RESEARCH **18**

2017-104

WHAT ARE THE CARP VIRUS BIOCONTROL RISKS AND HOW CAN THEY BE MANAGED?

NATIONAL CARP CONTROL PLAN

The likely medium- to long-term ecological outcomes of major carp population reductions

This suite of documents contains those listed below.

NCCP TECHNICAL PAPERS

1. Carp biocontrol background
2. Epidemiology and release strategies
3. Carp biocontrol and water quality
4. Carp virus species specificity
5. Potential socio-economic impacts of carp biocontrol
6. NCCP implementation
7. NCCP engagement report
8. NCCP Murray and Murrumbidgee case study
9. NCCP Lachlan case study

NCCP RESEARCH (peer reviewed)

Will carp virus biocontrol be effective?

1. 2016-153: Preparing for Cyprinid herpesvirus 3: A carp biomass estimate for eastern Australia
2. 2018-120: Population dynamics and carp biomass estimates for Australia
3. 2017-148: Exploring genetic biocontrol options that could work synergistically with the carp virus
4. 2016-170: Development of hydrological, ecological and epidemiological modelling
5. 2017-135: Essential studies on Cyprinid herpesvirus 3 (CyHV-3) prior to release of the virus in Australian waters
6. 2020-104: Evaluating the role of direct fish-to-fish contact on horizontal transmission of koi herpesvirus
7. 2019-163 Understanding the genetics and genomics of carp strains and susceptibility to CyHV-3
8. 2017-094: Review of carp control via commercial exploitation

What are the carp virus biocontrol risks and how can they be managed?

9. 2017-055 and 2017-056: Water-quality risk assessment of carp biocontrol for Australian waterways
10. 2016-183: Cyprinid herpesvirus 3 and its relevance to humans
11. 2017-127: Defining best practice for viral susceptibility testing of non-target species to Cyprinid herpesvirus 3
12. 2019-176: Determination of the susceptibility of Silver Perch, Murray Cod and Rainbow Trout to infection with CyHV-3
13. 2016-152 and 2018-189: The socio-economic impact assessment and stakeholder engagement
    Appendix 1: Getting the National Carp Control Plan right: Ensuring the plan addresses community and stakeholder needs, interests and concerns
    Appendix 2: Findings of community attitude surveys
    Appendix 3: Socio-economic impact assessment — commercial carp fishers
    Appendix 4: Socio-economic impact assessment — tourism sector
    Appendix 5: Stakeholder interviews
    Appendix 6: Socio-economic impact assessment — native fish breeders and growers
    Appendix 7: Socio-economic impact assessment — recreational fishing sector
    Appendix 8: Socio-economic impact assessment — koi hobbyists and businesses
    Appendix 9: Engaging with the NCCP: Summary of a stakeholder workshop
14. 2017-237: Risks, costs and water industry response
15. 2017-054: Social, economic and ecological risk assessment for use of Cyprinid herpesvirus 3 (CyHV-3) for carp biocontrol in Australia
    Volume 1: Review of the literature, outbreak scenarios, exposure pathways and case studies
    Volume 2: Assessment of risks to Matters of National Environmental Significance
    Volume 3: Assessment of social risks
16. 2016-158: Development of strategies to optimise release and clean-up strategies
17. 2016-180: Assessment of options for utilisation of virus-infected carp
18. 2017-104: The likely medium- to long-term ecological outcomes of major carp population reductions
19. 2016-132: Expected benefits and costs associated with carp control in the Murray-Darling Basin

NCCP PLANNING INVESTIGATIONS

1. 2018-112: Carp questionnaire survey and community mapping tool
2. 2018-190: Biosecurity strategy for the koi (*Cyprinus carpio*) industry
3. 2017-222: Engineering options for the NCCP
4. NCCP Lachlan case study (in house) (refer to Technical Paper 9)
5. 2018-209: Various NCCP operations case studies for the Murray and Murrumbidgee river systems (refer to Technical Paper 8)

DRAFT

NCCP: The Likely Medium- to Long-Term Ecological Outcomes of Major Carp Population Reductions

Final Report

Nichols S.J., Gawne B., Richards R., Lintermans M. and Thompson R.

August 2019

FRDC Project No **2017-104**

NCCP: THE LIKELY MEDIUM- TO LONG-TERM ECOLOGICAL OUTCOMES OF MAJOR CARP POPULATION REDUCTIONS
2017-104

2019

This publication (and any information sourced from it) should be attributed to Nichols S.J., Gawne B., Richards R., Lintermans M., and Thompson R. (2019). NCCP: The likely medium- to long-term ecological outcomes of major carp population reductions. Final Report. Prepared by the Institute for Applied Ecology, University of Canberra for Fisheries Research and Development Corporation, ACT.

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Researcher Contact Details

Name: Dr Susan Nichols
Address: Institute for Applied Ecology, University of Canberra
Phone: 02 6201 5408
Fax:
Email: sue.nichols@canberra.edu.au

FRDC Contact Details

Address: 25 Geils Court
Deakin ACT 2600
Phone: 02 6285 0400
Fax: 02 6285 0499
Email: frdc@frdc.com.au
Web: www.frdc.com.au

Contents

Tables

Figures

Acknowledgments

We acknowledge the assistance of Dr Jacki Schirmer and Brigitta Yabsley for their assistance with developing the survey.

Executive Summary

What the report is about

The National Carp Control Plan (NCCP), operating within the Fisheries Research and Development Corporation (FRDC), is developing a plan for smart, safe, effective and integrated measures to control invasive common carp (*Cyprinus carpio*: hereafter, 'carp') in Australian freshwater environments, including the potential release of the virus known as Cyprinid herpesvirus 3 (CyHV-3) virus (hereafter referred to as the 'carp virus'). The NCCP has commissioned a program of scientific, social, and economic research that will develop the knowledge required to enable an informed decision on whether virus release should proceed. Part of the scientific program requires an exploration of the medium- to long-term ecological effects likely to result from major carp population reductions.

This work undertaken by University of Canberra researchers, collected and analysed expert views and scientific literature to better understand the likely medium- to long-term (5-10 year) ecological responses to reduced carp populations. Experts from a wide range of disciplines were invited to participate in an online survey and workshops to predict how different levels of carp reduction would affect a variety of ecosystems (i.e. different types of lakes, rivers, wetlands) and ecosystem attributes such as native fish, water plants, macroinvertebrates (molluscs, water bugs, yabbies, shrimp), waterbirds, amphibians, algae, zooplankton and water quality. The methods used provided an assessment of the evidence underpinning the predictions of ecosystem response and the confidence of those predictions, and identified knowledge gaps. The outputs of this project informed NCCP by informing surveys of community and stakeholder attitudes to carp biocontrol, and informing the choice modelling component of the NCCP cost-benefit analysis.

Background

Release of the virus should be predicated on a sound understanding of the likely ecological effects of reductions in carp numbers both in terms of immediate effects and longer-term ecological responses. The focus of this project is on predicting the ecological effects resulting from carp population declines that may result from population control measures over 5-10 year (medium term) and > 10 year (long term) timescales. The essential needs this project addresses are a conceptualization of the role of carp across ecosystems to understand and predict likely ecological responses to carp control. Both expert elicitation and the published scientific literature were used because it was unlikely that enough location-specific and long-term information (i.e. site and species specific, long-term ecological field studies) were available on which to base conclusions. Recognizing and quantifying uncertainty around predictions was a critical component of providing advice on expected ecosystem effects and in communication to managers and the general public.

Aims/objectives

The project objectives were to develop a conceptual framework and identify ecosystem attributes expected to change in response to carp control; define attribute metrics and quantify attribute independence; assess the confidence of the scientific evidence underpinning the predicted outcomes, and; provide outputs that are clearly communicable to the public and other components of the NCCP.

Methods

The ecological predictions were informed by expert elicitation (undertaken using the 'Delphi' approach) and the published scientific literature. The online survey elicited expert opinion to develop a suite of conceptual models to help understand the causal pathways to ecological effects of carp and to predict the potential medium- to long-term ecological effects of reductions to carp populations. We invited 103 experts to participate in the survey. They were asked to forward the invitation to other experts they thought may be interested in participating. The results were collated, and then shared with the broader group during two face-to-face workshops. The responses were then aggregated with retention of the range of responses to represent the uncertainty and we graded expert's confidence in prediction.

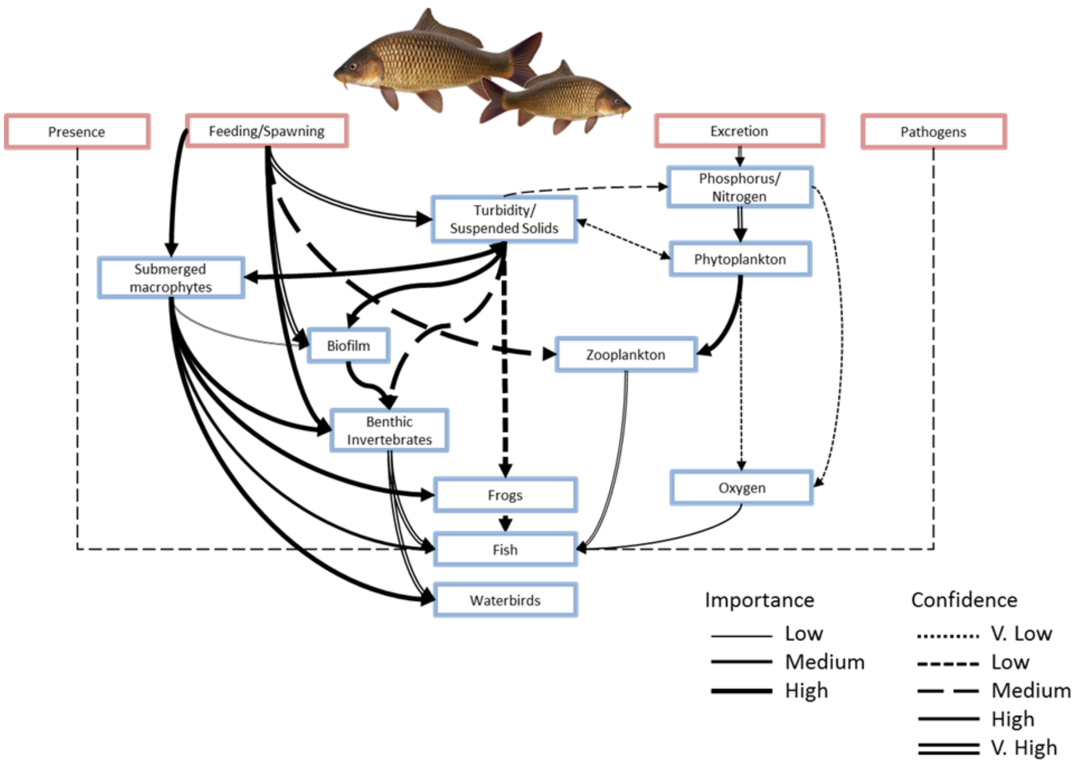
Survey questions asked participants about the evidence for the specific effects of carp (i.e. causal pathways), for example reproduction, recruitment, population structure etc., which also included consideration of taxonomic groups, ecosystem types (permanent rivers, temporary rivers, lakes and large reservoirs, small reservoirs, wetlands, floodplain habitats and estuaries), species or life stages affected. Their responses were used to further refine conceptual models with the aim of providing a better system understanding and define the 'current' known situation.

We asked experts to estimate the likely response of ecosystem attributes over the medium to long-term under four different scenarios. The 'without virus' scenario (do nothing to reduce carp) assumes carp abundance and geographic distribution remain at current projections. The 'with virus release' scenarios assumes carp control at three levels of effectiveness, low carp kill (25%), high carp kill (70%) and complete elimination of carp (100%). Note that these scenarios have been chosen to represent the full theoretical range of scenarios, but not all are considered likely to occur (i.e. 100% reduction may not be considered a realistic scenario).

To strengthen the framework (and conclusions drawn), a rapid literature synthesis method (Eco Evidence) provided a transparent and rigorous method and associated tools to aid evaluation of causal inferences.

Results/key findings

Of the 103+ experts invited to participate in the online survey, 65 responded but 16 of those just looked at the survey without participating. A total of 41 experts attended the two facilitated workshops. Using the feedback from the survey and workshops combined, conceptual models were developed for 8 biotic groups and a revised generic conceptual model (see below).



The survey results clearly identified that respondents expected ecosystem attributes in different ecosystems types to vary in response to carp and that ecological responses are expected to also vary through time. The low number of estuarine experts that participated in the survey resulted in the high number of ‘don’t know’ responses for estuaries. However, for those that did express an opinion, most considered the ecosystem attributes in estuaries would show a minor response to carp reductions. Some ecosystems, such as wetlands, were identified as being more likely to have a moderate to large response to carp reductions than others such as temporary rivers.

Summary of expert opinion on prediction of moderate-large and large ecosystem attribute responses to carp reductions by ecosystem type. A gradient of colour in any cell indicates the range of most common survey results.

	Ecosystems						
Ecosystem attribute	Permanent rivers	Temporary rivers	Lakes & large reservoirs	Small reservoirs	Wetlands	Floodplain habitats	Estuaries
Large-bodied native fish	[moderate-large – large]		[moderate]		[moderate-large – large]		
Small-bodied native fish					[moderate-large – large]		
Submerged macrophytes	[moderate – moderate-large]				[moderate-large – large]	[moderate]	
Macroinvertebrates	[moderate – large]		[moderate-large – large]	[moderate-large – large]	[moderate-large – large]		
Water quality					[moderate-large – large]		

Response	
Large	(blue)
moderate-large	(purple)
moderate	(green)

Under a ‘do nothing to carp control scenario’, experts confidently predicted that ecosystems are likely to continue to decline without management interventions to relieve the stress of both carp and other stressors. Furthermore, any small reductions in carp (e.g. 25%) are considered unlikely to achieve any significant ecological outcomes. For all ecosystem attributes considered in this study, opinion was that the achievement of >70% reductions in carp biomass is needed to gain any significant (30-70%) improvement over the current ecological situation (with greater confidence in predictions with greater carp reductions), noting that complete elimination of carp was considered an unlikely scenario. However, if complete elimination of carp could be achieved, experts predicted a significant ecological response in the long-term, especially for water quality, macroinvertebrates and submerged macrophytes (where confidence in predictions ranged from low to high) see table below.

Likely response of ecosystem attributes under four different scenarios of carp reductions and the experts’ level of confidence in that prediction. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp and assumes between 150kg/ha to 375kg/ha carp density; scenario 3: 70% reduction in carp and assumes below 150kg/ha carp density; scenario 4: complete elimination of carp. Response options were none = 0% response or ‘gets worse’; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%, noting that complete elimination of carp was considered an unlikely scenario). The gradient of colour in any cell indicates the range of most common survey results.

	Scenario			
Ecosystem attribute	Do nothing to reduce carp	25% reduction	70% reduction	100% reduction
Large-bodied native fish	M-v.H	M-H	L-M	L-H
Small-bodied native fish	M-v.H	L-H	L-M	L-H
Submerged macrophytes	M-v.H	L-H	L-M	L-H
Macroinvertebrates	M-v.H	L-H	L-H	M-H
Water quality	H-v.H	H-v.H	M-H	M-H

Response	
None = 0% response / gets worse	(grey)
Minor = <30%	(light blue)
Significant = <70%	(peach)
Proportionate = 100%	(yellow)
Excess = >100%)	(brown)

Confidence	Degree of confidence in being correct
v.H (Very high)	at least 9/10 chance
H (High)	~ 8/10 chance
M (Medium)	~ 5/10 chance
L (Low)	~ 2/10 chance
v.L (Very low)	<1/10 chance

Most survey respondents believed there is a low likelihood of broad-scale ecosystem recovery following carp reductions in the medium-term (apart from perhaps macroinvertebrates) but more experts considered it a greater likelihood in the long-term (see table below). In almost all cases, hysteresis or the development of a novel system was considered just as likely, or more likely, an outcome as was ecosystem recovery. Experts identified the risk of both hysteresis (where a degraded system does not follow a reversal of the degradation trajectory in its recovery - meaning that the ecosystem will be harder to repair than it was to degrade) and the development of a novel system (e.g. other alien species, such as Redfin, may do better without carp and occupy the habitat more effectively than native species, creating a novel system).

Likely ecosystem responses of ecosystem attributes to 70% reduction in carp over the long-term. The gradient of colour in any cell indicates the range of most common survey results.

	Ecosystem responses in long-term (10+ years) with 70% carp reduction			
Ecosystem attribute	Recovery	Other stressors	Hysteresis	Novel system
Large-bodied native fish				
Small-bodied native fish				
Submerged macrophytes				
Macroinvertebrates				
Water quality				

Likelihood of ecosystem responses
Low
Med
High

Experts emphasised that carp are not the only ecological stressor and without other ‘non-carp’ mitigation actions to address the widespread environmental problems, their confidence was not high that ecosystems could recover with carp reductions alone. Complementary actions are also considered necessary to facilitate ecological recovery.

For nearly every ecosystem attribute, experts identified a range of modifying factors that are believed to influence ecosystem responses and hinder recovery. Many of the modifying factors were other stressors associated with land use and flow. For native fish, these were water quality, flow, and the presence of native fish to recolonize. Whereas for macrophytes, modifying factors such as site and seed-bank condition will influence the system’s response to carp removal. Overall, the experts’ responses suggest that both the effects of carp infestation and subsequent ecological responses to carp removal are likely to be influenced by the temporal (e.g. flow history) and spatial (e.g. geographic location and ecosystem type) context as well as the other prevailing stressors acting on the system.

Few survey responses were taken from the participants that identified as experts on the following ecosystem attributes: amphibians, algae (both phytoplankton and attached) and zooplankton. Thus, these ecosystem attributes are not featured in the tables above. Those that did contribute made similar comments regarding the ‘do nothing’ scenario and commented that the adequacy of environmental flows is a major contributing factor regarding attached algae and zooplankton responses, as is high sediment loads.

The results for waterbirds are also not added to the above tables for two reasons; 1) the low number of experts contributing to the survey results, and; 2) that the likely waterbird response to carp reductions was a potential decline in waterbirds not an increase (and as such would not be consistent with the other attributes in the table). The risk of a potential decline in waterbirds was because carp are believed to play a significant role in the diet of waterbirds. While four experts predict a minor to significant decline for piscivorous waterbirds with >70% reduction in carp, they noted it should only be short term. The likelihood of recovery in the long-term was considered medium to high. The recovery would depend on the availability of an alternative food supply (such as native fish) and thus subsequent increases in native fish abundance (which is not certain).

Rapid evidence synthesis

The syntheses of literature provided evidence in support of some degree of ecosystem recovery following pest fish removal. Overall, the rapid evidence review has provided evidence for ecosystem recovery in terms of water quality (nutrients and turbidity), macrophytes and macroinvertebrates following the removal of non-native, non-predatory freshwater fish.

In relation to water quality, literature evidence supported the hypotheses that, under the right conditions, a significant reduction in pest fish can result in decreased turbidity (as measured by suspended sediments and water clarity) and a reduction in nutrients. Whereas the evidence for the relationship between reduced pest-fish abundance and chlorophyll a was not as strong.

Experts predicted that if elimination of carp could be achieved, a significant long-term ecological response for submerged macrophytes. The results from the rapid evidence synthesis support a recovery of biomass and diversity of macrophytes following the removal of carp. The literature also provided evidence for macroinvertebrate community recovery with improved richness and abundance as a result of reduced predation and in response to enhanced macrophyte growth and improved water quality.

In all cases of supporting literature evidence, the pest fish population was identified as the major driver of the degraded water quality or biological condition. In studies where other factors, such as variation in water depth, were not controlled the recovery was often difficult to detect. The limited evidence available from long-term ecosystem-scale studies made predictions and generalizations difficult regarding native fish responses. It appears that native fish responses to pest fish removal are highly variable in both space and time (because of the responses of different species and in different ecosystems), which was echoed in the of responses submitted during the expert elicitation.

Implications for relevant stakeholders

This work collected and analysed expert views and scientific literature to better understand the likely medium- to long-term ecological responses to reduced carp populations. Uncertainty in generalizations resulted from the expected variation in ecosystem responses to carp removal over both space and time. Contributing to the uncertainty and the complexity of trying to confidently predict long-term ecosystem responses is the likely variation in responses of different species, under different conditions and in different ecosystems, and the effects of other environmental stressors, including other alien fish, and the lack of long-term ecosystem-scale studies on the topic. Experts emphasised that carp are not the only ecological stressor and without other ‘non-carp’ mitigation actions to address the widespread environmental problems, their confidence was not high that ecosystems could recover with carp reductions alone. It is important to note that degraded systems may not return to their original state after the reduction of carp. Furthermore, complementary actions are considered necessary to facilitate long-term ecological benefits. The results of this study need to be read with the knowledge that they are necessary simplifications of complex ecological systems where context can be critical, but the generalisations provided can nonetheless be useful to better understand where the uncertainties lie.

Experts confidently predicted that ecosystems would continue to degrade under a ‘do nothing to control carp’ scenario, acknowledging that carp are considered an ecological problem. Evidence from both the expert elicitation and the scientific literature, indicates that under favourable circumstances the removal of benthivorous alien fish, such as the common carp, can have positive long-term ecosystem outcomes in terms of water quality, macrophytes and macroinvertebrates providing the benthivore was the major driver of the degraded environmental conditions. To achieve these ecosystem benefits, carp populations would need to be significantly reduced (70-100%) and the suppression of carp biomass would need to be sustained. Some ecosystems, such as wetlands, were identified as being more likely to show a significant response to carp reductions than others.

Keywords

Cyprinus carpio, carp, conceptual models, ecological responses, long-term, ecosystem attributes, native fish, water plants, macroinvertebrates, waterbirds, amphibians, algae, zooplankton and water quality, aquatic ecosystems, expert elicitation, rapid evidence synthesis, literature review.

Introduction

Background

The National Carp Control Plan (NCCP), operating within the Fisheries Research and Development Corporation (FRDC), is developing a plan for smart, safe, effective and integrated measures to control invasive common carp (*Cyprinus carpio*: hereafter, 'carp') in Australian freshwater environments, including the potential release of the virus known as Cyprinid herpesvirus 3 (CyHV-3) virus (hereafter referred to as the 'carp virus'). The NCCP has commissioned a program of scientific, social, and economic research that will develop the knowledge required to enable an informed decision on whether virus release should proceed. Part of the scientific program requires an exploration of the medium- to long-term ecological effects likely to result from major carp population reductions. This report documents the expert elicitation and literature synthesis used to assess the ecological changes likely to result from carp population reductions.

