electrical devices or explosives.

Recommendations and challenges for carp control planning

In New South Wales, natural resource managers must implement and follow the Department of Primary Industries Carp Control Policy. It is important that managers effectively plan for the application of available resources; for example before installing a carp separation cage, consideration must be given to determine if this control method will be feasible and efficient based on the waterway's characteristics and if there are ongoing resources to manage and maintain it.

Proposed control programs should include integrated management techniques such as multiple and/or sustained control methods combined with aquatic rehabilitation to increase overall environmental success. Managers also need to collaborate and coordinate programs with local government agencies and key stakeholder groups to share knowledge, resources and expertise to enhance both the environmental and community benefits of control projects.

Ongoing challenges to carp management planning include identification of funding for projects and maintaining realistic expectations in the community regarding the feasibility and limitations of control programs. As new technologies emerge, there is likely to be consultation challenges with stakeholder groups regarding the potential implementation of novel technologies such as koi herpesvirus.

Communication is also an ongoing challenge. It is critical that managers engage with and share knowledge with researchers, stakeholders and other groups undertaking carp management regarding the successes and constraints of control programs. The lessons learned can be used to improve future control programs.

Reference

New South Wales Industry and Investment (2010). *New South Wales Control Plan for the Noxious Fish Carp (Cyprinus carpio)*. New South Wales Industry and Investment, Orange, New South Wales.

Questions

Q: Totally support your disposing of the pest fish humanely, what do you recommend for people in carp groups, do you just tell them do it humanely or do you actually have some specifics that you recommend for them?

Brigid: We get the advice from the departmental animal ethics committee. We actually refer people to the website to get accurate information on it

Q: Has NSW done any studies on cost/benefit analysis of the impact of carp in economic terms not in environmental terms?

Ans: I am not aware of any studies.

Towards national emergency response arrangements for freshwater fish incursions in Australia

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Objectives / Background

Freshwater fish incursions are a significant issue in Australia and a major biosecurity risk to freshwater ecosystems. The introduction of freshwater fish to areas outside their natural range can exert numerous environmental, social and economic impacts. Currently 44 alien freshwater fish species have been recorded in Australian freshwaters, with a further 76 native freshwater fish found outside their natural range.

Preventing alien freshwater fish incursions into the natural environment, through quarantine, legislation and education, is the most cost effective management approach. Once an incursion has occurred, appropriate national emergency response arrangements are required to facilitate coordinated, cooperative and timely response actions to provide the best opportunity for containment and eradication.

Effective response to freshwater fish incursions in Australia has been inhibited by a lack of national emergency response arrangements. This project aimed to progress the development of such arrangements. The Steering Committee incorporated members from all state and territory jurisdictions responsible for invasive species management. Extensive consultation was also undertaken with national sectoral committee members and those involved within other sectors where comprehensive biosecurity arrangements are in place.

Summary of findings

Learning from the experiences of other biosecurity sectors

This project identified the clear need for freshwater fish incursion management to learn from the experiences of those within other sectors where comprehensive biosecurity arrangements are in place (i.e. AUSVETPLAN, AQUAVETPLAN, PLANTPLAN, National System for the Prevention and Management of Marine Pest Incursions). Emergency management includes a range of measures to manage risks to the environment, economy and society. A general framework commonly applied when managing pest and disease incursions in Australia incorporates governance and infrastructure, measures for prevention, emergency preparedness and response, ongoing management and control and supporting arrangements. Developing national arrangements for alien freshwater fish incursions in accordance with such a framework will facilitate coordinated, cooperative and efficient management of this risk.

Linking to relevant national processes

During the course of this project, a National Environmental Biosecurity Response Agreement (NEBRA) was in the process of development, as a component of the Intergovernmental Agreement on Biosecurity (IGAB). This intergovernmental agreement will provide national arrangements for response to nationally significant biosecurity incidents where there are predominately public benefits and will apply to freshwater fish incursions. The development of emergency response resources for freshwater fish incursions will need to be consistent with the conditions stipulated in this agreement.

The project also recognised the importance of linking with another national project relating to biosecurity arrangements - 'Harmonising Australia's Biosecurity Emergency Response Arrangements'. The National Biosecurity Committee formed the Biosecurity Emergency Preparedness Working Group (BEPWG) which is implementing an action plan to reduce duplication, increase alignment with the broader emergency management community, and align with existing nationally recognised standards.

Review findings

This project undertook a review of:

- international and national approaches to new alien freshwater fish incursions
- surveillance, eradication and control programs in Australia, and
- short-term barrier and containment methods.

The review of international and national approaches to new alien freshwater fish incursions highlighted the importance of understanding the issues, challenges and approaches to alien fish management. This enables learning from incursion experiences in countries which have advanced approaches, such as New Zealand and the USA, as well as understanding the potential risks of entry of alien species from other countries. Australian agencies should actively participate in key international forums such as the International Conference on Aquatic Invasive Species and international agency exchange programs to build relationships and learn about the latest scientific knowledge, research, technological developments, education and outreach programs, as well as legislative, policy and management approaches to aquatic invasive species.

The review of surveillance, eradication and control programs in Australia found that historically, response activities to alien freshwater fish incursions across Australia have been generally ad hoc, inconsistent and uncoordinated. Management of such incursions among jurisdictions in Australia is variable. Jurisdictions largely rely on passive surveillance to detect new incursions – a process hindered by limited community awareness of alien fish issues, as well as poor understanding of the vectors and pathways of introduction. Very few active surveillance programs exist and the majority of new incursions are detected through general fish survey and monitoring programs. The varying roles and responsibilities of agencies and staff are sometimes not clearly defined or embraced. In some jurisdictions, fisheries staff lack basic emergency response training and there are limited resources and staff with skills to manage incursions. Legislation and terminology relating to alien freshwater fish management is inconsistent across the country, although the process of incorporation of the National Noxious Fish Species List into fisheries regulations is an important step in addressing this inconsistency. There is no national community education program targeting alien fish species. Most jurisdictions have specific online information regarding particular pest fish issues, such as prevention of dumping of ornamental fish. There is no national reporting system for alien fish incursions. Most jurisdictions have specific arrangements such as phone hotline services. There is no universal national risk assessment procedure for determining whether to respond to an alien freshwater fish incursion and priority of response.

Previous management approaches for eradication and control of alien freshwater fish in Australia include physical removal, chemical methods, habitat manipulations and biological control. Well known and widespread species and those of greatest concern have received the greatest attention. There are limited examples of successful eradication and the majority of eradication exercises have involved application of rotenone. Control programs have included a combination of electrofishing, netting, screening and water manipulation. Documentation of the purpose, procedures and results of eradication and control programs is improving. Incorporation of monitoring within such programs is an essential component.

The review of short-term barrier and containment methods indicated that research, development and application of fish barriers have largely occurred in the USA, UK, Europe and New Zealand, with limited application in Australia. Fish barriers can be categorised as physical or behavioural. Effective physical barriers provide complete exclusion of fish, whereas behavioural barriers involve the application of an external stimulus to evoke a fish response. Fish barriers vary in design and thus also effectiveness, cost, construction and installation difficulty, operational and maintenance requirements, flow applicability and requirements, power supply needs and safety. Fish barriers to contain new fish incursions must be easy and quick to deploy and are often temporary.

Management Recommendations

The final report provided direction on how to advance the development of national emergency response arrangements. A suite of recommendations were identified; some recommendations are entirely new, while others link to existing processes that may require revision or expansion. The recommendations which were identified encompass the importance of learning from, and aligning with, existing processes within other biosecurity sectors. Recommendations also addressed gaps identified within the review regarding surveillance, eradication and control programs, and short-term barrier and containment methods.

Recommendations were grouped broadly within the following themes:

- raising national awareness and process initiation
- emergency response arrangements
- supporting arrangements.

Raising national awareness and process initiation

A key first step requires raising national awareness through national biosecurity forums to the relevant Ministerial Councils and ensuring a national sectoral committee is responsible for developing national emergency response arrangements.

Emergency response arrangements

These recommendations incorporate a variety of documents, programs and resources which are required specifically for freshwater fish incursions. These include creating risk assessment procedures and priority lists and species specific management/response plans. National operational manuals including for animal destruction, disposal and decontamination, and technical manuals for rotenone and electrofishing are also needed.

Supporting arrangements

These encompassed management support products such as decision support tools, a national freshwater fish incursion register and a national control program database. Many communication resources and training tools are also required including a taxonomic experts register, educational products and national training programs for freshwater fish incursion response.

Targeted research and development programs are required to address gaps identified within the review. These include physical and behavioural barriers, chemical treatment, pathway analysis, social analysis, detection capacity of survey techniques, molecular probes for species detection. A greater understanding of the biology, ecology and impact of alien freshwater fish would also assist more effective management.

Progress in National Freshwater Fish Biosecurity Arrangements

Since the completion of the project in 2010, there has been some progress in the management of national freshwater fish biosecurity risks. NEBRA now provides national arrangements for response to nationally significant biosecurity incidents where there are predominately public benefits. The BEPWG process is continuing to develop resources to reduce duplication across biosecurity sectors, increase alignment with the broader emergency management community, and align with existing nationally recognised standards. There have been changes to national committees, including the disbanding of the Environmental Biosecurity Committee.

A National Strategy for Management of Freshwater Pest Fish is currently being prepared by the Vertebrate Pest Committee – Freshwater Fish Working Group (VPC FFWG), and this project has contributed to its development. The Murray Darling Basin Authority has prepared an advanced draft of an Alien Fish Plan for the Murray Darling Basin. The Ornamental Fish Management Implementation Group (OFMIG) was established in 2007 to implement the national strategy for the management of the aquarium trade. In 2011, OFMIG merged with the VPC FFWG. It continues to review ornamental fish species for inclusion on the National Noxious Species List. The Invasive Animal Cooperative Research Centre has also funded the development of a decision-support tool for the management of freshwater fish incursions.

Acknowledgments

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Questions

Comment: I don't think NZ has a good invasive fish response plan.

Pam: I would argue that they are way ahead of us (Australia)

Comment: As someone who has looked at this in the US and NZ fairly thoroughly, NZ does not have a response plan that actually reaches the ground. There is not a response plan in terms of a team ready to go with rotenone or other control measures. The same goes for the US, although the State agencies have driven most of the response plans that do happen and most of those are to support recreational fisheries. Although federal agencies do have some pest fish people there is almost no on-the-ground action to remove fish. Action has not reached the ground where people are responding and the plans are not there for either country.

Pam: My response is still that you at least have some processes in place but implementation may be an issue. That is still well in advance of what Australia has.

Decision support tool for the management of freshwater fish incursions in Australia

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Background

There are no national emergency response arrangements for freshwater fish incursions in Australia. Individual states and territories vary widely in their current response arrangements to freshwater fish incursions, with many being dealt with on an ad-hoc basis and with varying degrees of efficacy. Actions to advance developing a national emergency response system for freshwater fish incursions in Australia were recommended in a recent review conducted by Ayres and Clunie (2012), including creating a web-based decision support tool (DST) to provide direction and assistance in managing freshwater fish incursions.

The development of the DST involved consultation with end-users from all Australian states and territories responsible for managing new freshwater fish incursions (eg natural resource managers and government agencies) as well as a Technical Pest Fish Advisory Group comprising field-based staff with expertise on capturing a wide range of fish species from a variety of habitats. Such consultation ensured that the DST's development included input form all jurisdictions and perspectives, and catered for the needs of end-users.

Aims

The aims of the DST for managing freshwater fish incursions in Australia were to:

- Maximize the speed and quality of reporting and response which are critical in the early stages of an incursion.
- Provide a logical and structured decision making process.
- Provide comprehensive planning documentation.
- Provide advice on the most appropriate management option considering circumstances of the incursion.
- Facilitate communication and consistency of approaches between agencies.

Users

The tool is targeted at scientific researchers and natural resource managers conducting surveys or monitoring programs, or those with background in ecological management.

Framework

The DST follows a question/answer format and the user is led through a series of questions relating to the species sighting, details of the fish and its capture, and site information. These questions address issues that managers consider when deciding on appropriate eradication or control techniques to apply (Figure 1). Two sections of the DST (fish details and site details) directly influence the decision making process and ultimately, the suggested eradication or control method to manage a freshwater fish incursion at a particular location.

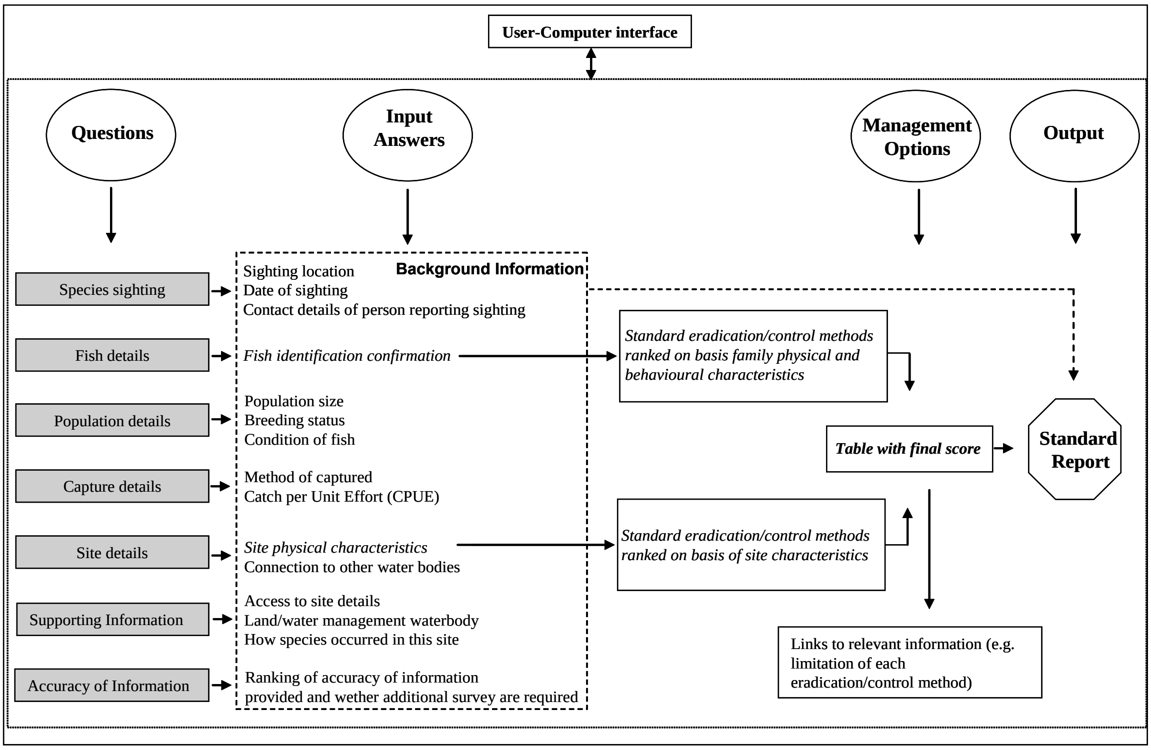

Figure 1. Framework of decision support tool for the management of freshwater fish incursions in Australia.

Final Product

A standard online summary report and management options report is produced once all sections have been answered by the user. The summary report with the management options is then submitted to and assessed by the relevant state government authority responsible for the management of freshwater fish incursion. Managers are then able to consider their options, taking into consideration current permits, resources and capability.

Future work

Stage two of the DST:

There is a need to continue to engage with key jurisdictional representatives to determine how this tool can best meet the needs of these managers and how it can complement existing processes efficiently.

Stage two includes:

- Compilation of feedback from practitioners and refinement of the tool to include specific state and territory requirements.

Stage three of the DST:

There is the potential for this tool to incorporate additional components in the future (subject to funding), such as:

- A national fish incursion register, providing information such as species incursion histories, incursion details for specific locations and incursion maps.
- A national control program database.

The DST could potentially also have applicability for the management of other terrestrial and aquatic invasive species.

Key messages

- The DST maximizes the speed and quality of incursion reporting and helps the responsible government agency decide on the most appropriate management action.
- The DST also provides government agency staff access to other relevant information and facilitates consistency in the decision making approach by government agencies throughout Australia.

The DST for managing freshwater fish incursions is free and can be accessed through the IA CRC PestSmart Toolkit website **http://www.feral.org.au/dss/**. The on-going support and maintenance of the tool is conducted by IA CRC.

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Questions

Q: The person who notifies you of the incursion, do they get some feedback on what happens?

Silvana: No, not from the tool but we can consider if there is some way that we can update the tool

Q: Have you incorporated any procedures for identifying fish or other portions, for example links to how to prepare samples for further analysis?

Silvana: As a tool it provides a list of where you can send the fish for ID and also provides a link to sites such as Fishbase

Q: Can you upload pictures?

Silvana: Yes, you can upload pictures and drawings

Q: Have you looked at including native fish into this? We have lots of requests for monitoring of fish-kills and there is nothing in place to be able to do that and if there is a tool that the community are aware of, having that option in there would be useful.

Silvana: You can provide information on native fish in the area when you log in to the tool.

Application of environmental DNA detection methods in management of aquatic invasive species: Lessons learnt from an impending Asian carp invasion of the Laurentian Great Lakes, USA

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Silver carp (*Hypophthalmichthys molitrix)*, and bighead carp (*H. nobilis*) (Asian carp hereafter) were imported into the U.S. for water quality and aquaculture purposes in the early 1970's (Kolar et al 2007) and actively stocked into wastewater treatment lagoons, impoundments and research ponds across several states including Illinois. By the early 1980's both species had been captured in the Mississippi River and by 1989 evidence of natural recruitment was documented in the Missouri River and soon after (1992) in the Illinois River (Kolar et al 2007). Thereafter, spread throughout the greater Mississippi River system was rapid with patterns of dispersal consistent with multiple points of introduction (O'Connell et al 2011). Resource managers concerned that Asian carp would invade the Great Lakes through the Chicago Area Waterway System (CAWS; – a series of canals and channelized rivers that artificially connect the Great Lakes to the Mississippi River) concentrated prevention efforts around a temporary electric barrier (constructed just north of the Lockport Lock and Dam) until a new permanent and stronger electric barrier could be constructed (Moy et al 2011). But by 2009, repeated monitoring using traditional fisheries gear (gill nets and boat based electric fishing) suggested the putative invasion front had stalled approximately 18 miles south of the electric barriers in Dresden Island pool (Lodge et al 2010).

However, dispersal modelling projected that Asian carp should have reached the electric barrier as early as 2006 (Lodge et al 2010), suggesting that the nominal distribution pattern might represent a detection failure in the deep (>8m) box shaped canal where collection of these fish was likely to be challenging (Kolar et al 2007, Moy et al 2011). Sampling using new environmental DNA (eDNA) methods in 2009 (Jerde et al 2011) provided the first evidence that Asian carp had reached the barrier, a result confirmed by the subsequent capture of a bighead carp in the lower Lockport pool (downstream of the barrier) in 2009, during a rotenone fish clearance operation to enable electric barrier maintenance. Furthermore eDNA sampling detected silver and bighead carp DNA in the upper CAWS suggesting that Asian carp had also spread upstream of the electric barriers (Jerde et al 2011), and the capture of a bighead carp in Lake Calumet in July 2010 appeared to confirm these results (Jerde et al 2011, 2013).

Detection of Asian carp eDNA throughout the CAWS stimulated the establishment of a federally coordinated regional response effort to prevent establishment of Asian carp in the Great Lakes (Asian Carp Regional Control Framework 2010; 2012) as well as federal litigation around legal efforts to close the last lock structures in the CAWS to prevent carp entering Lake Michigan (Darling and Mahon 2011). With eDNA results indicating that at least some silver carp had entered Lake Michigan, surveillance efforts expanded into the Great Lakes in an attempt to delimit the extent of the Asian carp incursion (Jerde et al 2013). Between September 2009 and October 2011, a total of 2822 water samples (2L each) were collected from tributaries and shallow embayments of lakes Michigan, St Clair and Erie (Jerde et al 2013). Sampling resulted in detection of bighead and silver carp DNA in Sandusky Bay and Upper Maumee Bay (Lake Erie) respectively in 2011 (Jerde et al 2013). A result that was perhaps not surprising given three bighead carp had been captured in Lake Erie between 1996 and 2000. Otolith analysis of two of these fish suggested a time of introduction around 1993 or 1994 (Morrison et al 2004).

From the outset, Asian carp eDNA results from the CAWS were controversial and met with scepticism, especially from fisheries practitioners undertaking monitoring using traditional fisheries tools. In part, the scepticism was to be expected because this was a novel method that had not been widely applied in freshwater systems (Lodge et al 2010). But it was also fueled by their ongoing failure to capture Asian carp particularly above the barrier where Asian carp eDNA was repeatedly detected (except for the one fish captured in Lake Calumet). This was despite recognition that traditional fisheries tools were not effective and development of the eDNA method was motivated by the need for improved detection sensitivity (Darling and Mahon 2011, Moy et al 2011). Initial criticism centred on marker specificity and whether appropriate quality control procedures had been adopted to avoid contamination and false positives (Darling and Mahon 2011). However, an independent US Environmental Protection Agency quality assurance and quality control review of the entire laboratory, field collection, filtration and data assurance procedures (Blume et al 2010) helped allay these concerns. Blume et al (2010) concluded that the marker, method and quality assurance protocols were sufficiently reliable and robust that the patterns of detection should be considered actionable.

Thereafter attention shifted to identifying an alternate source of DNA (sewerage, carcass, bird excrement, eDNA laden water) despite the fact that no other source alone could explain the patterns of detection (Jerde et al 2011). Substantial resources were allocated to studies designed to test these theories (Asian Carp Regional Coordination Committee 2010; 2012), but results were inconclusive and experiments often plagued with contamination issues (USACE 2013). On the other hand the USACE (2013) studies and other independent research have shown that detection sensitivity of the Jerde et al (2011, 2013) eDNA methods can be improved by adoption of alternate filtration, extraction and quantitative PCR methods (Liang and Keeley 2013, Pilliod et al 2014, Renshaw et al 2014, Turner et al 2014). Illustrating that perhaps managers should be wary that the limited number of eDNA detections reported across Great Lakes could reflect an unquantified level of false negatives (Jerde et al 2013).

The future rate of false negatives can be reduced by adoption of improved eDNA methods and increased sampling effort. The latter is being addressed following the transition of eDNA surveillance responsibilities to U.S. Fish and Wildlife Service who have projected they will collect over 8000 samples across the basin in 2014 (Strakosh pers. comm.), four times the previous annual sampling efforts.

Adoption of eDNA methods is transforming the way aquatic biosecurity surveillance is being undertaken in the Great Lakes. Methods are evolving rapidly and our understanding of the factors that influence rates of detection are advancing (Lodge et al 2012, Barnes et al 2013, Pilliod et al 2014). Furthermore the application of next-generation sequencing approaches is opening the possibility of screening samples for a full range of native and non-native species (Thompson et al 2012, Mahon et al 2014) and may provide managers with an aquatic biosecurity surveillance method that makes comprehensive early detection a realistic management option. However, with increased detection sensitivity it is also critical that appropriate quality assurance and control programs are established and maintained if management confidence in the method is to be sustained.

There are still numerous challenges to adoption and determining the appropriate management response following the first detection of DNA from a potentially incipient population of Aisian carp (Lodge et al 2010, Darling 2014). This is illustrated by mixed agency acceptance and response to the repeated detection of Asian carp DNA in the CAWS.

Nevertheless this experience has helped highlight some of the challenges facing successful integration of eDNA surveillance tools into the pest management tool box (Darling and Mahon 2011) and stimulated numerous improvements in the method.

Management Recommendations

1. Establish an appropriate team that includes expertise in genetics, sampling design, and field ecology.

2. Ensure appropriate sample replication (and volume) – sampling needs to achieve good spatial and temporal coverage.

3. Establish rigorous quality control procedures throughout the collection, filtration, extraction and PCR processes, including separation of critical processes (see Blume et al 2010, Willerslev et al 1999).

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Questions

Q: Thinking about detection of some of our rarer native fish species, there must be a lower level of detection for even DNA. Obviously DNA gets denatured by UV light and microbial consumers, so do you have any information about how many fish you need to have in a body of water and how long the DNA would last?

Linz: Yes, I think it has a lot of potential for detection of rare natives and as you move up into headwater streams I think it has fantastic potential. In terms of DNA degradation rates and expression rates that is going to vary with temperature and water quality and those sort of things. There are a couple of lab based studies that look at degredation rates using well-water which probably has low microbial breakdown and has been shielded from UV. That DNA is lasting upwards of 1-2 weeks. We have done some trial work where we have had mixed ponds containing a number of species and then we have taken our target species out and where you have got a much higher background BOD and an ongoing BOD, that DNA might only be lasting a few hours to a few days. In terms of your sampling, those issues have big implications especially as you move north (in Australia) to warmer water in terms of both how long the DNA will last and also how do you get it back to a lab.

Q. You did say there would be delay between taking the samples and getting a result. How long is that going to be?

Linz: That comes down to how many samples you collect and how good your lab is. We are processing about 120 samples a week but that is a university lab not a commercial lab. You could turn around samples in about 24 to 48 hours depending on how you are set up.

Q. In terms of calibrating to see how effective it is, have you done any experiments where you actually plant some material to see if you can detect it?

Linz: We haven't done that partly because we are working on a real management problem. We have done some blind samples where people collect samples and they know what is there. We have processed those and been able to compare what we found to what they know is present.

Q. Did you work out costs per sample?

Linz: It comes down to who is doing the work. Commercial labs doing the work are charging about US$120-150 per sample, it costs us somewhere between US$50-100 per sample. Those costs are going to come down. At the moment we are using a commercial extraction kit which is where the big cost is and the other issue is labour. Further work on the kit will get the costs down to cents rather than dollars.

Q: From a biosecurity perspective, how many negatives do you need before you can confidently conclude that a species is not there?

Linz: We have not gone there yet. There has been a heap of concerns around our positives but we are more concerned with our negatives because we are not always getting positives when we know fish are present. Fact is, it is a quantum step forward from what we have been doing.

Q: Do you know if there is a forum for sharing species specific primers so that we don't have to re-invent the wheel for these?

Linz: I don't know of a specific forum but we intend to publish these as they come out.

The biology, management, control and eradication of carp populations in Tasmania

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Introduction

The Carp Management Program (CMP) was established within the Inland Fisheries Commission (Now Inland Fisheries Service, IFS) in 1995, in response to an incursion of carp (*Cyprinus carpio*) found in Lake Crescent, at Interlaken, in the central highlands of Tasmania. The incursion was contained to Lake Crescent and the upstream Lake Sorell. The integrated pest management strategies used have resulted in the successful eradication of carp from Lake Crescent and are ongoing in Lake Sorell.

A manual for carp control: The Tasmania model has been developed as part of the IA CRC project which describes the progressive and integrated approaches that were successfully employed to control/eradicate carp in Tasmania and that are likely to be of relevance elsewhere.

Tasmanian inland waters are home to a diverse array of native fauna and flora, many of which are unique, with some threatened and endangered species. These waters also support a recreational angling industry and commercial eel fishery of significant importance to the State’s economy. The discovery of carp in the lakes and their potential spread to other water bodies across the State posed a severe threat to a range of environmental, economic and recreational values.

Lakes Sorell and Crescent are large, shallow, freshwater, interconnecting lakes located in the South-eastern corner of the Tasmanian Central Plateau. They are situated approximately 100 kilometres north of Hobart at 800 m AHD at the head of the Clyde River catchment and are about 5310 ha and 2305 ha in area respectively. In times of full supply both lakes have extensive wetland areas that connect to the main lake bodies which provide ideal spawning habitat for carp.

Initial incursion response

The following tactics and approaches are discussed in detail in the manual (Diggle et al 2012)

The formation of a task force

- Public relations and education
- Management options including;
    - do nothing
    - contain carp within lakes Sorell and Crescent
    - eradicate by draining, poisoning or physical removal

Closure of Lake Crescent

One of the important aspects of this initial phase was the support of the Tasmanian Government through legislation and funding. One of the first actions involved the closure of Lake Crescent. At the time of closure of Lake Crescent in 1995, the following public notice was placed in the three regional newspapers in Tasmania. It has since been updated to reflect legislation changes

> *In pursuance and exercise of the Powers conferred on me under Section 42L of the Fisheries Act 1959, I Wayne Fulton being the Commissioner of Inland Fisheries, declare the waters of Lake Crescent and its surrounds to its high water mark closed to the public for all purposes. The above action has been taken as a precaution to assist in preventing the spread of European carp which were recently found in Lake Crescent. As the carp have adhesive eggs which may be laid in summer, closure will prevent these eggs from being spread on boats, outboards, waders etc.*
>
> *Wayne Fulton*
>
> *Commissioner*

Figure 1: Signage used to enforce the lake closure

Further control powers were conferred by the following Government instrument;
Inland Fisheries (Delay or Prevention of Spread of Controlled Fish) Order
I make the following order under **section 152 of the *Inland Fisheries Act 1995***.
BRYAN GREEN
Minister for Primary Industries, Water and Environment
Delay or prevention of spread of controlled fish

> The Director is authorised to take any, or any combination of, the following actions to delay or prevent the spreading of controlled fish to other places or waters:
> (a) drain inland waters;
> (b) divert inland waters;
> (c) manipulate the level of inland waters;
> (d) augment, restrict, screen or otherwise control inflowing and out flowing waters to inland waters;

(e) restrict, totally or partially –
    (i) the access of any persons or animals to inland waters; and
    (ii) the activities of persons in or around inland waters.

Developing an integrated control program

Once the decision was made to eradicate carp an integrated program was initiated (See Diggle et al 2012 for further detail).

- Assessing the distribution and abundance of carp
- Screening outflows
- Carp population reduction

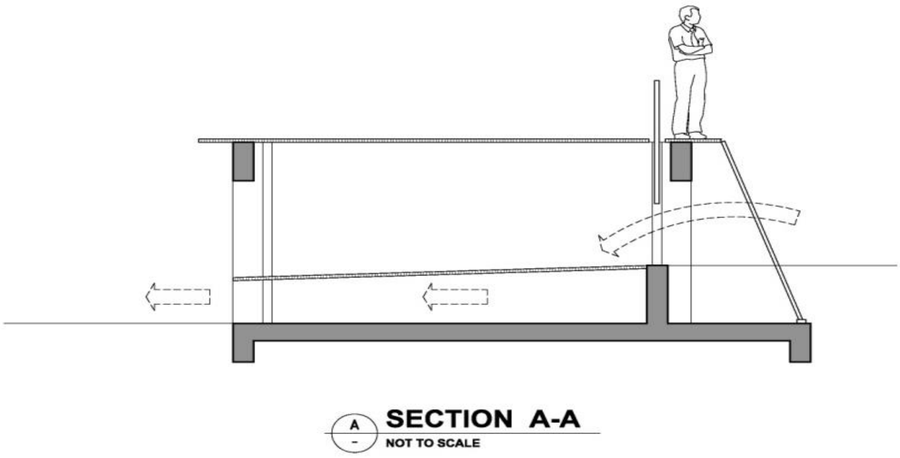

Figure 2. Drawing of outflow screen showing direction of water flow.

Figure 3: A haul of carp using a seine net

Technique development

A number of standard techniques have been adopted and developed or modified from experience obtained during the CMP. All of these have contributed to the reduction of carp numbers (Diggle et al 2012)

- Biotelemetry
- Smart Carp
- Chemo-attraction
- Berley trials
- Population estimation, age and structure
- Recruitment monitoring

Key vulnerabilities

The common carp is known to be a very hardy species, a trait largely responsible for its successful establishment in places of its introduction. However, a better understanding of its biology through years of observation has enabled the CMP to successfully exploit a number of weaknesses throughout the carp's life cycle. Below are some of the key life stages and environmental conditions that can be targeted and may be useful for other carp control programmes elsewhere;

- carp eggs
- juvenile carp (larvae to 3 months)
- juvenile carp (3-18 months)
- age at maturity
- narrow spawning window
- temperature
- schooling behaviour
- water levels and drought

The Lake Crescent example

The successful eradication of carp from Lake Crescent is to be looked at in the context of the Bomford and O'Brien (1995) model. In the case of the Tasmanian situation the most difficult criteria to meet proved to be that 'the rate of removal exceeds the rate of increase at all population densities'. Through the Tasmanian program it has been shown that the size of cohorts can be reduced systematically and within a window of seven years eradication is possible. The most difficult action was blocking spawning despite having reduced the population to a small size.

For detailed information about the techniques and approaches undertaken by this project please refer to the PESTSMART report 'A manual for carp control: The Tasmanian model'(Diggle et al 2012)

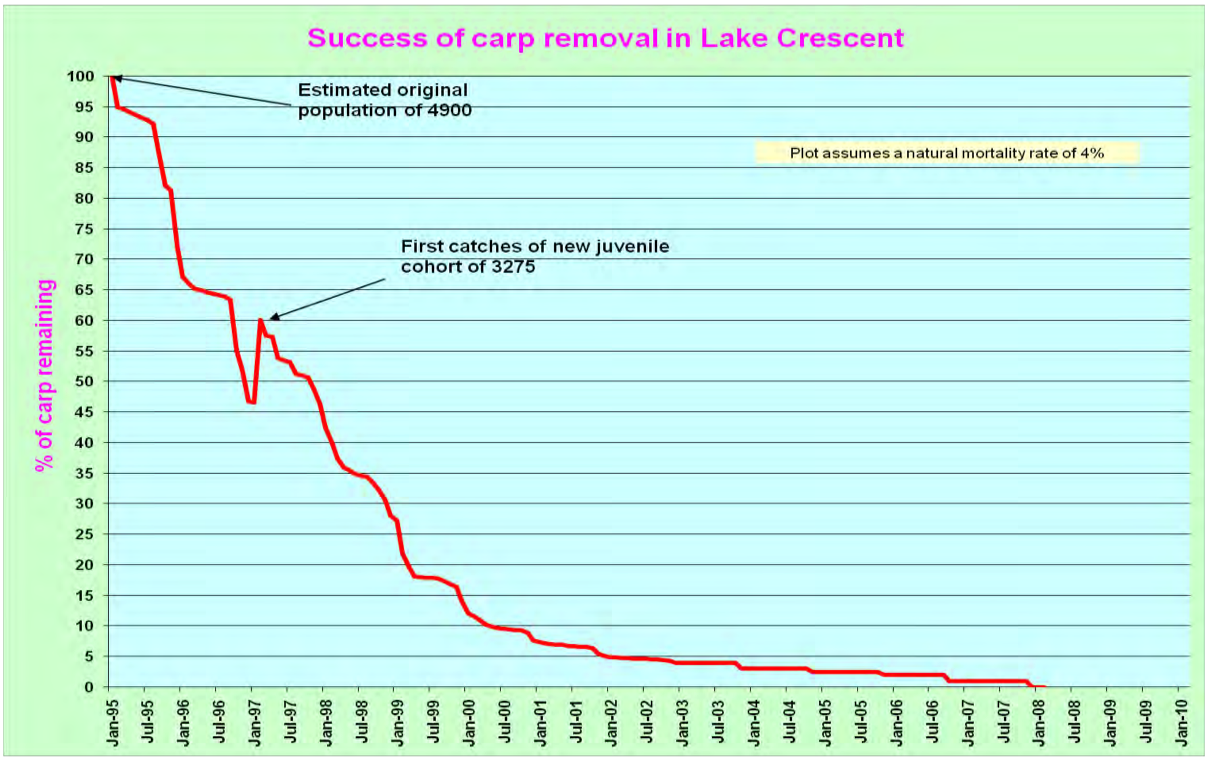

Figure 4: Carp removal rate from Lake Crescent

Acknowledgements

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Questions

Q: Did you check the populations of native fish and how they fared with the manipulations that you were doing?

John: The natives we had were the endemic golden galaxias and the short-finned eel. The eels were pretty happy. The galaxias struggled through the drought mainly. We did help with monitoring this species. The water level management program for the lakes has been designed to protect threatened fauna. We obtained funding for the development of this plan and it took into account the requirements of the golden galaxias. We actually had an intervention during the drought by the Federal Minister in favour of the galaxias and we also removed some trout from the system to help protect the galaxias populations.

Q: What impact are the eels having on new recruitment (of carp)?

John: We suspect there is an impact on the egg stage but we have not been able to investigate that. We do actually supplement the eel population in Lake Crescent in case it does work.

Preventative carp management during environmental watering of floodplain wetlands

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Background

Inflows into south-eastern Australian rivers are predicted to decline with climate change (CSIRO 2008). Prolonged periods of drought, such as the ‘Millennium drought’, are likely to become more frequent. During the Millennium drought managers were delivering environmental water to discreet floodplain wetlands to sustain their ecological health (Meredith and Beesley 2009, Conallin et al 2012). However, such deliveries were likely to also deliver incidental benefits to common carp (*Cyprinus carpio*), a destructive alien species that uses floodplain habitats as important spawning and recruitment grounds (Stuart and Jones 2006, Crook and Gillanders 2006). This paper uses data gained from managed watering events in the southern Murray-Darling Basin, in combination with existing literature, to inform managers about ways to minimise carp invasion and recruitment during managed wetland watering.

The managed watering events we draw upon were carried out at Banrock Station Wetland (South Australia) and in a range of wetlands along the floodplain of the mid-Murray (Albury to the SA border). For additional information regarding these studies see Beesley et al (2011), Beesley et al (in press) and Conallin et al (2012).

Recommendations

We suggest that water managers can minimise the benefits to carp associated with environmental watering of wetlands by implementing four strategies presented below. We recommend they be implemented in a consecutive fashion; however, we recognise this is not always possible and in some cases not desirable, and believe that benefits can still be attained by implementing a single strategy.

Dry wetlands prior to environmental water delivery

As carp have no adaptations that allow them to survive desiccation, wetland drying is an effective way of eliminating the entire population within a wetland. When only partial drying is possible, carp removal using additional carp control techniques (e.g. multiple-pass boat electrofishing) should be considered. Removal methods will be less effective than complete drying, because it is very difficult, if not impossible to remove all the carp and those remaining will eventually breed and replenish their numbers. Additional control methods are also recommended where drying is not an appropriate option due to the presence of important populations of native fish (e.g. threatened species). Control techniques employed under this scenario will need to consider the effects on non-target animals.

Restrict the movement of adult carp into wetlands during watering

The movement of carp into wetlands during environmental water delivery can be reduced by using physical barriers or traps. This includes the installation of fish screens (Hillyard et al 2010) or carp cages (Stuart et al 2006, Thwaites et al 2010) on the channels that connect the wetland to the river (or the source of the environmental water). Delivering environmental water via a pump can also prevent the invasion of carp, particularly adults (Vilizzi et al 2013, Beesley et al in press) and this technique can be improved further with screens on the inlet (see Boys et al 2012). Where barriers are not appropriate or practicable, carp movement can be reduced by choosing to water during months when carp movement is at a minimum. In the Murray River, the peak movement of carp is related to spawning and occurs during spring, particularly September-October (Conallin et al 2012). Watering outside this period is recommended if no techniques to deter carp entry are to be used.

Minimise the opportunities for carp to spawn and recruitment

The inundation of dry wetland sediments is known to stimulate carp spawning (Koehn et al 2000), hence we recommend watering outside of carp's spawning period. In the Murray River, carp spawn between August and April, with a peak in September (Conallin et al 2012), so we suggest managers' water between May and July (winter). In the past, watering in May and June has occurred not due to environmental imperatives, but to meet socio-political constraints. For example, governments have been more likely to use water once irrigator demands are met (i.e. post irrigation season), and before the June 30 deadline for annual water accounting purposes (Meredith and Beesley 2009). While some fish researchers question the appropriateness of watering during winter for native fish, because it is outside of their spawning period, this concern may be overstated because many native fish recruit in the absence of flow (Humphries et al 1999). Indeed, native fish in Gunbower wetlands that were watered in May displayed strong recruitment when spring arrived and carp did not (Beesley et al 2011).

Limit the movement of carp back to the river

If native fish gains within a wetland are to benefit the wider fish community, fish must be allowed to return to the river. 'Natural' river rises may facilitate this, or managers may use follow-up watering events to create a river-wetland connection. If managers are performing follow-up watering, there are steps they can take to maximise the return of native fish while minimising the movement of carp (Fig 1).

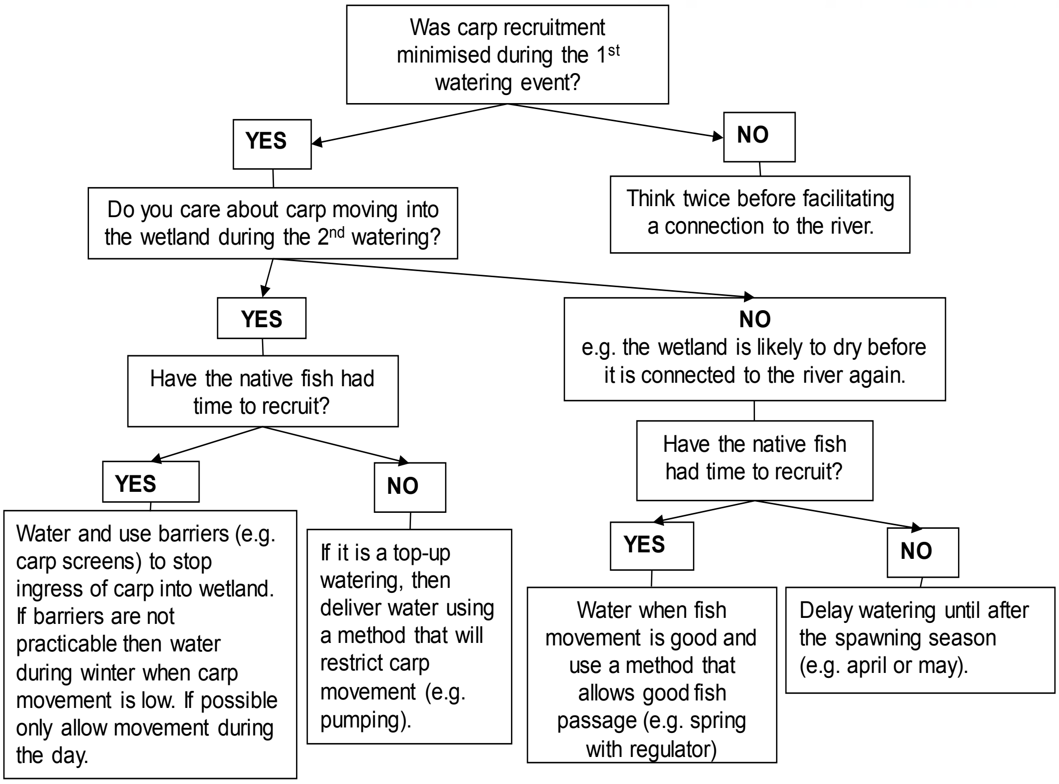

Figure 1: Dichtomous key to advise managers how to perform a follow-up watering of a wetland to maximise the return of native fish to the river and minimise the return of carp

Key Message

Our research suggests that floodplain wetlands can be watered in such a way as to maximise the benefits for native fish, while minimising the benefits to the alien pest species, common carp. One strategy that could be particularly successful is to water dry wetlands during May / June and then rewater them again the following year in April to allow native fish that have been spawned in the wetland to return to the river (see Fig 2). For this to work, the wetland must be deep enough to sustain water over the summer. If the wetland is likely to dry, we recommend topping-up the wetland with water in late October, early November – that is, after the peak period of carp spawning and movement, and before the wetland gets too hot so that the chance of creating a blackwater event is minimised (see Kerr et al 2013). The top-up could occur earlier if methods are used that limit carp movement into the wetland (pumping, fish screens etc). We recommend that managers trial this approach (and monitor the outcome) and compare it against watering in spring to test its efficacy.

We recognise that the strategies we have put forward are most likely to be successful during regulated conditions (i.e. non-flood periods), when river-wetland connections can be controlled.

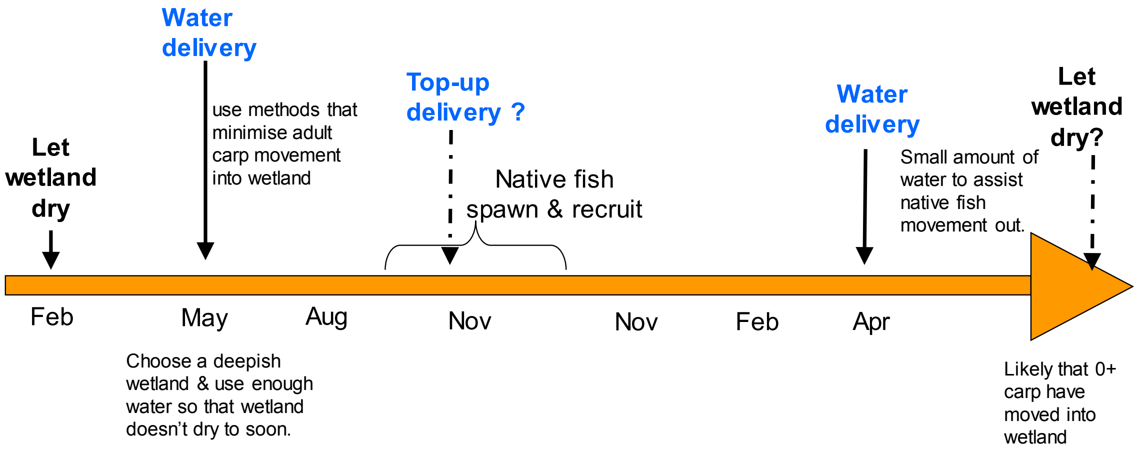

Figure 2: A timeline showing a theoretical wetland watering to maximise benefits for native fish while minimising benefits for common carp.

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Questions

Comment: Looking at what you are proposing, we have tried those sort of things numerous times as a basic approach. A lot of what you are suggesting there is that we understand how native fish move but in a lot of situations we don't, or we tried what has been suggested and they don't move.

Leah: You are right. There is a big hole in our understanding of lateral movement of small bodied fish and we do need to get a handle on that before we can do this.

Leah Comment: It is also relevant to think about the larger spatial scale. We are trying to minimise carp recruitment and help the native fish by facilitating that floodplain river connectivity. Whether we find that the large flood cycle is so much larger than anything we do at these small spatial scales during drought makes no difference then we are probably wasting our time. It could be that during periods of drought our native fish are really relying on some recruitment in the wetlands to bolster them up then it might be worthwhile. At the moment we just don't have any feeling for how important it is.

Carp Screens - better designs, better decisions.

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Objectives / Background

Carp screens are used in the Murray-Darling Basin (MDB) to prevent invasive alien common carp (*Cyprinus carpio*) from entering wetlands, locally minimising their ecological impacts, denying them access to spawning habitat and facilitating extirpation during wetland drawdown. The effectiveness of existing screen designs has not been evaluated however, and little is known of their incidental effects on the lateral (instream-offstream) movements of other fish and aquatic fauna. To address these deficiencies, a study was undertaken to;

1. determine the spatial and temporal nature of lateral fish movements in the River Murray, South Australia;
2. describe the location and design of carp screens across the MDB;
3. develop designs optimised to prevent the passage of sexually mature carp ≥250 mm total length (TL); and
4. compare and evaluate the new and existing designs.

To complement the improved carp screen designs and better inform appropriate implementation of wetland-scale carp management, guidelines have been developed to help landholders, community groups and wetland managers. These guidelines help determine whether carp management is worthwhile at a particular wetland, and what management technology is most relevant (Smith et al 2009).

Summary of findings

The lateral movements of fish between the channel of the River Murray and six perennially inundated wetlands in South Australia were monitored from August to November 2006 using directional fyke nets. Over the 13 weeks of sampling some 220 000 fish from 18 species (14 native, four alien) were recorded (Hillyard et al 2010, Conallin et al 2011). Small-bodied (<100 mm TL at maturity) native fishes, primarily Australian smelt (*Retropinna semoni*), comprised the bulk of the catch (c. 85%). Of the large-bodied (>100 mm TL at maturity) fishes, native bony herring (*Nematalosa erebi*) were dominant (c. 10% of catch). Carp accounted for only around 1% of fish caught, but were mostly of breeding size (>250 mm TL) (Conallin et al 2011, Hillyard 2011). Movement of fish was bidirectional, although the balance of fish movements, for most species, was from, rather than to wetlands, possibly in response to falling wetland water levels. The abundance of several small-bodied species moving through the wetland inlets increased, apparently in response to increasing water temperature and day length (Hillyard 2011). These generally bidirectional movements were likely in response to the stable water levels in the study reach, contrasting with those observed elsewhere in the MDB where clear directional patterns occur in response to water level fluctuation (Lyon et al 2010).

Following extensive literature review and Natural Resource Management (NRM), Catchment Management Authority (CMA) and researcher consultation, 54 carp screens were identified and visited across the MDB (mid 2007). Carp screens were mostly used in the Lower Murray (Hillyard et al 2010), where river regulation via weirs and barrages has resulted in approximately 70% of the wetland area becoming perennially inundated (Pressey 1990), creating ideal carp spawning conditions (eg Vilizzi 1998). Eight styles of screen design were identified; Alu-Tread walkway mesh (Locker Group, Melbourne Australia) was the most common design in use. Approximately 80% of wetland inlet structures fitted with carp screens had no means to facilitate water level control, diminishing the potential benefit of screens for within wetland carp extirpation. Two screen designs, square grid mesh and jail bars, were identified as suitable designs for optimisation.

Morphometric data (length-width-depth) from large-bodied fish (carp, redfin perch [*Perca fluviatilis*], goldfish [*Carassius auratus*], bony herring and golden perch [*Macquaria ambigua ambigua*]) captured during the lateral movement study were used to design carp screens that excluded sexually mature carp while minimising impacts on native fish passage. An exclusion threshold of 250 mm TL (c 225 mm caudal fork length (FL)) was chosen based on the known size of carp at sexual maturity in Australia (approximately 300 mm FL, 50% of population: Brown et al 2005). Two optimised meshes to exclude ≥250 mm TL carp were developed: a 44-mm square grid mesh and a jail bar mesh with 31.4-mm gaps. Modelling revealed that up to 92% of the carp caught in the lateral movement study would be excluded by either optimised mesh design, although few young-of-year carp, which would pass either screen design, were caught in the lateral movement study. Optimised screen designs would also exclude as few as 2% of the bony herring and up to 65% of the golden perch caught in the lateral movement study.

Initial field evaluation of the new square grid mesh and jail bar mesh designs was undertaken at 12 wetlands spanning three bioregions of the River Murray in South Australia (Hillyard 2011). The screens were tested using directional fyke nets rather than in wetland flow-control culverts where carp screens would be typically used, owing to the drought conditions which were present at the time of the study. The two new designs allowed the passage of more fish (including all small and medium-sized native species <200 mm TL), and larger fish, than the most common current design (Alu-Tread walkway mesh). Adult carp and turtles passed none of the screens.

Management Recommendations

We recommend the jail bars as the most promising carp screen design for future application in carp screens at wetland inlets in the MDB and potentially for incorporation into other carp management technologies. Whilst the square grid mesh design compared favourably with the jail bars in terms of passage of small and medium-sized native species, and both performed better than the Alu-Tread design, the jail bar design allowed the passage of more Australian smelt and larger bony herring, species dominant in the lateral movement study. Further, recent field application of both carp screen designs in high-velocity water (≈1.5 $m.s^{-1}$) revealed that the square grid mesh design clogs with debris much faster than the jail bar design, is harder to clean and requires more frequent inspection (Thwaites and Smith 2010). While the jail bar design indeed shows promise for basin-wide application based on initial exploratory field trials, ongoing evaluation and refinement across a range of wetland and habitat types is warranted to confirm the benefits of this new design over those designs currently in use across the MDB.

Where applied appropriately, screens offer a simple, effective and immediately available technology for denying large carp access to their desired spawning grounds, where their impacts are pronounced, while minimising impacts on offstream movements of native fish. However, screens should only be utilised when carp management is a recognised priority, and considered achievable, during the wetland management planning process. Carp management at the wetland-scale can locally improve wetland condition, but application of the carp screens at wetlands identified as spawning 'hotspots' may help achieve basin-scale carp management when integrated with other techniques such as carp screens fitted with a one-way pushing gate (Thwaites et al 2010).

Wetland managers, land-holders and community groups are directed to the IA CRC funded 'Guidelines for carp management at wetland inlets: A test case for South Australia' (Smith et al 2009). The guidelines help determine whether carp management at a particular wetland is feasible and what technology should be utilised. The guidelines describe the need for an initial assessment of the wetland in terms of landholder or community group support for carp management, as well as the need for support from government (e.g. NRM/CMA groups). With support available, the wetland's fish community should be clearly described and a wetland management plan prepared which has identified carp management as a goal. Following this initial assessment, the next phase requires characterisation of wetland access, infrastructure, hydrology, morphology and river connectivity. With these parameters documented, a decision tree is followed to determine what technology is appropriate.

Acknowledgments

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Questions

Comment: A comment really in relation to recommendations on carp screens that have come out relatively untested and now we are having to go round and replace these at significant cost.

Karl: There was testing but I agree it wasn't ideal. It did give us indications of how screens were going to perform in field-like conditions but perhaps not exactly as they would perform in a flow control structure

Q: Might it have been good to put some of these screens in demonstration sites to see how they performed before putting them all over the place?

Karl: Screens pre-date this project and at the moment this is the best available science. We know the new screen designs will allow more native fish through than the existing ones. Ideally that would be the best way to roll them out. The unfortunate reality is that we do have about 30 screens in use on wetlands across South Australia and within the basin with more infrastructure projects being rolled out as we speak and we have to work with the best available information.

Carp trapping: modernising an age-old technique to control an invasive pest

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Introduction

Common carp (*Cyprinus carpio*) are highly migratory making both longitudinal and lateral movements particularly for spawning (Jones and Stuart 2008). These movements occur annually, often through bottlenecks such as fishways and wetland inlets making them vulnerable to trapping (Conallin et al 2012). Traditional trap designs, however, are non-discriminatory and likely to affect native animals. Historically, non-target animals had to be manually sorted from traps which was stressful for the animals and time consuming for operators. More recently, two new trap designs have been trialled that automatically separate carp from native fish by exploiting unique behaviours. The results of these trials are described below.

Carp Trapping

Williams Carp Separation Cage

The Williams cage, designed by Alan Williams from Torrumbarry Weir, exploits the unique jumping behaviour of carp, allowing them to separate from native fish by jumping over a baffle into a separate holding area (Stuart et al 2006a;b). Native fish are released upstream and carp are harvested from the holding area. Initial trials in the Torrumbarry Weir fishway showed that the cage was very effective, separating 88% (*n* = 370) of migrating carp. Importantly, 99.9% (*n* = 8,031) of native fish passed through the cage during the trial.

The success of the Torrumbarry trial led to an up-scaled commercial trial in the Lock 1 fishway at Blanchetown, SA (Conallin et al 2008). This trial was also successful with 300 tonnes of carp (approximately 120,000 individuals) removed since 2007. Separation efficiencies were found to vary depending on the water temperature and spawning status of the fish with the highest separation of carp occurring during the spring spawning period. Incremental improvements were made during the trials to maximise carp catch and minimise impacts on native fish. For example, the incorporation of vertical bars into the mesh of the trap facilitated the unimpeded passage of native fish particularly juvenile large-bodied species (e.g. golden perch, *Macquaria ambigua*) and laterally compressed species such as bony herring (*Nematalosa erebi*).

Trials of the Williams Cage at unmanned weirs in the Lachlan River catchment were less successful with their isolation creating unforseen issues such as siltation of the trap, a build-up of floating debris on the mesh of the cage, low numbers of fish migrating during drought conditions and cage submersion due to fluctuating river levels. Learning's from the trials are being incorporated into new designs and trials are set to continue at other sites in the Lachlan and Edward river systems (Gilligan et al 2010).

Carp push trap

Thwaites et al (2007, 2010) developed a finger style trap that exploits the pushing ability of carp. Laboratory trials showed that 91.1% (*n* = 40) of carp pushed through the fingers and became trapped. A field trial at Banrock Wetland (Kingston-on-the-Murray, SA) removed 60% (*n* = 157) of carp entering the trap but few native fish were trapped limiting evaluation of their pushing ability.

Combination traps

Maximising the separation efficiency of traps is critical to their design as even a few carp released with native fish will soon breed and cause detrimental impacts. In an attempt to maximise the separation of carp during trapping, a prototype trap containing both jumping and pushing elements was trialled at the Banrock Wetland inlet and outlet. The combination trap was found to be superior to single element devices separating 92% of carp (*n* = 3736) that entered the trap at the outlet. As in the Lock 1 trials, separation efficiency varied with water temperature and spawning status with higher numbers of carp separated when they were capable of spawning (i.e. water temperatures > 16°C).

A separation cage trial was also run at the inlet to Lake Bonney, near Barmera during an environmental water allocation (Thwaites and Smith 2010, Thwaites 2011). In this instance, the cage was being used to separate carp from native fish attempting to escape the poor water quality conditions created from a partial drawdown of the lake during severe drought. The inflowing water attracted tonnes of carp below the inlet regulator but there was a major difference in head between the lake and incoming water resulting in shallow and high velocity water conditions around the cage. This resulted in low catches and limited evaluation of the cage. A subsequent water allocation failed to illicit a response from the carp within the Lake as water quality conditions had improved substantially between the trials. The trials did however, identify and overcome a range of issues related to use of the cage including work health and safety issues and facilitated the development of innovative trash screen designs.

Trap avoidance

Trap avoidance/shyness affects trapping success but is rarely measured. The Banrock Wetland trials showed that trap avoidance was high early in the trial when water temperatures were low and carp spawning was absent. However, this changed dramatically when water temperatures increased above 16°C and spawning was underway. No trials were run on modified designs because it was unclear due to our sampling regime (i.e. weekly removal of fish from in and in front of the trap) whether those carp avoiding the trap would have entered given more time (i.e. >7 days), such as when water temperatures were more conducive (i.e. increased to spawning thresholds) or if they would have just moved to another wetland that didn't have a trap. Further trials focussing on trap avoidance are recommended.

Applicability of separation traps

The applicability and effectiveness of trapping techniques will vary depending on where and when they are used and how well they are managed. For example, the effectiveness of separation cages is proven in fishways and at wetland outlets where carp are moving upstream but trials at wetland inlets where they are moving downstream with the flow have been limited due to low captures of fish. Preliminary results however, suggest that carp will not separate by jumping in a downstream direction and turn around in the trap and try to escape by jumping upstream. This observation led to a trial of a 'turn-around' trap at the inlet of Brenda Park Wetland (Murray River near Morgan, SA) that allowed carp to separate by jumping upstream (McNeil et al 2011). Unfortunately, few carp were captured limiting evaluation of this design.

Decision Support Tool

As there are many decisions to be made when considering carp control options on wetlands (i.e. wetland type, hydrology, fish community etc), Smith et al (2009) developed a 'decision support' tool to assist wetland managers in South Australia to make informed decisions to maximise environmental benefits. There is no decision support tool for fishways as they are relatively straight forward in comparison to wetlands. However, some obvious considerations for planning include;

- knowing what your potential yields of carp may be
- how you are going to dispose of them
- any ethical and legislative considerations that will need to be met etc.

Further discussion of these and other issues related to trapping at fishways is contained in Stuart et al (2006a) and Conallin et al (2008).

Key messages

- Carp Separation Traps can play a major role in carp management strategies but need careful planning.
- Separation Traps exploiting multiple unique behaviours appear superior to single element devices but the pushing ability of native fish needs further investigation.
- Trapping requires active management (they are not a 'set and forget' device).
- Trap avoidance is negligible during the spawning season (September-December) but could seriously affect trap performance at other times of the year requiring further investigation.
- Comprehensive planning considering trap design, placement, fauna welfare (ethics), compliance (fisheries permits), carp disposal, maintenance, monitoring etc are all critical to trapping success

Conclusion

Trapping and separating carp with devices that exploit unique carp behaviours appears to be an effective carp control option in the right place at the right time. However, traps are unlikely to be successful alone and therefore should be considered as a part of an integrated pest management framework involving clear objectives, multiple approaches, new techniques and refinement of old techniques. Further, it is imperative to measure the effects of control techniques such as trapping on local and regional carp populations to determine if they are making a difference.

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Commercial carp harvesting

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Specialising in fresh and frozen carp, K & C Fisheries Global Pty Ltd is one of the largest carp harvesting and carp processing company in the southern hemisphere, with processing targets in excess of 1,000 tonnes of carp per annum. Based in Victoria, K & C Fisheries Global Pty Ltd is export registered and EU export license accredited, with export products including carp trunks, carp fillets and carp roe. They supply whole fish to the domestic market. Value added products to the domestic market include bait to the crayfish industry and supply to the pet food industry and fertilizer industry and skins to the leather market for fashion goods.

K&C Fisheries Global Pty Ltd operates under a permit system in Victorian inland waters and under government license in New South Wales, working both privately and under contract to government departments and private organisations.

Keith was a partner of the IA CRC from 2003 until June 2012, and was contracted by the Lachlan Catchment Management Authority for the River Revival Project. At public events Keith helped promote the awareness of carp, their uses, techniques used to harvest them and the advantages to the environment by removing them from our waterways. The contract also subsidised 20 days of annual carp harvesting and data collection in the Lachlan River Catchment.

Commercial fishers can be very versatile and go where the carp are at any one time. Commercial harvesting can be undertaken in rivers, lakes, wetlands, dams, creeks and any areas where carp congregate. Techniques used can include traps, electrofishing, seine netting, fyke netting and fish pumps.

Catch rates vary, from 160,000 kg per hour (1990) to 2 kg per hour (2010). Over the last few years catch rates have declined due to drought conditions. Even though the biomass of carp will increase dramatically with the advent of good rains and floods over the last two years, the catch rates might not increase due to the restrictions being placed on commercial fishers.

Commercial fishing usually depends on profitable market returns, which makes it not viable for a lot of areas due to transport and logistical costs. State fisheries departments also have restrictions on allowable techniques and equipment so as to prevent any native fish by catch; and restrictions on allowable fishing times, which also can make commercial fishing non-viable.

[Abstract only provided]

The role of fishing competitions in carp management

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Background

Many community groups are concerned about the detrimental impacts carp are having in their local waterways and to actively address the issue some groups have organised 'fish-out' events. These events are becoming more popular as people see them as a fun way to help deal with the pest fish problem. A lot of competitions are organised by local fishing groups who see the events as an opportunity to have a real impact on local pest fish populations and/or raise money for the restocking of native species or other community-based projects.

It is well known that fishing pressure can run down fish stocks in a river (Templeton 1995), but it remains unclear as to whether community based fish-out events have a significant impact on their target species. Fishing clubs in small regional towns in many of the Queensland sections of the Murray–Darling Basin had already established or were interested in setting up carp fishing competitions. The regional catchment management group, the Queensland Murray-Darling Committee (QMDC), was also interested in investing in these activities. In 2007 QMDC helped fund several carp fishing competitions, and increased their investment in 2008 by helping establish and run the 2008 Regional Carp Busters Series which was comprised of six carp fishing competitions held throughout the year.

Our project quantified the proportion of the carp population removed in three of these 'fish-out' competitions and examined the social drivers behind participation at all six events in the 2008 series.

Impacts of pest 'fish-outs'

The three events selected to assess the impact of angling on the local carp populations were the Goondiwindi Carp Cull 2007 (40 km of the McIntyre River and its backwaters, 169 anglers), Thallon Carp Comp 2008 (6 km of the Moonie River, 305 anglers), and Goondiwindi Carp Cull 2008 (12 km McIntyre River, 266 anglers). These events represented a range of geographic and social parameters that may influence the impact of events on fish populations.

To assess the impact of angling on the carp populations at each competition, a series of monitoring sites were established. Prior to the events, carp were captured at these sites via electrofishing, marked with dart tags and released. The competition catch and post-event electrofishing enabled the carp population size at each site to be estimated from tag return rates. Population reductions from both the competition angling and the subsequent electrofishing were calculated.

The results demonstrated that carp angling competitions were not very effective as a direct form of carp management. The removal efforts occurred over large areas, resulting in low angling pressure and removal rates. Population reductions were observed in the range of 0.5% - 1.8% across the competition areas (Table 1). In comparison, removal via boat electrofishing resulted in reduction of 8.3% - 16.1%. When compared to electrofishing, the catch per unit of effort (CPUE) of competition angling was found to be nearly 100 times less in terms of carp per man-hour. Thus, the way these events are currently run, they are unlikely to have any significant impact on local carp population numbers.

Table 1. Proportion of the local carp population removed by carp fishing competitions and electrofishing

Event	*Estimated local carp population*	*Removal by angling*	*Removal by electrofishing*
Goondiwindi Carp Cull 2007	4465	0.5%	13.4%
Thallon Carp Comp 2008	8021	1.6%	8.3%
Goondiwindi Carp Cull 2007	5936	1.8%	16.1%

The second component of the project involved conducting social research to determine the drivers behind participation. A total of 509 people representing a broad cross-section of the community was surveyed. The most common reasons given for entering a competition were to socialize, have a good time and remove carp from the river (Figure 1). Competing and winning prizes were only rarely given as reasons for participating.