The focus of this project is on predicting the ecological effects resulting from carp population declines that may result from population control measures over 5-10 year (medium term) and > 10 year (long term) timescales. In addition, the project includes an assessment of the evidence available for predicted changes to ecosystem components and the confidence of predictions. The outputs of this project will inform NCCP in several ways, including:

- informing the NCCP by explicitly articulating the confidence of predictions for various potential ecological outcomes of carp control
- use in NCCP communications activities
- informing surveys of community and stakeholder attitudes to carp biocontrol
- informing the choice modelling component of a cost-benefit analysis.

Need

Release of the virus should be predicated on a sound understanding of the likely ecological effects of reductions in carp numbers both in terms of immediate effects and longer-term ecological responses. Recognizing and quantifying uncertainty around these predictions is a critical component of providing advice on expected ecosystem effects and communication to managers and the general public.

The essential needs this project addresses are;

a) A clear conceptualization of the role of carp across ecosystems was needed to predict likely responses of the likely effects of carp control using CyHV-3.

b) To understand how ecosystems may change under scenarios of carp control by CyHV-3

c) To be able to communicate the predicted change with defined levels of confidence to the public.

This project makes predictions about how different levels of carp reduction would affect a variety of ecosystems (i.e. different types of lakes, rivers, wetlands) and ecosystem attributes such as native fish, water plants, macroinvertebrates (molluscs, water bugs, yabbies, shrimp), waterbirds, amphibians, algae, zooplankton and water quality. The project identifies ecosystem attributes expected to change in response to carp control. These attributes were conceptualized into simple diagrams that summarize the likely effects of carp and carp control. These conceptualizations underpinned exploration of control scenarios (based on degree of carp population reductions achieved) and predictions of effects on ecosystem attributes. The predictions were informed by expert elicitation and the published scientific literature. A rapid literature synthesis method (Eco Evidence) provided a transparent and rigorous method and associated tools to aid evaluation of causal inferences. Both expert elicitation and the published scientific literature were used because it was unlikely that enough location-specific information (i.e. site and species specific, long-term ecological field studies) were available on which to base conclusions. These methods also provided an assessment of the evidence underpinning the predictions of ecosystem response, including:

- causal relationships between carp and ecosystem attributes, and the role of other variables (e.g. land-use, ecosystem type, geographic region), and
- identification of knowledge gaps.

Objectives

1. Develop a conceptual framework and identify ecosystem attributes expected to change in response to carp control.

2. Define attribute metrics and quantify attribute independence.

3. Assess the confidence of the scientific evidence underpinning the predicted outcomes.

4. Provide outputs that are clearly communicable to the public and other components of the NCCP.

Method

A ‘Delphi’ approach to expert elicitation (MacMillan & Marshall 2006) was undertaken. The Delphi method involves group elicitation processes in which the experts are first asked for independent input on some parameter(s) of interest. In this case we used an online survey to elicit views on the ecological responses to carp population reductions. The estimates were collated, and then shared with the broader group. We did this during two face-to-face workshops. The experts were then allowed to revise their estimates, if they so desired, to reflect the insights that arose from the group. This process can be repeated any number of times, until the experts are comfortable with their responses. The responses were then aggregated with retention of the range of responses to represent the uncertainty in the parameter(s). These structured methods have the advantages that negative aspects of group dynamics (such as dominance and anchoring) can be avoided and a wide range of independent viewpoints can capture the underlying uncertainty or confidence. We used the following method to grade confidence (Table 1).

Table 1. Confidence rating used to indicate the expert’s level of confidence in their assessment of likely responses, and list factors that represent either the greatest risks or contribute the most to your uncertainty (as used by IPCC https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch1s1-6.html).

Confidence	Degree of confidence in being correct
Very high	at least 9/10 chance
High	~ 8/10 chance
Medium	~ 5/10 chance
Low	~ 2/10 chance
Very low	<1/10 chance

To strengthen the framework, Eco Evidence (Norris et al. 2012) will be used to add rigor, transparency, and effectiveness to the expert elicitation process. Eco Evidence is a rapid evidence synthesis method to provide a mechanism to present objective evidence in a transparent and easy-to-understand format.

Expert Elicitation: Online Survey

Understanding the current state of knowledge and evidence

The potential medium- to long-term ecological effects of significant population reductions of carp in Australian aquatic systems is poorly understood. Yet, such knowledge is vital for ensuring the subsequent improved health of Australian aquatic systems and informing the public of the likely consequences of reducing carp populations. The online survey elicited expert opinion to develop a suite of conceptual models to help understand the causal pathways to ecological effects of carp and to predict the potential medium- to long-term ecological effects of reductions to carp populations.

We invited 103 experts to participate in the survey and they were asked to forward the invitation to other experts they thought may be interested in participating. These experts were selected to represent a range of discipline areas based on track record (publications), ecosystem representation, and spatial coverage. The discipline areas included water quality, algae, zooplankton, aquatic macroinvertebrates, fish, macrophytes, waterbirds and amphibians. Invited experts were from universities and other research organizations, Government and non-government organizations, and independent experts.

The survey asked the selected ecological experts to contribute their understanding of the likely ecosystem effects of carp and carp reductions, based on the areas in which they have expertise. This included, but was not limited to, the likelihood of effects, confidence in predictions, and likelihood of recovery or alternative ecosystem outcomes. Individual responses from different experts then contributed to the suite of models that represent the collective knowledge of all participants.

Participation in the research was completely voluntary and participants could, without any penalty, decline to take part or withdraw at any time without providing an explanation or refuse to answer a question. Human ethics approval for this research (both the survey and workshops) was applied for and approved by the Human Ethic Committee, University of Canberra (application number 20180276 - Carp ecological effects). Participants seeking additional information about the survey were referred to an information sheet (see Appendix 1: Human ethics). The survey opened on 24 May 2018 and closed 15 August 2018.

Develop Conceptual Model

We asked experts to provide their views on an initial conceptual model (Zampatti et al. 2018) of the effects of carp on freshwater systems developed based on reviews by Weber and Brown (2009) and Vilizzi et al. (2015) (Figure 1). The model is based on evidence from the scientific literature and represents an overview of ways carp affect biota, which are common management objectives. The survey asked the respondents to suggest refinements or adaptations to the model based on their expert knowledge.

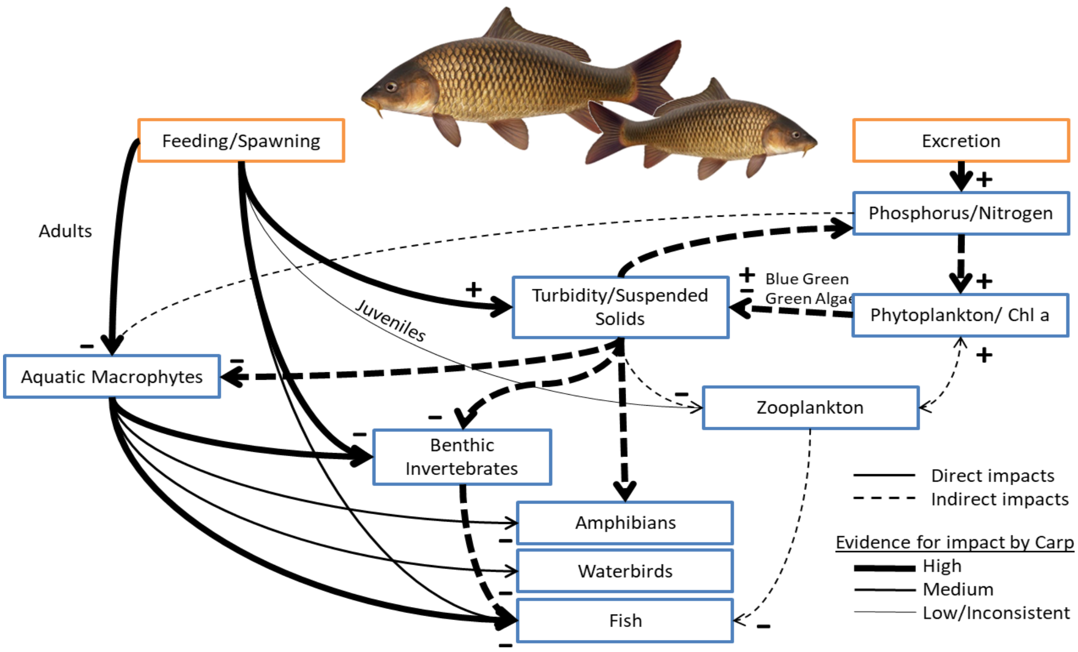


Figure 1. Initial conceptual model used to elicit expert views on the effects of Carp in freshwater systems (Zampatti et al. 2018), which is based on reviews and models by Weber and Brown (2009) and Vilizzi et al. (2015).

While not all invitees were able to contribute, we were confident that those that did choose to, represented a non-biased sample with a full range of knowledge across relevant ecosystem attributes, regions and research approaches.

Subsequent survey questions asked participants in more detail about the evidence for the specific effects of carp (i.e. causal pathways), for example reproduction, recruitment, population structure etc., which also included consideration of taxonomic groups, ecosystem types (permanent rivers, temporary rivers, lakes and large reservoirs, small reservoirs, wetlands, floodplain habitats and estuaries), species or life stages affected. Their responses were used to further refine the conceptual models with the aim of providing a better system understanding and define the 'current' situation.

The Scenarios

To inform the choice modelling project, we asked experts to estimate the likely proportional response of their selected ecosystem attribute (which they selected based on their area of expertise) over the medium to long-term under four different scenarios. The 'do nothing to reduce carp' scenario assumes carp abundance and geographic distribution remain at current projections. The 'with virus release' scenarios assumes carp control at three levels of effectiveness, low carp kill (25%), high carp kill (70%) and complete elimination of carp (100%). Note that these scenarios have been chosen to represent the full theoretical range of scenarios, but not all are considered likely to occur (i.e. 100% reduction may not be considered a realistic scenario but helps us identify changes relevant to modelling relationships i.e. identifying attribute independence).

Scenario 1: Do nothing to reduce carp

Carp densities range from 200kg/ha to 500kg/ha with densities fluctuating through time, declining and contracting during periods of drought and increasing during periods of flooding.

Under a 'do-nothing to reduce carp density' scenario, other scheduled management activities may still apply, for example the major expected changes to flow regimes across the Murray Darling Basin to increase environmental flow delivery (this might include wetland inundation that in some areas will be achieved through environmental infrastructure). There will also be climate change effects that may involve a decline in run-off and increases in the frequency and severity of extreme events including droughts, summer storms, heat waves and fires. In terms of flows, climate change may exacerbate the effects of flow regulation and effects on water quality may involve blue-green algal blooms, anoxic black water, acidification and increased sedimentation.

Scenario 2: 25% reduction in carp

Under this potential scenario, the virus release and subsequent complementary management reduce carp abundance across the region to between 150kg/ha to 375kg/ha.

Scenario 3: 70% reduction in carp

Under this potential scenario, the release and subsequent complementary management reduce carp density across the region to below 150kg/ha in the medium to long term.

Scenario 4: Complete elimination of carp

Under this potential scenario, the virus release and subsequent complementary management reduce carp density across the region to 0kg/ha over the medium to long term.

Magnitude of Response

We asked participants for their judgement on the likely magnitude of a response for the ecosystem attribute in question (i.e. water quality, large-bodied native fish, etc.) (Table 2).

Table 2. Options provided to assess the magnitude of effect.

Response	Definition
None	0% change or decline
Minor	< 30%
Significant	<70%
Proportionate	100%
Excess	> 100%

Confidence

For all scenarios, the participants were asked to rate their level of confidence in their assessment, and list factors that represent either the greatest risks or contribute the most to their uncertainty. The confidence terms are explained in Table 1.

The System's Response

We asked experts to assess the likely ecosystem responses if carp density was significantly reduced (e.g. by >70%) in the medium (5-10 years) and long term (>10 years). We asked experts to provide an assessment of the likelihood (low, medium, high) of each of the following possibilities and to provide some details about each.

1. **Recovery**: System recovers to sustain similar biota and ecosystem functions as recorded prior to carp infestation
2. **Other stressors will limit recovery**: Freshwater systems are subject to multiple interacting stressors (flow modification, alien species, fragmentation, habitat modification). Ameliorating one stress will not lead to rehabilitation if other stressors are either more important or constrain responses.
3. **Hysteresis**: The system's response may not be the reverse of its degradation response because of either lag effects, alternative stable states or rules of assembly.
4. **A novel system will develop**: Because of other stressors acting on the system, extinction of species and changes in the landscape within which the system is nested, removal of the stress (carp) may lead to development of a novel system that may or may not meet management objectives.
5. **Other**: some other system response not specified above.

Expert elicitation: Workshops

A core element of the Delphi approach involves a follow-up group elicitation process. Group elicitation enables individuals to gain insights from the collective wisdom of the whole group (or topic specific sub-group) and to use this to revise previous estimates made through the online survey.

The workshops enabled experts, selected across a broad range of carp ecosystem-effect topics and locations to come together to share knowledge and use a set of structured exercises to revise their previous estimates and provide group consensus on areas of core interest to the project objectives.

An additional benefit of the workshops was to enable a rich exchange of needs, desires, limitations and capacities of the researchers, the project team and representatives of other related NCCP projects such as the Choice Modelling and Risk Assessment teams. This provided valuable insights for project integration, gaps and ways forward.

Two facilitated expert workshops were held to enable this process to occur:

1. Albury, 12 July, 2018 involving 16 participants
2. Canberra, 18 July, 2018 involving 25 participants

Workshop Objectives

The expert workshops had the following objectives:

- Enable participants to revise their previous estimates provided during the online survey.
- Gain expert understanding of how ecosystem attributes are expected to change in response to carp
- Elicit expert knowledge for the scenario forecasts to assist the choice modelling project
- Seek expert input to inform the evidence synthesis of key areas of uncertainty
- Elicit expert assessment on confidence levels for the relationships between system responses and carp reduction scenarios.

Workshop Process

The agenda for the Canberra workshop is shown in Appendix 2: Canberra workshop agenda, and the Albury workshop followed a similar process. The early sessions in the agenda were dedicated to setting the context for the day including gaining a shared understanding of terms and definitions used, the relevance of the project within the bigger National Carp Control Program (NCCP) direction and how the workshop outputs and findings would be used to further the objectives of the NCCP.

The body of the workshop was structured around a set of presentations and group exercises, each aimed at eliciting data consistent with the project objectives. A core part of this was to enable participants to revise the estimates they provided during the online survey. To achieve this, each participant was provided with a printed hard copy of their survey responses and asked to revise any estimates that they had made.

The workshop activities were structured achieving the following:

- Discussing and gaining agreement on the utility of the generic carp model (Figure 1) and enabling participants to make any suggested refinements to this model
- Consider, discuss and agree on a set of draft topic-specific cause-effect conceptual models that were compiled based on the survey results. Draft conceptual models were developed for each of these topics based on the information provided by experts during the online survey. Workshop topics were selected based on the availability of subject expertise at each workshop resulting in the following sub-set of subject specific conceptual models being used:
    - Albury workshop – Aquatic macroinvertebrates, Large-bodied fish, Small-bodied fish, Emergent macrophytes, Submergent macrophytes and Amphibians. Group sizes ranged from 5 to 3.
    - Canberra workshop - Water quality, Waterbirds, Macroinvertebrates, Large-bodied fish and Small-bodied fish. Group sizes ranged from 2 to 8.

- Confidence around the causal relationships shown in the draft conceptual models and discussion of reasons for assigned confidence and adjustment of previous confidence assessments. The influence of contextual variables on the causal relationships was fundamental to this process.
- Consider, discuss and agree on the scenario forecasts, as described above, regarding confidence and the influence of contextual variables. Participants were provided with the opportunity to revise their previous estimates for these forecasts.

- Provide reference to any relevant evidence used in the participants expert estimates
- Provide feedback on the key areas of focus for the literature synthesis including discussion on the relevance of other research either internationally based or on functionally similar species or ecosystem effects.

Workshop Outputs

The workshops resulted in several outputs:

- Revised estimates to the online survey. Participants were provided with printed hard copies of their survey results and given the opportunity to make amendments to these.
- Revisions to the generic carp model (Figure 1) including new or altered casual relationships, new or altered confidence assessments. Participants made manual amendments to hard copies of the original model.
- Documentation of refinement of the more detailed component models (i.e. large-bodied fish, water quality etc.) including confidence assessments (and variance) and effect modifiers. Participants made manual edits to hard copies of the draft conceptual models that were compiled by the project team based on the online survey responses. Amendments included new or altered causal pathways, new contextual variables, new or altered confidence assessments and new evidence sources.
- Documentation of any amendments made to the scenario assessments made during the online survey.
- Documentation of key areas for evidence synthesis.

Literature Synthesis

The project involved a literature review using Rapid Evidence Synthesis (RES) methods. The RES provided a rigorous and repeatable procedure for synthesizing evidence for a specific question and provided associated estimates of confidence regarding the conclusions drawn.

Synthesis of the literature was used to strengthen the evidence-base gained from the expert elicitation process. This improves confidence in the evidence base and identifies any gaps in order to inform decision making by the NCCP team. Removal of alien or unwanted fish from freshwater ecosystems is a method used in freshwater ecosystem management for over sixty years in many European countries and especially in North America. It is important to explore the depth and breadth of this literature to understand the nature of the findings from studies that are relevant to the Australian context of reducing carp populations.

Rapid Evidence Synthesis

The development of methods for undertaking rapid reviews of environmental evidence have been driven by the need to meet the practical requirements of decision-makers (Webb et al., 2017). Rapid review approaches, such as Eco Evidence, have documented methods, use systematic searches, have clear inclusion criteria and weight relevant studies by quality, which provides a robust, yet rapid, review of the evidence for causal associations (Norris et al., 2012; Webb et al., 2015).

Eco Evidence is an aggregative approach to synthesis used to assess evidence for causation in the absence of strong experimental evidence. The method was originally developed by epidemiologists who must conduct research without true experiments in the presence of confounding factors, and with limited replication of sampling units (e.g. Hill, 1965). It builds on the premise that individual pieces of evidence alone may be weak but when combined and considered along with multiple 'lines of evidence' can build a strong argument for causality (Norris et al., 2005). For example, if different researchers, operating in different places, using different assessment approaches, consistently observe the same association between two variables, then it is more likely to be causal (i.e., Consistency of Association; Hill, 1965).

We conducted a rapid evidence synthesis, which comprises a systematic review and causal criteria analysis (hereafter referred to as Eco Evidence analysis), following the eight step Eco Evidence method (Figure 2) (Norris *et al.* 2012). A full description of the method can be found in the Eco Evidence methods manual (Nichols *et al.* 2011). Several key steps are involved in the literature synthesis and below we explain how it was applied in the case of this project. The topic of the RES was agreed on in consultation with project team and FRDC, which is documented within the results section.

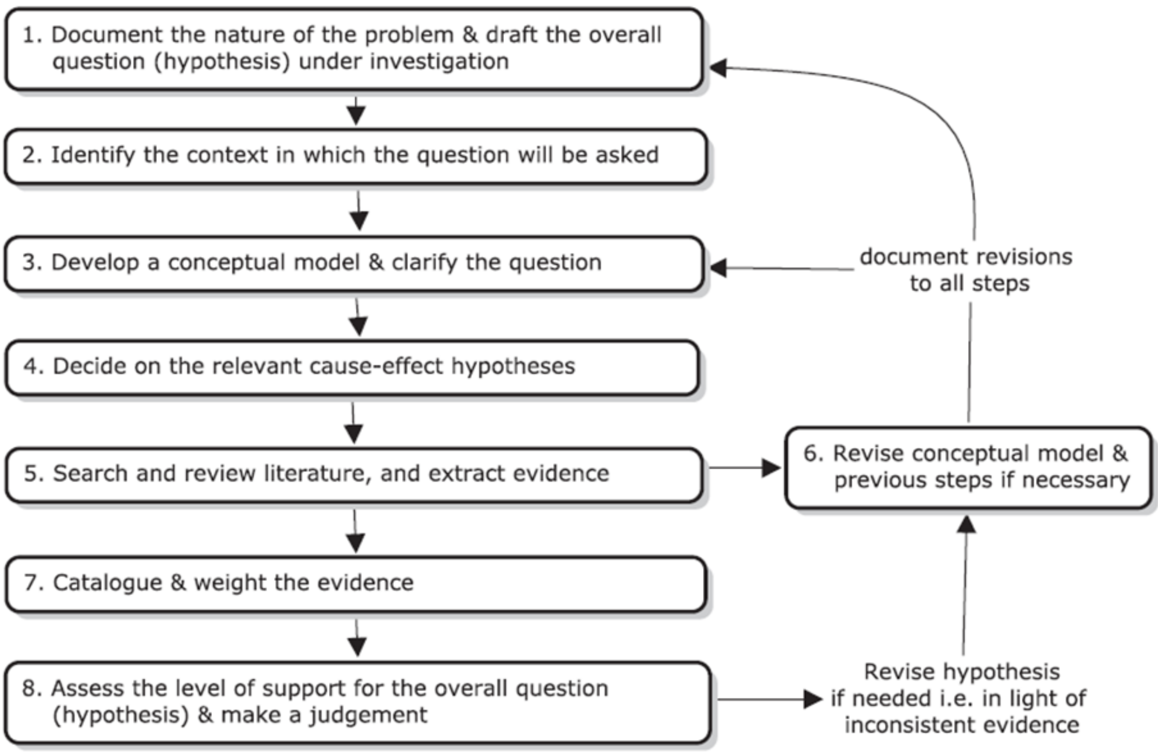


Figure 2. Eight step Eco Evidence method (reproduced from Norris et al. 2012).

Results

Expert Elicitation

Of the 103+ experts invited to participate in the online survey, 65 responded but 16 of those just looked at the survey without participating (Figure 3).

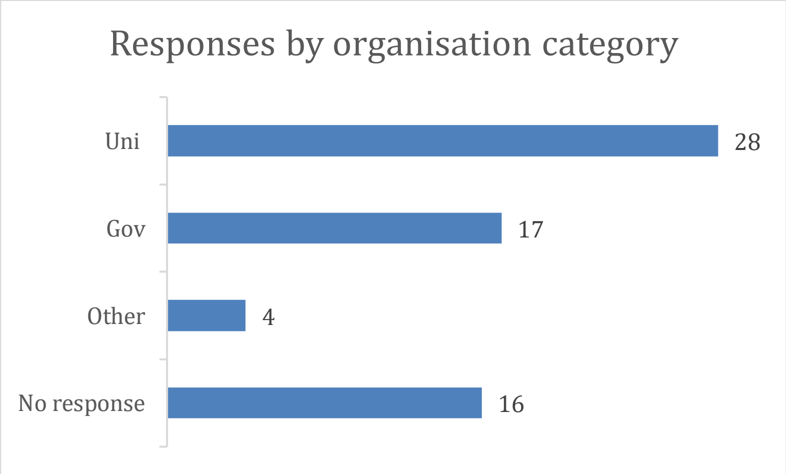


Figure 3. Survey responses by organization category

Participants were asked to identify their areas of expertise (subject expertise) and include all areas in which they have expertise enabling them to comment on the likely effects of carp reduction (Figure 4). Fish, macrophytes, macroinvertebrates and water quality were the top four areas of expertise represented by the survey participants. Phytoplankton, zooplankton and amphibians were least represented by the survey participants. Participants also identified the types of systems in which they have expertise (Figure 5). Permanent rivers and wetland experts had the greatest representation and estuaries were the least represented ecosystem type.

Other areas of expertise included:

- Ecohydrology and Hydrology
- Wetlands
- Riparian vegetation
- Biogeochemistry, ecosystem functioning
- Semi-aquatic mammals, reptiles (e.g. turtles, lizards, snakes), bush birds, raptors, other water-dependent birds that are not technically 'waterbirds', feral/pest mammals and birds.
- Aquatic Ecosystems
- Water management and observing environmental change
- Mathematician - population modelling
- Biofilms, trophic interactions
- Molluscs (gastropods and freshwater mussels)
- Floodplain, wetland and river management
- Environmental Water Management
- River-groundwater interactions

Water quality expertise specifically included:

- General physical and chemical properties (e.g. DO, turbidity, pH, temperature), Hg, emerging contaminants
- DO, turbidity, temperature, salinity, pH in relation to fish
- Nutrient dynamics
- Salinity
- Carbon, nitrogen, phosphorus
- Nutrients, turbidity
- Biological indicators of water quality
- Water quality monitoring with background in Murrumbidgee valley
- Sediment and sediment transport
- Cold water pollution
- Monitoring water chemistry effects on wetlands including
- Ionic concentrations / metals
- Elemental isotopes to trace water in the landscape especially groundwater
- turbidity and light limitation
- Pesticides

'Other' areas of fish expertise included:

- Non-native fish recreational species such as salmonids
- *Cyprinus carpio*
- Introduced species / Exotic / aliens in general
- Alien, *Poeciliidae tilapias* specifically
- Physical removal of carp - netting, electrofishing, traps, biotelemetry
- Threatened species

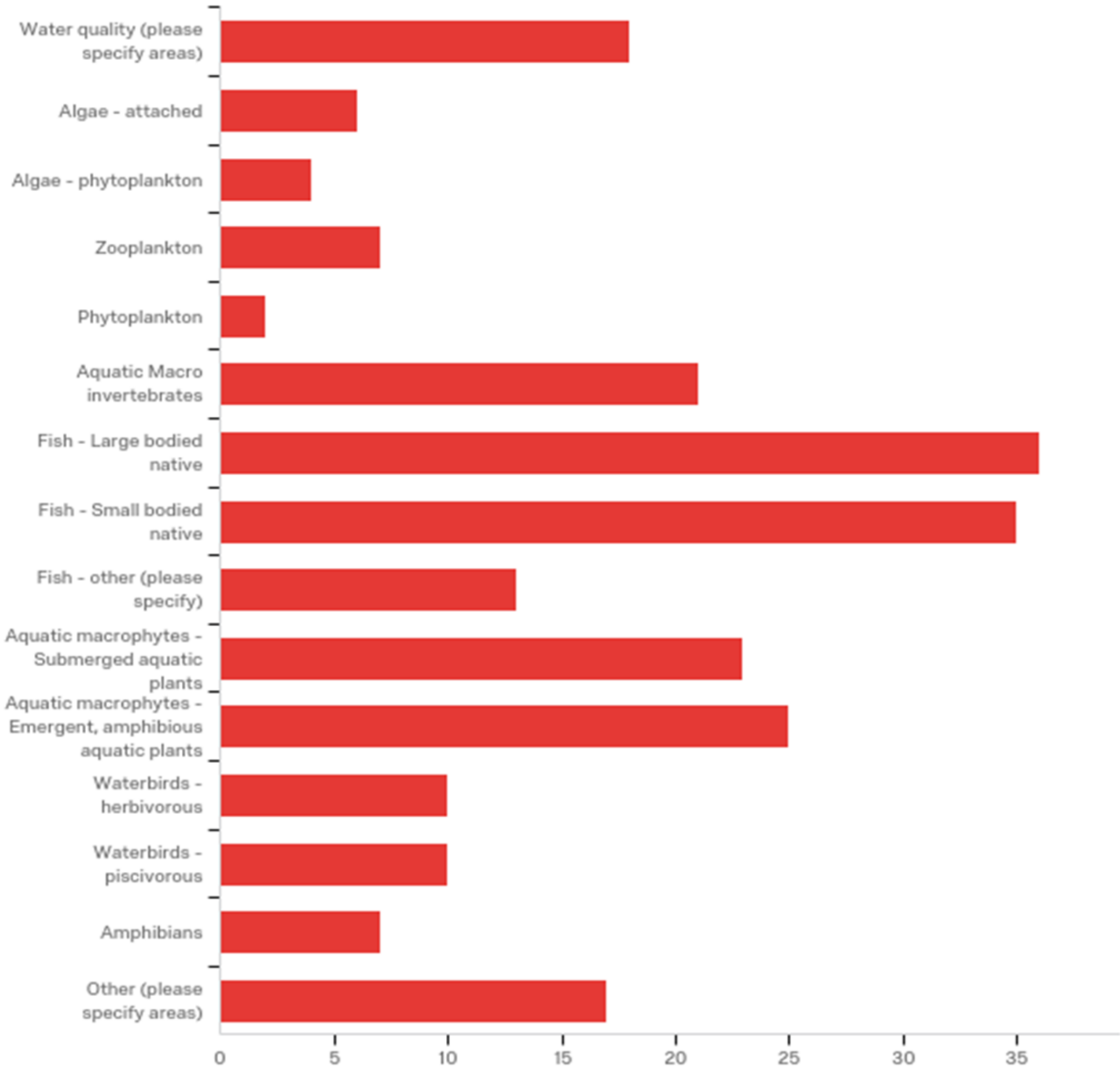


Figure 4. Participant's areas of expertise.

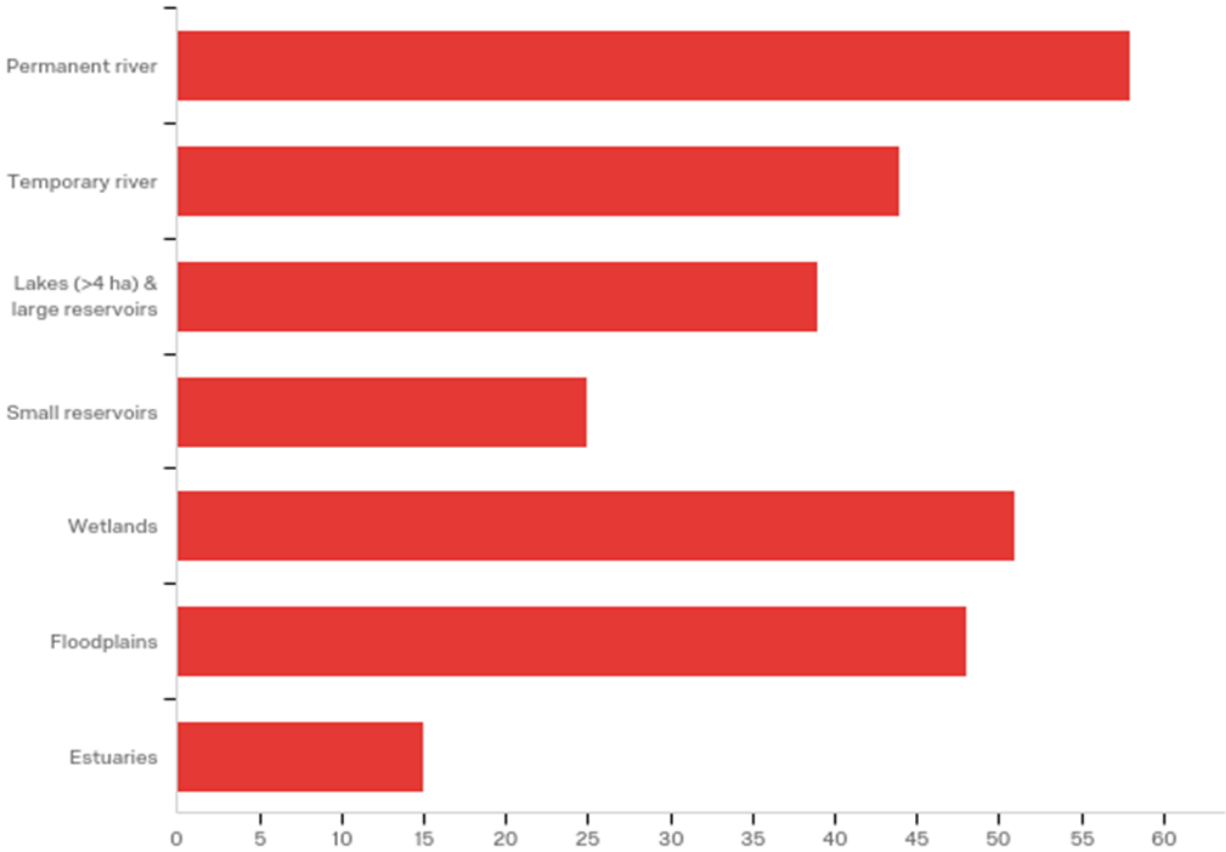


Figure 5. Types of systems in which participants have expertise.

Participants were asked to comment from the perspective of their subject area of expertise if the initial conceptual model (Figure 1) adequately represented their understanding of the effects of carp. Most participants indicated it was a good or reasonable representation (Figure 6).

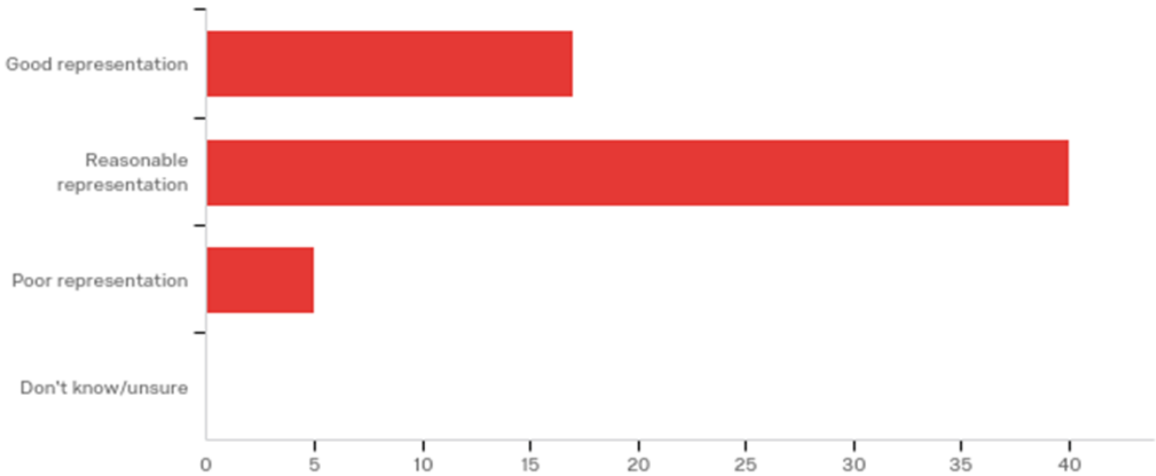


Figure 6. Adequacy of the initial conceptual model for representing participant's understanding of the effects of carp.

Conceptual Model

The generic conceptual model was updated using several inputs, specifically;

1. Survey feedback on the generic conceptual model
2. Causal pathways identified in the survey
3. Confidence ratings developed in the survey and subsequently refined in the workshops.

Feedback on the generic model

The majority of respondents stated that the initial generic model provided a reasonable representation of the effects of carp, with only 3 respondents believing it was a poor representation. All feedback is provided in Appendix 3: Survey comments on initial generic model. The feedback focused on three broad areas. First, feedback suggested that there was some inconsistency in the coding of arrows and that there were some arrows missing. The main area of inconsistency arose from the coding of direct and indirect effects within the model. Respondents pointed out that there needed to be additional arrows identifying carp as food for large fish and waterbirds, that carp consume tadpoles and that waterbirds consume macroinvertebrates.

The second area of feedback was identification of missing nodes in the model. Key among these were the physical presence of carp and pathogens. In this context, 'presence' means that the mere presence of carp in a system, their physical occupation of space and associated competition for habitat, and release of odours into the water, all of which in turn affects the behaviour and habitat occupancy of other species of fish and other biota. The third area of feedback was in the treatment of variation in effects and effect modifiers, which included variation in carp effects among species, ecosystem types and variations in both effect and magnitude through time. This issue is not easily dealt with in a single conceptual model and was one of the reasons that the project team developed individual conceptual models for each of the major biotic groups and used these as an input to the modification of the generic model.

Causal pathways

The survey asked respondents to identify the causal pathways by which carp affected individual biotic groups. The most commonly listed causal pathway for all groups, except waterbirds, was the disturbance of macrophytes and sediments. The next most common response related to the consumption of animals, which either directly (macroinvertebrates, zooplankton) or indirectly (large native fish, small native fish) affected the groups. Large native fish refers to fish that grow to > 30 cm and small native fish are < 15 cm. The effects of carp nutrient excretion, their physical presence and pathogens were less commonly included in causal pathways.

Confidence ratings

Survey respondents were asked to rate their confidence in each causal pathway. These responses were then reviewed at the Albury and Canberra workshops. The workshops facilitated development of a consensus view on expert's confidence around specific relationships. These assessments were then used to code the arrows in each of the conceptual models.

Generic conceptual model

Using the feedback from the survey and workshops combined, conceptual models were developed for 8 biotic groups. These models are provided in Appendix 4: Conceptual models for biotic groups. The individual biotic conceptual models informed revision of the generic conceptual model (Figure 7). One of the major areas of feedback was how variable effects and effect modifiers were included in the model. As noted earlier, this is a complex issue and was one of the major motivations behind the decision to develop conceptual models for each of the major biotic groups. In developing models for each biotic group, it was acknowledged that we would still not address expected variation between different ecosystem types or regions or variation through time. The project team did not believe that we had enough information from the survey and workshops to enable development of such detailed models.

The major changes to the generic conceptual model include;

1. Inclusion of additional nodes to describe the effects of the physical presence of carp and their role as a vector for pathogens. A node was also introduced for biofilm as this was frequently included in causal pathways by which carp influenced macroinvertebrates and native fish.
2. Arrows were re-coded according to importance. This coding replaced the direct and indirect effects coding originally included in the model. Importance rankings were based on the proportion of respondents who included a relationship in their causal pathways. In some instances, there was variation among responses from different biotic groups and so, the responses of experts on the relevant biotic group were used in the model.
3. Arrows were also re-coded according to confidence. The confidence ratings developed at the Albury and Canberra workshops were used to identify the confidence participants had in specific relationships.

The changes to the generic model and the development of models for each of the biotic groups represents an improvement in the representation of the influence of carp on aquatic ecosystems. The adaptation of the model does not, however, address one of the major areas of feedback, specifically that the models do not address expected variation in carp effects among different ecosystem types and through time. The survey results clearly identified that respondents expected different ecosystems types to vary in their response to carp. The survey also found that respondents believed effects in temporary rivers to differ from those in permanent rivers, raising the possibility that the effects of carp vary in response to the flow regime, an issue that was not explored in detail in the survey. In addition, responses for nearly every group identified factors that they believed would influence responses to carp. For native fish, water quality (particularly turbidity) is thought to modify carp effects, whereas for macrophytes, site and seed bank condition are likely to influence the response to carp removal. Many of the modifying factors were other stressors, such as those associated with land use. This issue emerged again in expert’s carp reduction forecasts in which a significant proportion of respondents believe that responses will be influenced by the presence of other stressors. Overall, these responses suggest that both the effects of carp infestation and subsequent responses to carp removal are likely to be influenced by the temporal (e.g. antecedent flow regime) and spatial (e.g. ecosystem type) context.

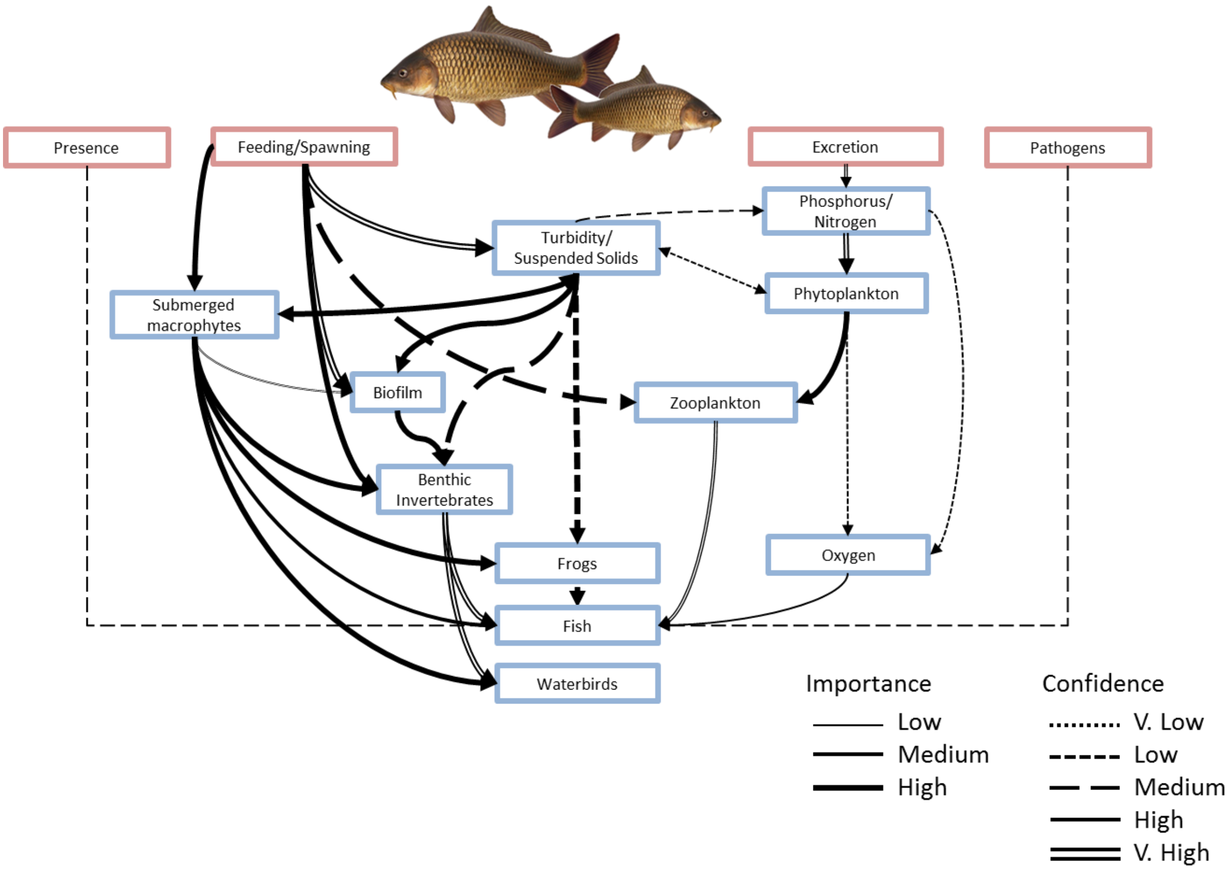


Figure 7. The modified generic conceptual model identifying the major pathways by which carp influence frogs, fish and waterbirds. The initial model was modified by the addition of two high-level influences (i.e. physical presence and pathogens) and recoding of arrows according to importance and confidence. We would like to acknowledge the work done by the Arthur Rylah Institute in developing the original conceptual model.

Evidence-base

We asked survey participants to identify the types of evidence on which they mostly based their assessment of confidence, the options were:

- Anecdotal information only = A
- Mix of anecdotal and personal observation = A & O
- Extensive management experience, limited published evidence = M & P
- Extensive published evidence (could be non-peer reviewed or peer reviewed) = P
- Extensive published literature and multiple lines of scientific evidence = X

Below are the survey results for the evidence-base overall (Figure 8) and for major causal pathways within each ecological group (Figure 9). Some did not respond to this question and this is indicated by ‘Not’ in the figures below.