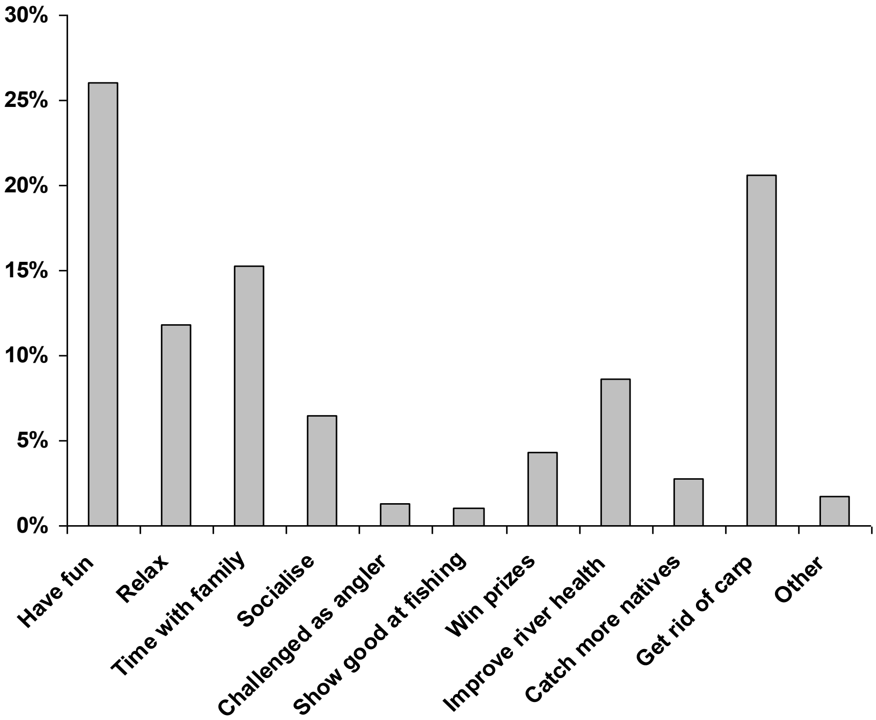

Figure 1. Main reasons for participation in carp fishing competitions (n=487)

Drivers behind participation

The vast majority of people believed that the presence of carp was a negative thing. Only 4% of respondents thought carp were beneficial. Nearly all participants believed carp were having negative impacts in local waterways. When asked what the worst impact of carp was, causing fewer native fish was by far the most frequent (53%) response. The family focus of carp fishing competitions attracted a range of people who may not ordinarily be involved in fishing competitions.

Whilst not having a significant impact on carp populations, fishing competitions do however have a range of more non-tangible management benefits. The events help educate the wider community on the detrimental impacts pest fish have, raise awareness and ownership of the pest fish issue and provide a social focal point for smaller regional communities. The competitions can generate revenue which can be directed into native fish restocking, river restoration or funding contractors to remove carp in high value areas.

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Questions

Q: We are trying to get community involvement in our carp programs and we have come up with a few ideas. I was wondering did you offer prizes such as for tagged carp?

Andrew: We did at all events. We had cash prizes for a mystery draw for those who caught carp. We also offered prizes for participation in our surveys using a prize draw.

Q: Also did you approach corporate sponsors for prizes?

Andrew: Most of these competitions are extensively funded by businesses and all the prizes are either donated or offered at less than wholesale. That demonstrates how strong the community support is for those events.

There were also several general comments regarding the value of carp fishing competitions as a vehicle for community engagement.

Destruction and disposal of carp captured during management: challenges and ways forward

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Introduction

Management activities to control carp in Australia will inevitably involve the capture of fish and the consequent need to destroy (euthanasia) and dispose of them. The numbers of carp involved will vary from a few fish to many thousands and biomasses from a few kilograms to many tonnes at sites like Lock One on the Murray River. Furthermore, carp management involves a wide range of stakeholders from local community members to catchment management groups and natural resource management agencies. Activities will vary from simple removal exercises to ongoing monitoring and research. Carp management also occurs over a number of jurisdictions with varying animal ethics requirements and disposal regulations. At present there are no comprehensive national guidelines for the destruction and disposal of carp or indeed alien fishes in general. This paper considers current policy and legislative requirements related to the destruction and disposal of carp and considers the challenges currently facing those undertaking carp management in Australia. Options for developing national guidelines that link in with existing national initiatives are considered.

The information presented here draws on two studies undertaken by the author on behalf of the Murray-Darling Basin Authority. The first study looked at options for the ethical and cost effective removal and disposal of carp from fishways along the Murray River (Jackson 2009). The second, currently in progress, examines issues associated with the destruction and disposal of alien fishes in the Murray-Darling Basin.

Destruction

Ethical Considerations

There has been continuing debate over the last decade on whether fish feel pain and the implications of this for animal welfare issues. More recently, a number of authors (e.g Braithwaite 2010, Sheddon 2011) have concluded that fish do in fact feel pain and should be treated accordingly. The main lines of evidence according to Sheddon (2011) and Brown, Laland and Krause 2011) are that;

- Teleost fishes possess nociceptors that preferentially detect painful stimuli and have neural pathways from the periphery to the brain.
- The brain is active during painful stimuli and fishes display adverse changes in behaviour and physiology indicating suffering that can be ameliorated by morphine.
- Fishes can detect, react to and show complicated and lasting behavioural changes that are indicative of how significant pain is to them.
- The learning abilities and complexity of behaviour are comparable to many land vertebrates.

Whether fishes undergo an “emotional experience” when undergoing painful stimuli (see the International Association for the Study of Pain in National Aquatic Council of Australia 2005) seems an unnecessary diversion. To quote Sheddon (2011) "It is suggested that fishes should be considered capable of experiencing poor welfare states and that these should be minimized".

Legislative and Policy Considerations

In Australia, animal welfare legislation is the prime responsibility of State and Territory governments. All animal welfare legislation in Australia includes fish with the current exception of South Australia and Western Australia. However, in Western Australia, provision for the welfare of fish exists in fisheries legislation. Copies of all state and territory animal welfare legislation can be downloaded from the AustLII data base: www.austlii.edu.au

The Commonwealth Government is responsible for trade and international agreements relating to animal welfare and also the development of national initiatives, standards and guidelines related to animal welfare.

Relevant national level strategies/guidelines include;

- The Australian Animal Welfare Strategy and Implementation Plan 2010-2014 (Commonwealth Department of Agriculture, Fisheries and Forestry).

  This document provides broad goals and objectives for animal welfare in Australia. The Australian Animal Welfare Advisory Committee, established in 2011, will oversee the establishment of a number of working groups and the development of action plans for each animal sector. Of most relevance is the formation of the Aquatic Animal Welfare Working Group which has produced the following documents;
    - Overarching principles for animal welfare in vertebrate aquatic species
    - Draft Animal Welfare Code (Rod-Hand line)
    - Draft Animal Welfare Code (Mesh Net)

- Australian code of practice for the care and use of animals for scientific purposes Edition 7, 2004 (National Health and Medical Research Council).

  This is a key document that requires the establishment of Animal Ethics Committees to review animal welfare issues related to all research and teaching projects. The guidelines are currently under review involving advice from a broad range of stakeholders. A revised edition of the document is expected to be available in late 2012 or early 2013.

- Euthanasia of Animals used for Scientific Purposes , 2 Edition, 2001 (Australian and New Zealand Council for the Care of Animals in Research and Teaching, ANZCCART)

  This document provides recommended, acceptable and not acceptable methods for euthanasia in fish used in scientific research and provides national guidelines for researchers and ethics committees. Published in 2001 it is expected to be revised in the near future. Comments and suggestions on revisions of the document may be directed to ANZCCART at the following email address: anzccart@adelaide.edu.au

Euthanasia Methods

The European Commission, DGXI Working Party (1996) defines euthanasia as a process that aims "to be painless, achieve rapid unconsciousness and death, require minimum restraint, avoid excitement, is appropriate to the age, species and health of the animal, must minimize fear and psychological stress in the animal, be reliable, reproducible, irreversible, simple to administer and safe for the operator, and so far as possible, be aesthetically acceptable for the operator”.

In Australia, national guidelines for animals used in research and teaching can be found in the ANZCCART (2001) guidelines and in the Australian Aquatic Animal Disease Emergency Plan (AQUAVETPLAN), Operational Procedures Manual- Destruction version 2.0 (2009a). Recommendations for euthanasia of fish are summarised in the Tables below:

ANZCCART (all situations)

Method	*Comments*
Recommended	
Chemical – Skin absorption (Halothane,MS-222,Benzocaine, Eugenol, clove oil)	For chemical methods death should be confirmed by destruction of the brain. Any chemicals used must be registered for the specific use by the Australian Pesticides and Veterinary Medicines Authority.
Acceptable with Reservations	
Chemical - Injectable (Sodium pentobarbitone)	Only acceptable with reservations because the injection of drugs involves the removal of fish from the water and handling resulting in stress.
Physical – Stunning and brain destruction, cervical dislocation, decapitation, spinal section	Stunning requires training, cervical dislocation can be used in small fish but may be stressful due to the handling required. Decapitation or spinal transaction should only be carried out in already anaethetised fish.
Not Acceptable	
Chemical - Carbon Dioxide	This causes hyperactivity before loss of consciousness indicating a level of distress
Physical - cervical dislocation (large fish), decapitation alone, removal from water	Difficult to break the backbone in large fish.
Hypothermia - Freezing, Ice Slurry	Removing fish from the water is unacceptable because of the length of time for fish to become unconscious. This period will be prolonged if the fish are cooled.

AQUAVETPLAN (situation specific)

Situation	*Method*	*Comments*
(a) Fish in oceans, lake or river systems (open systems	Any commercially caught fish be killed using methods similar to standard practices for that commercial capture technique.	This suggests the use of an ice slurry is acceptable.
	Where control of the spread is possible wild fish can be destroyed using rotenone.	This suggests the fish are not removed from the water but are destroyed *in situ*
Fish in sea and lake cages (semi-open systems)	Ideally fish are destroyed individually (percussive stunning, spiking the brain), but other methods are acceptable if it is a preferred routine harvesting method (e.g. ice slurry)	Again an ice slurry is acceptable
	Enclose cages with impermeable liner and add lethal concentration of anaesthetic or toxin.	
	Death may be caused by crushing and asphyxiation if large volumes of fish are removed from the water rapidly	Probably the case with carp at Lock One on the Murray.
Fish in ponds and raceways (semi-closed systems)	Ideally fish are destroyed individually (percussive stunning etc.) but an ice slurry is also acceptable if it is the normal routine method.	
	A lethal concentration of anaesthetic or rotenone to static water.	
Fish in aquariums etc (closed systems)	Ideally fish are destroyed individually (percussive stunning etc,) but an ice slurry is also acceptable if it is the normal routine harvest method.	
	Lethal dose of anaesthetic	

In summary, the main differences between the ANZCCART and AQUAVETPLAN guidelines are the accepted use of ice slurries and a greater understanding of the practical issues involved in dealing with large numbers of fish in the AQUAVETPLAN guidelines. However, it must be remembered that the AQUAVETPLAN guidelines were developed for emergency disease outbreak situations where time may be of the essence.

Issues

- There are national guidelines for research and emergency disease response only
- The national guidelines for research are out of date and do not address the practical issues of dealing with large numbers of carp in a short period of time.
- There are significant inconsistencies between the ANZCCART and AQUAVETPLAN guidelines (e.g. the acceptable use of ice slurries by AQUAVETPLAN)
- National guidelines are required that cover all situations and useable and safe for all stakeholders and these need to be formally recognized.
- Clarification is required regarding what constitutes research and when animal ethics committee approval is required. Exemptions for NRM and Community groups undertaking routine monitoring should be sought.

Disposal

There are three broad types of disposal:

a) Utilisation of the fish as a *direct* resource (e.g involvement of commercial fishers).

b) Utilisation of the fish as an *indirect* resource (fertilizer, compost etc.) .

c) Treating the fish as a waste product (burial, landfill disposal etc.)

The use of the fish as a resource, either through the engagement of commercial fishers or as compost etc, is likely to gain greater community acceptance than treating them as purely waste product.

Commercial fisher involvement

Commercial fishing has been undertaken in South Australia, New South Wales and Victoria since the mid 1800's and carp have been part of the catches for over 50 years (Toohey and Associates 2002).The markets include human consumption (domestic and overseas) and industrial use (bait for rock lobster/crayfish, liquid fertilizer). Key factors governing commercial fisher involvement include:

- Jurisdictional fisheries agency requirements (licensing etc.).
- Commercial viability (availability of sufficient numbers of carp, harvesting costs and effort, travel distances etc).

The involvement of a commercial fisher in the disposal of carp has been successful at Lock One on the Murray River. Commercial viability will vary significantly both spatially and temporally but options such as coordination between sites, temporary storage of fish on site (freezers) etc may help facilitate commercial fisher involvement over a greater number of sites.

Compost etc.

The Australian Aquatic Animal Disease Emergency Plan (AQUAVETPLAN), Operational Procedures Manual- Disposal, Version 2 (2009b), provides the only national guidelines for the disposal of fish. While the guidelines are designed primarily to contain disease outbreaks, they provide good general guidance for the disposal of fish whether diseased or not. The following are relevant to carp disposal:

Method	Comments
Commercial Composting	Most jurisdictions have commercial composting facilities. There are also companies (e.g BioBins in South Australia) that will sell or hire portable compost bins and if necessary collect the composted material. Ultimately the method chosen will depend on the amount of material to be composted.
Composting on site	The AQUAVETPLAN provides guidance for composting at an approved site. They could be used to allow composting close to the capture site.
Rendering	This is a process for mechanical treatment and thermal treatment of animal tissue. Rendering takes place in dedicated facilities and the end product can be used as fertilizer. It could not be undertaken on site.

Waste Product

Advice should be sought from relevant jurisdictional agencies and Local Councils before any carp are disposed of as waste. In general, harvested carp will be classified as "general solid, organic (putrescible) waste". The AQUAVETPLAN provides the following guidelines:

Method	Comments
Burial a) deep trench burial	The AQUAVETPLAN provides guidance on site selection (access, distance from watercourse, height of water table, proximity to housing etc.) together with guidance on pit construction, filling etc.
b) Landfill	Burial at local tips may be feasible if the necessary environmental protection measures have been catered for.
Cremation	This includes the use of pyres, incinerators and pit burning.

Issues

- The only national guidelines for the disposal of fish carcasses relates to emergency responses to disease outbreaks.
- Disposal of carp must be undertaken in a variety of situations (e.g. small/large numbers of fish, urban/remote locations, wide range of stakeholders)
- The is little coordination between carp management projects and a lack of shared learning.
- Trials on possible solutions such as BioBins have not been undertaken.

Recommendations

- Destruction and disposal requirements must be key considerations when planning any carp control project.
- Nationally accepted guidelines and codes of practice are required for both destruction and disposal.
- These guidelines must fit in with existing national initiatives and frameworks (see Ayers and Clunie 2010).
- These guidelines could initially be based on existing documents e.g. ANZCCART (2001) and AQUAVETPLAN (2009) but should be updated and the into account issues raised by practitioners of carp management in Australia.
- The current reviews of the ANZCARRT and National Health and Medical Research Council guidelines provide the opportunity to assist in updating these documents. The

issues and options paper for the destruction and disposal of alien fishes, currently in preparation, will be used to input into these reviews.

Acknowledgements

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Questions

Q: We have heard comments from people that carp are tying up carbon that could be taken up by other fish. Is there a contradiction in that on the one hand we are saying there is this carbon that is being taken up and now we are saying we should be taking it away. This essentially depletes the system of carbon, is there any way that we could get these fish back in a healthy way?

Peter: I don't have an answer at this stage. I think where the mortalities are only small they could be left in the system but it is where there are tonnes of fish killed that you have to do something with them. A good point that is worth looking at.

Comment: One option that has been looked at is composting and returning this to riparian vegetation so that it is not lost to the system.

Comment: In relation to the carbon we do not know what percentage of the carbon in the system we are talking about. Depending on this figure it may be important or it may not be an issue at all.

CARPSIM: Modelling the outcomes of fishing, water draw-downs, and biological carp control actions at a catchment scale

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Objectives and Background

Carp control activities proposed under a regional carp control plan for the Lachlan catchment (Gilligan et al 2010), were simulated in a computer model carp population. A range of currently available carp control tools and techniques were simulated, such as Williams' carp separation cages, wetland carp separation cages, pheromone lure traps, commercial fishing and recreational fishing and the potential effects. Alongside these we also simulated proposed biological-control options, cyprinid herpesvirus-3 (CyHV-3) and genetic sex-ratio distortion (via daughterless carp gene technology). Meta-population models were developed to mimic the geographic arrangement, biological connections and 'unfished' stock-structure of the pest population of carp in the Lachlan River catchment, New South Wales (see Fig 1). Models used the CarpSim 2.1 framework (Brown and Walker 2004; Brown and Roberston 2007) and were fitted to recent observations of biomass and abundance.

A review of published case-studies and technical reports yielded the parameters used to simulate fishing, water draw-down and biological control methods (Stuart and Conallin 2009; Stuart et al 2006; Saunders et al 2009; McColl et al 2007). With the models we compared the population abundance in six geographic units before carp control began (before 2009) and after a ~70 year period of sustained management. The Lachlan River Revival Project has set a carp control target of 80-90% reduction in biomass. We modelled the full range of uncertainties associated with KHV mortality rate and prevalence (0%–100%) to investigate potential performance targets as minimum thresholds (above which CyHV-3 can achieve biomass reduction targets). Further details are given in Brown and Gilligan (2014).

Table 1. Spatial management units used for the simulation of carp population dynamics and management scenarios

Zone No	*Geographic extent*	*Modelled area of carp habitat (ha)*
1	Lachlan River and tributaries between Wyangala Dam and Jemalong Weir	4,983
2	Lachlan River and tributaries between Jemalong Weir and Brewster Weir (excludes the Lake Cowal – Bland Creek subcatchment)	2,726
3	Lake Cargelligo	1,314
4	Lachlan River and all effluent creeks downstream of Brewster Weir	6,426
5	Lachlan River and all tributaries upstream of Wyangala Dam	4,939
6	Lake Brewster	6,278

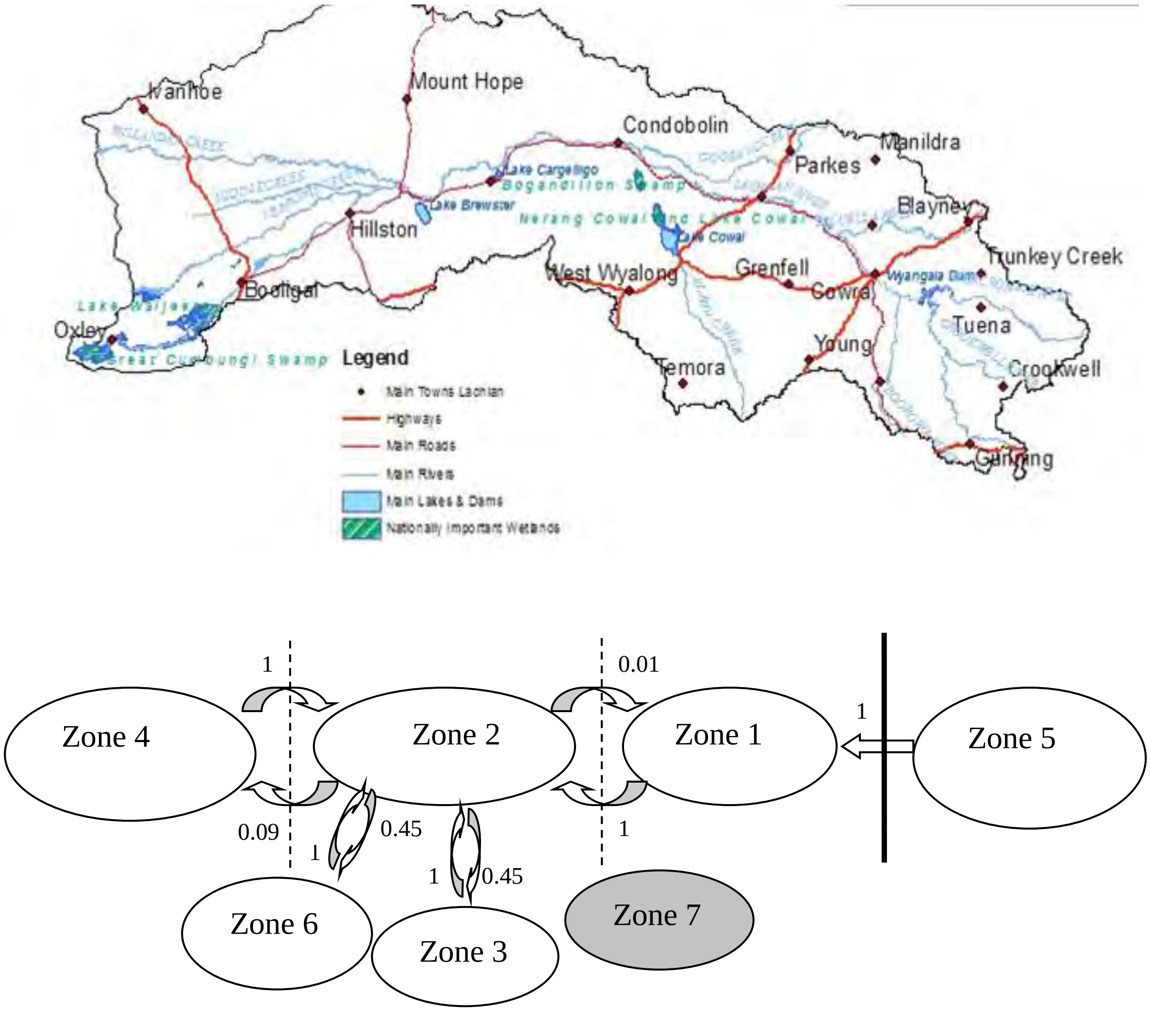

Figure 1. Map of the Lachlan River Catchment, New South Wales (upper panel) and the schematic depicting seven spatial carp habitat zones simulated in the model. See Table 1 for description of reaches. Ellipses represent carp stocks with individual population parameters and modelled as separate stocks in CarpSim 2.1. Arrows represent the direction of potential carp movement between stocks. Numbers adjacent to arrows indicate values of the source-sink matrix used to distribute emigrants from each zone. The solid line represents Wyangala Dam, an impassable barrier to upstream fish-passage. Dashed lines represent existing major weirs; Brewster Weir and Jemalong Weir that also prevent upstream fish passage under a vast majority of flow conditions. Numerous additional fish passage barriers exist within zones 1, 2 and 4, however these are drowned out more frequently. Zone 7 (the Lake Cowal – Bland Creek sub catchment) was not included in the model simulations due to a poor connection with the remainder of the sub-populations, relatively small available habitat area and uncertainty of the population dynamics of the carp population present.

Summary of Findings

An initial base model, with no carp control, was fitted to existing survey data until modelled carp density closely approximated observed carp density in the six reaches (Figure). Simulations of a range of carp control measures were then applied to this base model. In some zones, it was hard to achieve required biomass reductions with removal methods alone or in combinations (Table 2).

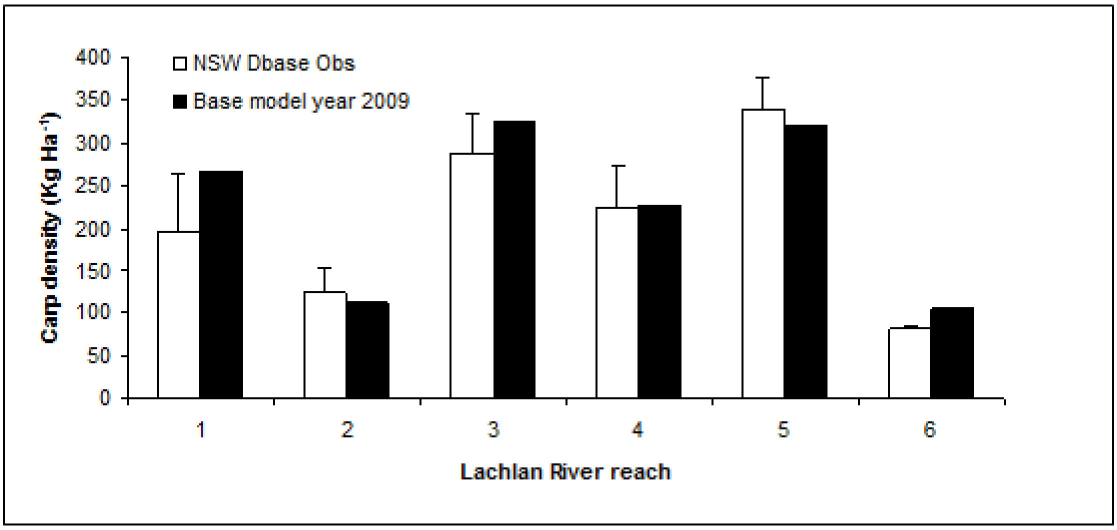

Figure 2. Comparisons of average (+ SE) carp biomass (kg ha-1) observed from surveys of sites within each reach and mean biomass predictions from 100 trials of the CarpSim 2.1 base model developed to simulate the Lachlan River carp population.

Table 2. Modelled change in individual zone population biomass resulting from seven simulated management scenarios using a range of carp-control tools proposed in Gilligan et al (2010). Change in population biomass is the mean differences between model years 2009 (before management) and the last modelled year (2076).

Scenario	Carp control strategies	% Change in reach biomass (kg ha^{-1})				
		Zone 1	Zone 2	Zone 3	Zone 4	Zon
Removal 1	Williams cages (WC)	2	-18	10	1	-1
Removal 2	WC + Wetland carp separation cages (WCSC)	0	-44	-27	-2	-5
Removal 3	Pheromone trapping (PT)	2	-5	13	19	8
Removal 4	WC + WCSC + PT	2	-51	-67	20	11
Removal 5a	WC + WCSC + PT +Dry-10%	-1	-66	-97	-14	-100
Removal 5b	WC + WCSC + PT +Dry-20%	0	-63	-97	-7	-96
Removal 5c	WC + WCSC + PT +Dry-35%	-1	-62	-97	-11	-100
Removal 6	Commercial fishing	0	-3	-9	3	-10
Removal 7	Recreational fishing	-1	11	-1	-4	73

A simulated CyHV-3 bio-control program was more effective at reducing carp biomass across the Lachlan River carp population over the seventy year period modelled (Figure 2). The simulations illustrated the trade-off that occurs between CyHV-3 mortality rate and frequency of outbreak occurrence. Biomass reductions averaging at least 70% could be obtained when a CyHV-3 mortality rate of 30% or higher occurred in at least 40% of years. Equivalent control was achieved with higher mortality rates (70–80%) and outbreaks occurring less frequently (20–30% of years). Biomass reductions of over 80% were achieved with CyHV-3 mortality rates of at least 30% if the outbreak occurred over 90% of years. If higher CyHV-3 mortality rates of 70% or greater were simulated in at least 40–60% of years, then biomass reductions of over 90% were predicted.

The simulation of daughterless carp stocked continuously at a rate of up to 10% of natural recruitment and containing up to eight copies of the daughterless gene showed that 70 year modelled period was too short to see benefits when used as the sole control measure. Carp with the wild type genes declined significantly but were replaced by daughterless genotypes that would then die-out over a longer period. If carp population density is initially reduced through CyHV-3 mortality prior to commencing the release of daughterless gene carriers into the population, the two controls acted synergistically. Even within the short-term, the biomass reduction of around 77% that resulted from moderately aggressive CyHV-3 treatment was improved to around 90% by stocking of moderate densities of daughterless carp gene carriers.

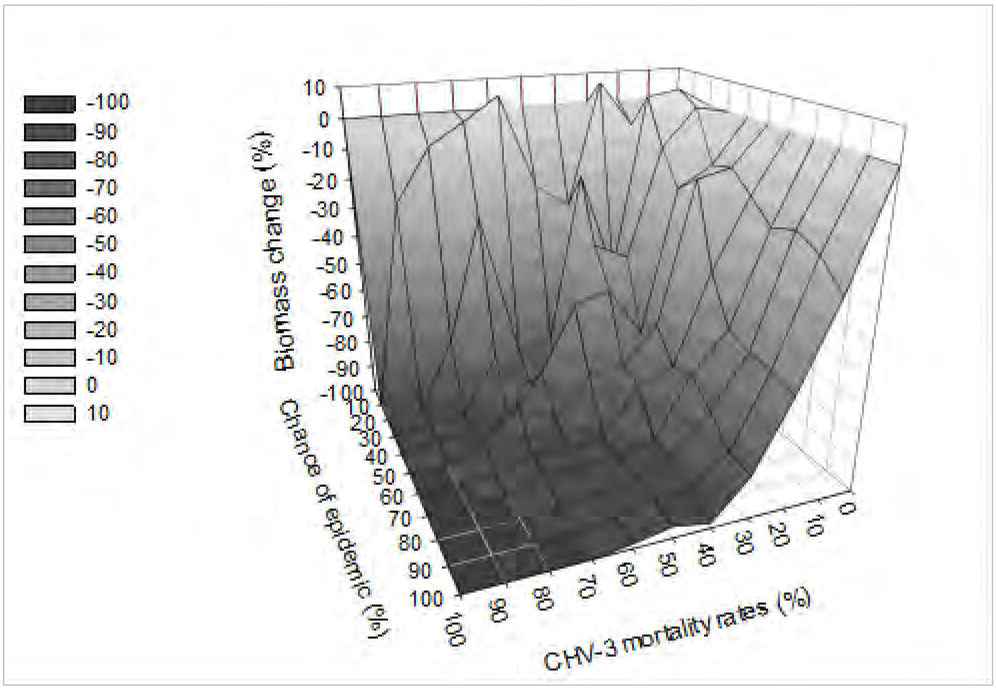

Figure 2. Model outputs simulating outcomes of CyHV-3 outbreak in the Lachlan River carp population as biomass change over a seventy year period (where 0% is no-change and 100% is reduction to zero) across a range of CyHV-3 mortality rates (0–100%) and a range of chances of an outbreak occurring (0% to 100%).

Key Messages

The models suggest that the proposed levels of carp control using trapping and controlled water draw-down specified in the regional carp control plan can reduce the average biomass by around 50%.

A Cyprinid herpesvirus-3 bio-control program has the potential to reduce carp biomass densities to, or exceeding target levels, if mortality rates exceed 30% and broad scale outbreaks occur in at least 40% of years.

A synergistic bio-control program using Cyprinid herpesvirus-3, followed by a gene technology based sex-ratio distortion program is potentially the most effective strategy for reducing carp biomass by over 90% in the long-term.

Management/Research Recommendations/Knowledge Gaps

While the present models simulate expected carp recruitment variability, the effects of flow and its variability on:

i. the carp population biology and

ii. the efficiency of various carp control methods should be investigated to determine how outcomes may vary during periods of drought or flood.

Simulation of the development of resistance to CyHV-3 by carp and of the rates of spread of CyHV-3 at a range of realistic rates would improve accuracy of predictions of expectations of successful control.

Future comparisons of actual harvest levels on application of the Lachlan River carp control plan with those predicted, may be a useful method of tracking progress against carp-control objectives in an adaptive management framework. If the harvest obtained in future years does not reach levels predicted, increased effort could be applied by increasing the number of fishing units or by improving catchability. The model could also be useful to set project milestones of observable biomass levels as stages in a long-term strategy to attain target carp biomass thresholds.

Acknowledgements

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Questions

Q: Seventy years is a long time to be considering this, have you got any ideas about trends over shorter timescales?

Paul: We didn't really look at intermediate timescales.

Q: Given the floods we have just had and the recruitment that resulted, how did the model deal with that stochasticity and variation or is that something that can overwhelm the model?

Paul: The model can deal with that, and for the purposes of modelling we previously used variability from the southern oscillation index that is indicative of recruitment highs and lows. We changed it to use similar, but non-related variability so the user inputs the amount of variability. But we didn't look at how sensitive it is to variability.

Q: On the koi herpes virus calculations, they look great but I am presuming they start off with an assumption of complete susceptibility to the virus and no growth of resistance across the years. As we have seen from the situation with rabbits the resistance to viruses is very different after 70 years. Can you build that sort of increase in resistance into the model?

Paul: That could be built in, I am aware of those aspects of epidemiology but we did not have any real information to use. So that is one of the reasons why we chose a flexible approach. From the model the virus still has a significant effect down at the low end, so even if you still have a mortality of 30-40% when an epidemic does come around, it is still going to work. The fact that you are also getting a result at the low end of epidemic frequency is also positive.

Q: Did you take into account that the hybrid carp are less susceptible to the virus?

Paul: There are no hybrid carp in the model.

Q: When you tooled the model to fit the biomass why did you tune just the immigration and emigration rate and why did you exclude recruitment dynamics and mortality?

Paul: We had some estimates of recruitment from Dean's data and we used those for each of the zones. We used estimates of mortality we had for each of the zones based on age distribution, wherever we had observations for data we used those. There were movement rates and one or two other things that we started out with what was our best guess and tweaked that to more reasonably estimate the observations we had.

Carp from a recreational angler's perspective

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VRFish, the Victorian recreational fishing peak body, was founded in 1994 and presents a united voice to contribute to setting the policy agenda that affects recreational fishers, now and in the future. Its core function is consultation. Through consultation, it is able to create policy and provide advice to Victorian government agencies such as Department of Primary Industries, Department of Sustainability and Environment, Department of Transport and Parks Victoria that is reflective of the views of Victoria's 721,000 recreational fishers (Ernst & Young 2009).