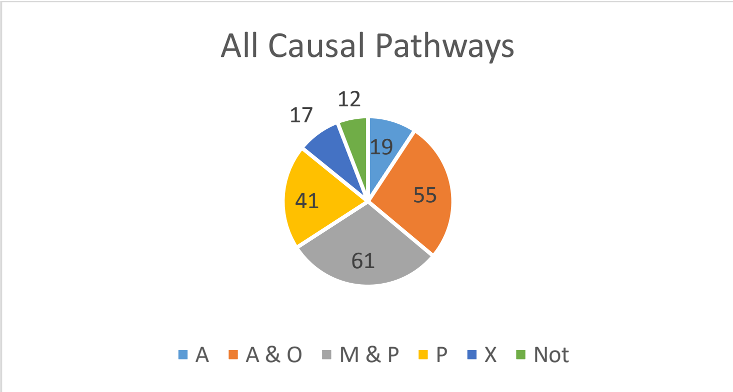


Figure 8. Types of evidence survey participants mostly based their assessment of confidence in all causal pathways they identified. *Anecdotal information only = A; Mix of anecdotal and personal observation = A & O; Extensive management experience, limited published evidence = M & P; Extensive published evidence (could be non-peer reviewed or peer reviewed) = P; Extensive published literature and multiple lines of scientific evidence = X; did not respond to this question = Not.*

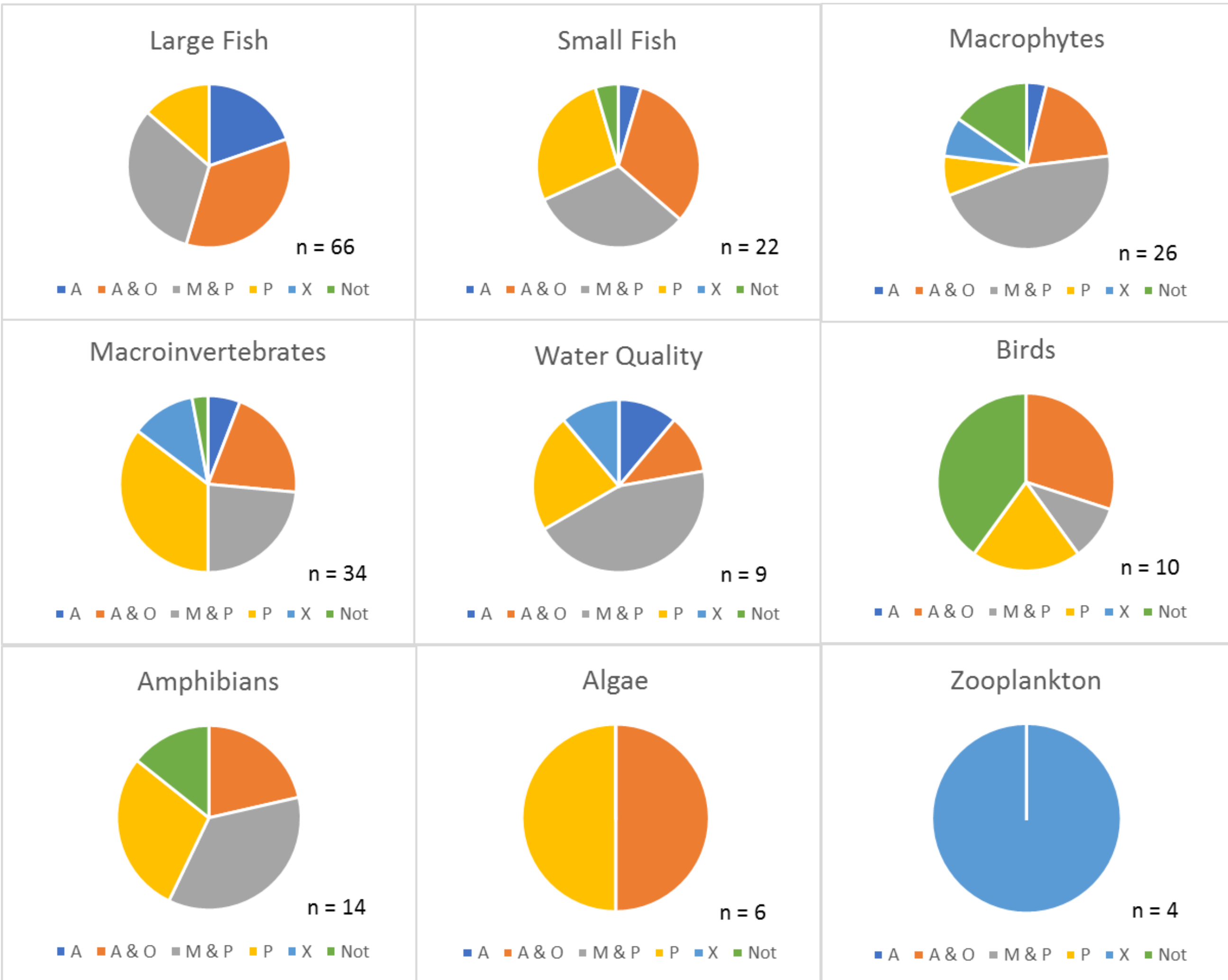


Figure 9. Types of evidence on which survey participants mostly based their assessment of confidence in causal pathways they identified for each ecological group (n = number of participants).

Ecosystem Response under Different Scenarios

The survey participants chose to respond on topics based on their area of expertise (Figure 10). The responses in this section pertain to these respondents.

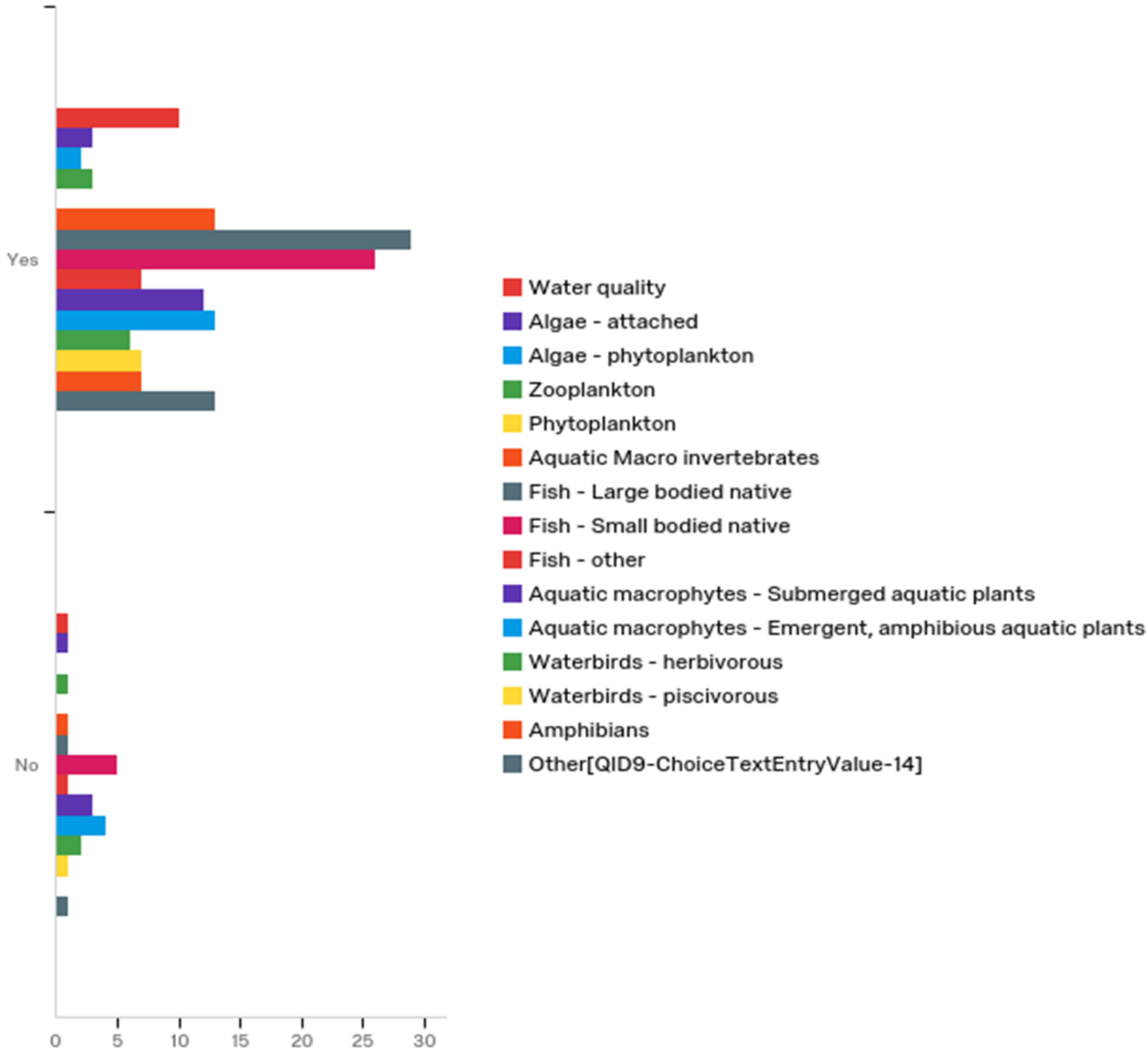


Figure 10. Areas of expertise that survey participants identified and chose to comment on.

Large-bodied native fish

Moderate-large and large responses of large-bodied native fish to carp reductions were considered more likely in wetlands and permanent rivers, while a moderate response was also considered likely in lakes, large reservoirs and permanent rivers. The low number of estuarine experts that participated in the survey resulted in the high number of 'don't know' responses for estuaries. However, for those that did express an opinion, most considered the large-bodied native fish would show only a minor response to carp reductions (Figure 11). Experts were varied in their predictions for temporary rivers, floodplains and small reservoirs.

Large native fish responses to the 'do nothing scenario' were predicted to change little or worsen from the current situation (with medium to very high confidence) (Figure 12). Several experts commenting that they expect native fish populations to continue to decline in the absence of any carp control strategies (Scenario 1) or other management interventions to relieve the stress on native fish populations. Achievement of >70% carp biomass reductions is predicted to lead to between 30-70% improvement to the current situation (with med-low confidence).

Most respondents believed there was a low probability of recovery in the medium term (14 respondents) with more considering it a greater likelihood in the long-term (Figure 13). Adding to the uncertainty, other stressors were considered to have high or medium likelihood of influencing recovery of native fish (both in the medium and long-term). Hysteresis (7 and 9 respondents) or development of a novel system (10 and 7 respondents) were predicted (with medium likelihood) to influence the fish response (Figure 13). An example, of a novel system described in the survey was that other alien species such as Redfin that may 'do better' without carp, in which case Redfin would hinder native fish recovery. Some commented that Redfin may feed on juvenile native fish and thus may present a greater threat to native fish than do carp.

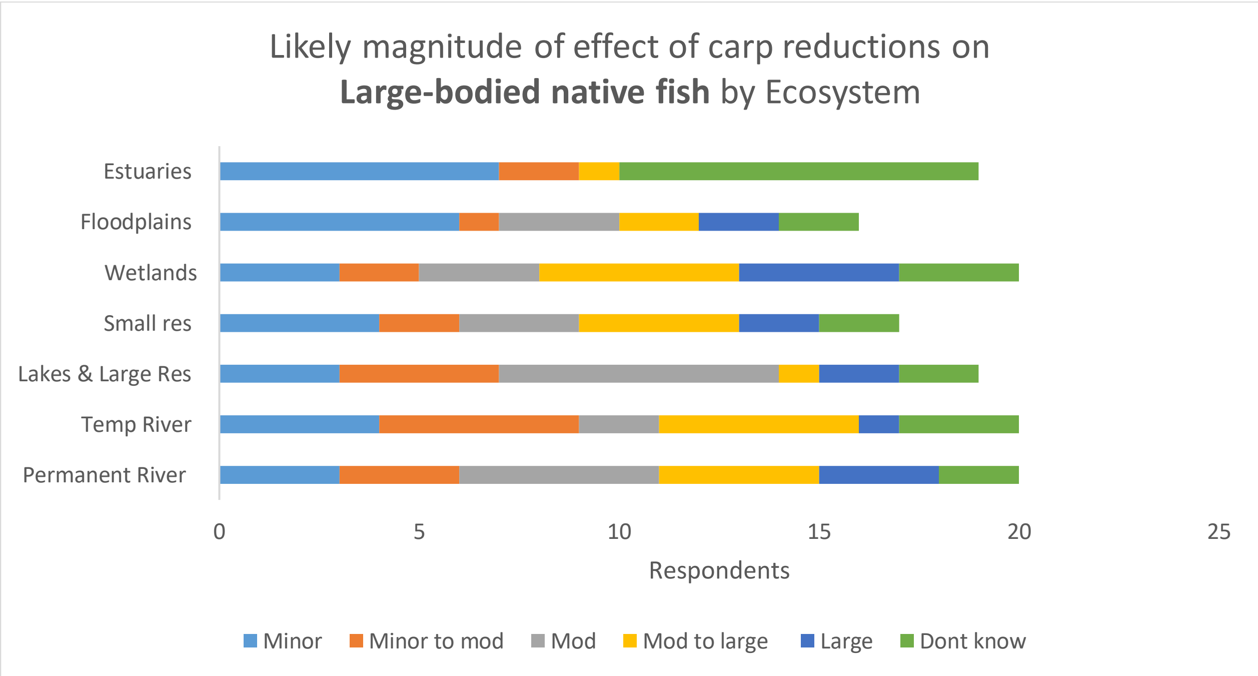


Figure 11. Likely magnitude of effect of carp reductions on large-bodied native fish by ecosystem.

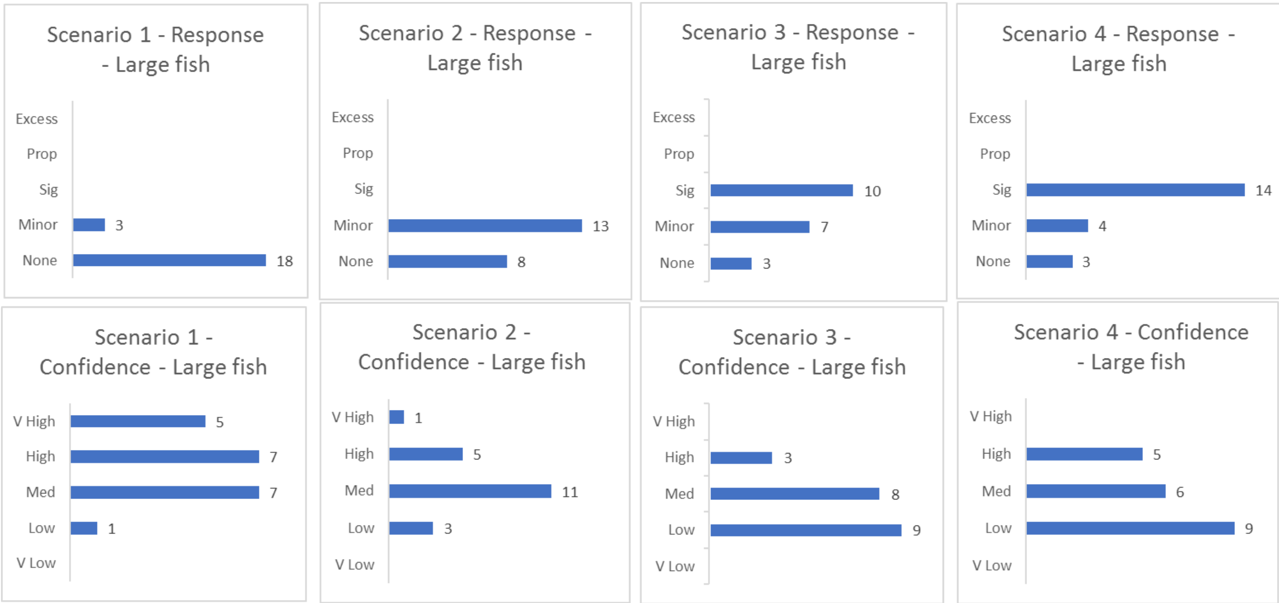


Figure 12. Likely response of large-bodied native fish under four different scenarios and the level of confidence in that assessment. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%).

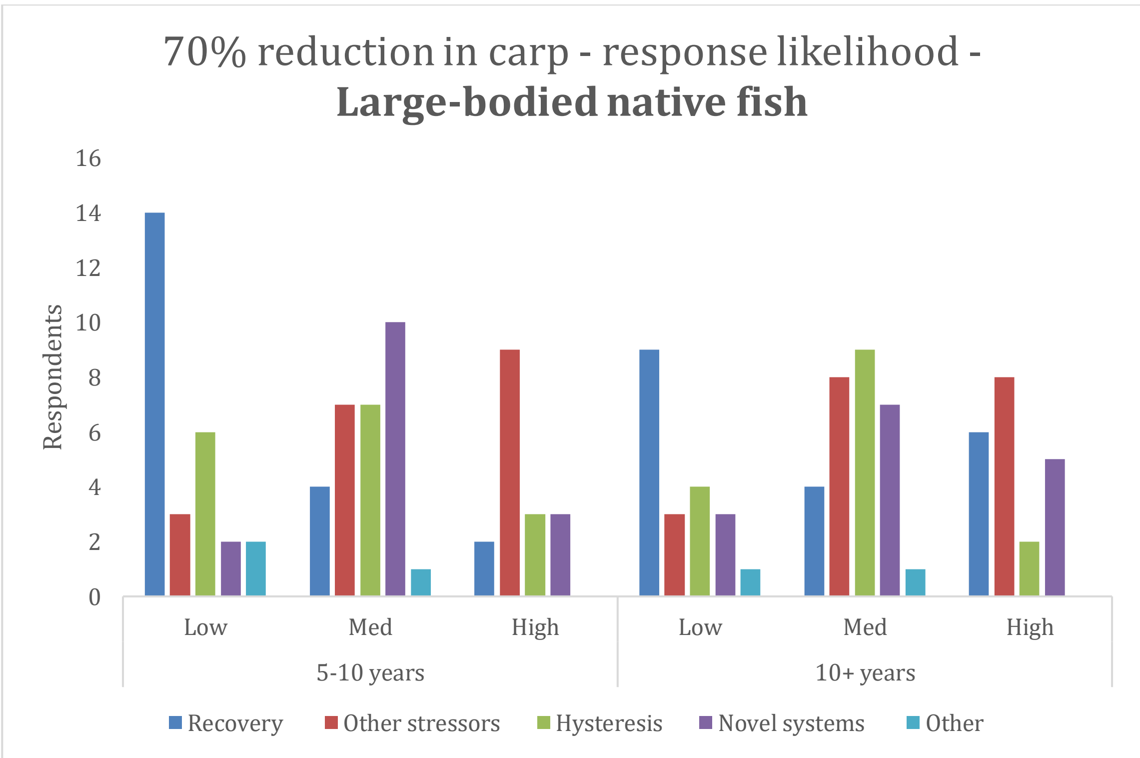


Figure 13. Likely ecosystem responses of large-bodied native fish to 70% reduction in carp over the medium and long-term.

Summary of comments: large-bodied native fish

Survey participants were asked to comment on what factors represented the greatest risks or contributed most to their uncertainty. These are summarized below, and all comments are provided in Appendix 5: Survey comments.

- Response of other alien fish species is largely unknown and reduction in carp biomass could potentially favour alien fish species.
- Not enough is known about the relative roles of other stressors that are likely to limit any true recovery.
- Capacity of native fish to recover may be a limiting factor to recovery.
- What the already stressed systems will do in response is difficult to predict.
- Responses of native fish will depend on ecosystem type.
- Lagged responses may be expected.
- Not enough know about the direct and indirect effects of carp on native fish.
- Small improvement may not be detectable given current monitoring of fish communities.
- Experts were more confident in recovery with significant (70%) reductions of carp but different fish species will respond differently.
- Uncertainty exists about whether carp will bounce back in numbers after initial reduction and how long numbers will remain suppressed.
- Absence of carp should produce detectable benefits but elimination on a broad scale is not likely.

A summary follows of the main issues commented on regarding the likelihood of recovery, the influence of other stressors, hysteresis and the development of a novel system.

Recovery

Large, long-lived threatened fish species will need a long time to recover from a very degraded state. Fish populations have a long way to bounce back and recovery would take many years and will be hindered by other stressors such as:

- Cold-water pollution
- Habitat loss
- Siltation and sedimentation
- Nutrient loadings
- Connectivity and barriers to fish passage
- Increased water extraction and flow regulation / altered flow regimes / flow diversions
- Climate change and reduced water availability.

Because broad-scale carp eradication is generally impossible the reduction of carp biomass is an ongoing cost. Will future funding be committed to this ongoing cost?

Other stressors

Carp are only one stressor and many more problems need to be addressed to see broadscale ecosystem recovery. While carp eradication may result in some recovery towards ecological objectives it will be limited by other stressors (listed above) and the already low standing-stocks of breeding fish. Other alien fish are also major stressors on native fish populations e.g. Redfin, goldfish. A confounding factor is climatic change, which may mask any carp-dependent responses.

Hysteresis

Hysteresis effects are unknown territory and the recovery trajectory will almost certainly not be the opposite to what occurred during degradation given how altered the aquatic ecosystems are now. Lag effects are expected but given the system has changed in so many ways it is highly unlikely to return to its 'natural' state. A resurgence of Redfin may result in development of an alternative stable state.

Novel system

Carp reduction will not reverse extinctions, thus by definition, the system is always moving into novel states. Almost certainly, in the medium to long-term, novel ecosystems will develop with their altered structure and function as a starting point. Further, other invasions of non-native animals are likely to occur in future. Novel systems are likely because some fish species recover well, and others do not, and other alien species may proliferate (e.g. Redfin in southern MDB). If Redfin again become abundant, they may predate heavily on juvenile native fish.

Small-bodied native fish

Responses concerning the effects of carp on small native fish were judged to be greatest (proportion of moderate to large and large) in wetlands (Figure 14). Experts were divided almost equally between a minor to moderate response and a moderate to large response for temporary rivers. Again, survey results showed high numbers of 'don't know' responses for estuaries but those that did express an opinion, most considered the small-bodied native fish would show a minor to moderately minor response to carp reductions. The patterns of predicted response were less clear for other ecosystems (Figure 14).

Small native fish responses to the 'do nothing' scenario (Scenario 1) were predicted to change little from current situation or worsen (with medium to very high confidence) with comments indicating that populations are likely to continue to decline without management interventions to relieve the stress of both carp and other stressors (Figure 15). A 70% reduction in carp biomass was predicted to lead to an improvement of between 30 -70% over the current situation (with med-low confidence) (Figure 15).

Most respondents believed there is a low probability of recovery following carp reductions in the medium-term (8 respondents) with more considering it a higher likelihood in the long-term (Figure 13). The most likely outcomes were that other stressors would constrain recovery in both the medium and long-term. Respondents also thought there was a medium to high likelihood that effect of hysteresis would influence responses and that a novel system may develop (Figure 16). Without other 'non-carp' mitigation actions to address the problem of native fish declines, there is little confidence amongst experts that native fish communities will significantly respond in a positive way. Additionally, alien species such as Redfin, Gambusia and Weatherloach may proliferate and occupy the habitat more effectively than native species, creating a novel system.