The study identified that the activity's direct expenditure in Victoria was valued at $2.3 billion in 2008-09 with the industry producing a Gross State Product (GSP) of $825 million. It went on to highlight that the recreational fishing industry contributed 5,200 jobs in the state in the same year. It was further identified that there was a strong regional component to the economic contribution with the GSP of the inland fishery in the north east and north west of the state being estimated to be in excess of $230 million. It is worthwhile noting that study was undertaken during a period of severe drought and that many recreation fishing opportunities in the north west of Victoria had literally dried up.

The importance of highlighting the economic contribution of recreational fishing to Victoria's economy cannot be underestimated and the study has lead on to other studies over the intervening years including the economic contribution of the Murray cod fishery to Victoria's economy released in 2010 (Ernst and Young 2010).

In 2011 VRFish provided leadership along with other key recreational fishing organisations in the states and territories that are part of the Murray-Darling Basin to form the Murray-Darling Basin Recreational Fishing Council (MDBRFC). This was in response to the release of the Draft Murray-Darling Basin Plan as it was a strongly held view that the plan failed to recognise the economic, social and environmental importance of recreation fishing to the Basin's economy.

With the support of DPI Victoria, DPI NSW, DPI Qld and PIRSA, Ernst and Young were engaged to produce a report on the economic contribution of recreational fishing to the Murray-Darling Basin (Ernst and Young 2011). The report identified recreational fishing as one of the largest economic contributors to regional economies in the Basin.

The study identified that recreational fishers spend around $1.3 billion when fishing in the Murray-Darling Basin and that recreational fishing contributed approximately 10,950 jobs. The results highlighted the importance of healthy habitats leading to healthy fish are critical to the economic viability of our regional communities.

Healthy rivers mean more fish. More fish mean more recreational fishers spending money in the Basin and that is a key ingredient for a healthy fishery.

Earlier in 2012 VRFish conducted a statewide forum in Shepparton to commence the planning process for the 2012-2017 Five Year Business Plan. It identified that the key focus areas over the next 5 years would be as follows:

- Community
- Sustainability
- Awareness
- Accountability
- Advocacy

These 5 Pillars would drive policies through to 2017.

Despite the worldwide popularity of carp as a sport and table fish in many European countries and a similar attitude amongst a relatively small segment of the recreational fishing community in Australia, the vast majority of recreational fishers want to see carp numbers controlled. However, there is an increasing concern that agencies are losing the fight against their spread. There is a growing disquiet that with no clearly defined objectives and a lack of agreed outcomes the resulting actions to control carp populations will not deliver measurable results.

During the recent fifteen or so years of reduced rainfall in south eastern Australia, carp numbers throughout the Basin were seen to be reducing and native populations, particularly Murray cod and yellowbelly were making a comeback. However, since the high rainfalls of 2010 and the resulting inundation of previously severely drought affected wetlands, carp numbers have exploded!

Some cynics in the recreational fishing community have noted that the best way to control carp is to have another fifteen year drought as physical removal is at best highly speculative and not cost effective. The overwhelming view of recreational fishers is that carp are here to stay and unless we kill nearly everything by poisoning waterways and wetlands, carp will continue to relentlessly take over.

Back in early 2005 there was a push by the Department of Sustainability and Environment to use rotenone to control trout numbers in 3 or 4 streams in the Victorian highlands as there was a view by some departmental scientists that trout were predating on spotted tree frogs and were affecting their populations. The resulting public outcry from recreational fishers in Victoria's leading regional newspaper The Weekly Times, particularly from the Council of Victorian Fly Fishing Clubs and the Australian Trout Foundation with the strong support of VRFish, lead to the unequivocal assurance by the then Victorian government that rotenone would no longer be used in Victoria. It should be noted that in a conversation with a journalist at the time I was told that in his experience there had never been such an overwhelmingly clear cut response to an issue than the response by recreational fishers to the planned use of rotenone in Victorian waterways.

The intervening years have not diluted or softened that stance. The overwhelming message to VRFish, through ongoing consultation with our constituents, is that Victorian recreational fishers will never support the poisoning of eco-systems.

In that case let us hope that any release of biological controls to carp populations such as the "carp virus" are checked and re-checked to ensure that there is no effect on those valuable introduced or native recreational fish species prior to any introduction into the environment. To date millions of dollars have been targeted towards controlling carp populations, what are the outcomes so far?

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Questions

Comment: Pleasing to see the number of recreational anglers attending this Forum, unfortunately they outnumber the fisheries managers and that is a concern. This Forum has been set up so that researchers and others can advise managers on what they have found and when the managers do not turn up that is frustrating.

Q: What do you think the recreational fisher's attitude would be to the targeted use of something like rotenone in a species specific bait as opposed to just the general application of rotenone?

Chris: I am answering from a Victorian point of view in that it was unequivocal that rotenone is off the list. Recreational fishers will not support the use of rotenone and VRFish will not support it. So unless there is a dramatic reversal of policy within our organisation it would not be supported.

Q: Do you think that is a head-in-the-sand approach?

Chris: Back in 2003 the campaign to use rotenone in some Victorian streams fired up the Weekly Times for 3 weeks and the journalist at the time commented that he had not seen that level of public response in his experience of 28 years.

Q: How do you deal with recreational fishers who want to catch and release carp?

Chris: Firstly I am not a fan of catch and release *per se* anyway. We are aware of what is happening in Europe with bans in Germany and Switzerland on catch and release. So to have a management practice that stipulates catch and release is something that we can't support from animal welfare issues as well as carp management issues.

Q: What exactly is VRFish doing to support carp removal and management in Victoria?

Chris: We have been supporting a policy on carp removal or eradication or reduction of biomass for the 17 odd years that VRFish has been in existence. Recreational fishing licence money in Victoria has contributed to a number of projects that would see the removal of carp.

Q: Is it a failure on our part as research scientists to get the message to fishers that localised use of rotenone would be, in terms of risk much lower that the release of a virus or genetically engineering carp? Another issue relates to the carp musters or competitions where there seems to be a perception that carp is much more serious than things like river regulation which I would suggest is much more serious. Do you think that is a failure on the part of researchers to get that message across?

Chris: I don't think it is a failure but I think there could be more effort to get that message across. VRFish has a role to educate and communicate and we have a number of avenues to get that message across. We would welcome the opportunity to have information about what is being done and to be a conduit for getting information out.

Freshwater toxins: The New Zealand experience

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Summary of the topic

Despite its geographic isolation and short period since colonisation, New Zealand Freshwaters have been subject to numerous intentional and unintentional introductions of freshwater flora and fauna (Table 1). While temperate waters have limited the extent of tropical fish introductions and spread, northern hemisphere exotic species are common. Exotic fish have reached almost every part of New Zealand's waterways. Some of these species require management (Figure 1) to protect indigenous aquatic biodiversity and the use of toxins, primarily the piscicide rotenone, is undertaken by the New Zealand Department of Conservation (DOC).

Table 3. Fish introductions to New Zealand. ([A] Accidental introductions)

Year	*Species*
1861-1880	brown trout, perch, tench, goldfish, brook char, catfish
1881-1900	rainbow trout
1901-1920	chinook salmon, sockeye salmon, Atlantic salmon, guppy, mackinaw
1921-1940	gambusia
1961-1980	rudd, (grass carp, silver carp)
1981-2000	koi carp, golden orfe, caudo, swordtail[A]
2000-2005	European gudgeon [A]

Freshwater Fisheries Regulations 1983		Biosecurity Act 1993	Conservation Act 1987	HSNO 1997	No Legal Status
Sports Fish	***Noxious Fish***	***Unwanted organisms***	***Restricted Fish***	***Prohibited Organisms***	
Trout (2spp)	Koi carp	Koi carp	Grass carp’	Stickleback	Brown bullhead catfish+
Salmon (3spp)	Rudd (except A/W)	Gambusia	Silver carp’	Pike family	Golden orfe
Brook char	Piranha	[Gudgeon]		Any venomous fish	Naturalised - aquarium fish*
Mackinaw	Pike	[Marron]			Aquarium fish in captivity
Tench	Walking catfish	Channel catfish			
Perch	Tilapia spp.		**Green - naturalised**	**Grey – only in captivity**	**Blue – not in NZ at all**
Rudd (A/W Fish & Game Region only)			**Pink – possibly eradicated from NZ**	**Orange – can only breed in captivity**	

Figure 3. **Legal status of** introduced **freshwater species to New Zealand.** (A/W Auckland Waikato. + Must kill on capture (Fisheries Regs). * goldfish, guppy, swordtail, sailfin molly, caudo. ’ Animal Welfare Act ‘pest’)

Except for use in a research trial in 1981, rotenone use only began in a concerted way after koi carp (*Cyprinus carpio*) and gambusia (*Gambusia affinis*) were found in the South Island of New Zealand in 2000. Following ongoing assessment of alternatives to rotenone, DOC has chosen rotenone as the piscicide to use. The Department of Conservation is the main and only agency seeking approvals and setting standards for use of Cube Root Slurry CRS (containing 1.2 - 1.8% rotenone). DOC staff are the only persons currently permitted to use CRS in New Zealand. DOC trainers have done the American Fisheries Society’s “Successful Rotenone and Antimycin projects” courses and lead the training of operational staff with people passing the course being Approved Handlers. Standards are maintained via, Rotenone Best Practice and Performance Standards for application methods.

DOC also has a series of data packages (Chemistry, Toxicology, Residue and Efficacy) to support the use of CRS as a Vertebrate Toxic Agent under the Agricultural Compounds and Veterinary Medicine (ACVM) Act. This includes the “label” (Figure 2) which is similar to piscicide labels used in the United States.

WARNING

Keep out of reach of children. Read label before using.

CUBE ROOT POWDER IN AQUEOUS SLURRY

Contains 12-18 g/kg rotenone

HSNO Approval Code: HSR007970 **Classifications: 6.1D, 6.3A, 6.4A, 6.9B, 9.1A, 9.3B, 9.4B**

WARNING: Toxic if swallowed or inhaled. Causes skin and eye irritation. May cause damage to blood or blood cell production through prolonged or repeated exposure. Ecotoxic.

PRECAUTIONS: Wear protective clothing including overalls, face protection, rubber gloves and boots. Use only outdoors or in well-ventilated area. Avoid breathing mist or spray. Do not eat, drink or smoke when using product. After use, wash hands and exposed skin thoroughly with soap and water. Wash protective clothing and dry before reuse

SYMPTOMS OF POISONING: Ingestion may result in symptoms such as stomach ache, nausea, abdominal cramps, muscle tremors and vomiting. Inhalation of spray or mist may cause respiratory stimulation followed by depression and convulsions.

FIRST AID: Contact a doctor immediately if poisoning is suspected. For further advice contact the National Poisons Centre, Phone 0800 POISON (0800 764 766). Have product label at hand.

IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.

IF INHALED: Move victim to fresh air, keep comfortable and at rest. If breathing is difficult, oxygen may be beneficial. If person has stopped breathing give artificial respiration.

IF ON SKIN OR IN EYES: Rinse with plenty of water for at least 15 minutes, removing contact lenses after 5 minutes if present and easy to do.

STORAGE: Store product securely in a dry, cool, well-ventilated area out of direct sunlight, away from children, animals, pets and foodstuffs.

SPILLAGE: Contain and prevent spillage from entering drains or water courses. Recover product into labelled containers that can be sealed for recycling or disposal.

DISPOSAL: Unused product must be disposed of at an approved disposal facility. Empty containers must be triple rinsed with water before disposal at an approved disposal facility or returned for refilling. Do not use the empty container for any other purpose. Avoid contamination of any non target waterway when washing equipment or containers.

ENVIRONMENTAL INFORMATION: Very toxic to aquatic life. Toxic to terrestrial vertebrates and terrestrial invertebrates. Ensure warning signs remain in place and livestock excluded until rotenone residues fall below 0.25 µg/L in the waterbody.

DIRECTIONS FOR USE: ***Preparation and application:*** Stir contents well before removing them from the pail. Final mixing concentration of rotenone in the target waterway should be 4 - 5 x the LC_{50} for the target species, but must not exceed 200 µg/L. To ensure complete kill of target fish, the rotenone must be dispersed throughout the waterbody.

Shore/boat application: May be applied by hose, spray unit, knapsack sprayer or gravity-fed dosing tank.

Aerial application: Use an aircraft equipped with suitable spray equipment or monsoon bucket.

SUPPLY AND USE LIMITATIONS: This product can only be used by a Warranted Officer or holder of a permit under s26ZR of the Conservation Act 1987.

The user must hold a special permit under s97 of the Fisheries Act 1996.

Only APPROVED HANDLERS (or person under the supervision of an Approved Handler) can mix and apply this product.

REGISTERED TO Department Of Conservation, 18 - 32 Manners Street, WELLINGTON 6011. PHONE: 0800362468

REGISTERED PURSUANT TO THE ACVM Act 1997, No. V9584. See www.foodsafety.govt.nz for registration conditions.

TRANSPORT INFORMATION: Proper Shipping Name: ENVIRONMENTALLY HAZARDOUS SUBSTANCE, LIQUID, N.O.S (contains rotenone); UN NUMBER 3082; HAZCHEM 3Z; PACKING GROUP III

NET CONTENTS 17 kg

Batch No.:

Expiry Date:

Figure 4. Cube Root Powder in Aqueous Slurry label for buckets of rotenone supplied for use in New Zealand.

An example of ACVM information is the graph of rotenone decay measured in New Zealand ponds below (Figure 3). Note that other approvals are still required under legislation such as the Resource Management Act, Conservation and/or Fisheries Act.

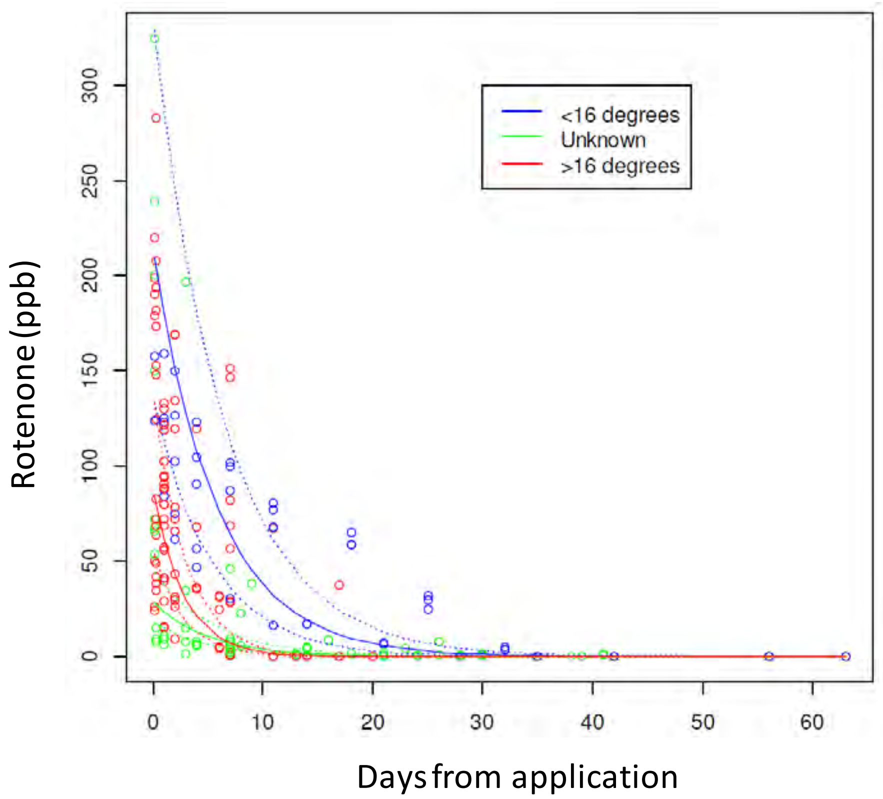

Figure 5. Decay of rotenone in New Zealand ponds of different temperature, (Goodman 2012).

All of the operational uses of rotenone have been in small lakes/ponds and associated drains (Table 2). Many of these ponds were artificial waterbodies such as irrigation ponds close to urban centres. A single experimental use of rotenone in streams was successfully completed in 2011.

Table 4. Types of habitat from which exotic fish have been eradicated in New Zealand.

Habitat	Number	Area (ha)		
		Avg	Min	Max
Drain	13	1.71	0.01	5.00
Pond	106	2.08	0.0005	68.00

Key messages

Human mediated spread of exotic fish continues although it has slowed since the peak during early colonisation of New Zealand. Invasion of new waterways due to colonisation by exotic fish also continues and the upstream movements of brown trout have been identified as the cause of extinctions of isolated populations of threatened non-migratory galaxiids (McIntosh et al 2010). Knowledge of invasive freshwater invertebrates in New Zealand is improving. A possible increased rate of spread and impacts of invasions are yet to be understood and consequently there have been few efforts to control invasive invertebrates. The eradication of Marron (*Cherax tenuimanus*) from ponds around Auckland is one of the few documented control operations.

From the 1980's onwards the rapid proliferation of koi carp in the Waikato River and introductions of pest fish into the South Island raised the expectation of, and need for methods to eradicate new populations of pest fish. Despite an early successful experimental use of rotenone by MAF in 1981, the use of rotenone was not implemented until 2001 when pest fish were found for the first time in the South Island. In fact during this early period, other eradication methods such as draining and use of lime were trialed. Draining occurs today in the limited circumstances where it is possible but rotenone is the sole piscicide used (Table 3).

Thus far locations of most operations have not been pristine so effects on sensitive species and ecosystems have not had to be fully assessed. The majority of habitats have also been small ponds (Table 2) able to be closed off from flowing or larger waterbodies before treatment. However recent failures to eradicate gambusia from some south island sites has been attributed at least in part to the presence of springs within drains and ponds treated with rotenone.

Exotic fish species targeted were gambusia, koi carp, rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) (Table 4). Gambusia are the species most often targeted for eradication with rotenone as this species is the focus of the eradication attempt from the South Island (Table 4). Koi carp are the second most treated species although as surveys for pest fish have increased, more populations of illegally introduced sports fish such as rudd and tench have been found.

Table 5. NZ DOC exotic fish eradications, methods by year. Note excludes brown trout removals from streams and one instance where electric fishing boat was used for eradication.

Method	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	TO DATE
Rotenone	1	17	3	8	3	4	9	9	2	1	14	4	6	81
Lime		3		2										5
Drainage	1	1			1			12		2				17
Netting etc.		2	1	1	2	3	1	4	1		1			16
Total	2	23	4	11	6	7	10	25	3	3	15	4	6	119

Table 6. NZ DOC exotic fish eradications: target species by year.

Target Sps	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Gambusia	1	18	3	7	3	3	1	3	1		6	1	6	53
Koi Carp	1	5		4	3	4	1	14		2	3			37
Rudd			1			1	8	1	1	1				13
Tench								7	1		6	3		17
Grand Total	2	23	4	11	6	8	10	25	3	3	15	4	1	120

Knowledge gaps

Recent testing of pest fish tolerance to rotenone in simulated New Zealand lake conditions has re-iterated the tolerance of goldfish and brown bullhead catfish to rotenone (N Ling pers comm). Should these species be the target of eradication attempts a more effective toxin or combination of toxins and/or application methods will be needed. Some failures of gambusia eradications using rotenone may be the result of live young surviving within poisoned female bodies and emerging after rotenone levels have dropped to non-lethal levels. The possibility of this needs to be investigated.

Conclusion

Despite legislative hurdles it is worth the effort of applying for the various permissions required to use rotenone to eradicate fish. Effective and substantive tools are needed to turn the tide in favour of native aquatic biodiversity. Toxins are only part of the package needed to control invasive fish. Other tools such as, public awareness, penalties for illegally spreading invasive fish, built barriers to stop re-invasion and surveillance/signage to stop re-release are also required.

Acknowledgments

Many operational staff from DOC are involved in pest fish operations so without their expertise and teamwork the use of toxins would be impossible.

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Questions

Q: You mentioned eradicating marron, what happened there?

Dave: It was in fish farm ponds in Auckland. They could drain most of the ponds and then they used lime. DoC did not lead it but it was a combined National response.

Q: Would you like to expand on any discussions between DoC and trout anglers about eradicating trout and how that is progressing in New Zealand?

Dave: Very similar responses (to Australia) such as "thin edge of the wedge" etc. We have got a Fish and Game Council that manages recreational fishing in New Zealand and a lot of the staff members understand the situation our native biodiversity is in and they are receptive to using rotenone in certain places and we would only ever use it in small streams. But there are anglers who have taken exception to DoC. We have been able to counter that in the media. There was a recent article in NZ Fish and Game Magazine explaining why you would consider using rotenone and that had a comparatively good response from anglers.

Can native predatory fishes control invasive carp in south-eastern Australia?

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Introduction

Carp are widespread throughout the Murray–Darling Basin and eastern drainages of Australia. Their management in these areas is a major fisheries priority. Community groups, fisheries managers and some scientists suggest that enhancing native fish populations through the release of hatchery-reared native predatory fish can provide a form of biological control for carp populations in south-eastern Australia. The Invasive Animals Cooperative Research Centre and the University of Queensland jointly funded research to assess three fish species for the potential biological control of carp populations in Australia — Australian bass (*Macquaria novemaculeata*), which occurs only in the eastern drainages of Australia, and two species that are located throughout the Murray–Darling Basin, namely golden perch (*Macquaria ambigua*) and Murray cod (*Maccullochella peelii*). These species are currently stocked for recreational fishing and conservation purposes.

Australian bass in the eastern drainages of Australia

Australian bass predation on carp in the presence of native prey species was relatively frequent, but Australian bass were limited in what size carp they ate, in part because of gape size limitations. The maximum dorso-ventral gape measurement of Australian bass was 47 mm. When plotted against carp body depth and length, Australian bass are theoretically restricted to eating carp that are <150 mm in fork length (FL), because these fish have a body depth of 50 mm or less. In microcosm trials, however Australian bass mostly consumed carp that were much smaller than this limit (<60 mm FL; 15 mm body depth). Furthermore, the literature shows that Australian bass avoid the shallow floodplain-type habitats where most of the small size class individuals of carp are located. These features indicate strongly that Australian bass are limited in their potential to control carp.

Golden perch and Murray cod in the Murray–Darling Basin

The potential for golden perch and Murray cod to control carp in the Murray–Darling Basin was examined. Based on gape limitations, golden perch are restricted to carp <190 mm FL (<60 mm body depth). In microcosms, like the bass, golden perch consumed more carp that were far smaller (<60 mm FL; 15 mm body depth) than their maximum gape (56 mm). In contrast, Murray cod have a large dorso-ventral gape (up to 150 mm) and can consume a wide range of carp sizes (<510 mm FL; <150 mm body depth). In microcosms, they consumed all size ranges of carp at about the same frequency, and so were different in this respect from Australian bass and golden perch. Golden perch and Murray cod exposed to carp and native prey species at equal and altered relative prey abundances in microcosms consumed carp relatively infrequently compared to native prey species. In particular, when the abundance of carp was increased relative to native prey abundance, carp were rarely consumed by either predator species because of their 'grouping' behaviour.

Field sampling during a flood event supported the hypothesis that most individuals of the early life stages of carp (<250 mm FL) are located in shallow, floodplain-type habitats, whereas golden perch (n = 105) and Murray cod (n = 139) were all caught in main channel habitats. Like Australian bass, golden perch are limited by gape restrictions and their habitat requirements and so are predicted to have only minor predatory impacts on carp populations at best. Stomach flushing of Murray cod collected from rivers of the southern Murray–Darling Basin similarly revealed that carp consumption by wild Murray cod was low, with <7% of Murray cod stomachs sampled (n = 96) containing carp. Although Murray cod have a large dorso-ventral gape, they are restricted to predation on carp in the main channel and anabranch habitats, and the rate of carp consumption by them is probably too low to warrant their release to control carp.

Conclusions

The majority of the early life stages of carp (eggs, larval stages and juveniles) are most likely to be found in shallow (<1 m), slow flowing floodplain-type habitats. Native predators are, by contrast, main channel specialists and generally do not enter the shallow floodplain-type habitats inhabited by the early life stages of carp. Thus predation on carp is restricted to the main channels of the Murray–Darling Basin, where the vulnerable juvenile stages are mostly absent.

Despite carp presenting a highly abundant prey resource, their behaviour, morphology and environmental requirements, together with the dietary and habitat specialisations of native predatory fish species, are likely to substantially restrict predatory impacts on carp populations by these native predators.

Questions

Q: You said that predatory native fish may not be the answer to control carp but I am thinking that it probably should not be just one approach. Your research seemed to show that the large Murray cod very much predated on carp, especially the 1 metre plus fish. We have a slot size in Victoria that sees the large fish being released and to me that seems to be a good policy as they will also contribute to the predation on carp.

Katie: Agree that it should be an integrated approach. Managing the native fish population for their impact on the carp should also be considered as a benefit.

Q: Have you done any theoretical work to calculate the numbers of fish that would need to be consumed say on a daily basis to make an impact on populations particularly in light of the recruitment that has occurred as a result of recent floods?

Katie: I have not looked at that but over the last 5 years I have provided the baseline data to do that.

Q: As a control method did you consider the risks that might be involved in stocking such as the benefits you may or may not get versus the risks in genetic variability in wild populations?

Katie: That was one of the first components to my theses "what are the risks involved" but I did not discuss that here as it is another issue.

Development and integrated use of odour-donor and sterile Judas fish for carp control.

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Background and Objectives

Carp is a major feral pest in Australia. Development of control options has consistently been identified as a high research and management priority. When carp were discovered in lakes Crescent (2365 ha) and Sorell (4770 ha) in 1995, the Inland Fisheries Service (IFS) decided to eradicate both populations. While the Lake Crescent population has been successfully eradicated, the extant Lake Sorell population continues to threaten the State's aquatic biodiversity and the premier trout fishery.

The presence of an endemic galaxiid in lakes Crescent and Sorell prevents the use of poisons and draining the lakes is not feasible. The IFS is therefore committed to a continued campaign of containment and eradication through fishing. Effective containment was achieved by placing a weir with a series of mesh screens at the outlet of the lakes. Mesh sizes are small enough to prevent eggs and juveniles leaving the lakes. In addition, Lake Sorell is closed to anglers to reduce the risks of translocations (Diggle et al 2012).

Over the years, developing and integrating a variety of techniques and approaches has increased the effectiveness of the fishing operations in the two lakes. Presented here are rationale for developing and integrating odour-donor and sterile Judas fish techniques into the Tasmanian carp management program.

Odour-donor carp (Chemo-attraction)

Consistent observations that mature carp are attracted to one another particularly in the breeding season and that even the 'smart' carp are vulnerable to capture during such aggregations prompted the idea of developing a chemo-attraction based capture technique. We trialled the use of large female carp as pheromone generators to attract other mature fish, based on the premise that fish, including cyprinids, produce reproductive pheromones that can attract and recognise conspecifics. These odour donor fish were primed using either pituitary extract from other mature carp (a technique known as hypophysation) or Ovaprim® (Syndel Labs, Canada), a commercially available spawning agent (Patil et al 2006). Typically the odour donor carp was placed in fine mesh holding bags behind traps set to attract and capture wild carp. The ability of odour-donor female carp to attract conspecifics was measured by recording the movement of radio-tagged male carp as well as the number of fish recovered from traps located at vantage points. Trials conducted in 2005-2006 using pituitary extract were particularly successful in attracting and trapping fish from as far as 4 km away in Lake Crescent. Broadly, results demonstrate the feasibility of deploying odour donor carp to assist in trapping and removing mature feral carp, (some of which were known to evade other methods of capture) under field conditions. The best results were obtained when ovulation coincides with vital environmental cues. These cues include warming water (>15°C), rising water levels and calm conditions.

These trials were successful in capturing carp that had persistently evaded capture by other methods, highlighting the vulnerability of mature breeding-driven carp to the technique.

However the molecules (pheromones), mechanisms of chemoreception and the influence/interaction of environmental factors remain poorly understood. We believe the selection of a suitable site is critical to the success of chemo-attraction trials. Drains and channels that provide access to the wetlands, with gentle flows to capture, carry and disperse chemical (pheromone) plumes into the lake are ideal. A significant concern with deploying live odour-donor fish is their inadvertent contribution to recruitment. Whilst such risk posed by odour-donor females can be contained more readily, those posed by the donor males is a challenge.

Trials using Prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$), in the USA (Lim and Sorenson 2012), Tasmania (Oct 2010 to Jan 2011) and New South Wales (2011, M Asmus personal communication) have also been carried out. Here the donor carp were surgically implanted with osmotic pumps containing $PGF_{2\alpha}$, a known carp pheromonal attractant, which extends the duration of 'attractivity' (Lim and Sorenson 2010).

Sterile 'Judas' carp

In 1997, radio-tagged male fish were first used as tracker or 'Judas' fish to identify aggregations and to help understand carp habitat preference and behavior in the Tasmanian lakes. Detected aggregations were targeted using fishing techniques most applicable to the situation. The use of radio-tracked fish (Judas males) increased the effectiveness of the fishing by signalling when an aggregation was occurring. This technique of targeted fishing assisted by Judas fish contributed to about 63% of the total fish caught in Lake Crescent, from the time of its introduction in 1997 to eventual eradication of carp in the Lake in 2007. Unfortunately, the Lake Sorell population is still lingering, owing to inadvertent spawning and recruitment in 2009 —contributed to by Judas carp. Responding to this crisis and urgent need to mitigate future recruitment risks, we explored sterilization options with a view to replace male 'Judas' carp with sterile 'Judas' carp.

The primary objective here was to develop reliable sterilization technique/s that did not significantly compromise the behavior of the sterilized individuals. Behavioral integrity of the sterilized individuals when fitted with radio-transmitters and deployed as Judas fish (i.e. to assimilate and integrate seamlessly into the wild populations) was/is critical to betraying the locations of aggregations allowing targeted fishing and removal of feral populations.

Three different surgical sterilisation procedures were attempted—the first employing sutures and the second metal clips, to tie the severed ends of sperm ducts. The third 'Essure' technique was originally developed for female contraceptive in humans. Suturing and clipping were used as preferred techniques for surgical sterilization, wherein the distal tubular section of each lobe was tied or clipped at two places (2-3 cm apart) and the intervening tissue excised. The approach completely blocked sperm production in over 77% of the individuals operated. The post-operative mortality rate was low (4.5%) and the surgery did not significantly impair the growth and levels of key steroid hormones, indicative of little or no physiological and behavioral impairment. Individuals that were not successfully sterilised (~23%), showed remarkable testicular repair i.e. re-establishing connections of single or both lobes to the urogenital sinus and expressing milt. In a single case the testicular lobes had fused with the intestinal tract and the individual expressed milt via the anal pore. The failure of surgery in some (30%)of individuals suggests further room for improvement.

Management / Research Recommendations/Knowledge gaps

Both approaches have become an integral part of the Tasmanian carp control program and could be of direct relevance to carp control in Australia and elsewhere. However, there remains scope for refinement of both the techniques. Particularly the odour-donor approach requires more systematic investigation with a view to develop a potion-in-bottle solution, wherein the live donors can be effectively replaced by synthetic attractant/s.

Acknowledgments

We thank the staff of the IFS carp management team for their help and assistance in carrying out the experiments in the field. The $PGF_{2\alpha}$ trials were conducted under the guidance of Prof Peter Sorenson, University of Minnesota and Dr M Asmus (NSW Fisheries) provided the information on NSW trials.

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Environmental attractants: Isolation and identification of carp attractants from wetland plants

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Background

Carp were first introduced into Australia in 1907/08 at the Prospect Reservoir in Sydney but it was not until the release of carp of the "Boolarra" strain in the 1960's that they began to take hold in the Murray-Darling Basin (Barnham 2007, Gardner 2007, Koehn 2004, Smith and Fleer 2007). Widespread flooding through the 1970's led to carp populations migrating to previously inaccessible areas within the basin and today carp can be found throughout the basin (Koehn 2004). In Europe and Asia, carp have been farmed as a source of food and as a control for blue green algae (Gardner 2007, Norris and Fennical 1982, Vaccari et al 2005, Gassmann et al 2006). However, in Australia they are one of the most damaging pest species on the continent. Carp are responsible for the degradation of water systems by dredging up the banks when feeding causing extremely turbid water that is unfavourable for native aquatic species. Severe overpopulation is also a problem, with carp maturing after 1 year and producing up to 1,000,000 eggs in a spawning season (Barnham 2007, Gardner 2007, Koehn 2004). To date multiple strategies have been implemented to combat the damage caused by carp but overall they have had little effect in managing the impact of carp or controlling the populations and their spread in open water systems.

Isolation of attractants

Carp have a very sensitive and complex olfactory system that may be able to be manipulated as a part of a broad scale pest management program (Carr 1996, Doving et al 1980, Hamdani and Doving 2007, Ishid et al 1996, Kohler 1976, Lastein et al 2008, Sorensen et al 1998). Wetland flora studies conducted on known aggregation sites in Lake Sorrel and Lake Crescent Tasmania have been used to identify 7 plant species (V*allisneria australis, Potamogeton cripus, Potamogeton tricarinatus, Chara australis, Egeria densa*, *Myriophyllum aquaticum,* and *Cabomba caroliniana*) common to these sites (Heffer 2003). Plant samples were sourced from wetlands and lakes throughout Victoria in conjunction with the Department of Environment and Primary Industries and assessed for their bioactivity in controlled bioassays. Water samples also collected from the wetlands were used to identify potential plant species that may be responsible for the observed carp aggregations, and in conjunction with the Inland Fisheries Service Tasmania, to determine if an environmental attractant can be extracted from water at one location and be effective on carp from a different water system.

Attraction was determined in a similar manner to the method employed by Sorensen and Caprio (1998), Sorensen et al (1991), Sorensen et al (1998) and Sorensen et al (1995) for assessing pheromone response on mature carp. Attraction was observed for 3 of the 7 plant species assayed; *V. australis, E. densa,* and *M. aquaticum*; with bulk isolates having a similar response to those observed for the crude extract of each plant species (Figure 1).

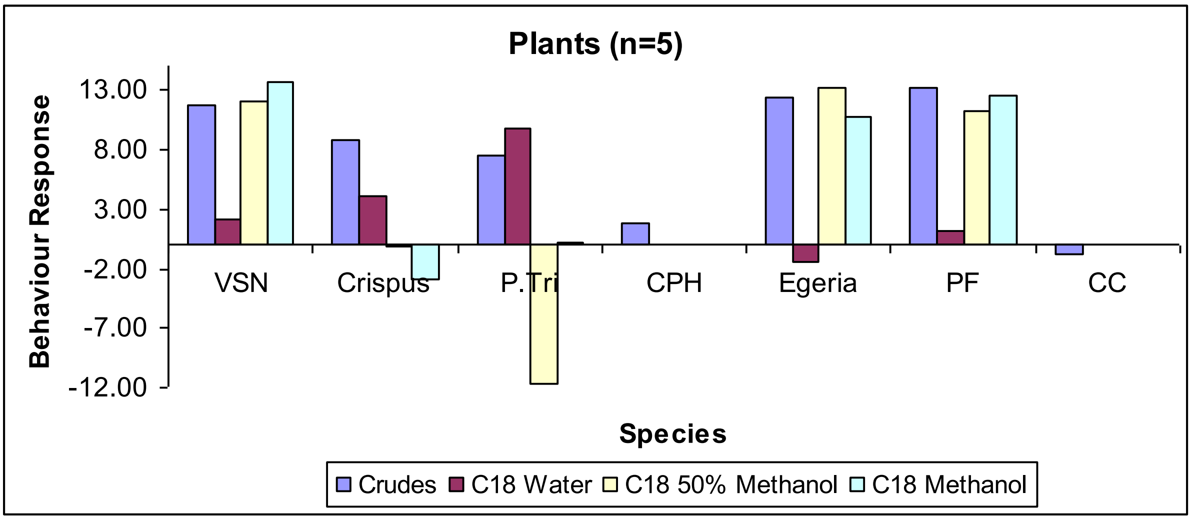

Figure 1: Behavioural response to 7 different plant species and 3 different extraction solvents.

Samples were collected from 3 wetlands (Silver Plains Marsh, Kermodes Marsh and Dogshead) in Lake Sorrel and from 3 locations at the Banrock Station wetlands (wetland inlet, wetland outlet, and Lock 1 downstream). The bioassay results show that the three water samples collected from Lake Sorrell all show some level of attraction, with water from the Silver Plains wetland having the highest response, while only one of the samples collected from the Banrock Station wetland elicited a response (Figure 2).

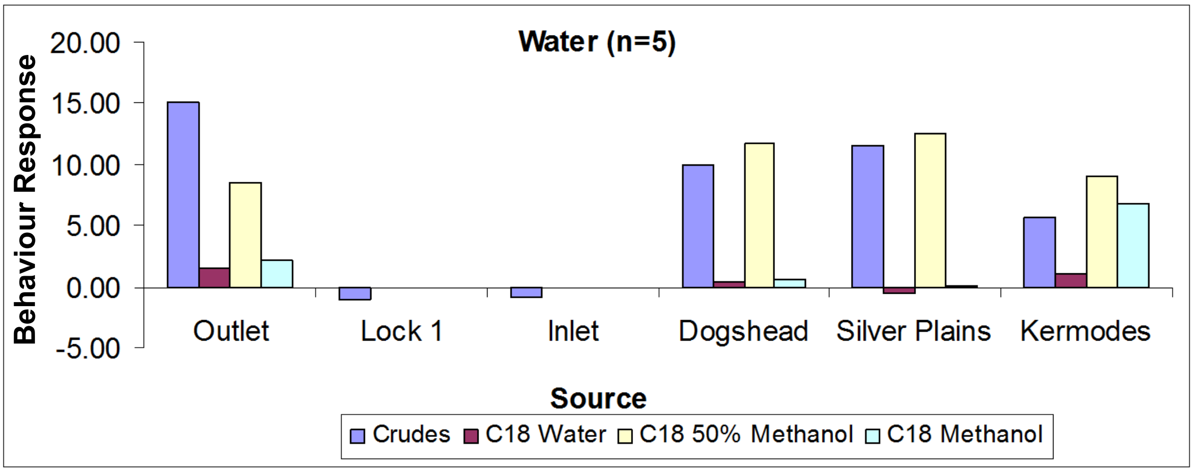

Figure 2: Behavioural response to 6 different water sources and 3 different extraction solvents.

Once the bioassay analyses were complete, a check of the Inland Fisheries tracking data of radio-tagged carp in Lake Sorrel (Figure 3) around the collection period and the observations recorded when collecting the samples from the Banrock Station wetland match extremely well. At the time of collection the majority of the radio-tagged carp were recorded in and around the Silver Plains marsh. Similarly when samples were collected from the Banrock Station wetland, carp were clearly observed at the outlet of the wetland swimming upstream trying to enter while no carp were observed at the other collection sites.

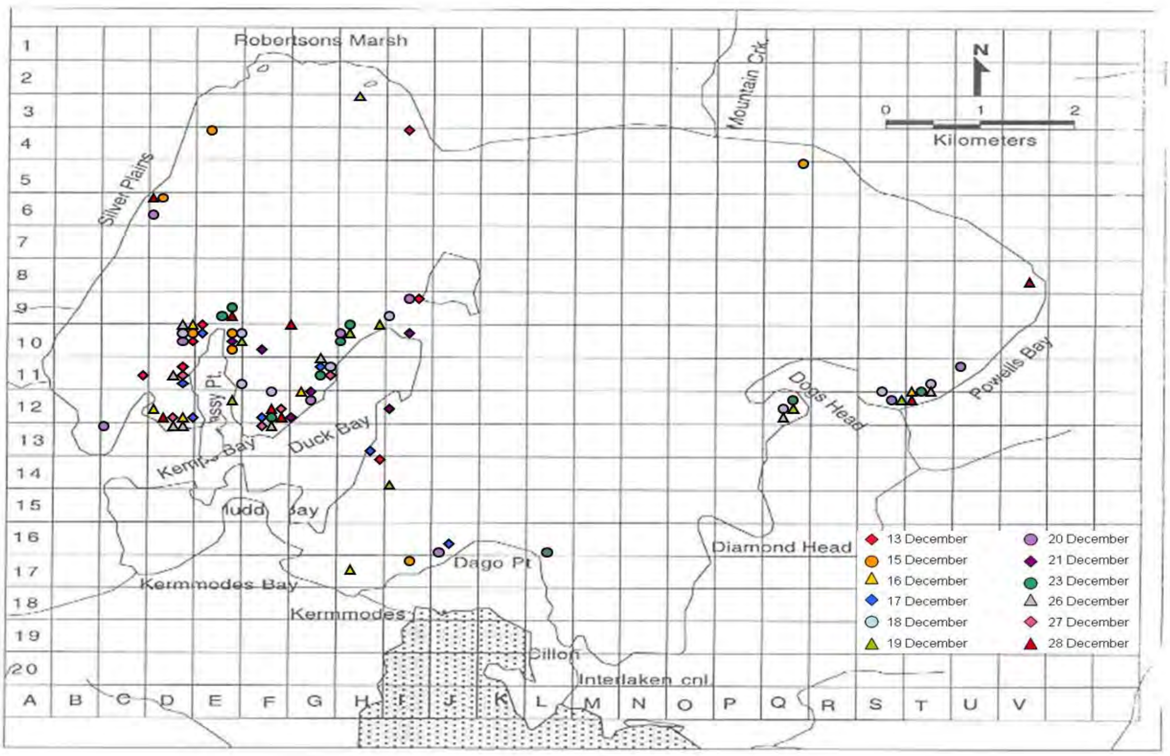

Figure 3: Radio-tagged carp tracking data from Lake Sorrell in Tasmania, showing aggregation sites during collection of water samples used in the bioassay to assess attraction to water samples.

Isolation of the compounds within the extract was conducted by eluting the compounds off a Phenominex C18 preparatory column connected to a Dionex preparatory liquid chromatograph (LC). UV data was used to identify the collection range of individual fractions. Peaks were collected across multiple injections and combined based on peak location and retention time. The combined isolates were subsequently assessed by LCMS to assess purity. Isolates above 90% purity were infused directly into the mass spectrometer resulting in an accurate compound mass (Figure 4) and then analysed by ^{1}H NMR spectroscopy by four different experiments, each experiment providing different structural information on the compound.

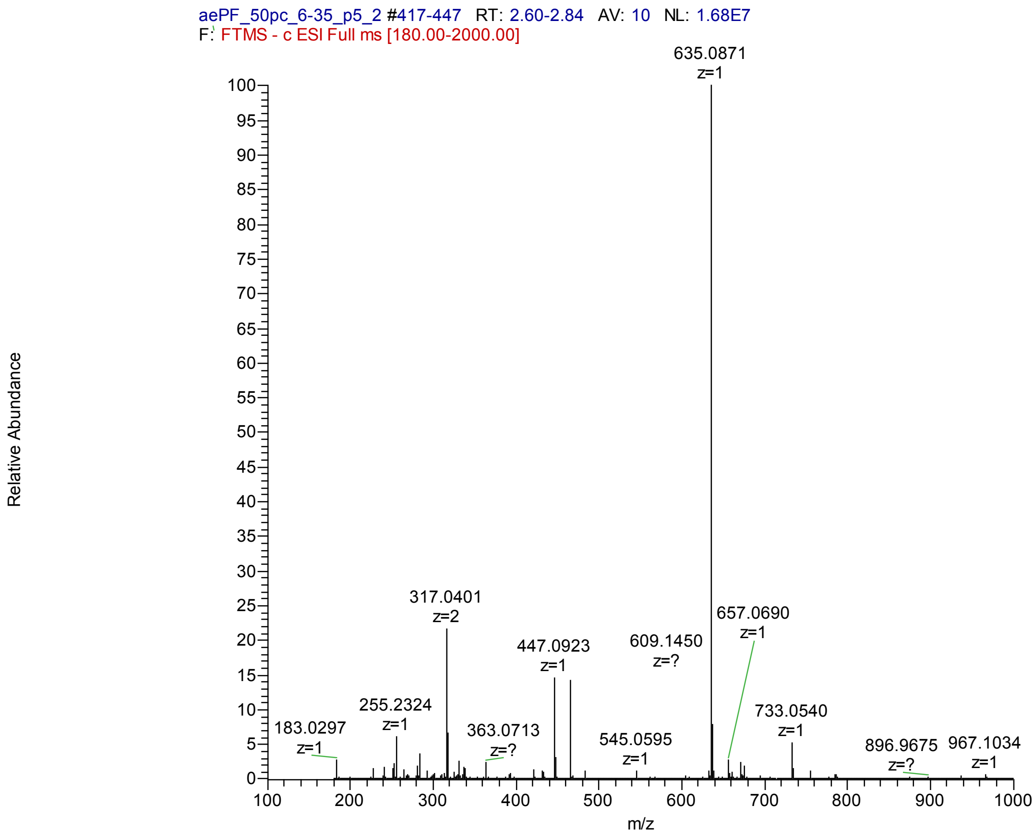

Figure 4: MS infusion data indicating the parent mass and fragments of 1 potential environmental attractant.

^{1}H NMR (Figure 5) provides information on the number of protons present in your sample, and neighbouring protons and can be used for direct quantitation if a known concentration internal standard is used. Heteronuclear single quantum coherence spectroscopy (HSQC) (Figure 6) indicates a carbon-hydrogen one bond length apart, correlation spectroscopy (COSY)(Figure 7) indicates a hydrogen-hydrogen correlation two or three bond lengths apart, and heteronuclear multiple-bond correlation spectroscopy (HMBC)(Figure 8) indicates a hydrogen-carbon correlation two or three bond lengths apart. This information is used to piece together the compound and when combined with the MS data the unknown isolate is able to be identified with a high level of confidence.

In total, 33 compounds have been isolated and assayed as individual compounds to assess the potential as carp attractants; 16 of these compounds show significant attraction but all of the NMR and mass spectrometry data is being collated to allow for the final identification of these compounds.

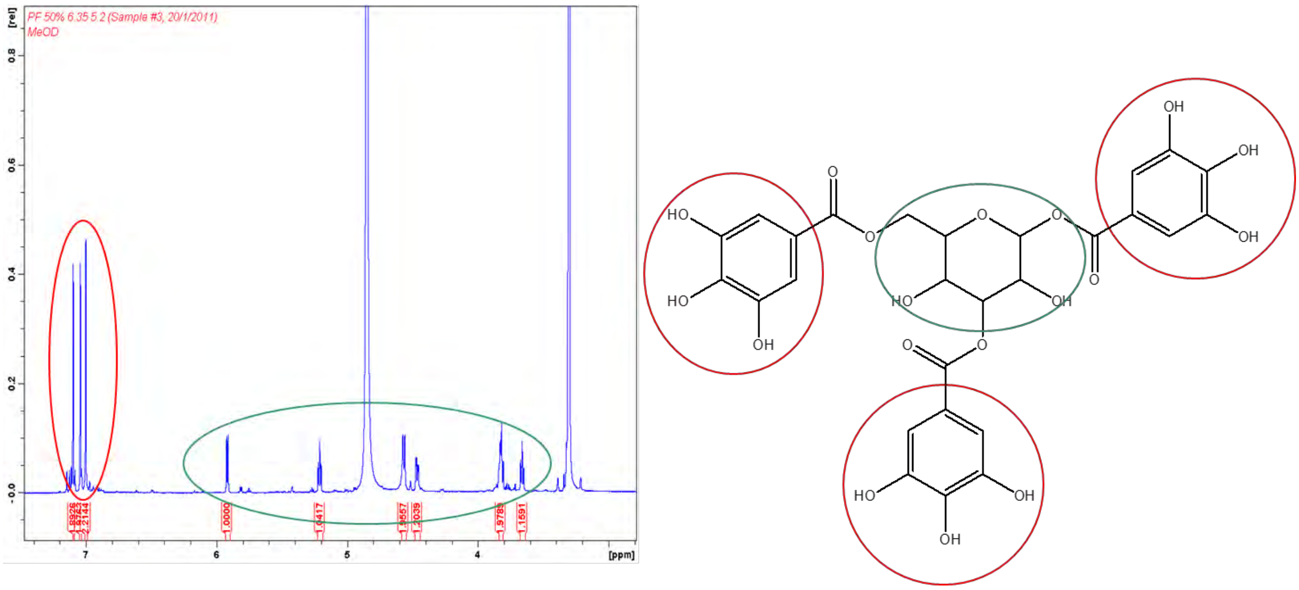

Figure 5: [1]HNMR indicating the number of protons present in the isolate. Highlighted areas indicate where the proton signals are within the compound.

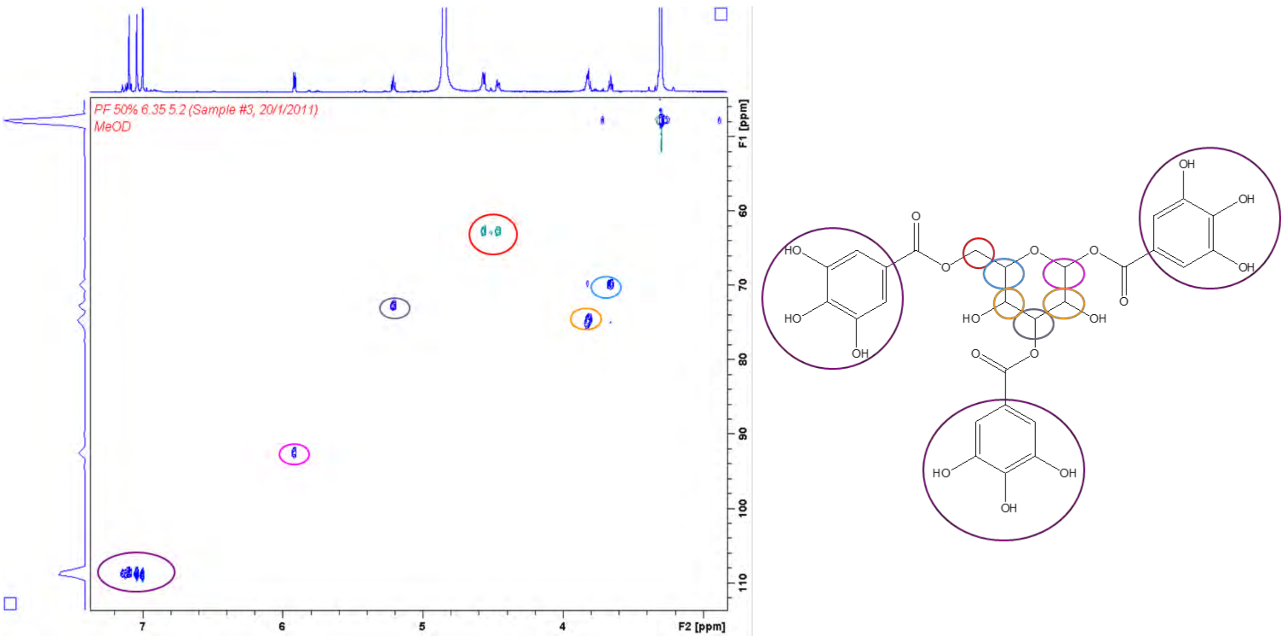

Figure 6: HSQC NMR indicating the single bond correlations (^{1}H-^{13}C) present in the isolate. Highlighted areas indicate the observed correlations within the compound.

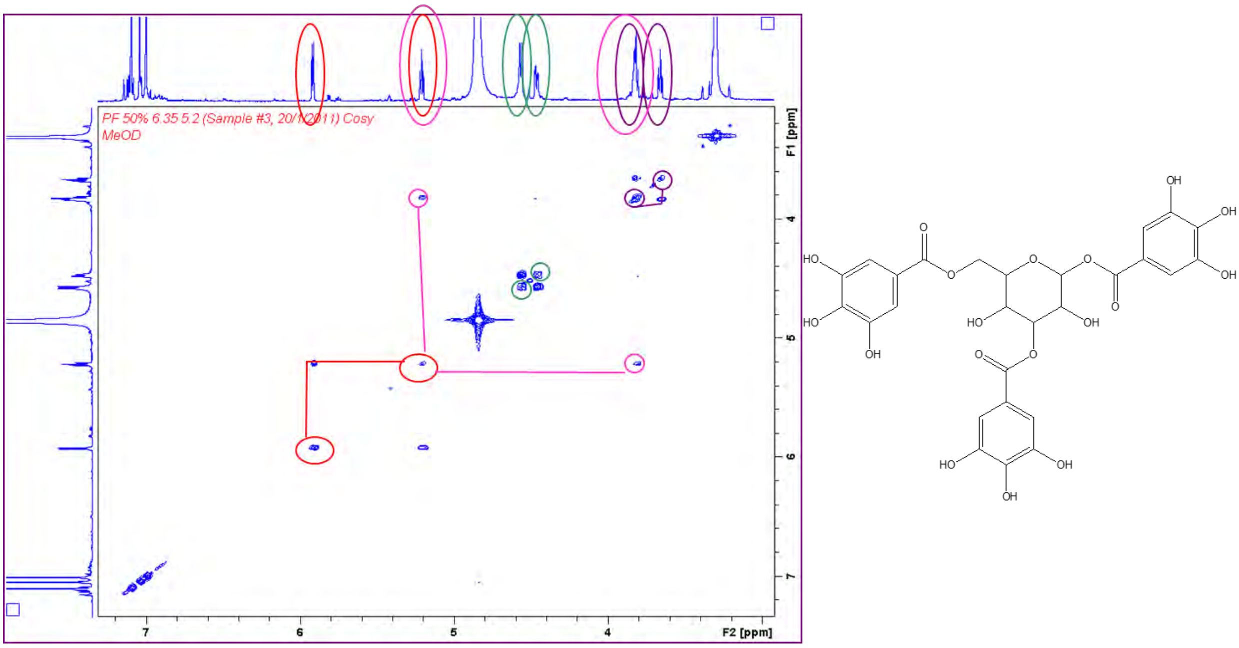

Figure 7: COSY NMR indicating the 2-3 bond length correlations (^{1}H-^{1}H) present in the isolate.

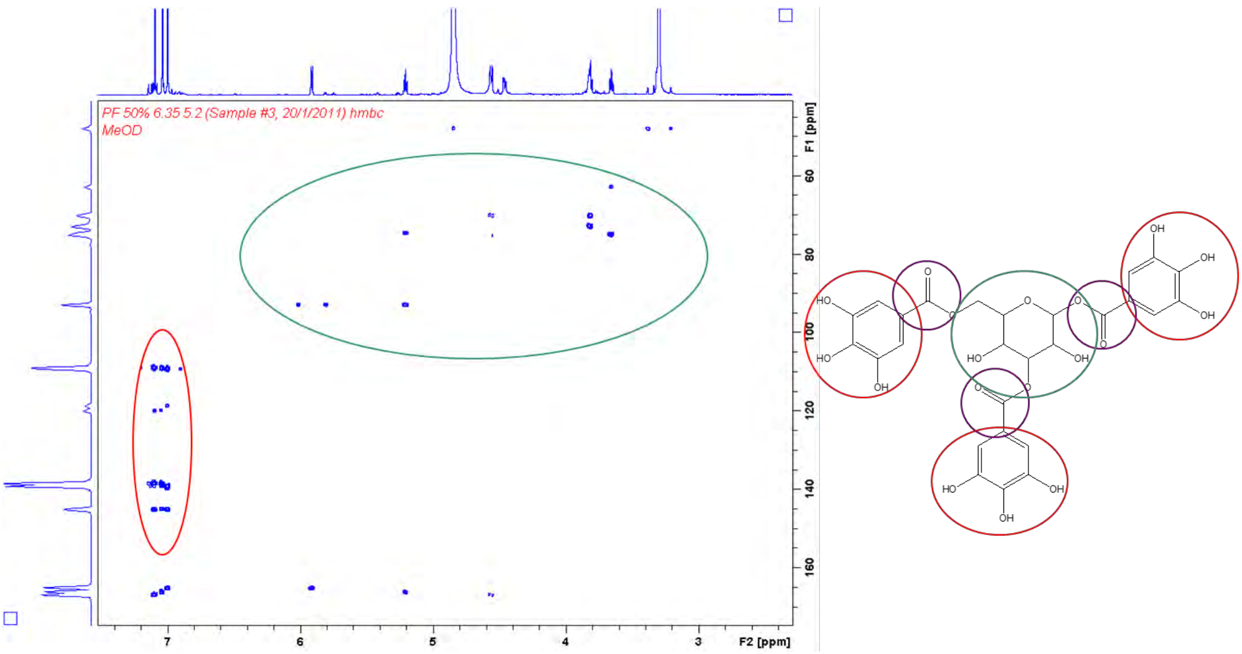

Figure 8: HMBC NMR indicating the 2-3 bond correlations (^{1}H-^{13}C) present in the isolate. Highlighted areas indicate the observed correlations within the compound.

Summary

It has been shown that;

- Carp behaviour can potentially be manipulated by the addition of compounds derived from environmental sources.
- This would need to be incorporated as a part of a broad scale pest management plan to be effective.
- The attraction of juvenile carp may aid in eradication by allowing for their removal prior to reaching maturity.
- The use of chemistry in further investigations may prove to be invaluable in combating some of our most destructive pest species.

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Questions

Q: Where did you get your carp from, were the carp that you were testing for the Banrock experiments from Banrock wetlands?

Aaron: No, the carp were all reared at Snobs Creek and transported out to the Queenscliff facility, so they had never been in a wetland environment at all so there is no reason why they would be attracted to any vegetation.

Q: In thinking pragmatically about how to harness this, am I right in thinking that the molecule that you showed there was one example of the 16 attractants, have you got chemical structures for others and do they actually relate to other molecules that are known to have biological activity just to help with registration to get them out into the environment?

Aaron: The one I showed isn't actually one of the 16 attractive ones because I am not sure of the IP involved. Some of them are commercially available. I haven't quite finished determining the structure of all of them but that will be in the thesis. Of the ones that I have completed there is a lot of structural similarity between ones from a certain plant, slight differences between them but there is a core group.

Comment: It is actually exciting if you can see consistency between the attractants from different plants as well which gives you something to focus on.

Aaron: There is definitely scope for more work but whether it is going to be continued or not is subject to funding.

Q: Wondering how you selected your sites for water samples in Tasmania as from some work we had done in New Zealand we collected water from sites where we knew carp had spawned and there was some correlation with those sites with zooplankton, have you looked at this at all?

Aaron: No, nothing at all from zooplankton. The sites were selected in conversation with Chris (IFS, Tas) from where they had seen carp aggregating, so we wanted two sites where they had seen carp aggregations and one site where they were not commonly seen.

Q: Thinking about flood plain inundation and the rapid response of carp to those areas, have you looked at terrestrial grasses?

Aaron: No we focussed on the wetland areas and aquatic plants.

Carp acoustics: Attractants and repellents

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Background

Experimentally, the application of underwater acoustical equipment to reproduce 'fish' sounds has been tested on cyprinids to illicit trained responses (eg Willis et al 2002), restrict movements (eg Taylor et al 2005) and most notably, to attract and concentrate dispersed populations (eg Hashimoto and Maniwa 1966). Regarding the latter, the authors successfully used carp feeding sounds to lure carp to specific locales within baited and unbaited lakes. This behavioural response was often immediate and resulted in large aggregations of carp at the sound projector. Further, carp are positively rheotactic and will actively seek the source of flow (SARDI, Unpublished Data). This rheotactic response can be so strong that carp will vigorously move upstream against receding waters only to become stranded and perish in draining/drying wetlands, ie observations at Banrock Station (Riddell 2007). While there are several potential sensory triggers for this movement (ie flow, entrained scent, sound), sound can travel vast distances underwater and is therefore a key sensory component that is likely to initiate exploration for the source of flow- particularly in fish at larger distances from the source that may not yet 'feel' or 'smell' the flow.

Notwithstanding, an attractive sound can be a repulsive sound if not played back at natural levels (Hashimoto and Maniwa 1966, 1971). While this requires careful experimentation in order to capture and replay attractive sounds at appropriate sound pressure levels (SPL), it also opens up the possibility of using acoustic repellents to dissuade spawning fish from entering spawning grounds or to help herd fish to areas where they can be captured easily. Thus, when used in conjunction with current integrated pest management technology, acoustics may increase carp harvesting success; particularly in lentic systems (ie wetlands) where traditional sensory cues (pheromones, amino acids) that rely on current flow are not effective.

Objectives

The specific objectives of this study were to determine the utility of underwater sounds for attracting and repelling carp for management purposes. Two attractant sounds (carp feeding, SPL 115 dB re 1 μPa and flowing water, SPL 124 dB re 1 μPa) and one repellent sound (high ≈ 9500 Hz, low/mid ≈ 125 Hz, and very low ≈ 47 Hz frequencies coupled with explosion sounds; SPL 141 dB re 1 μPa) were tested over a series of 28 experiments at three different locations within an experimental lake.

A VEMCO VPS array was used to monitor the response of eight acoustic tagged carp. This system provided positional data of each tagged carp approximately every 60 seconds. As a measure of attraction or repellence, a customized Eonfusion analytical model was used to determine the time each tagged carp spent within four distances from the playback system (5 m, 10 m, 25 m and 50 m) both before and during each experimental period.

Summary of findings

Although calculated sound pressure levels (SPL) confirmed that all experimental sounds were played at biologically relevant levels, the results indicate that feeding and flowing water sounds have a limited effect and therefore do not appear suitable for aggregating carp for harvesting purposes. As Hashimoto and Maniwa (1966, 1971) conducted their experiments in clear lakes, it is hypothesized that the attraction they reported could be partly attributed to the visual stimuli provided by the researchers standing at the lakes edge during the experiments. There were no visual stimuli offered during the current experiments as they were conducted in a turbid lake and care was taken to stand away from the lakes edge during experimental periods. Interestingly, the repellent sound seemed to act as an attractant. Even though tagged carp where aggregated near the speakers by broadcast feeding prior to the repellent experiments there were distinct behavioural differences between feeding and experimental times. During feeding, carp displayed exploratory movements while during the experimental period the vast majority of tagged carp formed a tight aggregation directly at the speaker. This indicates that a component of the repellent sound (ie low or mid frequency) may be a useful attractant and this warrants further research.

Key messages

Further research is likely to produce an acoustic carp attractant that will aid in increasing the harvesting efficiency of physical control techniques.

Research recommendations

Given that there appears to be a degree of attraction associated with the repellent sound, it is recommended that future research evaluates the utility of these and other frequencies both singularly and in combination.

Acknowledgments

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Questions

Q: You have already attracted the fish into an area using food so the results seem to me more like an aggregation response like a response to a predator rather than an attraction response. I think you would have to try it with individual fish without the initial (feeding) attraction.

Leigh: We probably hypothesised that there would be an initial flight response and the idea was to bring them in first off. The behavioural differences could be explained by that (flight response). They were generally moving around further away but then they chose the spot right in front of the speaker to aggregate. You would think that if it was a flight response they would have aggregated elsewhere. The behavioural difference was distinct and lasted for the whole hour.

Promising new developments in the containment and control of aquatic invasive species — some Asian Carp Control Strategy Framework initiatives

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Background

Environmental DNA evidence of the presence of silver carp (*Hypophthalmichthys molitrix)*, and bighead carp (*H. nobilis*) (Asian carp hereafter) above the electric barriers in the Chicago Area Waterway System (CAWS) prompted a major incursion response to prevent establishment of Asian carp in the Great Lakes (Jerde et al 2011, ACRCC 2010, Chadderton 2014). Initial response efforts and expenditure were primarily focused on preventing movement of Asian Carp into the upper CAWS. This included construction of the final electric barrier array and associated barrier infrastructure on Des Plaines River and Illinois and Michigan canals that had the potential to enable carp to bypass the barriers during large floods, and Asian carp population suppression efforts below the barriers (Figure 1., Asian Carp Control Strategy Framework (ACRCC 2010, 2011, 2012, 2014). However, an increasing proportion of the budget has been directed towards development of new control and containment methods, a number of which could be adapted for application to other aquatic invasive species.

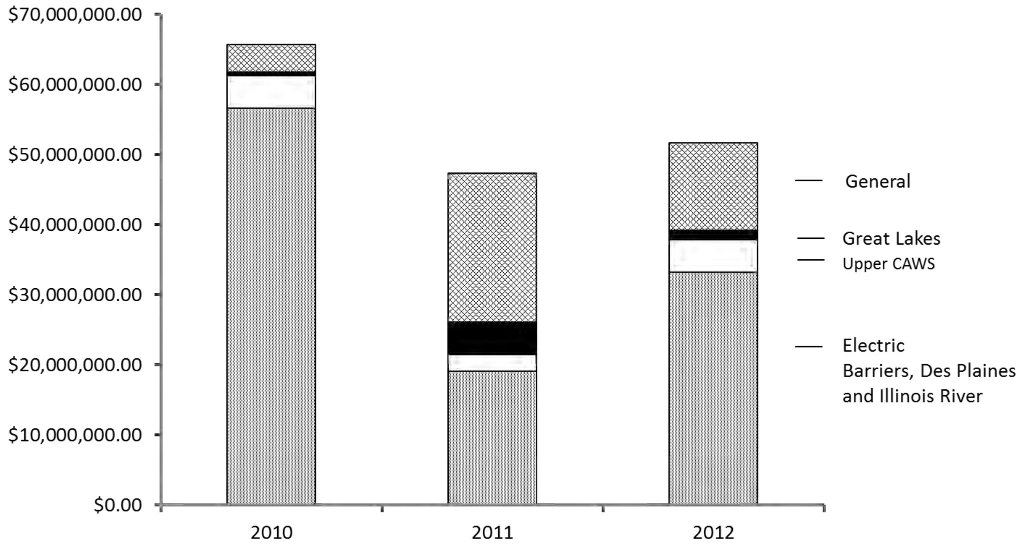

Figure 1. Asian Carp response expenditure partitioned by the location where the response actions would take effect. General category covers generic actions that could be applied to Asian carp management at any location. (Numbers derived from Asian Carp Control Strategy Framework, 2010, 2011, and 2012.)