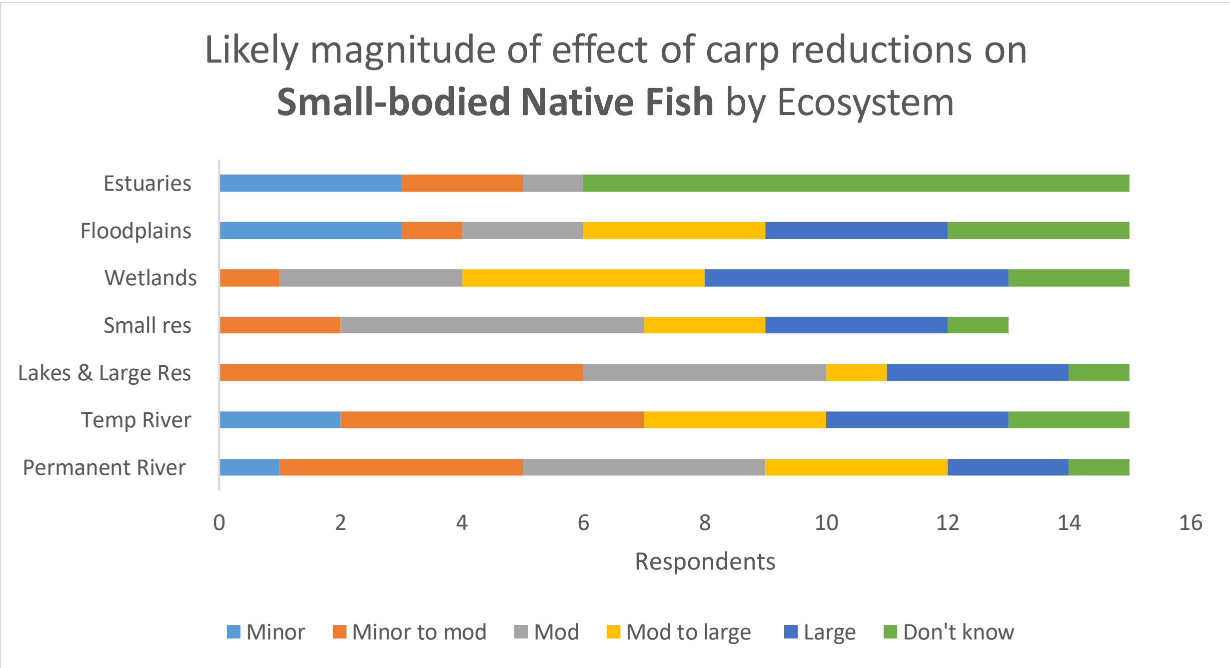


Figure 14. Likely magnitude of effect of carp reductions on small-bodied native fish by ecosystem.

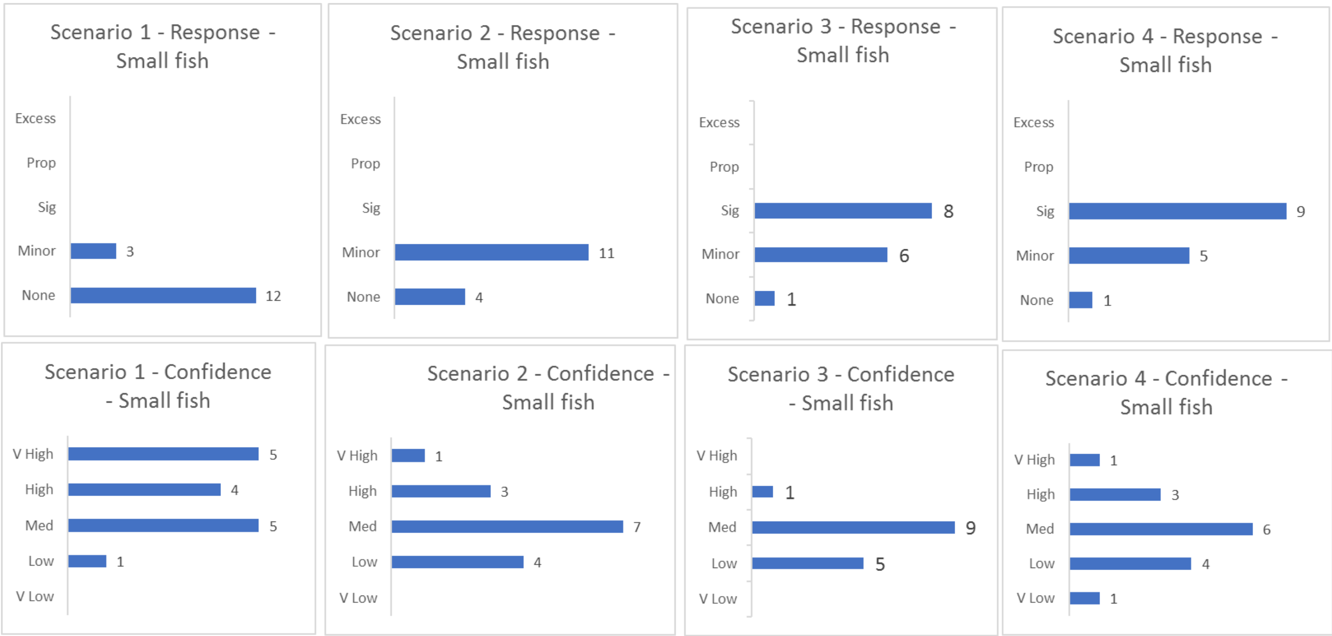


Figure 15. Likely response of small-bodied native fish under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

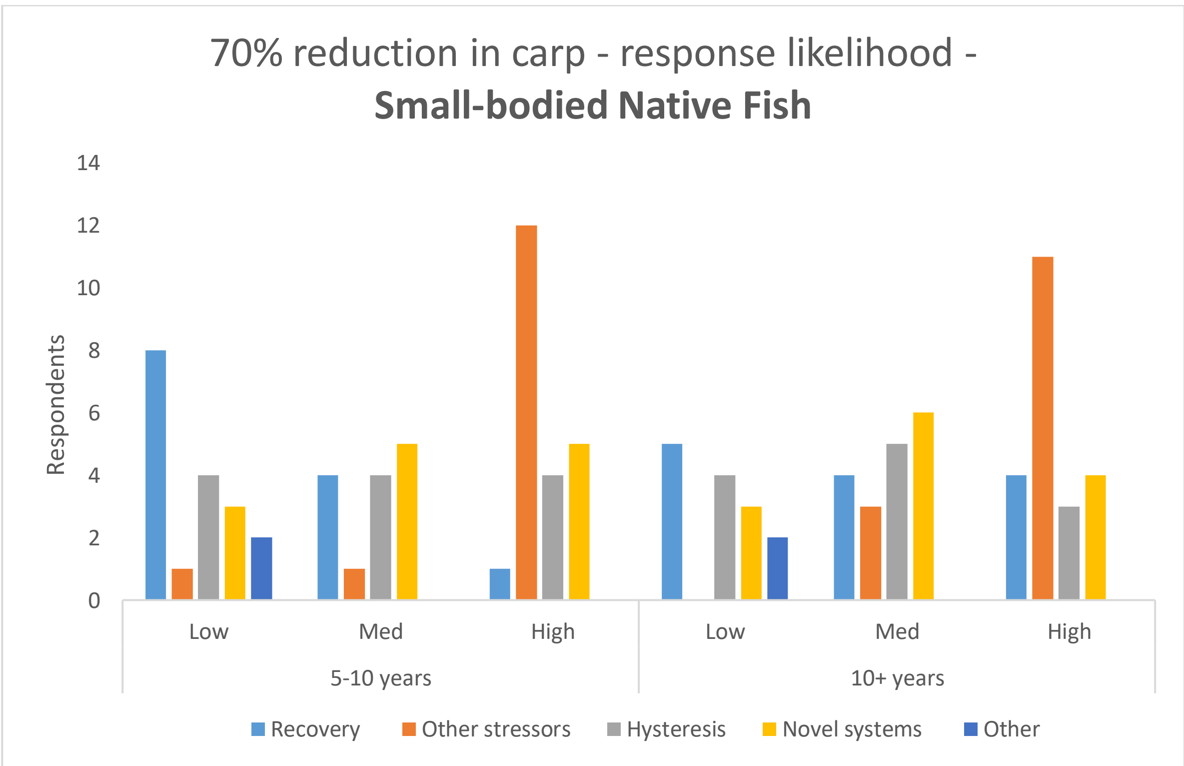


Figure 16. Likely ecosystem responses of small-bodied native fish to 70% reduction in carp over the medium and long-term

Summary of comments: small-bodied native fish

Survey participants were asked to comment on what factors represented the greatest risks or contributed most to their uncertainty. All comments are provided in Appendix 5: Survey comments. A summary of the key influencing factors is provided below.

Recovery

The short life cycles of small fish could mean rapid recovery of small-fish populations in suitable habitats. In some areas, the macrophyte communities will need to recover before small-bodied native fish can recover, so there will be a lag in response. However, the continued decline of small-bodied native fish is a high likelihood because of the other active stressors in the system. Uncertainty remains about how much effort will be directed at mitigating other stressors such as (not necessarily in order of importance):

- cold-water pollution
- alien species
- habitat loss
- barriers to fish passage / fragmentation
- siltation
- increase water extraction and flow regulation / regimes / diversions / wetland drainage
- climate change

The effectiveness of mitigation is uncertain and captive breeding and stocking of small-bodied species may yield better results than it does for large-bodied species, but capacity for this option (hatcheries, funding) is severely limited by the cost. Furthermore, some species are already extinct. If a system without carp favours a resurgence of Redfin, then small-bodies native fishes may be in worse trouble than with carp.

Other stressors

May see some recovery towards ecological objectives but recovery will be limited by other stressors as listed above (which may pose a greater problem than do carp) and the already low standing stocks of fish. Other stressors may mask any carp-dependent responses. Other alien fish are also major stressors on native fish populations e.g. Redfin that may exert predation pressure on small-bodied native fish.

Hysteresis

The recovery trajectory will almost certainly not be the opposite to what occurred during degradation given how altered the aquatic ecosystems are. Lag effects are expected but given the system has changed in so many ways it is highly unlikely to return to its 'natural' state. A resurgence of Redfin may result in an alternative stable state developing.

Novel system

Some change in fish community composition is likely, but rather unpredictable, which over time may extent to the development of a novel ecosystem.

Fish (other)

Five experts identified as having expertise in fish other than native fish. These included salmonids, carp and introduced species in general. Across ecosystem types, responses suggested that carp's greatest effects on fish other than natives would occur in reservoirs and permanent rivers, and the effects in estuaries minor or unknown (Figure 17).

Forecasts for all scenarios were associated with low to medium confidence, but like responses for the native fish, doing nothing would maintain the status quo and larger reductions in carp were associated with larger responses (Figure 18).

The likelihood of recovery in the medium term received three responses saying there was low and one saying there was medium likelihood. There was no clear consensus in terms of recovery in the long-term. One respondent nominated a highly likely effect of other stressors influencing the response (Figure 19). Other stressors may create conditions that favour alien species, and they may fare better than native species even if carp are removed, Thus, the development of a novel ecosystem following carp reductions is considered a possibility in the long-term (medium to high likelihood with low-med confidence).

One respondent commented that they did not know of any evidence that carp reductions will give native fish better chances of recruitment than any other alien species in the system. Thus, it is important to consider the implications of carp reductions on other alien species, and possibly also translocated fish species. One expert considered that the total recovery of Redfin populations is probably unlikely because of the EHN disease now being prevalent in Redfin populations. However, other stressors may create conditions that favour alien species, which may fare better than native species even if carp are removed. Other alien fish, such as Redfin, are a major stressor on native fish populations and if their abundance increased it may exert predation pressure on small native fish.

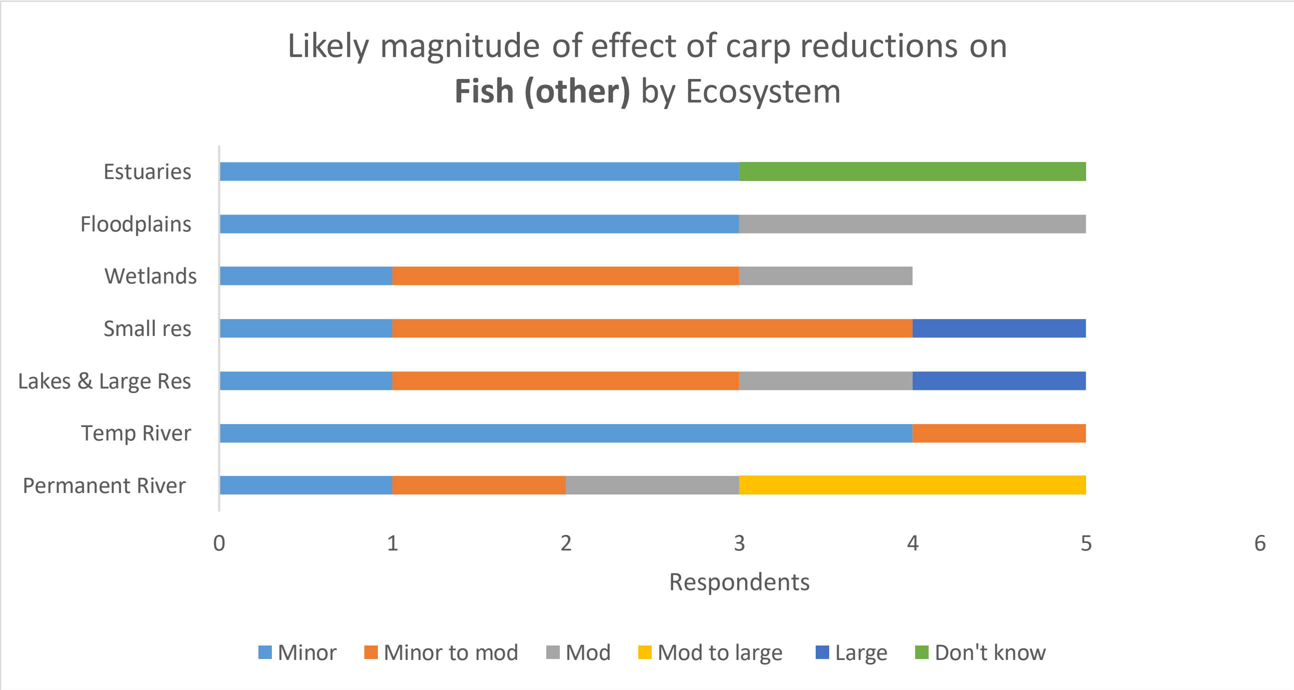


Figure 17. Likely magnitude of effect of carp reductions on fish (other) by ecosystem.

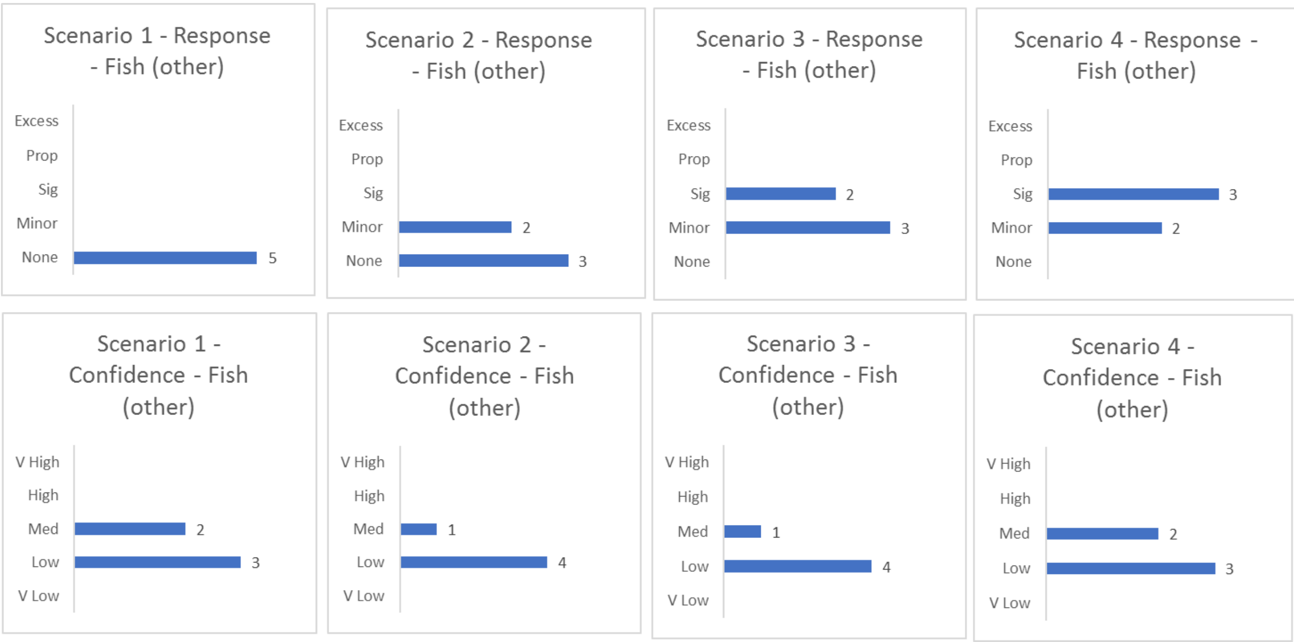


Figure 18. Likely response of fish (other) under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

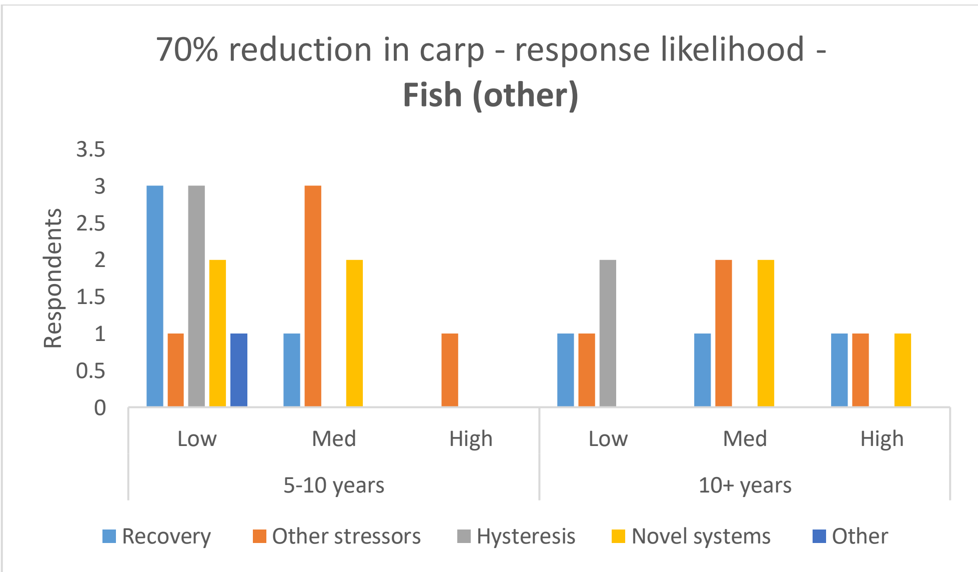


Figure 19. Likely ecosystem responses of fish (other) to 70% reduction in carp over the medium and long-term

Emergent macrophytes

The relative effects of carp on emergent macrophytes in different ecosystem types were assessed as being greatest (moderate to large) in wetlands and least (low and low-moderate) in temporary rivers, and minor or unknown in estuaries (Figure 20).

Under a 'do-nothing to reduce carp' scenario experts where confident (med-very high) that the macrophyte situation would remain on the same trajectory or worsen (Figure 20) and the predictions were similar with only 25% reduction in carp. Experts predicted (with med confidence) that greater decreases in carp would be associated with increased response from emergent macrophytes but respondent's confidence decreased in the higher carp reduction scenarios (Figure 21). At the Albury workshop, the two macrophyte experts concluded that effects on emergent macrophytes would be of less magnitude than that on submerged macrophytes because emergent plants often have rhizomes that are resistant to carp disturbance and seed dispersal is often aerial. This may suggest that experts are less confident about the effects carp removal on emergent plants and how these effects vary among species, and therefore may have exercised more caution in making predictions.

Very few responses, including recovery of emergent macrophytes, were rated as highly likely under a 70% carp reduction scenario (Figure 22). Any recovery is expected to be slow initially, thus the low likelihood of responses in the medium-term and generally still low to medium in the longer-term (Figure 22).

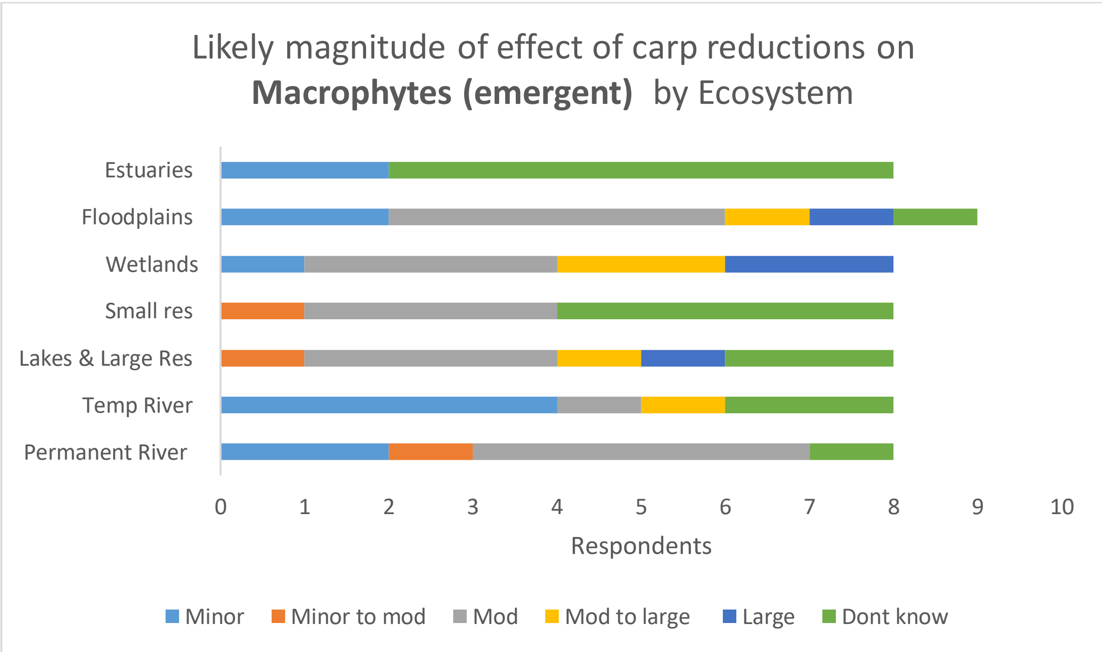


Figure 20. Likely magnitude of effect of carp reductions on emergent macrophytes by ecosystem.

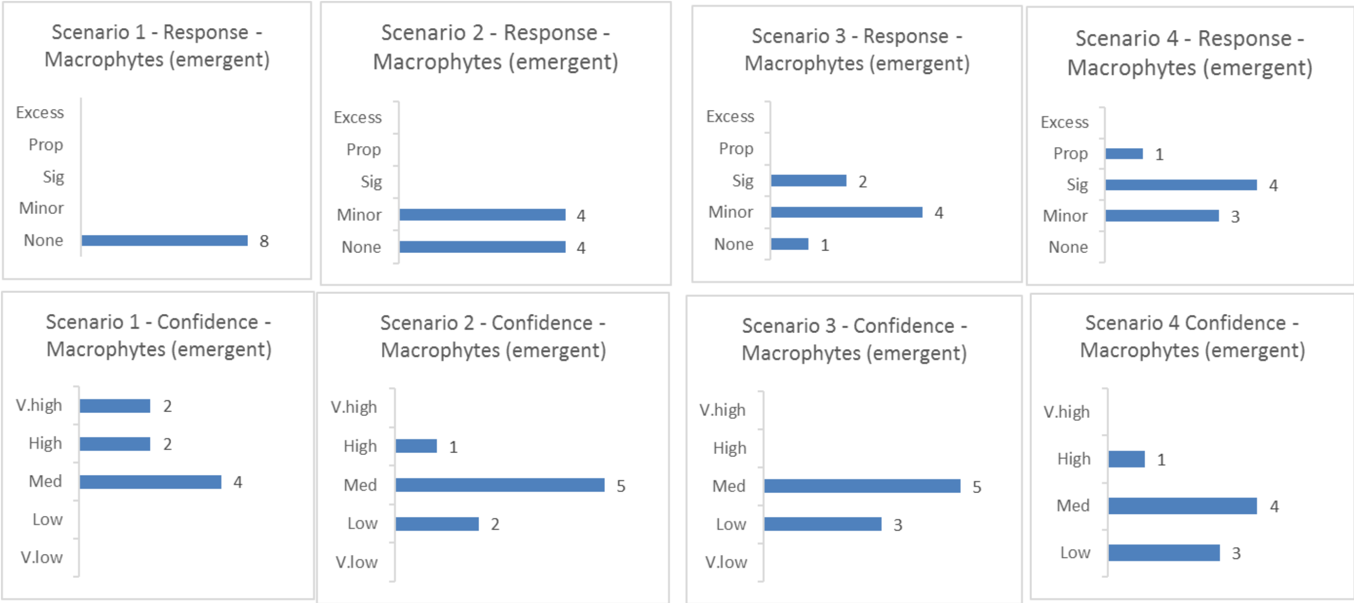


Figure 21. Likely response of emergent macrophytes under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

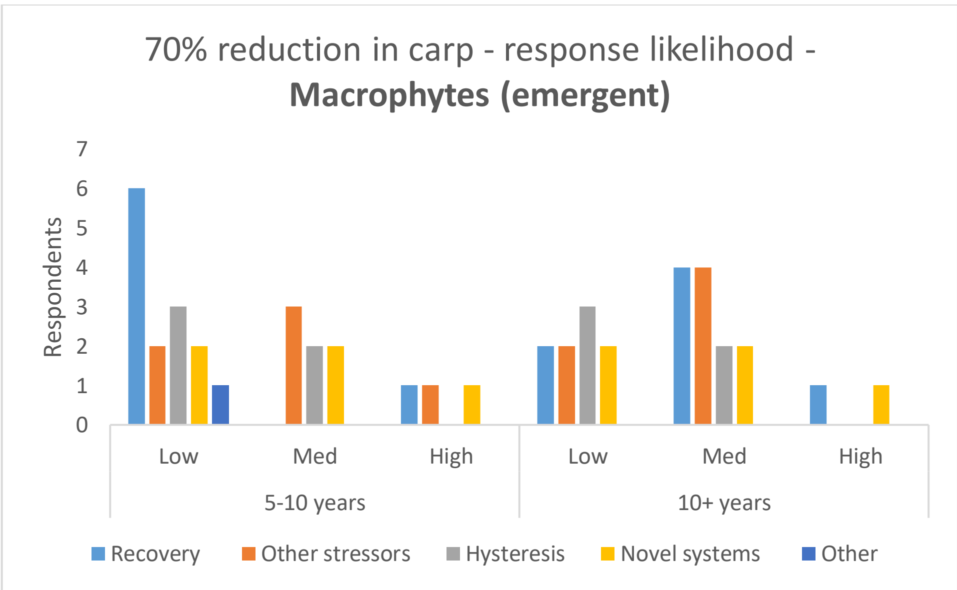


Figure 22. Likely ecosystem responses of emergent macrophytes to 70% reduction in carp over the medium and long-term.

Submerged macrophytes

The relative effects of carp reductions on submerged macrophytes in different ecosystem types were assessed as being greatest (moderate, mod-large & large) in wetlands, floodplains, and permanent rivers, and least (low and low-moderate) in temporary rivers, and largely unknown in estuaries (Figure 23). Opinion was divided on the effects of carp in permanent rivers spanning minor (2 responses), moderate (3 responses) and moderate to large (3 responses).

Under a ‘do-nothing to reduce carp’ scenario experts predict that the situation for submerged macrophytes would remain on the same trajectory or worsen (Figure 24) and experts emphasise that other stresses also contribute to the decline of macrophytes. One expert commented that under a 25% carp reduction scenario, Carp numbers would recover quickly thus macrophytes would probably see very little response in macrophytes. Experts predict (most with medium to high confidence) that submerged macrophytes would respond in a significantly positive way with significant decreases in carp (Figure 24).

Most respondents predicted that recovery of submerged macrophytes under a 70% carp reduction scenario had low likelihood in the medium-term and hysteresis, effects of other stressors and the development of a novel system had greater likelihood (medium) (Figure 25). However, the likelihood of recovery increased to medium in the long-term (Figure 25) but the other factors are still likely to influence that recovery. As with emergent macrophytes, very few responses were rated as highly likely (Figure 25).

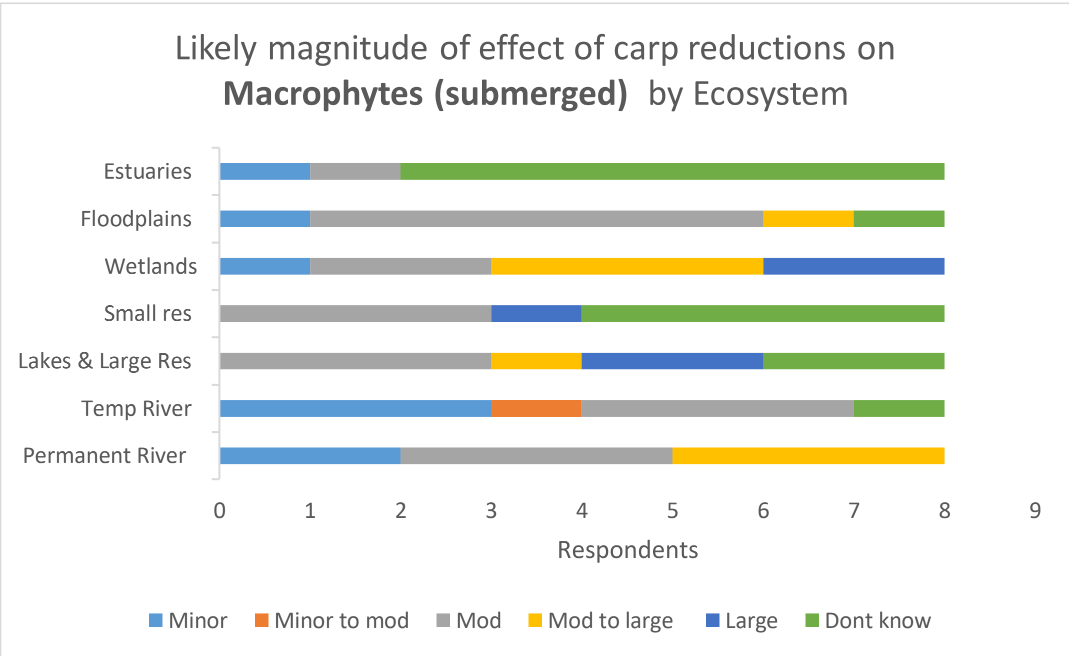


Figure 23. Likely magnitude of effect of carp reductions on submerged macrophytes by ecosystem.

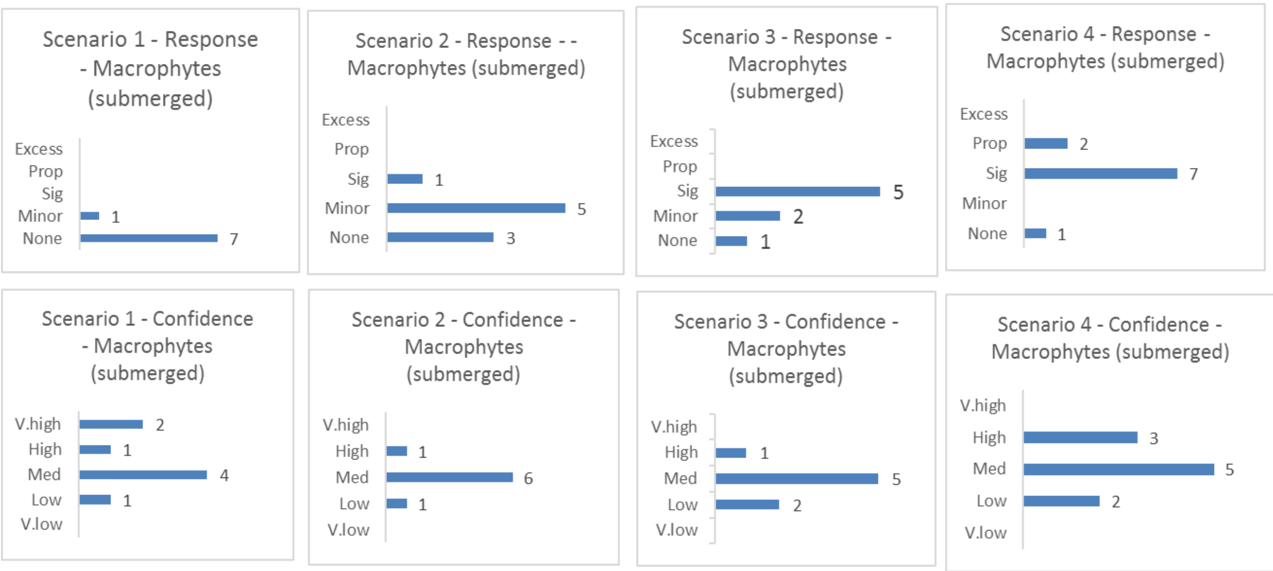


Figure 24. Likely response of submerged macrophytes under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

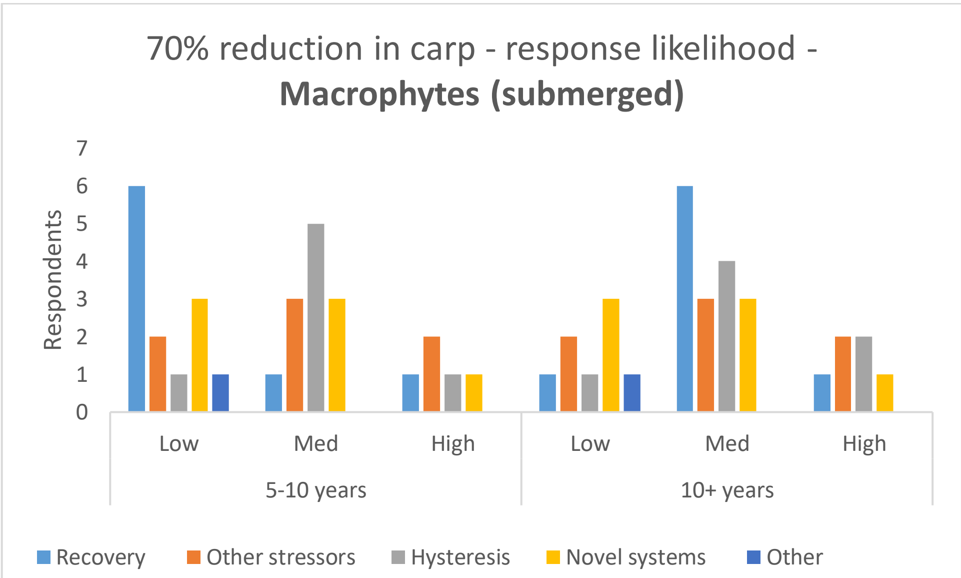


Figure 25. Likely ecosystem responses of submerged macrophytes to 70% reduction in carp over the medium and long-term.

Summary of comments: macrophytes

Recovery and other stressors

Some caveats around any prediction of recovery are that changes may be short-term if carp numbers recover and the presence of other stressors will determine recovery. For example, alien species of submerged aquatic plants (e.g. Elodea) may expand to occupy the habitat more effectively than native plant species. Recovery of emergent and submerged plants will be linked to the availability of propagules and the ability to disperse. The required connectivity must also exist, and the recovery timeframes will be long.

The ability to recover will vary significantly across river-floodplain systems. Comments are based on a large spatial scale in general. The opportunities for recovery on small spatial scales are likely to be high. Any recovery is expected to be slow initially and will depend on site condition prior to carp removal. Carp numbers may recover quickly after an initial knock down and if so, this will limit macrophyte recovery. A large reduction in carp would be needed to get a response in the macrophytes. If carp reductions are associated with improved water quality, it should promote germination and growth. Facilitating macrophyte recovery with revegetation and seed bombing is likely to help (see all comments in Appendix 5: Survey comments). Emergent plants are considered more robust than submergent, so emergent plants are probably not affected by carp to the same degree. Plants are affected by numerous other stressors:

- flow modification
- connectivity / fragmentation
- habitat modification
- climate change / water availability
- other disturbances e.g. pigs, cattle, horses, sheep, waterbirds, landuse, runoff climate
- poor water quality

Novel system

There are alien species (e.g. Elodea) that may capitalize on the reduction in carp biomass and affect the response.

Hysteresis

As noted above, the condition of the site will have an influence on the response and issues such as the condition of the sediments and associated seed bank may affect recovery of submerged plants. This may be exacerbated if the historical sources of seeds have also been removed through fragmentation. Revegetation and direct seeding can overcome these issues, however, if they are widespread the costs will be significant.

Macroinvertebrates

Participants varied in their responses regarding the magnitude of effect of carp reductions on macroinvertebrates as a function of ecosystem type, which emphasizes the context dependency of ecological responses. However, standing waterbodies including reservoirs and wetlands were thought to experience the greatest effects, while rivers, both permanent and temporary, had the largest number of minor to moderate effect nominations. Effects on macroinvertebrates in estuaries was largely unknown or minor (Figure 26).

As with other attributes, predictions for macroinvertebrates were for little charge or worsening of the current situation (with confidence ranging from low to very high) without strategies to control other stressors as well as carp (Scenario 1) and similar for scenario 2 (25% reduction in carp) (Figure 27) with comments that macroinvertebrate communities would continue to show stress (Appendix 5: Survey comments). Predictions were for between 30-70% improvement in macroinvertebrate communities over the current situation (with confidence that ranged from low to high) if control strategies could reduce carp biomass by >70% (Figure 27).

Most respondents predicted that recovery of macroinvertebrate communities under a 70% carp reduction scenario had medium likelihood in both the medium and long-term but the other factors like effects of other stressors, hysteresis and the development of a novel system are still likely to influence that recovery. Very few responses were rated as highly likely (Figure 28).

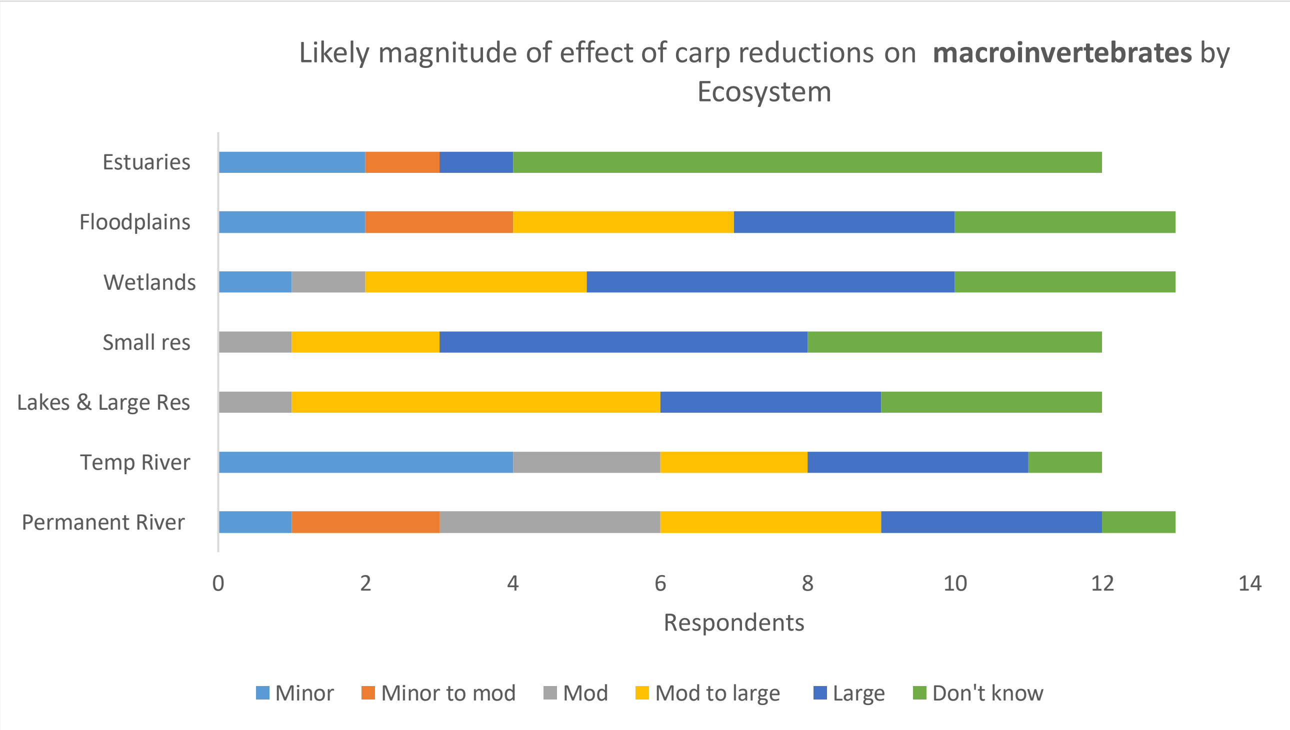


Figure 26. Likely magnitude of effect of carp reductions on macroinvertebrates by ecosystem.

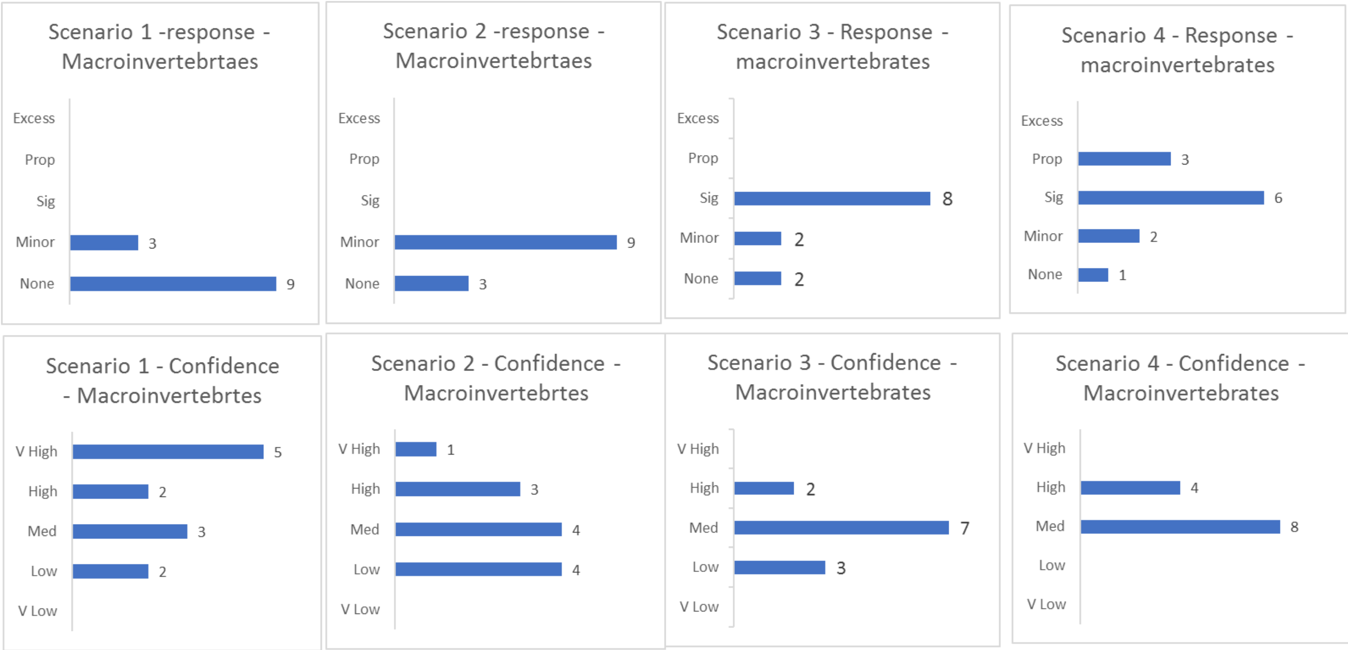


Figure 27. Likely response of macroinvertebrates under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

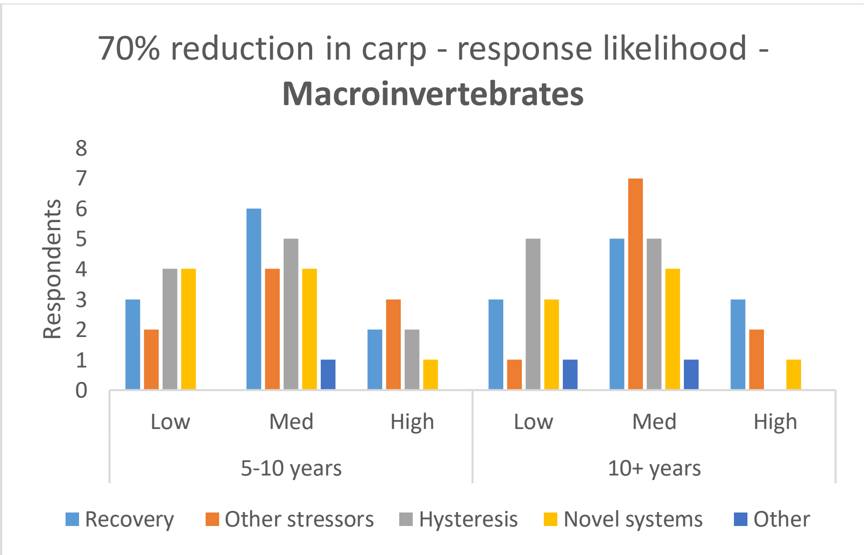


Figure 28. Likely ecosystem responses of macroinvertebrates to 70% reduction in carp over the medium and long-term

Summary of comments: macroinvertebrates

Recovery and other stressors

Many Australian macroinvertebrates disperse fast and can recolonize quickly, but response will vary with ecosystem type. However, experts commented that carp are not the only stressor in the system and the effects of multiple other stressors such as agriculture and urban stressors will also determine recovery. Uncertainty was expressed regarding the sustained reduction of 70% of carp, which would be needed to expect a long-term ecological response. Another commented that the recovery trajectory will depend on the colonization sequence, and those with very limited dispersal ability would require active intervention to aid recovery (*Notopala* provided as an example).