Toxins

Researchers at the U.S. Geological Survey's (USGS) Upper Midwest Environmental Science center: (http://www.umesc.usgs.gov/aquatic_invasives_team.html) are undertaking work to develop a novel toxin delivery mechanism that ideally will have high species specificity (ACRCC 2014). The approach uses a toxin encapsulated into a micro-particle. The micro-particle is sized to reflect these planktivore's preferred food size and field trials have shown that both species will consume bioactive micro-particles in the 50-200um size range (Jensen et al 2014). Investigators has settled on Antimycin as the preferred toxin for oral delivery, with the intestinal enzyme trypsin used to trigger release (ACRCC 2014,

http://www.umesc.usgs.gov/aquatic/tools_to_control_carp_mussels.html). Physiological and behavioural research hopes to determine whether seasonal activity patterns or behaviours can be exploited to reduce non-target impacts on native planktivores.

Acoustic technology

The USGS is also working with Smith Root Inc. (SRI) to assess the efficacy of seismic or Acoustic Pulse Pressure technology to repel, herd or kill Asian carp (http://www.smith-root.com/barriers/water-gun/). Water guns developed for seismic geological surveys in the 1980 act as a low-energy implosive source that generates a wave of sound energy in the 20-1500HZ frequency range (Jackson et al 2013, ACRCC 2014). Their use in seismic surveys was discontinued in part because they proved to be harmful to fish and invertebrates in close proximity to the guns. However, it was these properties that motivated Jackson et al (2013) to begin investigations into seismic technology's potential as an aquatic invasive species suppression tool. These authors documenting mortality, haemorrhaging organs and ruptured gas bladders when northern pike (*Esox lucius*) were exposed to sound energy at 3, 6 and 9 meters distance from a water gun. Since 2010 USGS and SRI have undertaken various field and pond trials to characterize distribution of sound pressure and quantify behavioural responses of Asian carp and other fish species to water guns.

Initial efforts examined whether specific frequencies could be used to kill Asian carp (http://www.glmris.anl.gov/documents/docs/anscontrol/AcousticFishDeterrents.pdf), whereas recent field trials appear primarily to have focused on the ability of the guns to clear an area of carp and/or drive them into commercial nets (ACRCC 2014). Water guns are also being considered as a potential integrated barrier technology along with electricity and CO_2 to deter fish from entering locks on the lower CAWS. Impacts on infrastructure will also be assessed to allay fears that repeated exposure to acoustic pulses could cause damage.

Electric barriers

Concurrent research has raised further questions about the effectiveness of the existing electric barriers established in the Chicago Area Water System (USACE 2013). There have been ongoing concerns about electric barrier effectiveness, owing to occasional shutdowns for maintenance or short term power failures, periods of extreme high conductivity or flow, and the challenge of operating in an active industrial canal (Moy et al 2011, Lodge et al 2010). But recent monitoring has begun to quantify barrier effectiveness. Using Dual Frequency identification SONAR (DIDSON) the U.S. Fish and Wildlife Service documented significant numbers of fish accumulating below and persistently challenging the barrier (USACE 2013). More alarmingly, over half (61%) of the 72 x 10 minute recordings obtained showed at least one school of fish passing through the barrier.

Furthermore, barge experiments, including trials where caged fish tethered to a variety of barge configurations were transported through the electric barrier, found that fish can be entrained, trapped and transported through the electric barrier, and that certain barge configurations affected field strength. Indeed some areas between barges were identified where fish including common carp were not incapacitated by the barrier (USACE 2013).

The existing barriers were originally envisioned as a temporary prevention mechanism and were fitted to the existing 7.7m deep, 57m wide canal channel (Moy et al 2011). With an average flow of $77cm^3/s$ where about 70% of annual discharge is derived from sewerage and storm water (Jerde et al 2011), barrier success was always going to be challenging. To overcome these challenges one of the proposals in the Great Lakes and Mississippi Inter-basin Study (GLMRIS 2014) commissioned to assess feasibility of preventing passage of aquatic invasive species through the CAWS, was to establish electric barriers in shallower engineered channels immediately adjacent to CAWS locks structures. At the same time SRI and agencies partners have continued to evaluate modified electric fields to identify more effective and efficient fish deterrents.

Conclusions

In conclusion, since 2010 there has been an unparalleled investment in the development of an integrated suite of structural and non-structural Asian carp surveillance and control technologies in the Laurentian Great lakes region (ACRCC 2014). While programmatic focus is on preventing the introduction and establishment of bighead and silver carp in the Great Lakes, these investments have already expanded the range of technologies in the global aquatic pest management tool box, with more likely to follow.

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Koi herpesvirus: its potential as a biological control agent for carp in Australia.

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Background

Disease associated with koi herpesvirus (KHV; more formally known as Cyprinid herpesvirus-3, CyHV-3) was first described in common carp (*Cyprinus carpio carpio*) in Germany and Israel in 1997–1998, although retrospective studies have since shown that the virus was responsible for mortality in common and koi carp (*Cyprinus carpio koi*) from about 1996. Most outbreaks of disease were associated with a very high mortality (70–100%). Since the initial outbreaks, the virus has spread throughout much of Europe and Asia, and to South Africa and the USA. Carp are the fourth most farmed fish in the world, and, in many countries, KHV represents a serious threat to important carp aquaculture industries. Consequently, significant resources are currently being directed toward developing control strategies for the disease.

By contrast, Australia and New Zealand remain free of the disease. Carp in Australia is an introduced pest, and KHV represents one of a number of potential weapons that might be used in a multi-pronged attempt at controlling them. Previous work has shown that, other than common and koi carp, most other species of fish are not affected by KHV (although a small number of species may be infected but show no clinical signs of disease). In carp, transmission appears to be largely horizontal, and very low doses of virus are required for infection. Most disease occurs in the spring in water temperatures between 17–28°C. KHV is most closely related to two other viruses that occur in Australian waters, carp pox virus (CyHV-1), and a virus that causes disease in goldfish (CyHV-2).

Objectives

The specificity of KHV, and the sensitivity and high mortality in the target species makes KHV a potentially good biological control agent for carp in Australia. For these reasons, the Invasive Animals Cooperative Research Centre funded this research, aiming to develop a comprehensive understanding of the epidemiology of the disease caused by KHV — by using both previously published information and laboratory experimental work. This would allow knowledge of the biology of carp to be integrated with an understanding of the biology of KHV and the disease that it causes.

Summary of findings

After developing a range of technical procedures that allowed work with KHV, the first major question addressed was whether Australian carp are susceptible to KHV. We have demonstrated high mortality in juvenile Australian carp, and have noted that the time from the first signs of disease until death is almost always less than 24 hours. This is important from an animal welfare point of view.

A lower mortality was observed in mature fish. This may be because older carp are more resistant to KHV. It was also hypothesized that there may be a high proportion of carp-goldfish hybrids in some populations of carp, and, given that hybrids are known to be less susceptible to KHV, this may have accounted for lower mortalities in older fish. Subsequent work suggested that, apart from transient water bodies, the proportion of hybrids in most natural carp populations in the Murray–Darling Basin is low (1–3%).

Another potential cause of lower mortality in older fish is that they have been exposed to other cyprinid herpesviruses (CyHV-1 or -2, or, as yet, unidentified viruses) that confer some immunological protection against KHV. An extensive survey of carp collected from eight sites across the Murray–Darling Basin showed no evidence for any cross-reactive cyprinid herpesviruses that might compromise the efficacy of KHV were it to be released into the Murray–Darling Basin.

The specificity of any potential biological control agent must be tested to ensure that it does not affect native fauna. At this stage, no evidence of virus replication or disease has been found in four native non-target species of fish that were exposed to virus — Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and a galaxiid (*Galaxias maculatus*). These findings were also replicated in an introduced species, the rainbow trout (*Oncorhynchus mykiss*). All fish were exposed to KHV either directly (intraperitoneal inoculation) or via a natural route of infection (bath inoculation).

To help us understand the epidemiology of KHV disease, a preliminary trial was conducted to determine the temporal pattern of excretion of virus by an infected immature carp. As with most viruses, it appears that KHV is excreted for 1–2 days before clinical signs of disease are seen in infected carp.

Finally, the sensitivity of juvenile carp to infection with different doses of KHV was determined, although this work may have been compromised by the lack of availability of immature carp at the time.

Together, these findings provide the basis for developing an epidemiological modelling system for KHV in Australian waterways, and for opening broad-scale discussions on the possible use of KHV as a biological control agent for carp in Australia.

Key messages

- Koi herpesvirus causes high mortality in juvenile Australian carp.
- Mortality is lower in older carp. This is unlikely to be due to the presence of morphologically-indistinguishable carp–goldfish hybrids in wild populations of carp.
- Exposure of carp to closely-related, less virulent cross-reactive viruses that might confer protection from KHV is unlikely to be a problem in the Murray–Darling Basin.
- KHV has been found to have no effect on four native fish species (Murray cod, golden perch, silver perch, and a galaxiid), and on one introduced species (rainbow trout).
- Infected carp excrete KHV for 1–2 days before signs of disease are apparent in the fish.

Management / Research recommendations

It appears that there is great potential for KHV to be used as a biological control agent for carp in Australia. For optimal use, however, it is critical that:

- we learn from past biological control experiences in Australia with myxomatosis and rabbit haemorrhagic disease
- we use a targeted, strategic release of the virus, possibly at carp 'nursery hotspots' or in other (natural or induced) concentrated aggregations of carp
- we use KHV in conjunction with other carp control procedures that have been tested, or developed, with the support of the Invasive Animals Cooperative Research Centre.

Knowledge gaps

The major gaps in our knowledge that impact on the potential use of KHV as biological control agent are threefold. Firstly, if the requirements of the Australian Pesticides and Veterinary Medicines Authority (APVMA) are to be satisfied, there needs to be an expansion of the number of non-target species that are tested for their susceptibility to KHV. It is likely that at least a further 12 native fish species, together with an amphibian, a reptile, a mammal and a bird, will be tested in the subsequent extension of this project.

Secondly, given that it is unlikely that KHV will be tested in the field prior to any future release, it is critical that, once all the epidemiological information about KHV is acquired, an epidemiological model is developed that will improve our understanding of the spread and effectiveness of KHV. This would then aid in the development of strategies for release of the virus. Much of the necessary information is already available (either in the literature, or as a result of Invasive Animals Cooperative Research Centre research across a number of projects). For example, we already know a good deal about: the biology of carp, the infectivity of KHV, mortality in carp, persistence of KHV in the environment and the temperature sensitivity of KHV. At this stage, we still lack precise information on: the age-susceptibility of very young carp (which will be important if the virus is to be released in hatchery sites of carp), the amount of virus excreted by infected carp and the hydrology of river systems and swamps where the virus may be released.

The third major area of investigation will be developing an understanding of how KHV will be delivered in the field if a biological control program is eventually initiated. As an exotic pathogen of Australia, KHV is currently only held in the microbiologically-secure area of the CSIRO Australian Animal Health Laboratory in Geelong. Prior to use in the field, we need to obtain permission to remove KHV to the non-secure laboratory, prepare freeze-dried aliquots of the virus, and test the efficacy of these aliquots.

An aspirational aim, if time and resources permit, would be to try to develop variants of KHV that could be used in those specific situations where it is unlikely that the standard strain of KHV will be very effective. For example, given that the optimal temperature range for activity of KHV is 17–28°C, it would be very useful to have a variant that would operate effectively at lower temperatures, since carp are certainly known to occur in Australian waters that are less than 17°C. Two other useful variants would be one that was effective against carp–goldfish hybrids (for use in transient water bodies where hybrids are known to occur), and another that is more virulent for mature carp.

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Questions

Q: The real challenge is getting this virus out and putting it into effect. From the science perspective there is always the feeling that we do not want to be premature and there is the attractiveness of doing further research. But from the credibility of taking on carp you are really going to need to stick to the 5 year timeline. Even at the release point there can be further research once it is out there so I would really urge you and others to stick to the timeline and get it out there so that it can start having an impact. Are you confident that you are going to be able to meet the 5 year timeline, can we continue to be able to advise anglers that it is going to happen?

Ken: We are in the process of finalising the funding proposal for the next extension of the project. It runs for 3 years and at the end of that 3 years the aim is to have virus in the non-secure area of the Animal Health Laboratories (CSIRO) ready for distribution. How it is distributed will be determined through collaboration with a number of groups including consultation with the public.

WF: I totally disagree with there being time for more research after the virus has been released. Once it is released it is too late for research. So we need to get it right before it is released. The processes that we need to go through include the Quarantine Act, the EPBC Act, the Biological Control Act, the APVMA Act and then the various State legislations and consultation processes. If the bureaucrats get organised then maybe we can get it done in 5 years time. I think the research will be there but there are a lot of other processes to go through. I certainly would not want to be the one that is proposing the release and then having it go wrong through lack of research to make sure that it is safe.

Ken put up a list of fishes (that need to be tested for susceptibility to KHV) and for instance we haven't tested the ones that are most closely related such as the silurid catfishes which share a very close habitat with carp. They definitely need to be tested.

I had prepared another list after putting Ken's original list to SEWPaC for consideration under the EPBC Act. They suggested some changes but basically approved the radial taxonomy approach that we were taking. They actually cut out some of the species on the basis that if you are confident in your science that shows that the virus does not replicate above about 30^{o}C then why are you worrying too much about testing animals that live at 37^{o}C. I agree with that to a point but there will be a consultation process that will take place along the way in relation to the testing.

Q: Is there any possibility at all for the disease to mutate in decaying fish?

Ken: The question of mutation is always a difficult question. What we can do is draw on precedent with previous successful virus releases such as rabbit haemorrhagic disease, myxomatosis and feline panleucopaenia virus, and that experience is that there has been no evidence of mutations allowing virus to spread into other species.

Q: Do you have any plans to look at the carp/goldfish hybrid issues because of the different resistance characteristics?

Ken: Hybrids don't figure in our three year plan at all. Maybe Travis was talking about these sorts of issues when he was talking about further research after the release of the virus. Issues such as this could be followed up later. I mentioned the possibility of developing a variant of the virus that attacked hybrids; this is not an impossibility. Similarly a low temperature variant of the virus is a possibility because it will not operate at low temperatures and this is another option after the virus has been released.

Q: On the graph where you showed the mortality according to inoculation method, am I right in saying that the ones that didn't die were not infected or did they get a low infection and survive?

Ken: We looked for evidence of virus in those fish that survived but did not find any.

Q: Is it possible that we could divide the research tasks and throw more resources at it to shorten the time-span given the fact that we have floods across Victoria and New South Wales that are exacerbating the problem?

Ken: There is not much that can be done outside of AAHL until the virus is released. Once it is released then lots of organisations will be free to work on the virus as well. Until that time we are limited to AAHL because it is an exotic disease to Australia. Within AAHL we are limited by our fish holding facilities. AAHL was primarily built to work on foot and mouth disease and our fish holding facilities are limited.

Comment: Not suggesting cutting corners in any way but what I am concerned about is working to a time line. I want to be able to say that we are working to a 5 year time line and be confident that it will be met. That assists with funding and it galvanises the community. If that is going to change for some reason we need to be up front with that early. Not find out at four and a half years that it is going to be another two and another two.

Ken: I don't see any reason why, if things go according to the plan, that it shouldn't be at the appropriate stage in 5 years time. The regulatory processes will be very important and there are statutory timelines on some of those. Geoff's point is also valid and some extra resources could shorten that timeline.

Q: Some of the timelines might not be held up by technical processes but they might be held up by public acceptance so what processes have been put in place to test that?

Ken: Having been involved in the rabbit haemorrhagic disease process in Australia I have maintained for sometime that we need to learn from that experience and one of the things that we did learn was that we needed some form of public interaction at some stage, probably at the stage where we have sufficient information on, and knowledge of the virus that it is worth talking to the public about it.

WF: That is why we will use the provisions of the Biological Control Act because that is set up to deal specifically with any points of conflict because it has a structured public consultation process within it.

Q: How is the virus actually going to spread and how is it going to go through the population. What modelling or what thought has been given to that?

Ken: We are talking about targeted and strategic release of the virus, perhaps at nursery sites or at any other points where we can target large aggregations of carp.

Daughterless technology — a recipe for eradicating carp in Australia

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Objectives / Background

Since 1997, CSIRO has been working to develop a biotechnological solution for the control of invasive pests, including carp — 'Daughterless Technology'. The technology can be described as: "A genetic construct using species-specific genes that is inheritable and that biases off-spring sex ratios towards males". Logically, a sex-biasing genetic construct that slowly spreads through a population will inevitably lead to massively distorted sex ratios, reproductive failure and extinction. Initial studies on the feasibility of the technology were funded by CSIRO. On the basis of promising early results, the MDBC/MDBA provided subsequent support, through the Pest Animal Control and Invasive Animals CRCs, which allowed the option to be explored in detail.

Modelling studies indicate three classes of constructs have the potential to distort fish population sex ratios: a 'sex-change' construct (genetic female to functional male), a 'female-lethal' gene, and 'female-sterile' construct. We have made progress in all three and a technical paper describing the work is in preparation.

Summary of findings

Integrated lines of zebrafish have been produced carrying female lethal and female sterile prototypes. Transient (non-integrated) assays in carp are underway at Auburn University for the sex-change construct. The female lethal construct is based on the combination of a female-specific liver gene, which is involved in egg yolk production, and a cell death sequence (of which several have been determined to be effective). It has worked effectively in zebrafish through four generations, producing about 90% males when present as a single copy, and 100% males when two copies of the construct are present (Figure 1). All of the fourth generation fish (a mixture of copy number one and two) were male.

Male carriers suffer no apparent fitness costs from the construct. Preliminary trials in carp, just reaching sexual maturity, suggest it is effective in it as well; 76% of potential carriers are male, as opposed to 50% of fish potentially carrying control plasmids. For purposes of producing brood stock, the female-lethal construct needs to be repressed for copy numbers greater than or equal to two. We have tested an option for doing so using a female-lethal variant that incorporates a viral-based sequence called 'Tet-off' (Bujard and Gossen 1992). Tet-off represses expression when in the presence of tetracycline or doxycycline. In initial trials the sex ratio of dox-treated fish was the same as that of normal fish (about 45% female), whereas all carriers in the no-dox treatment were male.

Thus far, only one integrated generation of female sterile fish (copy number = one) have been produced. Females carrying one copy of the construct have about 85% lower fertility (% of eggs hatching) than their full siblings with no construct, although their rate of egg production is similar. Male fitness and survival of hatched fry is unaffected by the construct.

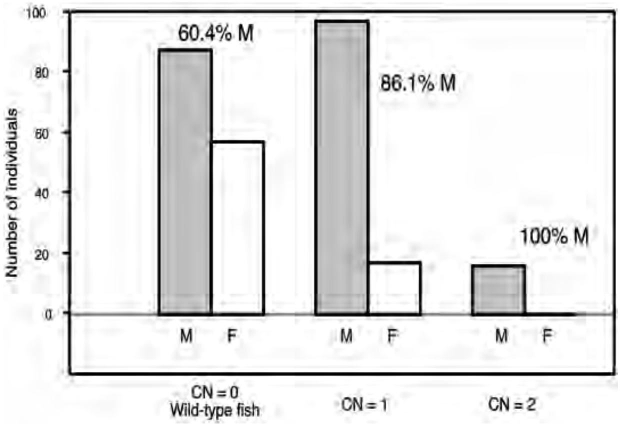

Figure 1. Sex ratios of full sibling zebrafish carrying 0, 1 or 2 copies of the prototype female lethal daughterless construct.

Tests with the sex change construct in medaka, our original test species, proved it to be ineffective. We suspect this is related to the unusual genetics of sex determination in the species (Thresher et al 2011). As the central question was whether the construct would work in carp, trials on carp were started at Auburn University in 2009. Initial results of maturing fish are consistent with the construct biasing sex ratios, with 78% of mature fish male (as opposed to 50% in control groups).

Modelling studies indicate daughterless technology alone can eradicate carp. However, they also indicate eradication is much faster and at lower cost if coupled with complementary control options, such as koi herpesvirus (KHV) (Figure 2). In theory, a similar level of control is possible using an alternative genetic sex-biasing technology — Trojan Y (Gutierrez and Teem 2006, Thresher et al (2014). The latter relies on the stocking of YY females, which in theory can be produced using off-the-shelf hormonal methods of phenotypic sex change. YY male carp have been produced (Bongers et al 1999), but the viability and fitness of YY females is unknown.

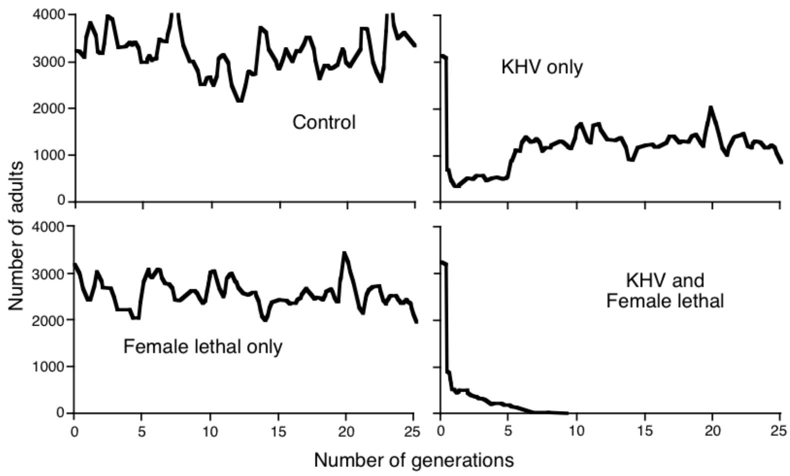

Figure 2. The effects of KHV and stocking female lethal carriers on a modelled carp population, alone and in combination, beginning in year five. The KHV is assumed to be 80% lethal in year one, 50% and 30% in years two and three, and 20% lethal in subsequent years. The female lethal carriers are males, carry four independently segregating copies of the construct and are stocked at 3% of mean virgin recruitment annually. Based on Bax and Thresher (2009).

Key messages

- Daughterless technology works. At least two different versions (female lethal and female sterile) appear to heritably distort offspring sex ratios as planned. Preliminary assays in carp suggest both the female lethal and sex change options work in the target species; it is too early to determine if the female sterile construct works in carp as well. The carp results are promising, but preliminary and require testing in integrated carp lines. This will require 3–5 years of effort, given the two year generation time, assuming the potential carriers currently being reared for us at Auburn University (USA) are not sacrificed due to lack of funding.
- A hypothetical method of sex ratio distortion based on chromosome manipulation — Trojan Y — may be as effective as daughterless recombinant technology and avoids many of the potential problems associated with the latter; it does not require Office of the Gene Technology Regulator (OGTR) oversight, is limited to interbreeding individuals (and hence only carp and goldfish in Australia) and because it is not recombinant, may be more acceptable to the public. The main unknown, however, is whether the YY females required by the technique are viable, fertile and competitive.
- With the availability of daughterless technology, eradication of carp in Australia is possible. Eradication is faster and more cost effective when combined with complementary control options, such as KHV, spawning ground sabotage and commercial and recreational fishing.

Management / Research recommendations

- Research on KHV should continue, as a valuable complement to Daughterless technology.
- Carp trials at Auburn University should be completed (a 3-5 year exercise), to confirm that the daughterless constructs work in common carp and to develop brood lines that can be used as the basis for large pond or bio-secure field trials. In the absence of continued support, the 5,000+ fish being reared for us in the USA will be terminated, which will add several years to the analysis if it is decided to pursue it at a later date.
- The Trojan Y should be investigated, as a potentially more socially acceptable form of genetic control. This work can be done effectively in Australia.
- Recent success in developing daughterless technology should be promulgated in the media, and community attitudes to the further development of the technology, possibly leading to field trials, canvassed.

Knowledge gaps

- determining whether or not the constructs work in integrated carp lines
- determining whether Trojan Y females are viable and competitive.

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Questions

Q: Has anyone done any work to see if you can make your daughterless construct resistant to KHV?

Ron: The short answer is no. The longer answer is that for years we have talked about ways to give the carrier a competitive advantage. For example using hatchery reared fry you may be able to release them prior to the appearance of wild bred fry to give them a big competitive advantage. It may also be possible to find KHV resistant carp to use as broodstock and use those as our carriers in which case we would wind up with a huge advantage. All of our models at the moment assume that the carriers are just as vulnerable to KHV as non-carriers. Just whether you would want to deliberately release a KHV resistant carp into the wild is something I would need to think about in some detail. On the other hand it is probably going to happen anyway.

Q: We had a timeframe for KHV before, do you have a timeframe for daughterless?

Ron: There are two relevant timeframes. It will take us 4-5 years to get the integrated fish at Auburn (university) and find out what we need to do to produce broodstock because of the two year generation time. Similarly if we are going to test whether the Trojan Y provides an alternative approach it will take about 3 generations which is about 4-5 years. Happy coincidence that it is about the same timeframe proposed for release of KHV. So if you want to look at a combined attack of KHV and a genetic approach, the timeframes for both are similar.

Q: If KHV turns out to be no good would you still go ahead and roll it out?

Ron: Daughterless technology will work. The issue is not will it work but how much effort do you want to put into it. If you have good complementary control efforts to add to a daughterless technology it speeds it up considerably. For example recreational fishing on its own has very little impact but if you can get recreational fishers to target older, non-carrier fish along with a daughterless technology, it speeds up the process substantially. There are lots of things that you can do that don't depend on KHV to make it work, it just provides a really good opportunity.

Q: Are there examples from anywhere else in the world where daughterless has been used to wind back populations at the stage where carp are in Australia?

Ron: No, because the technology is brand new and in terms of daughterless itself we are world leaders in this technology development. In relation to insects, which have 2 day generation times, researchers have been able to make huge leap-frogs in terms of where we have been over the last couple of years. There is a female-lethal cohort now that has been field trialled for mosquitoes in a couple of spots in the Americas and it is working. They are only using it for local disease suppression at this point but the dynamics look to be just fine. It is a very similar system using a similar set of gene constructs and similar descriptive models. So there are field trials going on but not in fish.

Identifying significant hotspots of carp recruitment offers opportunities for the control of carp populations

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Background

This project identified high priority carp recruitment areas across the Murray-Darling Basin (MDB). The original project plan was to expand on the use of an inexpensive larval drift sampling strategy, which had been trialled during the Pest Animal Control CRC (PAC CRC) and found that carp spawning was very localised, with a large proportion of carp larvae originating from only a small number of key breeding areas ('hotspots'). For this project, the larval drift sampling strategy was to be applied across the whole of the MDB, with 26 sampling locations in Queensland, 33 in Victoria and 10 in South Australia and the previously un-sampled Culgoa, Paroo, Castlereagh, Macquarie, Bogan and Lachlan catchments in NSW. Sampling was undertaken at 152 sites in 11 different river systems within the Murray-Darling Basin over three sampling seasons (2005-06, 2006-07 and 2007-08)(Figure 1). Four catchments were sampled twice within the three year period in order to provide data on temporal variability. This was a lower number of catchments and sampling occasions than was anticipated (303 sites and 25 catchment areas), as sampling opportunities were substantially limited by drought conditions in many river systems throughout this three year period. Despite this, we were able to identify six key carp recruitment areas using the larval drift sampling strategy; Lower Boomi River, Gwydir Wetlands, Namoi Wetlands, Macquarie Marshes, Lower Warrego Wetlands and Barmah-Millewa Forest.

However, analysis of temporal variability and a comparison of the results of larval drift sampling with available electrofishing data suggested that inter-net variability within samples (4 replicate nets per sample) and inter-annual temporal variability at sites was very large. Together, this meant that whilst we could be confident that if larval drift sampling suggested a carp spawning hotspot existed it was true, the risk of a false negative result was unacceptably high. Whilst collecting a single larval drift sample was quicker and cheaper than alternative sampling strategies (ie. electrofishing), many more nets need to be deployed during a sampling event in order to obtain a reasonable mean larval density estimate, and each catchment needs to be sampled over many carp breeding seasons in order to minimise false negative results.

Validation of 'hot-spots' concept

If a 'hot-spots' concepts holds and these larval drift data do represent recruitment hotspots, then;

i. A large proportion of sites should have no YOY carp and

ii. YOY abundance should be greatest adjacent to LDN hotspots.

Therefore in order to further validate these findings, more data were needed in addition to Fisheries NSW (Freshwater Fisheries Research Database) standardised data.

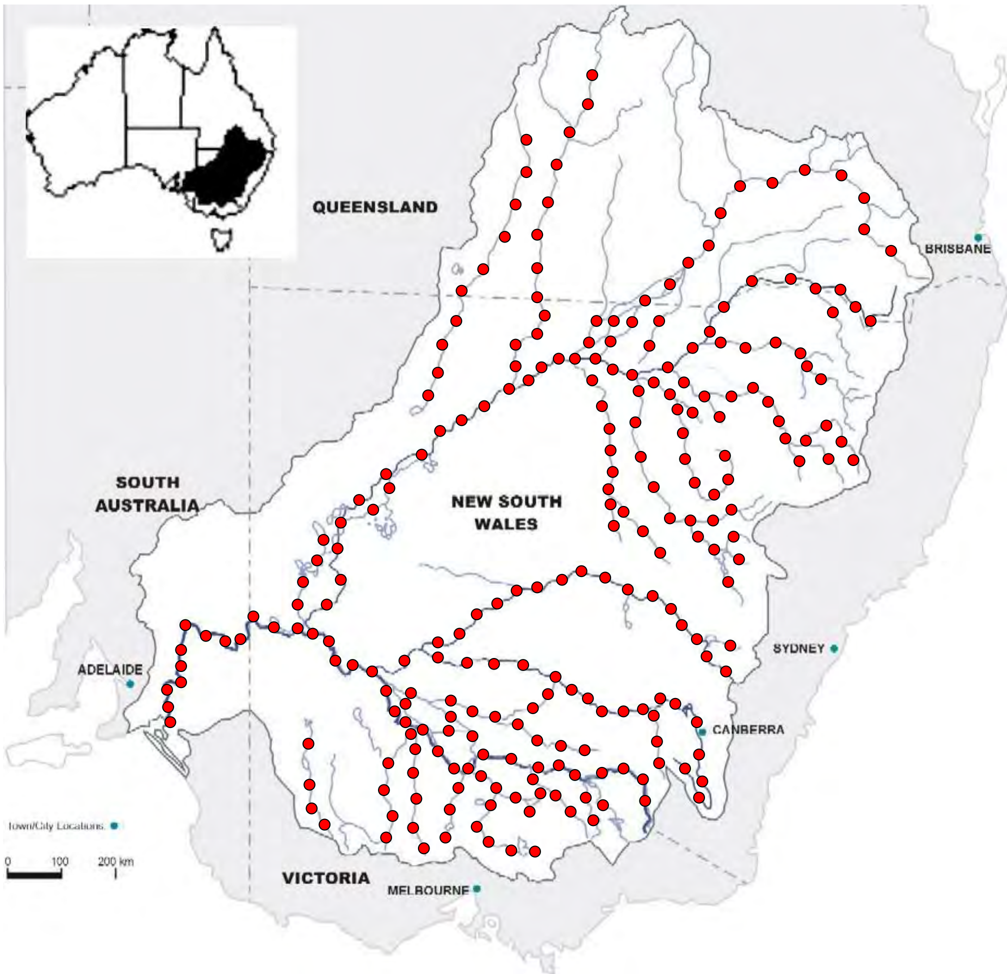


Figure 1. Locations of larval drift sites sampled across the Murray Darling Basin (2005 – 2008). Sampling sites are shown as red circles and were spaced approximately 50km apart.

Fortunately, during the course of our larval sampling study, the MDBA commenced a basin-wide fish sampling program (the Sustainable Rivers Audit : 2005 - 2010) which collected data on carp abundance and length-frequency. Together, these datasets provided data from 1,677 sampling locations in the MDB, sampled on a total of 3,294 occasions. Of these, 68% were only sampled once, 14% were sampled twice and the remainder sampled on average 7 ± 3 times between 1 January 1990 and 3 August 2011.

Sampling location, electrofishing effort and catch and length data were extracted from the FFRD and SRA databases. Abundance was standardised to catch per one minute of electrofishing effort (CPUE) at each sampling location. Length data were used to calculate the proportion of the *Cyprinus carpio* population that was YOY (< 151 mm), sub-adult (> 150 and < 301 mm) and adult (> 300 mm) size classes. YOY were considered any individual < 151 mm fork length based on data provided by Brown et al (2005), where at one year of age, mean length is 150 mm with a 95% CI of ~ 90 – 210 mm. A maximum length of 300 mm was used to distinguish sub-adults based on the median length at first maturity (307 mm for males and 328 mm for females: Brown et al 2005). The total Catch Per Unit Effort (CPUE) was multiplied by the proportion of YOY, sub-adult and adult individuals in the sample to estimate CPUE of each size class.

Results

Of the 1,677 locations sampled, *C. carpio* were present at 64.6% of sites. However, sampling locations were not randomly selected in all cases, and even when they were, most were stratified into altitude zones. Therefore, this figure does not represent the proportion of the MDB occupied by carp. Of the 1,084 locations where carp were present, the YOY and sub-adult size classes were recorded at 636 (58.7%) and 669 (61.7%) sampling sites respectively. The adult size class was present at 926 (85.4%) of locations. There were 252 locations (23%) where only adult fish were recorded and there were 158 locations (14.6%) where only juvenile fish (YOY or sub-adult) were recorded. The distributions of abundance for YOY and sub-adult size classes were heavily skewed. Over 90% of the total standardised abundance of YOY carp was recorded at just 3.14% (34) of the locations where carp were present, with 50% coming from just 1.38% (15) of sites. Sub-adult abundance was similarly skewed with 50% of the total standardised abundance recorded at 1.48% (16) of sites, but with 90% of fish coming from 16.4% (178) of sites.

CPUE of the sub-adult size class was positively correlated with CPUE of the YOY size class at each location ($r = 0.664$, $p < 0.0001$). CPUE of adult *C. carpio* was also positively correlated with the CPUE of the sub-adult size class, although much more weakly than the former relationship ($r = 0.180$, $p < 0.0001$). There was no significant correlation between the CPUE of adult fish and the CPUE of the YOY size class at each location ($r = 0.046$, $p = 0.130$).

Analysing this data confirmed that carp recruitment was generally localised to specific regions, with juvenile carp only collected at around five per cent of sites where data were available. All spawning hotspots identified by larval drift sampling were supported by the electrofishing dataset which confirmed that they were also carp recruitment hotspots. However, because of its longer temporal scale and greater spatial coverage, the electrofishing data identified a further 12 hotspots in catchments that were not sampled using the larval sampling strategy (due to persistent drought conditions).

Getis-Ord Gi Hot Spot Analysis*

Spatial analysis determined that there was significant structure within all three size classes. CPUE data for each size class were loaded in a GIS (ArcGIS 9.3.1, ESRI Inc., Redlands, CA) and analysed using the Getis-Ord G_i^* Hot Spot Analysis tool in ArcGIS (Fischer and Getis 2010). This analysis identifies spatial clusters of high values (hotspots) and spatial clusters of low values (coldspots)(Figure 2). Statistical significance is dependent on a location with a high (or low) CPUE being surrounded by other locations with high (or low) CPUE as well. The local sum of CPUE values is compared proportionally to the sum of all locations. When the local CPUE is significantly different from the expected local CPUE (i.e. the difference is too large to be the result of chance) a statistically significant *Z* score results. CPUE of YOY, sub-adult and adult size classes were used as analysis fields. Fixed distance was used to define spatial relationships using the default distance parameter estimated to maximise spatial auto-correlation. Data were analysed using the complete and flood-excluded datasets at the whole of MDB scale. Subsequently, the dataset was partitioned into individual valleys within the MDB (using the MDBA's SRA catchment boundary layer) and analyses were undertaken at the valley scale for each of 21 valleys within the MDB.

Hotspots of YOY abundance

There were three statistically significant clusters of sites with high YOY abundance within the MDB (Figure 2a). The largest was centred on the Barwon River upstream of Bourke and the lower reaches of its tributary valleys, including the Bogan River, Macquarie River, Castlereagh River, Namoi River, Gwydir River, Border Rivers, Moonie River and the distributary streams of the lower Condamine-Culgoa River. The second significant hotspot was centred on the Murray Riverina extending from the Murray River at Tocumwal downstream to Nyah and including the Barmah-Millewa Forest, Koondrook-Perricoota-Gunbower Forest, and Werai Forest, the entire Edward-Wakool anabranch system and the lower reaches of the Loddon and Avoca Rivers. The third extended along the Darling River from near Tilpa in the north to Burtundy in the south and included the Menindee Lakes system.

Re-analysis of the YOY abundance data after excluding samples influenced by major flood events also identified the Barwon region hotspot and central Murray Riverina hotspot, with both encompassing generally the same areas and waterways as the all-inclusive analysis (the major exceptions being that much of the Condamine-Culgoa catchment and the Barwon River downstream of Walgett were no longer part of the Barwon region hotspot). In contrast, the mid-lower Darling River hotspot was not evident when flood affected data were removed. Instead, four additional hotspots were identified. The first being the Great Cumbung Swamp and lower Lachlan River upstream to Booligal, the second the lower Murrumbidgee River between Hay and Redbank Weir and the third and fourth corresponding to single sites in the Lachlan River near Lake Cargelligo and Willandra Creek near Roto, both in the Lachlan Valley.

Hotspots of sub-adult abundance

The Barwon region hotspot was still present for sub-adult carp (Figure 2b) but was reduced in extent and intensity compared to that for the YOY size class (Figure 2a). The upper limits had retracted from the Border Rivers and Gwydir catchments downstream to below Collarenebri on the Barwon River and similarly had retracted downstream in each of the Namoi, Castlereagh, Macquarie and Bogan rivers. But the downstream extent of the hotspot at Bourke had remained stationary. Similarly, the upper extent of the central Murray Riverina hotspot had retracted downstream in the Murray Valley, leaving the Goulburn-Broken, Campaspe, Loddon and Avoca valleys and shifting downstream to west of Barham in the Murray and west of Wakool in the Edward-Wakool system (Figure 2b). However, in contrast to the stability of the downstream limit of the Barwon hotspot; when comparing YOY and sub-adults, the downstream limit of the central Murray Riverina hotspot had expanded downstream as far as Chowilla in South Australia (Figure 2b). Similarly, the southern extent of the Darling River hotspot had expanded downstream to the confluence with the Murray River and merged with the central Murray Riverina hotspot. In the lower Murrumbidgee Valley, either sub-adults from the Murray Riverina hotspot had expanded upstream into the lower Murrumbidgee region, or YOY carp in the lower Murrumbidgee hotspot identified by the non-flooded affected analysis had shifted downstream as sub-adults to occupy the lower Murrumbidgee region and merge with the Murray Riverina sub-adult hotspot.

Hotspots of adult abundance

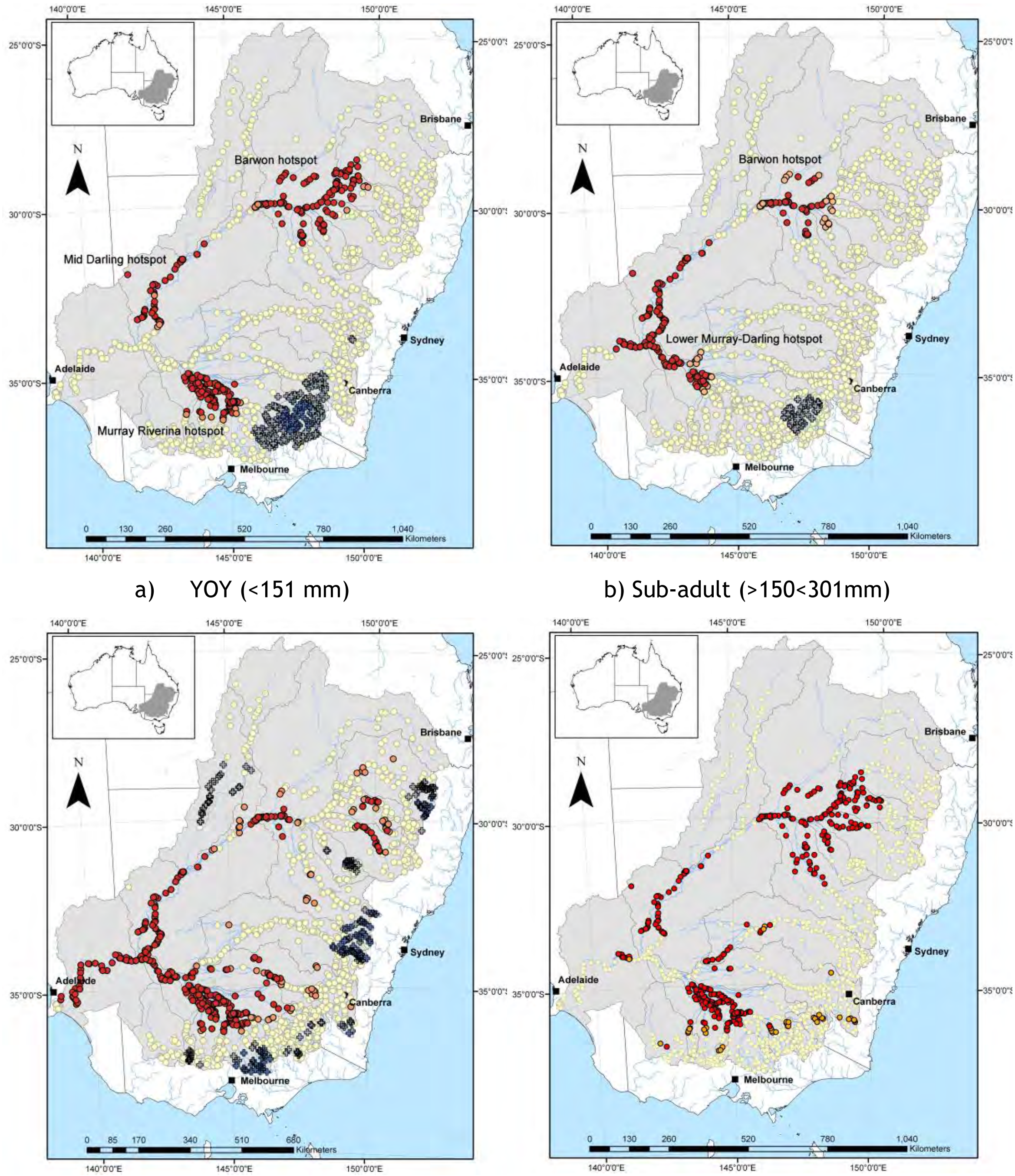
While there were consistencies in the size and distribution of YOY and sub-adult hotspots, the size, number and distribution of hotspots for adult carp abundance were markedly different (Figure 2c). Whilst some adult carp hotspots overlapped with those of smaller size classes, adult hotspots were also detected in regions where sub-adult or younger size classes were much less abundant. Notably, adult carp were not abundant over much of the area characteristic of the Barwon region hotspot for smaller size classes. Hotspots in adult abundance were also evident in many of the most heavily regulated reaches of the MDB.

Valley-scale analyses

Because of the potentially overwhelming influence of the three major YOY hotspots identified at the basin-wide scale, the data were sub-divided into individual valleys and re-analysed at that scale in order to determine whether any localised hotspots existed within other regions of the MDB. Valley-scale analyses identified 12 statistically significant YOY hotspots (Figure 2d). Of these, 9 were encompassed within those identified at the larger MDB scale, with four within the Barwon hotspot, three within the Central Murray Riverina hotspot, one corresponding with the Darling hotspot and one corresponding with the Lower Lachlan – Great Cumbung Swamp hotspot. Only three additional hotspots were detected at new locations; One within the lower Murray River between Lake Victoria and Chowilla, a second within Lake Brewster in the Lachlan Valley and the third in the endorheic Wimmera Valley in Victoria.

Two thirds of all key recruitment hotspots were in or adjacent to large low-lying marshy floodplain wetland habitats. Several of which are Ramsar listed wetlands of international importance. Spatial analysis at a basin-wide scale suggests that the abundance of small carp recruits is correlated with swamp area at a 50 km^2 scale. Collectively, it is highly likely that as few as around 18 carp recruitment hotspot areas exist within the Murray-Darling Basin. However, of these, the density of carp recruits produced is highest at only six to seven sites.

Identified hotspots will help define the spatial structure of carp populations of the MDB by specifying the population units (nodes) that contribute most to recruitment within the Basin (source populations). Population sinks can also be identified. Accounting for this spatial variation will create more realistic CarpSim modelling of carp populations and assist in the development of an effective integrated pest management strategy.



a) YOY (<151 mm)

b) Sub-adult (>150<301mm)

c) Adult (>300mm)

d) All size classes, all forms of analysis

Figure 2. Distribution maps generated from Getis-Ord Gi* Hot Spot Analysis of carp abundance within the MDB. Each point represents a sampling location. Darker points represent sites belonging to statistically significant hotspots and darker crosses represent sites belonging to statistically significant coldspots.

Conclusions

- Larval drift net (LDN) sampling is much cheaper than electrofishing (25% of electrofishing costs), but the risk of false negative results is unacceptably high.
- Those using LDN should use many more than 4 replicate nets per sample to achieve a decent estimate of mean density of larvae.
- The availability of *SRA* and *NSW* electrofishing data proved extremely useful for identifying hotspots of YOY, sub-adult and adult carp abundance.
- Over 90% of the total standardised abundance of YOY carp was recorded at just 3.14% (34) of the locations where carp were present, with 50% coming from just 1.38% (15) of sites. Sub-adult abundance was similarly skewed. No YOY or sub-adult carp were sampled from ~40% of sampling locations.
- Spatial analysis suggest that sites with high abundance of YOY and sub-adult carp were significantly clustered.
- This approach assists Integrated Pest Management strategies by guiding targeted control of adult carp migrating towards spawning areas, exclusion of spawning adults from spawning areas and control of dispersing juveniles from spawning areas.
- Seventeen discrete, statistically significant YOY hotspots were identified by valley-scale analyses.
- Hotspots of adult abundance are sometimes remote from YOY hotspots, suggestive of a source-sink population structure.
- Most hotspots are adjacent to large floodplain wetland systems. E-water programs are likely to exacerbate the carp problem.
- Local-scale larval sampling or otolith micro-chemistry analysis within each hotspot may allow identification of key nursery sites within each wetland system and allow targeted control.

Acknowledgements

Funding for this study was provided by the Invasive Animals Cooperative Research Centre and NSW Department of Primary Industries - Fisheries. We would like to thank all of the many people involved with collecting the huge volume of data extracted from the NSW Freshwater Fish Research Database. We would also like to thank those fisheries ecologists from the Victorian Department of Sustainability and Environment, Queensland Department of Employment, Economic Development and Innovation and South Australian Research and Development Institute for the data they provided via the Murray-Darling Basin Authority's Sustainable Rivers Audit, without which a basin-scale assessment would not have been possible. We also thank Frederick Bouckhaert and the Sustainable Rivers Audit team for providing access to the data.

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Questions

Q: How confident are you that the hotspots will remain static over time?

Martin: It is not disputing that carp are recruiting in other areas but this defines where a large amount of recruitment is coming from over that particular scale. They may change but knowing where they were under those conditions gives us a starting point.

Q: It would be useful to overlay this data with patterns for native fish before it was used for any interventions. Can you do that?

Martin: It can be done and Dean has done those analyses for native fish.

Get out, stay out! Restoring a small New Zealand floodplain lake: removal and exclusion of carp

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Introduction

Ornamental common carp (koi; *Cyprinus carpio* L.) were introduced to New Zealand in the 1960s for the aquarium trade and were subsequently released in farm ponds in the Waipa tributary catchment of the Waikato River, northern New Zealand. By 1983, eel fishermen were reporting catches of juvenile koi carp in the main Waikato River system (Pullan 1984). Koi carp have since expanded their range throughout the Waipa River system and the lower 152 km of the Waikato River downstream of the Karapiro hydroelectric dam. They have also been introduced to many other localities throughout the North Island (Figure 1).

The lower Waikato River floodplain contains many shallow lakes ranging in size from a few hectares to the 3400 ha Lake Waikare. The floodplain has been highly developed for pastoral agriculture, primarily dairy farming, resulting in extensive drainage and flood control measures to regulate river and lake levels. Most lakes have degraded water quality as a result of nutrient and sediment enrichment, and the additional impacts of pest fish such as carp, goldfish (*Carassius auratus*), brown bullhead catfish (*Ameiurus nebulosis*) and rudd (*Scardinius erythrophthalmus*) have generally resulted in the total collapse of submerged macrophytes and progression to a highly eutrophic state. Of all New Zealand lakes monitored regularly for water quality, around 25% of those categorised as supertrophic or hypertrophic are on the Waikato floodplain (Verburg et al 2010).

Study Site and Methods

Lake Ohinewai is a shallow (4.5 m depth), 16.8 ha lake on the Waikato River floodplain. The lake has a 331 ha primarily flat catchment dominated by intensive pastoral farming and minor residential development with several inlet drains. A single outlet drain leads to Lake Waikare via Lake Rotokawau (Figure 1) and passes through a circular 1400 mm diameter road culvert 930 metres from the lake outlet. Lake Ohinewai deteriorated from a stable oligotrophic state (macrophyte dominated) to a stable eutrophic (algal dominated) state during the early 1990s and currently lacks aquatic macrophytes. In 1981, 80% of the lake was covered in aquatic macrophytes and by 1991 none remained (Edwards et al 2005).

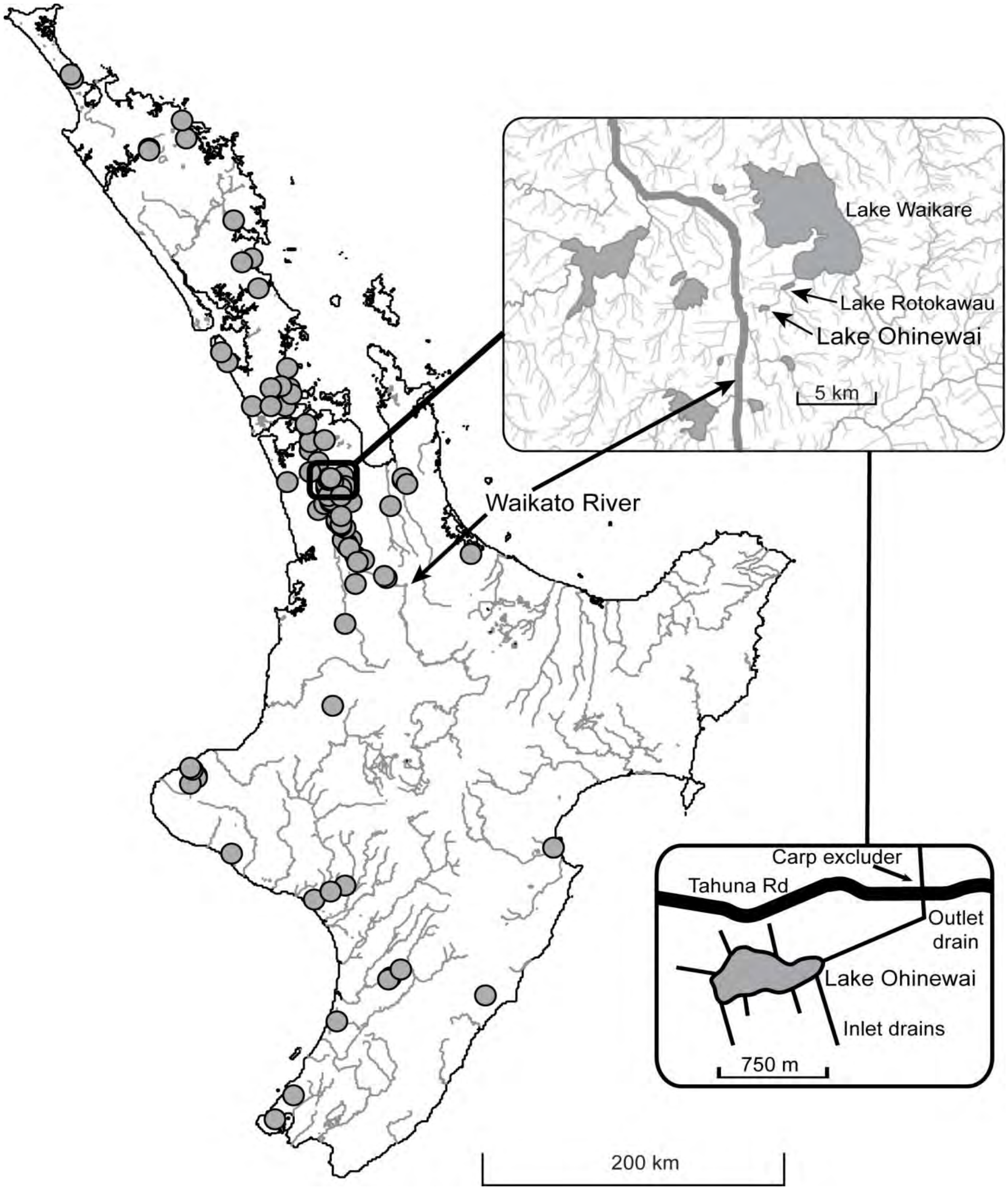

Figure 1. Distribution of ornamental common carp (koi) in New Zealand's North Island. Insets: Lakes and streams of the lower Waikato River floodplain and Lake Ohinewai drainage.

Fish were captured for marking and removal (24 January to 2 May 2011) using fyke nets, minnow traps, electrofishing, beach seining and baited traps. Bow fishing was trialled for fish removal in drains where other methods were not effective. Electrofishing was conducted using a total of 34 separate 20-min sampling periods (11 during marking and 23 during the removal phase) and concentrated on productive shallow-water habitat near the shore. Forty fyke nets were set from 17-19 January (marking) and 24-28 January (removal) for a total of 240 net nights. Fyke nets were cleared daily and sites were distributed evenly around the lake. Seining was conducted using a purpose built 100-m seine (40-mm mesh size) that was hand-pulled from the western shore of the lake. Baited and unbaited fish traps were used from 24 January until 2 May for a total of 85 net nights. Traps were placed in five locations but were limited to relatively shallow locations (>2 m) due to the wall height of the traps (2 m). All non-native fish were removed from the lake and donated to a fertiliser processor while native fish were released. Traps were set in various formations to determine the most productive configuration including baited and unbaited sets. Pen traps consisted of a 0.1-ha net enclosure with two one-way doors, two automatic feeders distributing chicken layer pellets, and two traps located on the outer corners of the pen.

Fish were marked using left pectoral fin clips (eels, rudd, goldfish and koi carp) or dorsal spine removal (brown bullhead catfish) and released on the western end of the lake (17-19 January 2011). To satisfy the assumptions of a Lincoln-Petersen mark recapture study (closed population) the fish population sampled at Lake Ohinewai was isolated using a temporary barrier in the drain consisting of 30-mm mesh netting. Population estimates were calculated using the Lincoln-Petersen method using the programme Mark-recapture (Jungck 2011). Biomass estimates calculated are for fish >75 mm due to the bias of sampling methods toward larger fish. Due to the length of the recapture operation (>90 days) fin clips became indistinguishable from fin injury due to fin regrowth by the end of the third month of removals. Accordingly, population estimates are based on data collected during the first three months of the removal operation (24 January to 31 March 2011).

Following the removal operation in 2011, a permanent adult pest fish barrier (Figure 2) was installed on the 1400 mm diameter culvert under Tahuna Road to block upstream movement of adult pest fish into Lake Ohinewai. Telemetry tracking of koi carp in the lower Waikato River and riverine lakes has suggested that up to 75% of koi carp will leave lakes at some point in their life history (Daniel et al 2011). The one-way fish barrier is designed to allow fish to leave the lake but not return. The barrier was designed with horizontal bars to allow debris <30 mm to pass through unobstructed and was hinged at the top to allow for easy cleaning in the case of blockage. The bar spacing of the one-way gate (Figure 3) installed in the barrier was based on the fish trap design of Thwaites et al (2010) and included a set of weighted swinging bars at the base of the trap that would allow adult carp and eels to push through the trap when moving downstream but not allow them to return. Although it is possible for juvenile pest fish to enter Lake Ohinewai it was deemed impractical to design a barrier capable of blocking all pest fish movement due to the potential impact on migratory native species. The bar spacing of 30 mm will likely allow native fish to pass through the barrier in both directions with the assumption that large adult eels will only be passing in the downstream direction (out of the lake).

In November 2011 and February 2012, a second mark recapture study was undertaken to assess the status of pest fish populations in the lake following installation of the one-way barrier.

Figure 2. Permanent fish barrier installed on downstream side of road culvert outlet to Lake Ohinewai showing around 60 adult koi carp attempting to pass the barrier.

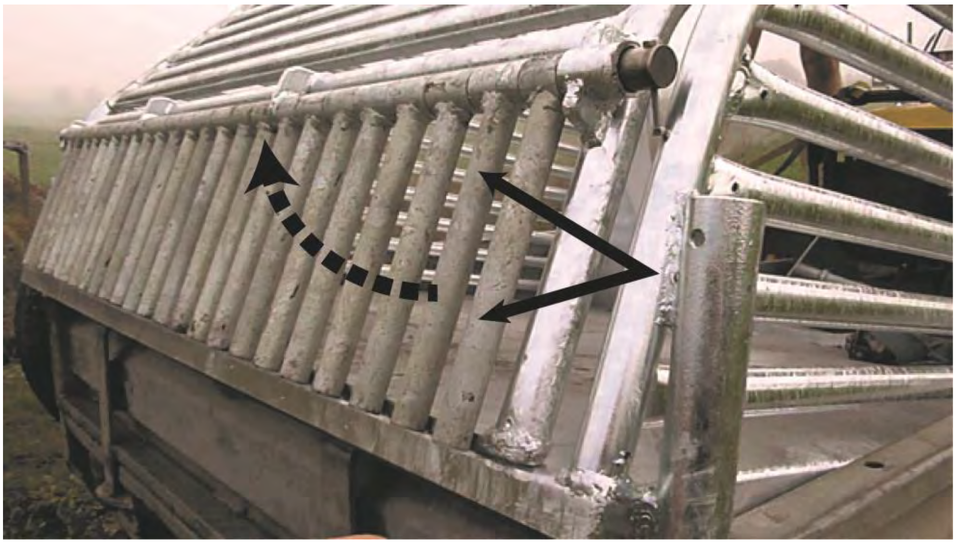

Figure 3. Detail of the permanent fish barrier. The weighted hinged bars (arrowed) swing upwards as indicated to allow adult fish to push through the trap when moving downstream to exit the lake but prevent upstream passage.

Results

The initial mark recapture effort in early 2011 removed 2.74 tonnes of exotic fish comprising koi carp (89.3%), goldfish (7.0%), brown bullhead catfish (3.3%), rudd (0.3%) and carp-goldfish hybrids (0.1%). Initial biomass estimates for these species at the start and end of this period are given in Table 1 along with biomass estimates determined in the fish removal the following summer. More than half of the carp biomass in the lake was removed during the initial fish removal, reducing the estimated biomass to below 100 kg/ha. However, initial estimates of carp biomass in the following summer were around 50 kg/ha indicating significant loss of carp biomass from the lake in the intervening period presumably resulting from downstream movement of carp through the one-way barrier.

Table 1. Mark-recapture estimates of exotic fish biomass (95% confidence limits in parentheses) in Lake Ohinewai prior to and following fish removals. The solid vertical line corresponds to installation of the permanent fish barrier on the lake outlet.

Species	*Estimation of fish biomass (kg/ha)*			
	February 2011	May 2011	November 2011	February 2012
Common carp	242 (185 – 299)	96 (39 – 153)	55 (31 – 85)	47 (18 – 69)
Goldfish	19 (0 -28)	7 (0 – 16)	17 (8 – 27)	16 (7 – 25)
Brown bullhead catfish	14 (12 – 17)	8 (5 – 10)	10 (8 – 12)	8 (6 – 11)

The lake outlet barrier seems to only have reduced the biomass of carp. Adult carp are known to undertake significant migrations between suitable feeding and spawning habitat as adults whereas the biomass of other exotic species in the lake remains unchanged. It is therefore inferred that the reduction in carp biomass occurred as a result of adult carp leaving the lake during winter. Subsequent fish surveys using boat electrofishing reveal some biomass recovery as indicated by relative catch per unit effort (CPUE) but carp biomass has not returned to original levels prior to the mass removal (Figure 4) whereas goldfish biomass has remained fairly constant. The biomass recovery of carp may be due to growth of juveniles.

Following carp removal there were promising signs of improving water quality with an average increase in Secchi depth (Figure 5) and a corresponding decrease in total suspended solids (data not shown).

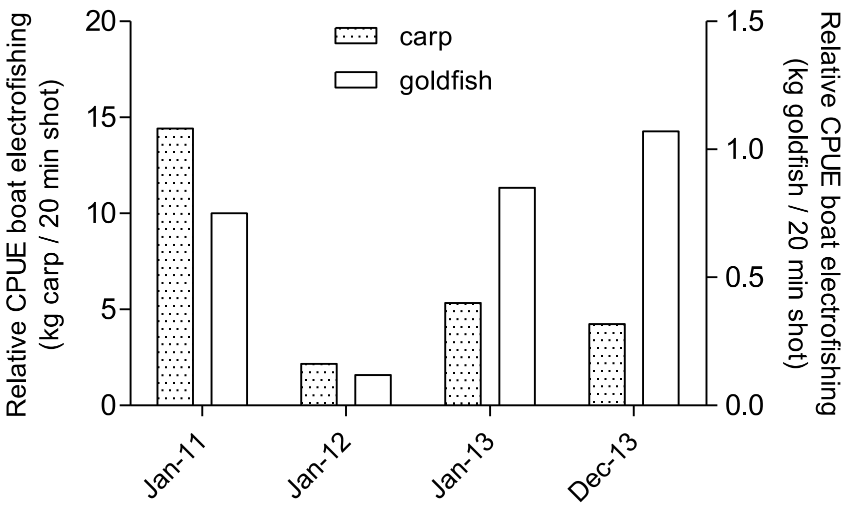

Figure 4. Relative catch per unit effort (CPUE) by boat electrofishing in Lake Ohinewai for common carp and goldfish since the start of the mass removal in January 2011.

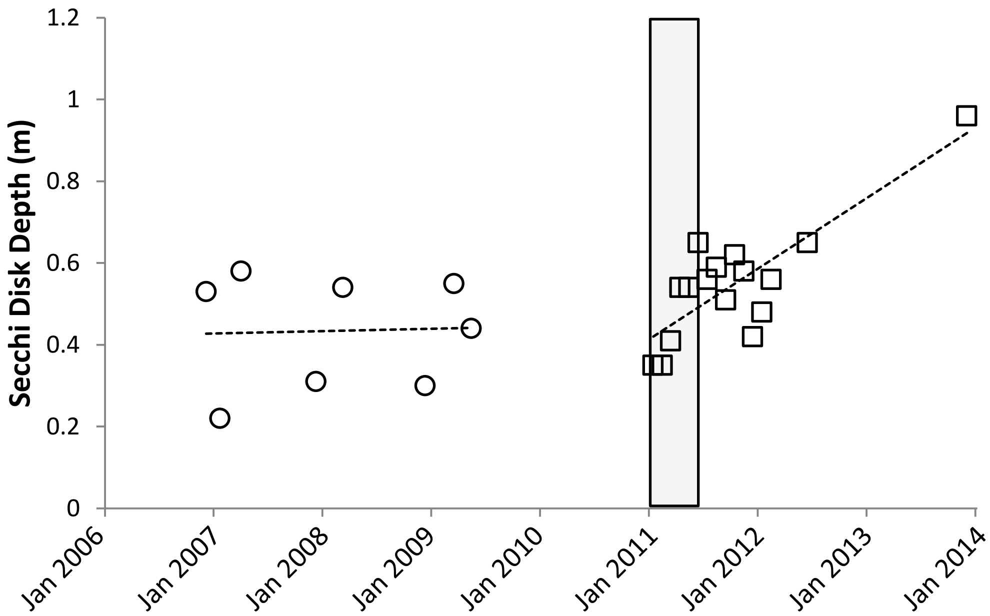

Figure 5. Secchi disk depth (m) in Lake Ohinewai. Open circles – historical data. Open squares – data obtained during and following pest fish removal (vertical bar).

Discussion

The purpose of this study was to reduce carp biomass in a shallow eutrophic lake to examine medium-term impacts on water quality from pest fish removal and to test the effectiveness of a cheap, simple exclusion device for adult carp. It is highly likely that the biomass of carp in this lake contributed to persistently poor water quality and the algal-dominated eutrophic state. Estimates of carp biomass thresholds that cause negative ecological effects vary. The review by Weber and Brown (2009) settled on a threshold of 450 kg/ha. However, many studies have measured ecological impacts at much lower fish biomass. Haas et al (2007) found that carp biomass of 120-130 kg/ha was sufficient to depress macroinvertebrate and plant biomass and Bajer et al (2009) determined that the ecological integrity of a shallow lake was compromised at a carp biomass of ~100 kg/ha.