Hysteresis and novel system

Adding to the uncertainty around predictions is a medium likelihood that the reduction of carp may lead to development of a novel system. An example was that other alien species may continue to hinder recovery of macroinvertebrate communities. Novel ecosystems are likely to develop over time in the complete absence of carp and recovery trajectory will depend on colonisation sequence.

Water quality

Ten respondents identified as experts in water quality, three specifying turbidity/suspended solids, dissolved oxygen, nitrogen, phosphorus, and water quality in intermittent / dryland rivers in particular.

Participants varied in their responses regarding the magnitude of effect of carp reductions on water quality as a function of ecosystem type, again emphasizing the context dependency of ecological responses (Figure 29). Water quality in wetlands was predicted to experience the greatest effects, while effects in estuaries was largely unknown or minor (Figure 29).

Experts predicted no charge over the current situation (with high to very high confidence) without strategies to control carp and other stressors (Scenario 1) (Figure 30). Predictions were for between 30-70% improvement over the current situation (with med-high confidence) if control strategies could reduce carp biomass by >70% (Figure 30).

Placing these predictions within a broader context and adding to the uncertainty of recovery was the high to medium likelihood of other stressors influencing water quality responses (Figure 31). Experts commented that catchment soil properties, land use, history, suspended sediment residence time are strong influencing factors and the influence of general catchment erosion on water quality (turbidity) and is likely to continue to exert a strong influence even in the absence of carp.

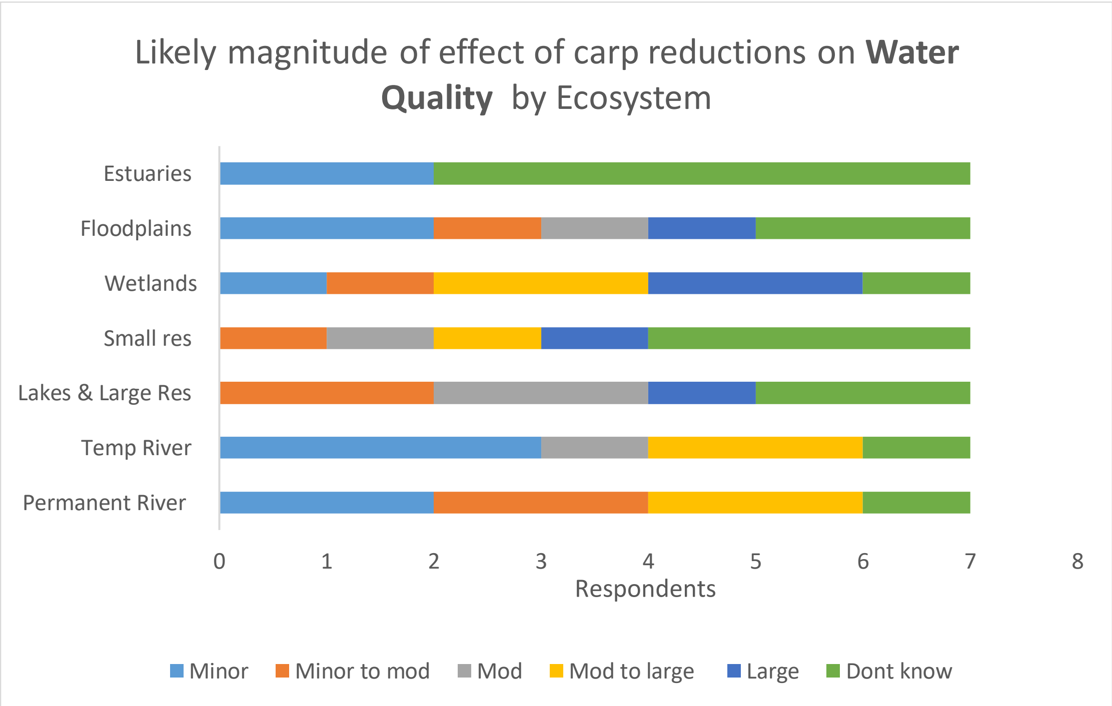


Figure 29. Likely magnitude of effect of carp reductions on water quality by ecosystem.

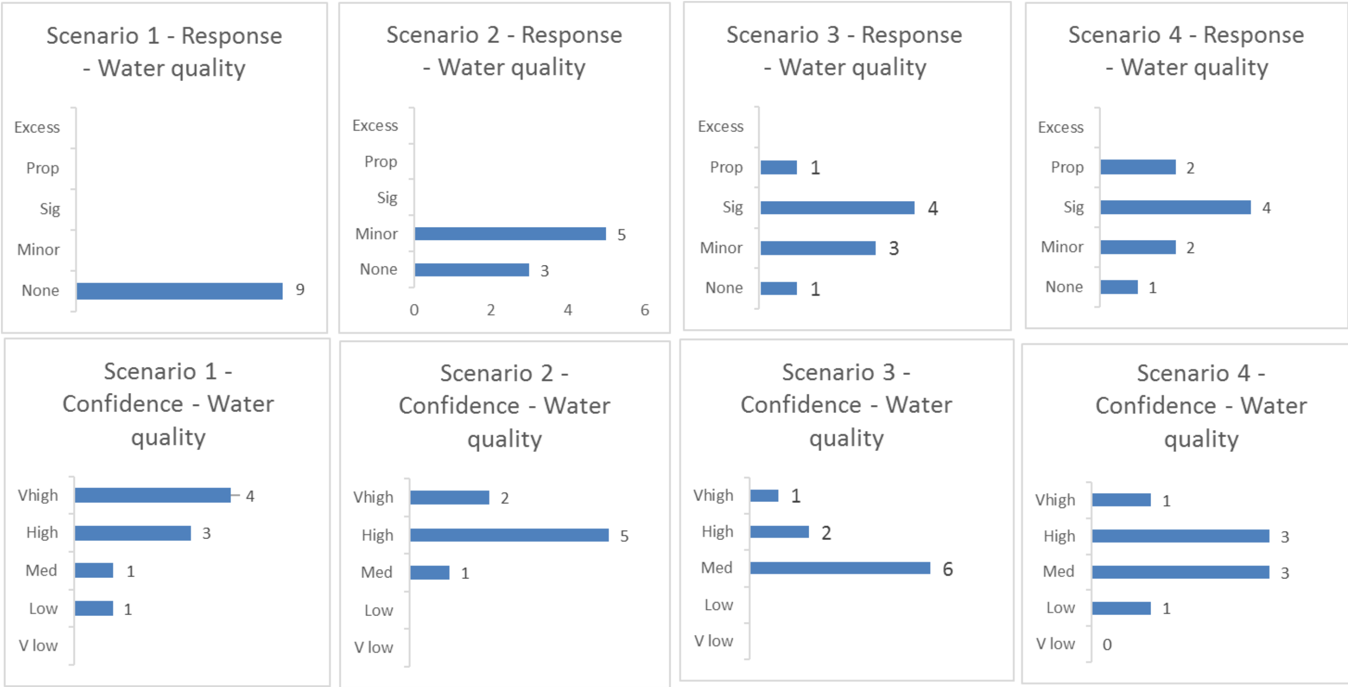


Figure 30. Likely response of water quality under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

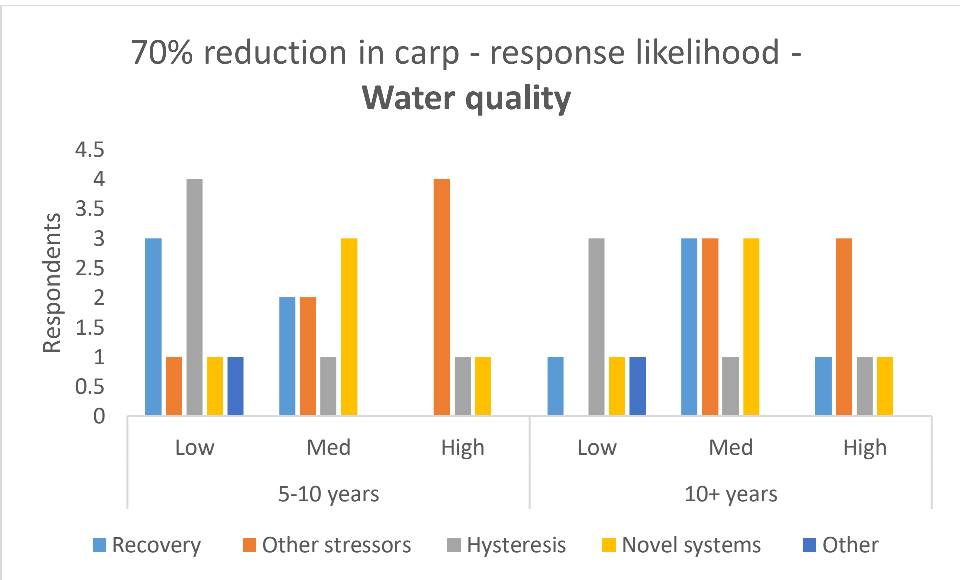


Figure 31. Likely ecosystem responses of water quality to 70% reduction in carp over the medium and long-term

Summary of comments: water quality

Recovery

Several comments related to different aspects of recovery including that it will take many years for macrophyte communities to recover in order to stabilise sediments, that recovery may occur only in some sections of rivers, that other stressors will limit recovery and that turbidity was already high in some places prior to carp introduction.

Other stressors

Several experts commented on the effect of other stressors on water quality, most notably the influence of catchment sources (e.g. from vegetation clearing in catchments) providing long-term increased nutrient and sediment loads. One comment related to the influence of highly flow-regulated sections and cropped agriculture on high levels of suspended solids.

Hysteresis and novel system

Altered channel morphology and loss of macrophytes may influence the recovery trajectory. Another comment posed that suspended sediment residence times were 1000's of years. This comment is partially supported by a study suggesting that a non-significant response of suspended sediments and chlorophyll a after biomanipulation may have been caused by hysteresis or feedback between biotic and abiotic factors (Thomasen and Chow-Fraser, 2012).

Herbivorous waterbirds

Up to seven respondents identified as experts on waterbirds, and of those, only four commented on the response of herbivorous waterbirds. Those four participants varied in their responses regarding the magnitude of effect of carp reductions on herbivorous waterbirds as a function of ecosystem type, emphasizing the context dependency of ecological responses (Figure 32). One respondent indicated a minor to moderate effects in estuaries whereas others did not know. These experts believed there would be a minor to moderate effect in permanent rivers and all varied in their response for temporary rivers. Standing waterbodies is where they predicted the greatest effect of carp reductions on herbivorous waterbirds.

All these experts predicted no charge to the current situation (with low to high confidence) without strategies to control carp and other stressors (Scenario 1) (Figure 33). They predict a minor response to 70% reduction in carp (with low to medium confidence) (Figure 33) stating that river regulation stressors, reduced overbank flows, and floodplain modification were major factors likely to influence recovery.

The likelihood of recovery under a 70% carp reduction scenario over the medium term was low but this increased to medium in the long-term (Figure 34). However, some also considered the likelihood of hysteresis and the effects of other stressors was high in both the medium and long-term.

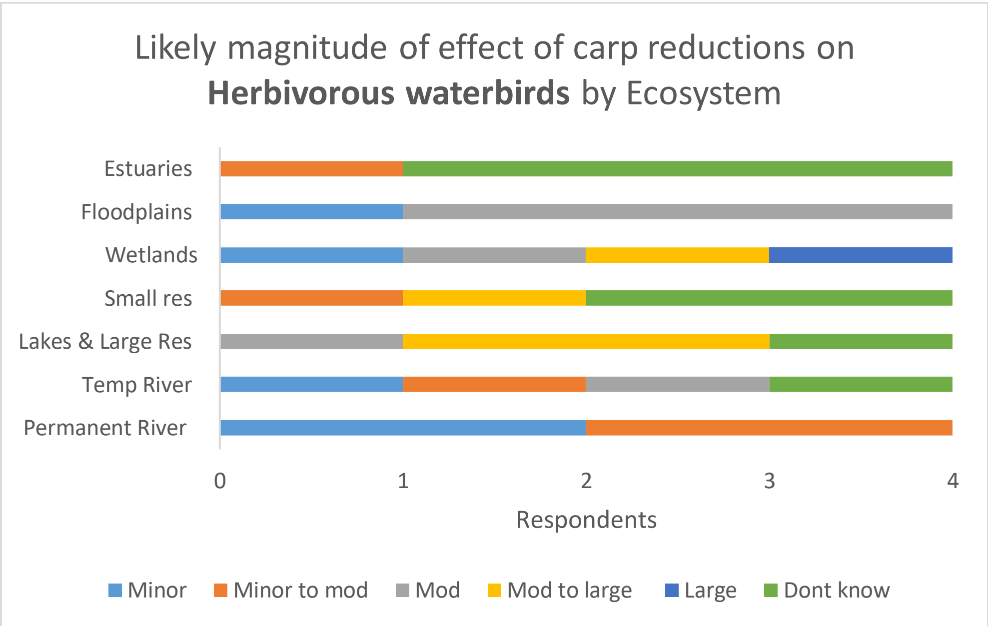


Figure 32. Likely magnitude of effect of carp reductions on Herbivorous waterbirds by ecosystem.

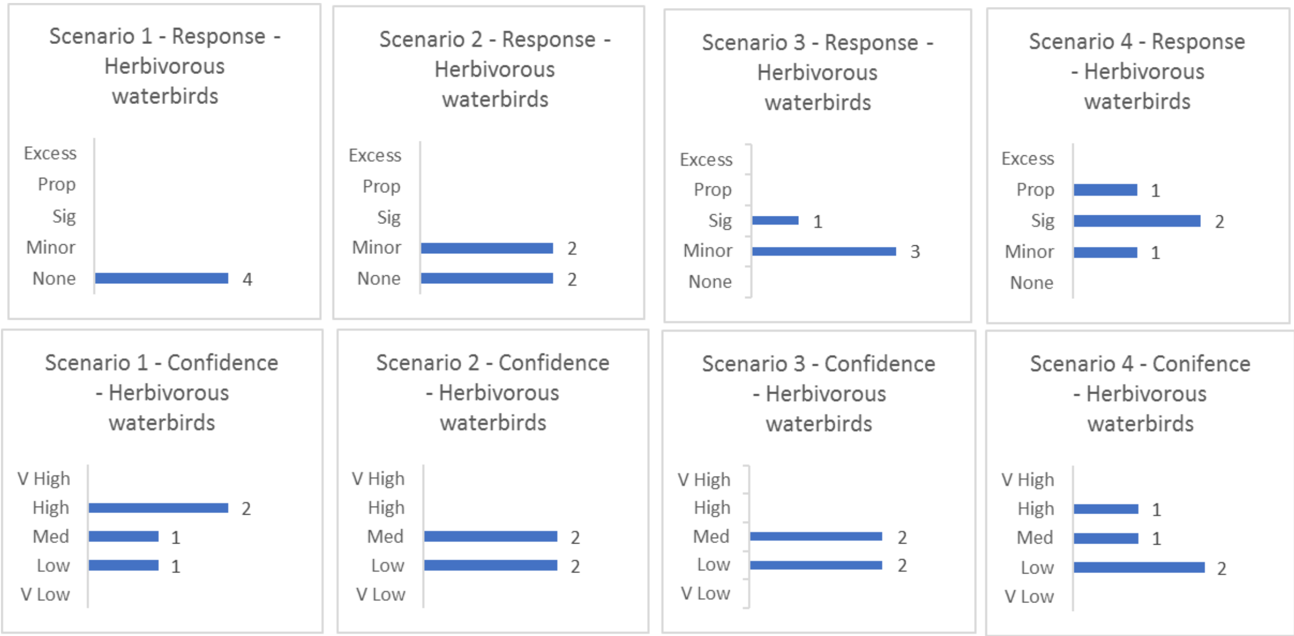


Figure 33. Likely response of herbivorous waterbirds under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

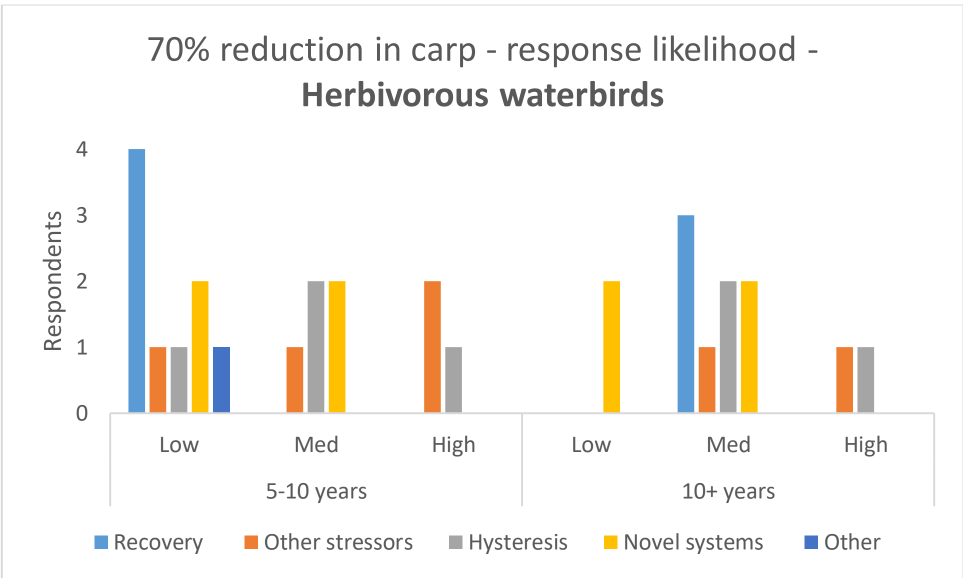


Figure 34. Likely ecosystem responses of herbivorous waterbirds to 70% reduction in carp over the medium and long-term

Piscivorous waterbirds

Up to seven respondents identified as experts on waterbirds, and of those, 5 commented (but not for all questions) on the response of piscivorous waterbirds.

Participants predicted no greater than a moderate response of piscivorous waterbirds to carp reductions in any ecosystem type, with floodplains and permanent rivers receiving the most nominations for a likely response (Figure 35).

The experts that participated in the survey predicted no charge to the current situation (with low to med confidence) without carp control strategies (Scenario 1) (Figure 36). They predict a minor to significant response (note this was a decline in waterbirds) with > 70% reduction in carp (with mainly low confidence regarding all scenarios) (Figure 36). They note that the risk to food resource for piscivorous waterbirds should be short term, unless native fish abundances do not increase.

The likelihood of recovery under a 70% carp reduction scenario over the medium term was low to medium but this increased slightly in the long-term (Figure 37). However, experts also considered the likelihood of hysteresis and the effects of other stressors was just as high or greater.

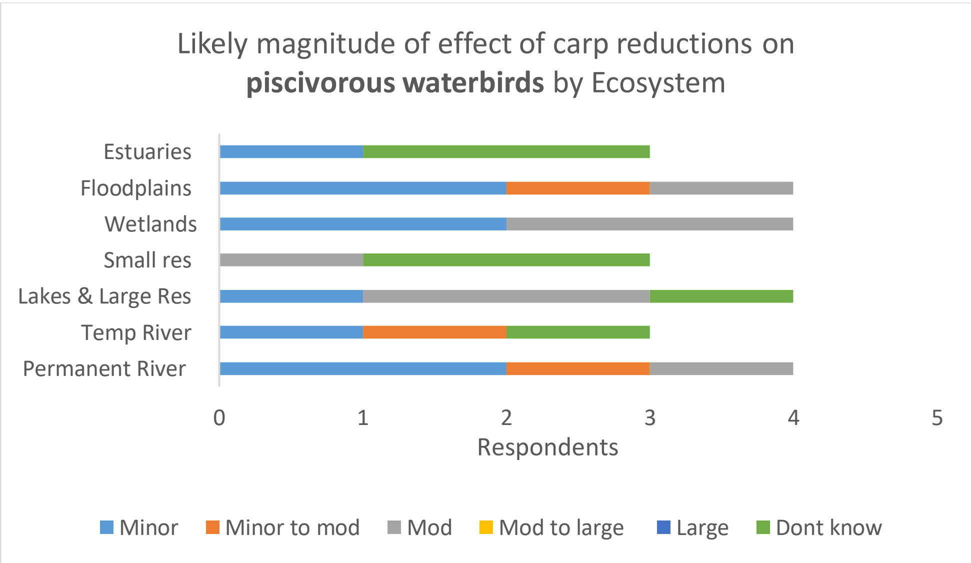


Figure 35. Likely magnitude of effect of carp reductions on piscivorous waterbirds by ecosystem.