Eradication of a population of carp from a water body is unlikely to be achieved using active fishing methods without resorting to options such as poisoning, and the costs required to reduce biomass by active fishing rise exponentially as fish biomass declines. In other words, it is much cheaper to fish a population biomass from 400 to 300 kg/h than it is to fish a population from 200 to 100 kg/ha. Cheap and effective devices that reduce fish biomass in passive ways are therefore highly cost effective if they can exploit particular fish behaviours such as migration. In this study, the installation of a simple barrier to allow adult carp to leave but not return to the lake appears to have achieved quite an effective reduction in fish biomass from ~ 100 kg/ha to ~50 kg/ha thereby removing some 850 kg of carp biomass from the lake. The cost of actively fishing the population with a wide range of active fishing methods including 40 fyke nets, multiple other large nets and traps, seining and electrofishing over several months that achieved a reduction in biomass from 250 to ~100 kg/ha was estimated at around 1288 person hours and in excess of $NZ40,000. The installation of the carp exclusion screen that achieved a further 50 kg/ha biomass reduction was therefore highly cost effective at around $NZ5000 and required relatively little maintenance at around 6 visits per year to clear it of debris and ensure that the hinged weighted bars were still moving freely. Such devices may be effective aids to reduce carp biomass if installed at locations which exploit the migratory movement of adult carp.

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How not to mess up a carp telemetry project

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Introduction

Telemetry based technology has been successfully used to study a wide range of common carp (*Cyprinus carpio*) behaviour and ecology including: habitat use (Butler and Wahl 2010), seasonal movements (Daniel et al 2011, Penne and Pierce 2008), detection of aggregations (Diggle et al 2004; Penne and Pierce 2006), survival estimates (Donovan and R. 1995) and identifying exploitable stages in the common carp life history (Daniel 2009). Although simple off the shelf technologies are now available and accessible knowing the limitations of equipment and properly scoping a project are essential for success. Improper planning can lead to costly mistakes and underutilized data.

Planning

Clearly defining objectives, scale, budget and estimating staff time are essential to the success of a telemetry project. Many managers underestimate the scale and time required to conduct a telemetry study resulting in stressed staff and under budgeting. In terms of scale it is wise to assume that the study species will move frequently covering all available habitat and budget resources accordingly. It is far easier to scale back a project than it is to find additional funding to expand the scope of a project. Habitat use is also frequently included in the objectives of behaviour based telemetry studies but it is quite onerous to classify all available habitats to quantify habitat selection in large study areas. Classifying habitat via remote sensing is an option but is difficult in rapidly changing landscapes or where fine scale data are needed.

Underestimating staff time is also a common mistake and needs to be planned in accordance with the temporal resolution necessary and technology implode to achieve the study objectives. For example managers within the Waikato River Basin wanted to know if koi carp were moving to determine if large numbers of fish could be intercepted and harvested. The original attempt to track common carp movement in the Waikato River was done using dart tagging (T-bar anchor tags) and used angler, bow hunter and electrofishing returns requiring a relatively small investment of personnel time (Osborne et al 2009). This resulted in annual returns from local bow hunting competitions and spawning aggregations that occurred in the same location annually and did not detect any movement of fish. University of Waikato staff conducted a second radio telemetry study to monitor the movements of common carp on the Waikato River over a 120 km area using weekly radio tracking and monthly flights (2300 h of staff time over 18 months) and never detected common carp using lateral habitat aside from fish that were tagged in lateral habitat (Daniel et al 2011). Fortunately fixed site acoustic telemetry was also utilized during the study and multiple movements to lateral habitat, likely spawning runs, in easily exploitable areas were documented. In this example it would have been necessary to double staff time to detect the movements missed by weekly sampling and fixed site monitoring was far more cost effective. Similarly if the project had utilized only fixed site acoustic telemetry study, fish would have travelled well beyond their estimated range and equally valuble information would have been missed.

Appropriately estimating the duration of monitoring necessary to properly describe a species behaviour can also be difficult and is often determined by budget rather than good preplanning. Recent long term telemetry studies (Daniel et al 2011, Jones and Stuart 2009) have highlighted drastic shifts in behaviour potentially influenced by habitat availability that have exposed potential pitfalls of short term monitoring. For example the above mentioned study of common carp movement in the Waikato River was conducted over an 18 month period that happened to include record drought and record floods in consecutive summers. During the first summer of drought, fish moved frequently, often utilizing lateral habitat. In contrast the second summer had record high water that provided ample habitat and most study fish moved less than 100 m. Either field season evaluated on its own would have given an incomplete description of the species life history and could have led to misinformation being passed on to managers.

There is no shortage of telemetry equipment providers so choosing a vendor should be based on technology, price and service. If radio telemetry can be utilized and a small sample size will achieve project goals, multiple vendors are available and prices are competitive. Unfortunately when large code sets are necessary or acoustic telemetry is used, vendors have a captive audience. A common pitfall for organisations conducting multiple telemetry studies has been purchasing receivers based on proprietary technology and then becoming dependant on a single vendor for transmitters. The development of the open source Juvenile Salmon Acoustic Telemetry System (JSATS) by the U.S. Army Corps of Engineers Portland District (McMichael et al 2010), will allow researchers the option of purchasing compatible transmitters from multiple vendors allowing for true competition between vendors. Checking with other researchers to evaluate potential vendors is also critical, as many well planned projects have been devastated by faulty or nonfunctional equipment. We have personally experienced transmitters with signal drift, up to 15% failure of transmitters, late shipments, duplicate frequencies and incorrect duty cycles.

Coordinating telemetry projects with other researchers is good practice even in small countries like New Zealand and essential when working in high traffic areas like the Columbia Basin in the USA. Countless hours have been wasted by researchers that have been sold duplicated frequencies by a single vendor resulting in detections of transmitters from another study. As open source equipment becomes more popular it will become vital for researchers to coordinate their frequency use for both radio and acoustic equipment. Networking with other researchers can also be beneficial for acquiring equipment that is not being utilized as telemetry gear is often purchased for one-off studies and then shelved.

Transmitter selection

Transmitter selection can be quite complex and it is beneficial to work out the desired pulse rate, maximum size of transmitter and battery life prior to contacting vendors. Pulse rate can drastically impact the total battery life of transmitters with high pulse rates (>4/second) consuming more battery life than low pulse rates (2/second). Likewise if daytime monitoring is sufficient to meet the study goals then transmitters can be manufactured with a duty cycle that only runs during the day. Transmitter size is largely determined by fish size and although it is good practice to have a transmitter as small as possible it is generally thought that <10% of body weight (Brown et al 1999, Perry et al 2001) is acceptable for studies where survival estimates are not an objective. If size is not an issue then choosing a transmitter with a fast pulse rate and long battery life are very beneficial.

Regardless of the battery size storage is an important consideration as some transmitter batteries can lose 2% of the total battery life each month if stored at high temperatures (>15 °C). Consequently using old transmitters or implanting used transmitters can result in high failure rates and is arguably not worth the effort in most cases. As a general rule it is best to use all of the transmitters purchased as soon as possible after delivery and store any unused transmitters in the refrigerator.

Data processing and display

One of the most overlooked aspects of telemetry research is the complexity and volume of the data collected with fixed site monitoring stations. Unfortunately some highly technical and expensive telemetry studies have been unusable to managers due to the difficulty of displaying the results in a manner that is comprehendible to resource managers. Although the commercially available software are prohibitively expensive, data display products like Eonfusion (Myriax, Hobart, Australia) are essential for the presentation of highly complex 3D data or the comprehension of data taken over varied temporal scales. Using a fake raw data set to test your filtering, display and analysis of telemetry data is highly recommended. Displaying the movements of terrestrial or marine species using GIS software like the Animal Movement extension to ArcView (Hooge and Eichenlaub 1997) is quite straight forward but animals confined to rivers can be quite challenging and are better suited to programs like Network Analyst (ArcMap 9.2, ESRI, Redlands, CA, USA) that confine potential movements to a network (river) rather than automating movements along the shortest distance between the two consecutive detections (Daniel et al 2009). If your organisation requires high frequency data to achieve your project goals but lacks technical expertise to manage data, hiring a contractor can be a good investment.

Fish capture and tagging

Although fish capture is relatively straight forward, using a sterile environment and being aware of potential complications like electrofishing injury will save time and money. From personal observation, about 10% of carp are injured by burns or spinal fracture during collection via boat electrofishing and abrasion related injuries that can lead to fungal infection can also occur from collection via trapping. Simply looking over a fish and rejecting those with burns or injury can save time and money. Practising surgery to ensure that surgeons are skilled will also prevent unnecessary transmitter loss and is a good investment in time. The recovery time and release location of implanted fish are important to consider if fish are in danger of predation but in general large common carp are robust and will return to their place of capture within hours if released within a couple of kilometres of the capture location.

Figure 1. Surgically implanting a transmitter in carp.

Tracking equipment

One of the most common problems when collecting telemetry data is the failure to detect non-functional gear resulting in lost data and wasted time. Regardless of whether you are downloading fixed sites or preparing for a day of tracking using a test tag, checking your gear will save you some major headaches and only takes 30 seconds.

Figure 2. Boat with tracking equipment

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Questions

Q: Are juvenile carp migrating back into the system?

Adam: We don't know. We are going to check that when we go back this year and see whether we have a large number of small fish back in there. They could be recruiting within the lake or they could be coming back up. There is some evidence from other lakes in the system that you do occasionally get large migratory fluxes of juveniles coming back into the system. It is difficult to get that balance right to allow natives in and not allow other species to get in. We had planned to temporarily block the screens with fine mesh if we did see migrations just for a short period and to allow native fish to move in but we did not see movements.

Q: I was interested that your 'koi' have remained 'koi', maintaining their bright colour. Obviously there is no selection pressure to go back to more of a 'carp' type colour which normally happens?

Adam: It may be that we just don't have the significant large predators in the system that may be picking off those coloured fish and actually driving selection for the 'normal' coloured fish. This is standard for almost all the fish we get except for about 1% of fish which are carp/goldfish hybrids and these show the typical goldfish olive colouration, they don't show the koi colouration at all.

Q: In relation to your trapping do you have any air breathing aquatic animals that you have to eliminate from your by-catch at all?

Adam: No, no turtles, no water monitors.

Using otolith chemistry to identify carp recruitment hotspots in rivers

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Introduction

Determining the relative importance of recruitment 'hotspots' (i.e. key spawning and nursery areas) for alien fishes such as common carp (*Cyprinus carpio*) is critical to the development of effective control strategies, as it allows interventions to be specifically targeted towards locations that make disproportionately high contributions to reproductive output (Crook et al 2013). Here, we describe an approach to identifying carp recruitment hotspots that has been implemented and evaluated in the Murray and Lachlan river systems in the southern Murray-Darling Basin (Crook and Gillanders 2006, Crook et al 2013, Macdonald and Crook 2013).

Otolith chemical signatures

Otoliths are paired calcified structures located in the inner ear of bony fishes that play an important role in balance and hearing. Otoliths grow continuously throughout the life of a fish and are composed of a calcium carbonate matrix that is not re-metabolised once deposited (Campana 1999). The chemical composition of otoliths reflects the chemistry, temperature and salinity of the water in which a fish has resided at different stages of life (Elsdon and Gillanders 2002). If these parameters differ sufficiently among recruitment hotspots, then the portion of the otolith accreted during the larval phase (near the otolith core) will record the unique chemical signature of each hotspot.

The chemistry of otoliths can be measured in a number of ways, but the most common method for this application is laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). This technique uses a tiny laser beam (<0.1 mm diameter) to blast material from specific parts of the otolith, such as the otolith core. The "ablated" material is then transferred to a mass spectrometer which measures the abundance of various trace elements, which can then be used to characterise the chemical signatures of fish nurseries.

Estimating recruitment sources of young-of-year carp

The approach used in the Murray and Lachlan river studies consists of a two stage process. First, intensive field sampling of larval carp (Fig. 1) was carried out in the study region during the breeding season to characterise the multi-elemental otolith chemistry signatures of potential recruitment sources, including main channel habitats and off-channel wetlands. We sampled during the breeding season in November using a fine mesh seine net. These samples were analysed for a range of trace elements using LA-ICPMS (Fig. 2) to determine whether there were sufficient differences between putative recruitment hotspots to allow for accurate discrimination.

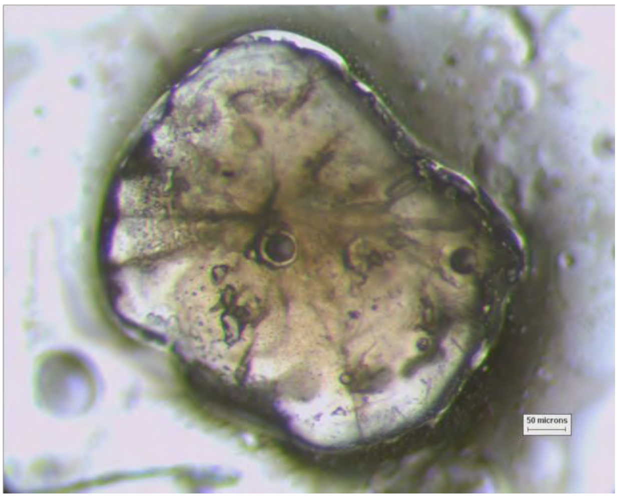

Figure 1. Post-larval carp collected for characterisation of otolith chemical signatures of recruitment hotspots.

Figure 2. Lapillus otolith of a young-of-year carp showing laser ablation sampling locations in the core and edge.

Once it was established that potential recruitment sources could be well discriminated based on otolith chemical signatures, the second stage of the process was to sample young-of-year carp from the same cohort as the post-larval carp. These fish were collected in the following year from the main river channel when the fish were 3-11 months of age. We analysed the core region of the otolith of young-of-year fish to characterise the growth region representing the larval phase, and used maximum likelihood analyses to classify each fish to one of the previously sampled recruitment hotspots (Table 1).

The Lachlan River study also utilised strontium isotope ratios ($^{87}Sr/^{86}Sr$) as a marker to identify the likely sources of young-of-year carp (see Crook et al 2013). Unlike the trace elements described above, physiological regulation does not affect Sr isotope ratios in otoliths, and it is therefore possible to directly match otolith and water $^{87}Sr/^{86}Sr$ (Amakawa et al 2012, Hughes et al 2014). Thus, we were able to sample water $^{87}Sr/^{86}Sr$ across the Lachlan catchment and directly match otolith and water $^{87}Sr/^{86}Sr$ to determine the likely sources of young-of-year carp.

Table 1. Results of maximum likelihood analysis used to estimate the nursery zone of YOY *C. carpio* collected from sites in the Murray River at Torrumbarry Weir and the Goulburn River at Yambuna based on otolith core chemistry of the corresponding post-larval cohort. Data are actual and estimated % compositions for 1000 simulations (with re-sampling) of natural log transformed data for post-larvae collected in November of (a) 2005, (b) 2006, (c) 2007 and (d) 2008, and the estimated % composition of the YOY sampled at Torrumbarry Weir and Yambuna each year that are sourced from each nursery zone. Source: Macdonald and Crook 2013).

		Post-larvae		YOY
Cohort	Nursery zone	Actual (%)	Estimated (%)	Estimated (%)
				Torrumbarry Weir (*n* = 60)
	Barmah	45.1	46.3	80.8
	Murray River	7.6	7.5	0.0
	Broken Creek	13.1	15.5	0.0
	Campaspe River	14.7	14.6	0.0
	Lower Goulburn River	14.1	11.1	19.2
	Shepparton	5.4	5.0	0.0
(a) 2005/06				Yambuna (*n* = 42)
	Barmah	45.1	46.3	77.6
	Murray River	7.6	7.5	3.0
	Broken Creek	13.1	15.5	5.0
	Campaspe River	14.7	14.6	0.0
	Lower Goulburn River	14.1	11.1	14.4
	Shepparton	5.4	5.0	0.0
				Torrumbarry Weir (*n* = 3)
	Barmah	25.1	24.3	0.0
	Upper Murray River	11.0	11.0	0.0
	Mid Murray River	12.3	8.4	0.0
(b) 2006/07	Torrumbarry Weir	5.8	3.9	33.1
	Broken Creek	21.3	26.8	0.0
	Goulburn River	11.6	12.7	66.9
	Campaspe River	12.9	12.7	0.0
				Torrumbarry Weir (*n* = 6)
	Barmah	18.0	20.4	30.1
	Moira	49.6	51.5	36.9
(c) 2007/08	Upper Murray	10.1	8.6	15.6
	Mid-Murray/Broken Creek	5.8	5.8	0.0
	Goulburn River	4.3	4.4	17.5
	Campaspe River	12.2	9.3	0.0

Cohort	Nursery zone	Post-larvae		YOY
		Actual (%)	Estimated (%)	Estimated (%)
				Yambuna (*n* = 19)
(d) 2008/09	Barmah/Moira/Upper Murray	46.6	43.3	27.1
	Mid-Murray/Lower Broken Creek	31.5	34.1	27.5
	Upper Broken Creek	15.7	15.8	45.4
	Campaspe River	6.2	6.8	0.0

n, number of YOY *C. carpio* sampled in March, April or May in 2006, 2007, 2008 and 2009.

Conclusions

The studies undertaken in the Murray and Lachlan rivers (Crook and Gillanders 2006, Crook et al 2013, Macdonald and Crook 2013) provide a “proof-of-concept” for using otolith chemistry analysis as a standard monitoring tool to determine the relative importance of carp recruitment hotspots over time and under different environmental conditions (e.g. under managed flow regimes; Macdonald and Crook 2013). However, there are several issues that future studies should consider in the design, implementation and interpretation of data.

Firstly, it is essential that hotspots can be accurately discriminated based on otolith chemical signatures. As variation in otolith chemical signatures is largely driven by regional-scale factors that affect water chemistry (underlying geology, salinity), this requirement will often limit the spatial resolution at which conclusions can be reached. It is also essential that early stage larvae or post-larvae are used to characterise potential recruitment sources in order to ensure that dispersal away from the larval source has not occurred prior to sampling.

Secondly, the otolith and/or water chemistry signatures used to discriminate hotspots must either remain stable over time or should be repeatedly sampled to allow temporal variation to be accounted for. Several studies, including ours, have reported significant inter-annual variation in otolith and water chemistry, thus necessitating annual sampling of recruitment sources (eg Feyrer et al 2007, Walther and Thorrold 2009, Crook et al 2013, Macdonald and Crook 2013).

Finally, it is important that all potential sources have been characterised, as many statistical techniques (maximum likelihood, discriminant function analysis) will assign an individual to the source whose signature it most closely resembles, even if there is not a good match. Whilst recent studies have described techniques to deal with this issue (e.g. Standish et al 2011), it remains critical to ensure that sampling of potential recruitment sources is as exhaustive as possible in order to accurately characterise the relative importance of different regions to carp recruitment. Our experience in the Lachlan River demonstrated that catchment-wide analysis of water $^{87}Sr/^{86}Sr$ to allow matching with otolith core $^{87}Sr/^{86}Sr$ provides an important adjunct to trace element signatures that can assist in identifying whether un-sampled recruitment sources are present (see Crook et al 2013).

In conclusion, whilst caution needs to be exercised in the design and interpretation of otolith chemistry studies, our experiences on the Murray and Lachlan rivers suggest that otolith chemistry analysis holds much promise as a practical method for identifying the sources of invasive fishes in rivers.

Acknowledgements

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Questions

Q: Your categorisation that you had for your otolith matching. Did that allow for the possibility that some of those young-of-the-year fish were actually from spawning sites other than from the three you had in your categorisation?

David: We used the strontium isotope ratios to exclude any fish that could not have come from there based on the strontium value and then ran the maximum likelihood analysis. We also did a fair bit of work attempting to find young-of-year from other spots around there and just couldn't identify any other catchments.

Q: you showed large year to year variability in the strontium isotope ratios for a couple of different sites. Given that strontium isotope ratios are meant to be geologically driven, to what would you attribute the variation in isotope ratios and how much would other sources of variability in isotope ratios be likely to be a factor affecting your interpretation?

David: It is perhaps one of the main findings of this. Most of the work in North America has found very stable isotope ratios but they have mainly worked on salmonids in headwater streams with fairly uniform rainfalls. We are talking about the bottom end of a system that has lots of upstream sub-catchments and you may get rainfall events that make one input relatively more important and I think that is contributing to it, not to mention water management regimes leading to a lot more variation in strontium signatures than previous studies have found. Where we were lucky in some ways is that we had a tight grouping of hotspots in the bottom end of the catchment that didn't vary much. That gave us an ability to look at large scale variation across the catchment.

Overview of the Invasive Animals Cooperative Research Centre Freshwater Program pest fish research extension activities

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Summary

The Freshwater Products and Strategies Program within the Invasive Animals Cooperative Research Centre has been responsible for a portfolio of projects on freshwater pest fish over the past seven years. Projects included product development, field demonstration, and national and offshore collaborative research on carp and tilapia. The research program was designed to incorporate all areas of an integrated pest fish program:

- prevention and detection
- control options/techniques
- target species information
- support framework
- education/community engagement.

Research projects within all of these categories were initiated on both carp and tilapia in various parts of Australia and internationally.

The Invasive Animals Cooperative Research Centre (Phase one) concluded at 30 June 2012 and in the final six months primarily concentrated on concluding research projects and reporting and extending the results. The processes for extension of the Freshwater Products and Strategies Program included:

- the PestSmart RoadShow (National extension activities to directly demonstrate the use and benefits of new products to land managers and farmers, January to June, 2012)
- Pest Fish Management Forums for both tilapia and carp (May and June, 2012)
- pest fish toolkit initiatives (focusing on carp and tilapia).

The PestSmart toolkits

The PestSmart toolkits projects aimed to develop a web-based information package of factsheets and case-studies (in addition to reports and scientific journal manuscripts) on best-practice pest animal management. These were designed to guide and inform next users and assist them to utilise the research findings of the Invasive Animals Cooperative Research Centre work. The toolkits aimed to distil the seven-year research program findings to provide a legacy of innovations through an easy to use tiered approach. The 'toolkit' of information is accessed through the IA CRC PestSmart Toolkit website: **www.feral.org.au/pestsmart/**

The information available can be accessed in different ways, for example, by pest species, by information type (eg factsheet or report), or by relevance to different categories of user (eg land managers, community groups or students)

As new material has been added to the website, updates have been broadcast in 'Feral Flyer', the email news broadcast of the Invasive Animals Cooperative Research Centre (subscribe online at www.invasiveanimals.com), also via the PestSmart facebook page at facebook.com/Pestsmart, Twitter @PestSmartCRC twitter.com/PestSmartCRC and via the PestSmart youtube channel: youtube.com/PestSmart

Carp toolkit materials

The carp toolkit consists of general pest fish management factsheets and a pest fish incursion decision support tool, specific *Cyprinus carpio* information factsheets eg impacts of carp, the biology of carp and the distribution of carp. Management information is provided in the form of pest fish control case studies and research reports and journal articles.

Success

It is hoped that the toolkit will be accessed by individuals, fisheries managers, natural resource and catchment management officers, policy makers, funders, scientists. The toolkit has the potential to increases the awareness of the pest fish (tilapia and carp) problem in Australia and options for control and management. It is anticipated that fisheries managers, natural resource and catchment management officers, policy makers, funders and scientists will use the information from the Invasive Animals Cooperative Research Centre work, accessed via the toolkit, to change operations, policy and investment.

Acknowledgements

The PestSmart toolkit writing team is acknowledged, as are the contributions of the Invasive Animals Cooperative Research Centre editorial and communications team.

Questions

Q: I think that is a very good product. Do you think there is still a need to explain to the general public, and not just recreational anglers, that they are an important stakeholder group and why we are tackling invasive species such as carp and what the detrimental impacts are to both recreational fisheries and the environment or do you think that job is already done and people accept that we just need to tackle them and this is how we are doing it?

Kylie: In the current climate funding is going to be a key, so the more people that are behind the message the better. So I do believe that we need to get the message out and not just ride on general feeling, so I don't think we can rest on what we have done we still need to work on that.

Comment: One of the frustrations I have seen is that generally speaking the community is aware of the problems posed by carp. Their frustration comes in knowing who is responsible for directing the management of carp.

Carp outreach, engagement and extension: Past, present and future

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Introduction

Since the mid-1990s, communities across the Murray–Darling Basin have demonstrated a keen interest in being actively involved in better managing (and even eradicating) exotic fish, including carp, while also wanting to improve native fish populations and habitats.

Engagement activities

Engagement and education activities on carp and exotic fish have been undertaken by a range of organisations, including the Pest Animal Control Cooperative Research Centre, the Invasive Animals Cooperative Research Centre, the Murray–Darling Basin Authority and the National Carp and Pest Fish Taskforce. Activities include:

- community workshops and information sessions
- carp fishing competitions
- community information sessions
- media interviews
- publications — including facts sheets, posters and brochures
- electronic and hard-copy newsletters
- articles in magazines and journals
- engagement with Indigenous communities
- information sessions during natural resource management (NRM) tours and excursions for local, national and international participants
- workshops with teachers and students
- preparation of teaching materials — including the newly developed pest tales website
- presentations to local government
- development of videos and DVDs
- activities as part of communicating the Native Fish Strategy
- forums and conferences
- PestSmart Roadshow.

PestSmart Roadshow

The PestSmart Roadshow was a significant engagement activity in 2012. At 20 venues across Australia, scientists, researchers and program managers met with communities to explain progress with carp and other feral animal research, engaged with communities at the local level, and allowed communities to give direct feedback in a relaxed and informative atmosphere. It has also shown the importance that when we engage communities, we have to also explain big-picture issues — that is, managing exotic fish populations don't occur in isolation from other natural resource management programs including rehabilitating native fish numbers and habitats. Upstream communities also need to understand the impact of their activities downstream, while downstream communities need to understand the limitations and attitudes of upstream community activities.

Consistent messages

All engagement activities about carp have been done to:

- ensure consistency of messages
- ensure community expectations are not raised unrealistically about any likely management technologies, such as daughterless carp
- use scientists, managers and researchers where possible
- ensure messages are consistent with a range of commonwealth, state, local government and research policies and strategies.

Why engage communities about carp?

Regardless of how good the science is, how well the technology is tested and how thorough the awareness strategies are, history tells us that if the community has different attitudes to pest animals, does not feel engaged or involved in the management of these any pest animals, it will be difficult to implement control measures. So we need to engage communities about carp and alien fish and what have we learnt because:

- The health of fish and their habitats are increasingly seen by the Murray–Darling Basin community as a key indicator of river health and the success of waterway management and the Basin Plan — carp are seen as undesirable in this process.
- A fundamental principal of the Native Fish Strategy, which provided significant funding for the Invasive Animals Cooperative Research Centre's carp program, is that if Murray–Darling Basin communities are not involved and engaged, then the strategy will not succeed.
- Fish provide a key link between people and their waterways. Communities have a stake in their local rivers, whether they draw water for their homes, irrigation, industry or the environment.
- River communities have close connections to fish — this was well-demonstrated last year in the Basin-wide Talking Fish project.
- Communities in the Murray–Darling Basin will have to live with the research outcomes for native fish long after scientists, researchers and managers have retired or moved on.
- Community participation can provide leverage for funds and other resources.
- Fish are relatively easy natural resource management (NRM) issues for communities to relate to. Discussing fish has proven to be a useful tool to 'hook' communities into broader NRM issues, and has engendered a greater understanding of river health issues and needs.
- History shows clearly that people who live along the Murray–Darling Basin's waterways have important skills, knowledge, interest and expertise about carp. Some of this skill, knowledge and expertise may not be in formats or styles or even language that some of us are familiar or even comfortable with but nevertheless it is there, is valuable and should be identified and used.

- Fish have great cultural significance and value for Aboriginal people, continue to be a value food source, and play a role in customs and ceremonies. Healthy rivers, healthy fish populations and fewer carp are also critical in addressing Aboriginal health and social issues.
- School teachers have indicated that anything to do with fish is an important way for students to learn about NRM issues because a third to a half of all students that have been engaged on carp go fishing and can easily relate to fish.

It has been interesting to observe how people have been able to understand complex issues such as herpes viruses, daughterless carp, carp traps, pheromones, etc.

Are carp the real problem?

Engaging the community has also been important in helping the community to identify whether carp are responsible for all the problems of degraded waterways and declining aquatic habitats. Workshops undertaken in the past ten years have been important to engage with and work through local issues that often found that it was not carp that were the problem, but poor river or stream management.

Attitudes to carp

Much of our current attitudes to carp and exotic fish have been determined very much by our predominantly European heritage, although this may be changing with attitudes from other cultures and countries. However, it is unclear if we understand very much about the attitude of more recent immigrants to fish and fishing in the Murray–Darling Basin. The Murray–Darling Basin community is generally unaware of the other exotic fish in the Murray–Darling Basin or the threats they pose.

All groups involved promoting and engaging on carp issues have been good at raising awareness, developing control strategies and engaging communities on carp issues. However, there is a need to research attitudes that can play a key role in managing or eliminating these problem fish. The Pest Animal Control Cooperative Research Centre made an attempt in 2005 to quantify community attitudes to using gene technology to manage carp. In 2009, an attitude study in the Lachlan River catchment showed that the community see carp as responsible in some way for a decline in river health. The report called for:

- greater communication from researchers and managers to help communities better understand carp control methods
- research to determine what community members might be willing to invest in a carp control program
- communication to ensure that managers have an understanding of the community’s expectations.

This study is a positive step for carp management not only in the Lachlan River catchment but for management at a national level. The survey suggests that the community will support carp management programs but will have certain expectations about what the outcomes should be for improving river conditions.

From a number of student workshops conducted over the past ten years, many young people are not aware that carp are an introduced species and incorrectly identify carp as a native fish, while new generations have never experienced our rivers free of carp.

'The community'

It is my view that understanding community attitudes to carp will be increasingly important to ensure that new and emerging control technologies are acceptable to Murray–Darling Basin communities. Also, it is not only community attitudes on carp that need to be addressed. Many groups involved in communicating native fish issues sometimes think that 'the community' is everyone 'out there', away from Melbourne, Canberra, and other capital and regional cities. I take the view that 'the community' is inclusive — and includes everyone with an interest in carp. Therefore, 'the community' includes state and commonwealth agencies, other staff within the Invasive Animals Cooperative Research Centre, politicians, researchers, natural resource and catchment management groups, and community groups. It also includes people who live within and outside the Murray–Darling Basin.

The challenges ahead

- We have to continue to acknowledge and explain that it is still people who spread exotic fish, sometimes accidentally, sometimes out of ignorance or fear, sometimes deliberately.
- We must improve our engagement with Indigenous communities and acknowledge that they will have differing and varying attitudes. Aboriginal communities see the huge numbers of carp as denying them the opportunity and right to catch native fish to supplement their diet, an activity that is firmly embedded in their culture. It also needs to be stressed that when Aboriginal communities participate in controlling exotic fish, they need to be involved as mainstream partners, not singular or separate identities.
- It would be helpful if agencies across Murray–Darling Basin states and the Australian Capital Territory could develop consistent policies and approaches to carp to avoid community confusion, especially along state borders.
- We need to find opportunities for communities to be involved in implementing the research results of carp research.
- Communities need to understand that carp and other exotic fish cannot be managed in isolation from rehabilitating native fish populations and habitats. An integrated approach is required which will also contribute to the success of the Native Fish Strategy.
- Referring to some exotic fish as 'pests' can be a problem in itself as it may focus attention on just getting rid of the fish and not addressing the key issues of degraded habitats and changes to river environments that encouraged the exotic fish in the first place.
- Community members want to participate at various levels and capacities.

Communication

There are a number of terms that get 'flung around' on this topic — education, outreach, awareness, communication, participation, extension and engagement. They can all mean slightly different things. There can be lots of community awareness but poor community engagement. Great community education strategies can be developed, but if there are no people to carry it out, then they are worthless. Good information does not assume good community engagement, and lots of media releases does not mean good communication!

Conclusions

Engaging the community has been, and will continue to be, an important component of managing carp and other exotic fish. These activities not only ensure the spread of ownership of the problem and developing partnerships in management programs, but are also harnessing community skills, knowledge and attitudes.

Future Work

A very brief open forum at the conclusion of formal presentations invited comment and discussion on future directions for carp research and management. The question was posed: "Where do you think there are gaps in present work and what areas should we take further or concentrate on?"

Several areas were suggested for further work;

- Embrace long-term studies for example in relation to the breeding hotspots work.
- Environmental water and environmental flows and how this can be used to advantage natives and disadvantage carp.
- Need to continue the work on daughterless carp
- More work on impacts of carp particularly in relation to defining densities at which carp are detrimental
- Defining objectives of management eg water quality or macrophyte protection
- Need to target area based funding for control of pests for 3-5 years. Need efficient use of the funding that is available.

By far the majority of discussion related to various aspects of community involvement and engagement. While not strictly research focussed, it was readily apparent that many persons thought that this was an important area to address.

Issues raised included;

How to go about community involvement

What can they do?

Who to involve

- Indigenous engagement and benefits
- Non-english speaking engagement
- Coarse fishers
- Involvement of community champions
- Involvement of local government and other authorities
- Engagement of community organisations
- Involvement of school children an ideal time

It was felt that we often lacked the ability to monitor remote locations such as traps. This presented an opportunity to involve lay people, particularly those on the land who would like to be involved perhaps through Landcare etc. Issues to consider in this eg compliance and safety issues

Need to be conscious of the difference between engagement and talking

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