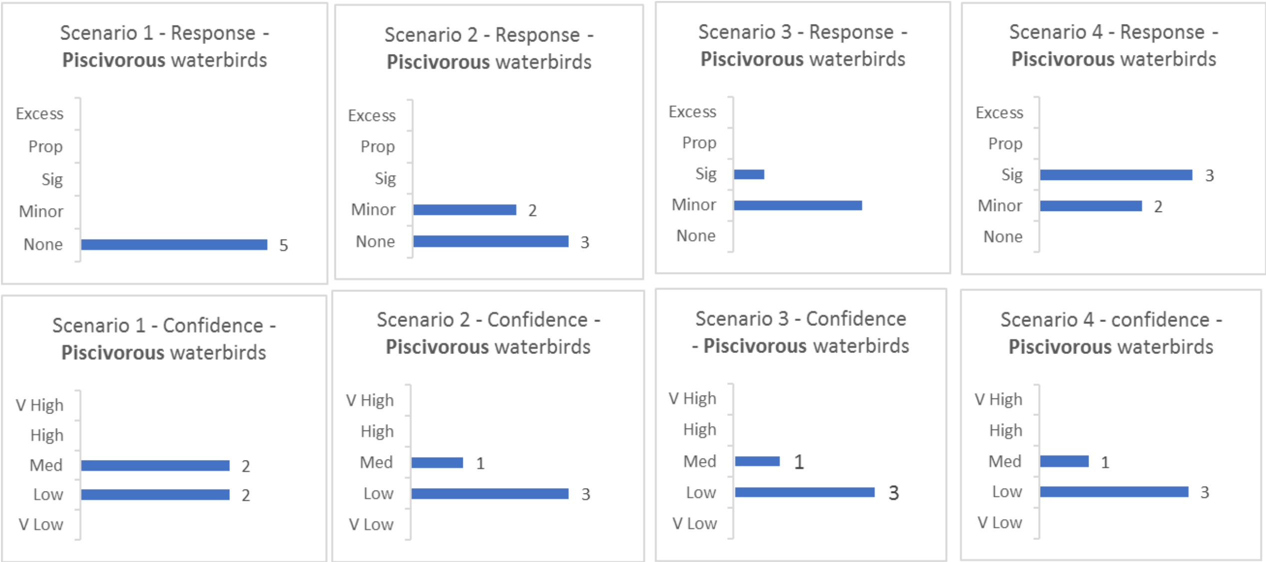


Figure 36. Likely response of piscivorous waterbirds under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

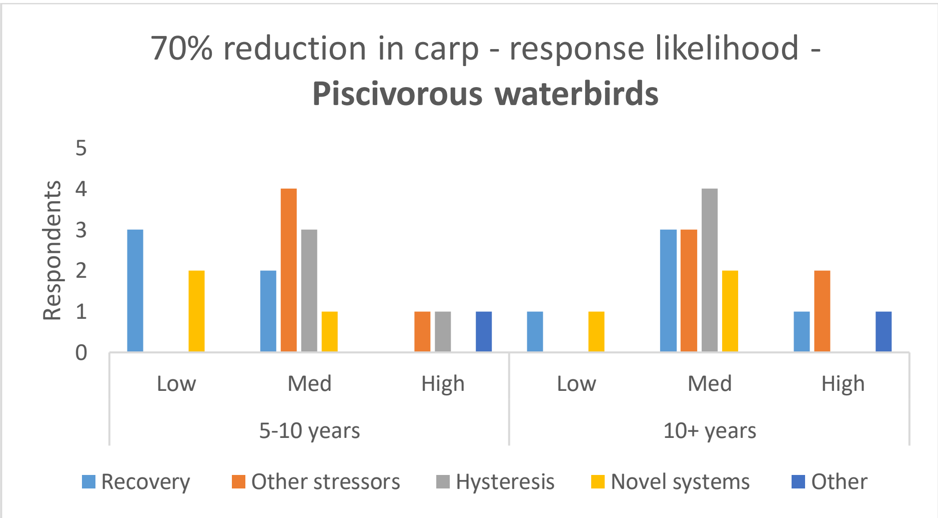


Figure 37. Likely ecosystem responses of piscivorous waterbirds to 70% reduction in carp over the medium and long-term

Summary of comments: waterbirds

<u>Recovery and other stressors</u>

Factors contributing the most to uncertainty were stressors associated with river regulation (e.g. less overbank flows and floodplain alienation) and uncertainty regarding adequate environmental flows. The actual effects of carp on herbivorous waterbird food sources is not well understood. While four experts predict a minor to significant decline for piscivorous waterbirds with > 70% reduction in carp, they note it should only be short term. The likelihood of recovery under a 70% carp reduction scenario over the medium term was low to medium but this increased slightly in the long-term because of a lag in the recovery of an alternative food supply (such as native fish). Thus, recovery would depend on increases in native fish abundances.

Amphibians

Seven respondents identified as experts on amphibians.

Participants varied in their responses regarding the magnitude of effect of carp reductions on amphibians as a function of ecosystem type (Figure 38) but four of the six respondents predicted moderate to large responses in floodplains and wetlands. Little was known about amphibians' responses in estuaries.

The experts that participated predicted no charge to the current situation (with confidence that ranged from low to high) without carp control strategies (Scenario 1) and this did not improve greatly with 25% reduction in carp (Scenario 2) (Figure 39). Most predicted a significant (30-70%) response with >70% reduction in carp (with confidence that ranged from low to very high) (Figure 39), with some predicting a greater response if carp were eliminated.

The predictions for the likelihood of recovery under a 70% carp reduction scenario ranged from low to high in both the medium and long-term (Figure 40). However, experts also rated the likelihood of hysteresis and the effects of other stressors similarly. However, there are other stressors and other exotic fish in the systems that might influence recovery for some species .

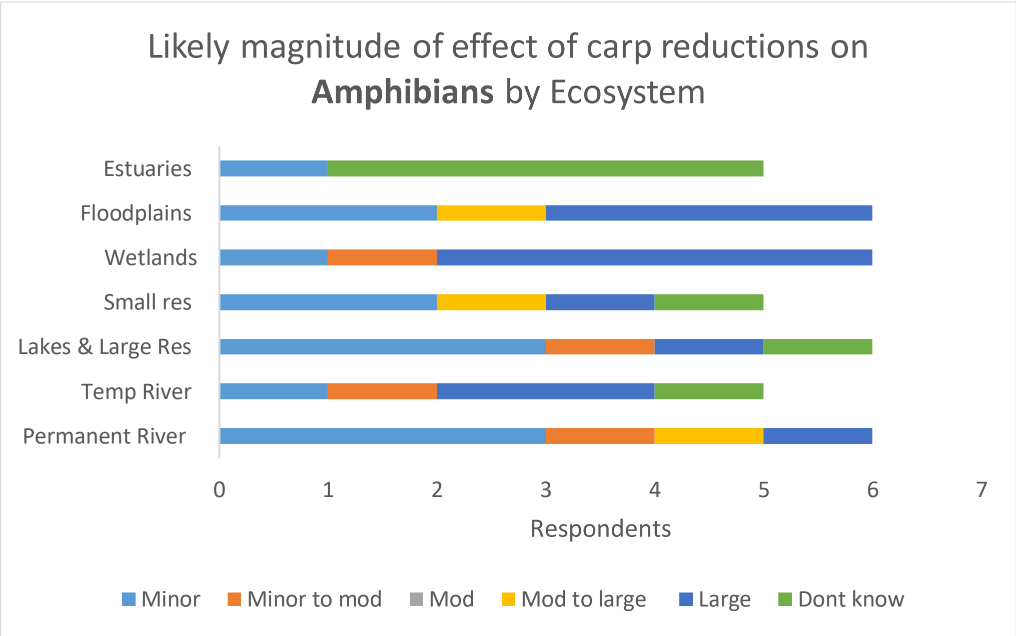


Figure 38. Likely magnitude of effect of carp reductions on amphibians by ecosystem.

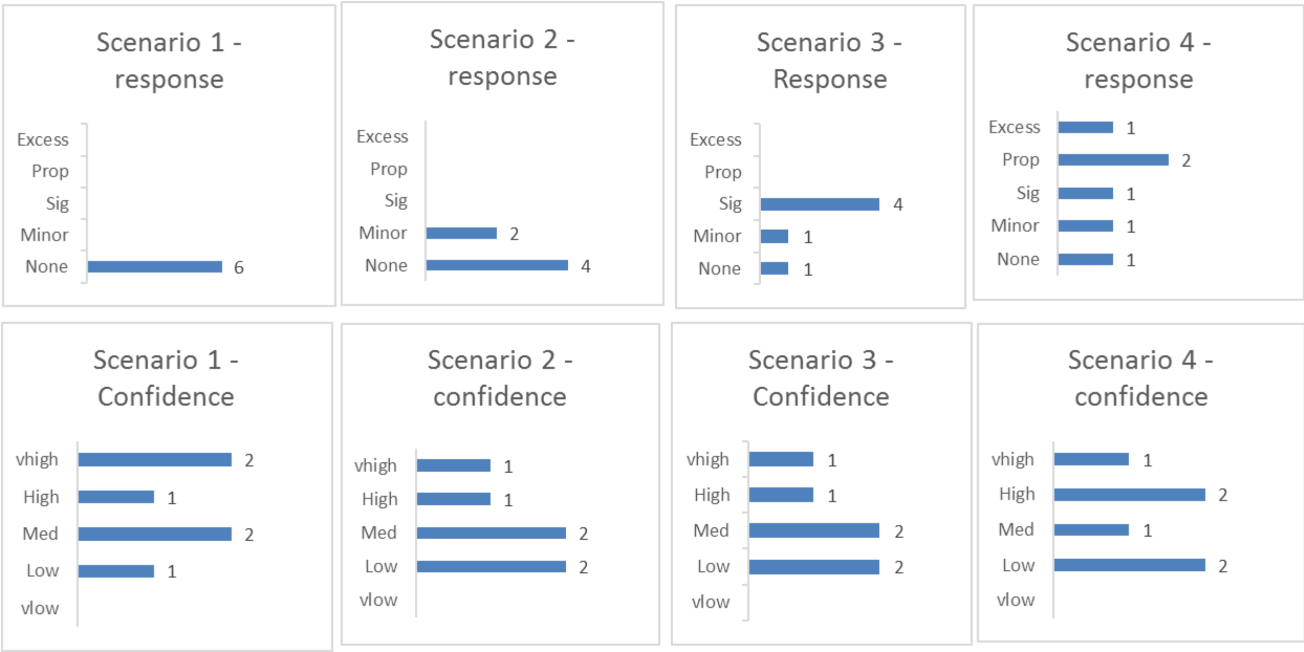


Figure 39. Likely response of amphibians under four different scenarios. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

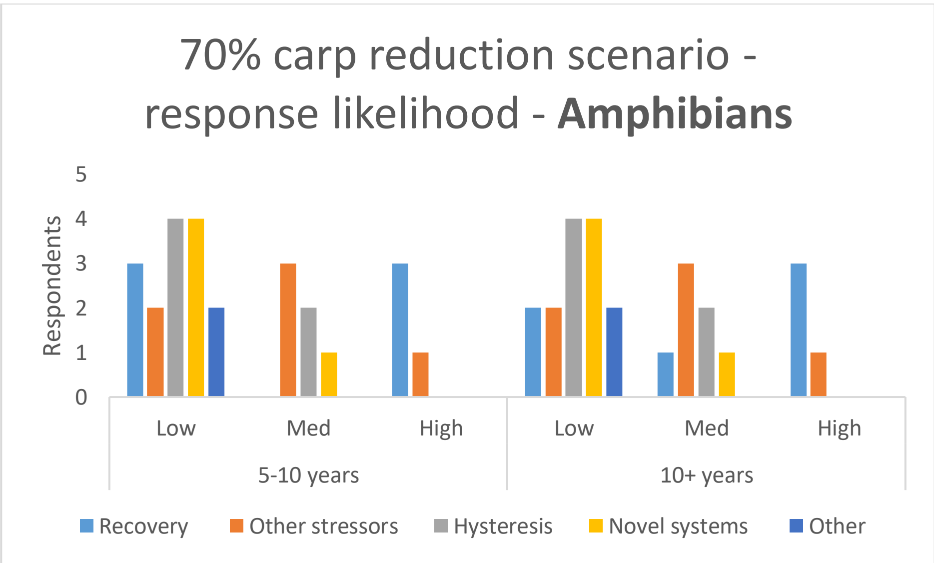


Figure 40. Likely ecosystem responses of amphibians to 70% reduction in carp over the medium and long-term

Summary of comments: amphibians

Recovery and other stressors

The lack of experimental data was noted as a factor contributing to uncertainty of a frog response. Threshold relationship are likely for some species, whereas others may exhibit a more linear response to decreasing carp abundance. Based on some carp exclusion trails in wetlands, a significant recovery might be expected for most frog species. The carp exclusion trails show large increases in tadpoles and adults over short timeframes. However, there are other exotic fish in the systems that might influence recovery.

Algae – phytoplankton, algae (attached) and zooplankton

Few responses were from the participants who identified as experts on the following ecosystem attributes: algae – phytoplankton (1), algae – attached (2) and zooplankton (1). Information that contributed to the conceptual models relied largely on causal pathways identified by other participants and the face-to-face workshop engagement.

As with other attributes, the participants varied in their responses regarding the magnitude of effect of carp reductions as a function of ecosystem type.

Comments: Regarding algae (attached), the quality of the environmental flows is a major contributing factor, as is high sediment loads, which pre-date carp.

Comments: Regarding zooplankton: water quality will remain poor under a do-nothing scenario. Other factors such as flow and climate will limit recovery.

The likely response under four different scenarios are tabled below. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp; scenario 3: 70% reduction in carp; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%) and the level of confidence in that assessment.

	Response - Phytoplankton					**Confidence**			
Scenario	None	Minor	Sig	Prop	Excess	Low	Med	High	V high
1	1							1	
2		1					1		
3		1				1			
4	1		1				1		1

	Response - Attached algae					**Confidence**			
Scenario	None	Minor	Sig	Prop	Excess	Low	Med	High	V high
1	1	1						1	1
2		1	1			2			
3			2			2			
4			1	1		1	1		

	Response - Zooplankton					**Confidence**			
Scenario	None	Minor	Sig	Prop	Excess	V.low	Low	Med	High	V.high
1	1									1
2		1				1				
3		1					1			
4		1					1			

Survey responses regarding the likely ecosystem responses to 70% reduction in carp over the medium and long-term.

Response of Phytoplankton to 70% reduction in carp	5-10 years			10+ years		
	Low	Med	High	Low	Med	High
Recovery		1			1	
Other stressors		1			1	
Hysteresis						
Novel systems						
Other						

Attached algae response to 70% reduction in carp	5-10 years			10+ years		
	Low	Med	High	Low	Med	High
Recovery	1		1	1		1
Other stressors		1			1	
Hysteresis	1			1		
Novel systems		1			1	
Other						

70% reduction in carp	5-10 years			10+ years		
	Low	Med	High	Low	Med	High
Recovery		1			1	
Other stressors		1			1	
Hysteresis						
Novel systems						
Other						

Literature Review and Evidence Synthesis

Aims and Objectives, Context and Agreement on the Question

In developing the question used to direct the synthesis, several factors were considered:

1. Ensuring that the findings represent a novel contribution to the literature – rather than a re-working of existing publications in this space
2. The utility of the findings to assist in informing management decisions (and managing risk)
3. Questions that are about cause and effect with a focus on the contextual variables influencing the relationship
4. Questions that avoid having to prioritize one environmental attribute (fish, macrophytes etc.) or aquatic ecosystem over another.

In considering the above, and with feedback from the NCCP project team, the following question was agreed:

"***What is the evidence for ecosystem effects from the removal of non-native and non-predatory freshwater fish?***"

The next steps involved describing important contextual factors to help identify published studies that were relevant to the question. Primary research that investigated the effects of non-native fish removal on ecosystem attributes were considered potentially relevant for the literature review.

The synthesis question will explore studies in the context of the elements shown in Table 3. These studies will include manipulation experiments such as fish eradication and exclusion. The literature review was not geographically constrained.

Table 3. Key elements of the study primary research question

Subject	Intervention	Comparator	Outcome
Common carp, other carp species such as Silver carp and grass carp and other functionally similar benthic feeding species.	Removal of fish from the freshwater ecosystem through poison, netting, electro fishing, exclusion barriers or drainage	Where carp or other fish have not been removed from the freshwater system. We did not include studies that compared the effects of varying densities or abundance of carp/other fish without removal	Observed effects (increase, decrease, change or no change) on native fish, macrophytes, macroinvertebrates, water quality, amphibians and algae from removal of carp or other functionally similar non-native fish.

The synthesis gathered evidence to explore the causal linkages between the removal of carp or other functionally similar benthic feeding species on freshwater ecosystem attributes. These attributes were identified in the conceptual models of how carp influence ecosystem attributes (see Figure 7 and Appendix 4: Conceptual models for biotic groups).

A set of sub-hypotheses were then developed to test the question:

Will the ecosystem recover following the removal of non-native and non-predatory freshwater fish?

Where recovery was measured as:

- An improvement in water quality (clarity, decrease in nutrients, fewer algal blooms)
- An increase in macrophyte biomass, abundance and taxa richness
- An increase in macroinvertebrate abundance, density and richness
- An increase in native fish abundance and richness
- An increase in amphibian abundance

We did not include the ecosystem attributes of zooplankton and waterbirds in this investigation because of the lack of direct linkages and because their response would be dependent on many other factors that would confound the effects of carp removal. Thus, the following were not considered:

- An increase (or return to previous) in zooplankton abundance
- An increase in waterbird abundance and richness

In addition to the existence of relationships, we were interested in the form of the relationship between carp (or similar) removal and ecosystem attributes and shifts in ecosystem states. Therefore, we explicitly investigated studies that described system recovery, hysteresis (resistance to recovery), generation of novel systems or interactions with other stressors.

Literature Review and Evidence Extraction

Search strategy protocol to guide the collection of evidence

The search method aimed to capture an unbiased, comprehensive and representative set of literature within the constraints of the project resources available. Published and unpublished literature were sourced. Search sources included published peer-reviewed literature and web-based gray literature, in a range of sources including universities, government and non-government organizations.

Search terms

Subject: "Common carp" or "Grass carp" or "Silver carp" "Bighead carp" or "Fish*" or "Carp" or "invasive species" or "exotic species" or "introduced species" or "nonnative species" or "non-native species" or "alien species" or "non-indigenous species,"
Intervention: "remov*" or "extraction"
NB: At a later stage in the search the terms "biomanipulation" and "exclusion" were also used

Comparator: Studies that compared sites with no carp or alien fish removal (but note this was used as a control in some studies)
Outcome: "impact*" or "effect*" or "consequence*" or "change*" and "Freshwater" or "ecosystem" or "lake" or "wetland" or "river" or "creek" or "reservoir" or "estuary"

Search strings

The search strings developed were broad in nature and aimed to find any studies that investigated the relationships between fish removal and impacts or effects on freshwater ecosystems rather than conducting a series of more specific searches for each ecosystem attribute i.e. conducting specific searches for macroinvertebrates and macrophytes and native fish etc.

1. “Carp remov*” AND (effect OR impact OR change)

2. "freshwater fish" AND removal OR control AND "non-native" OR "non-predatory" AND (effect OR impact OR consequence OR change)

3. ("non native" OR non-native) AND fish AND (remove OR eliminate OR reduction) AND (impact OR result OR consequence OR outcome OR change)

4. Freshwater AND “non-native fish” AND (removal OR control)

5. carp OR fish AND (extraction OR biomanipulation) AND removal AND impact

Study inclusion and exclusion criteria

A number of inclusion and exclusion criteria were used to ensure that study relevance is fit for purpose according to the nature of the synthesis question and the type of evidence most appropriate in answering the question.

Relevant subjects

- Freshwater fish
- Benthic feeding fish including all carp species such as Bighead, Silver and Carpet carp
- Freshwater systems – rivers, creeks, lakes, reservoirs, wetlands and estuaries
- Alien or introduced species to Australia or other country
- Non-predatory fish

Excluded subjects

- Native fish
- Non-benthic feeding fish
- Marine fish species
- Marine environments
- Predatory fish (however, note that studies involving predatory fish were considered relevant for the effects of removal on macroinvertebrates. This is because carp were identified as feeding on macroinvertebrates).

Relevant interventions

- Removal or exclusion of fish from field based or natural freshwater environments
- Removal of fish – studies that include complete removal of fish or studies that have involved partial removal of fish but with the aim of removing all fish or dramatically reducing fish biomass. The removal technique may include poison (i.e. rotenone), netting, electro-fishing or drainage of the water body

Excluded interventions

- Removal of native fish
- Non field-based experiments
- Experiments involving the establishment of ponds or other artificial water bodies that carp or other fish are added

Relevant outcomes

- Observed effects in macroinvertebrates in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in native fish in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in macrophytes in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in water quality (clarity, total suspended solids, turbidity, nutrients, chlorophyll-a, blue green algae blooms) in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in amphibians in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in zooplankton in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in algae in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries
- Observed effects in waterbirds in response to removal of carp or other non predatory and non-native fish in rivers, creeks, lakes, reservoirs, wetlands or estuaries

Excluded outcomes

- Modelled changes in any of the target ecosystem attributes (as described in the "relevant outcomes"
- Changes in ecosystem attributes other than those described in "relevant outcomes"
- Changes in ecosystem attributes where causality is not hypothesized to be the consequence of carp or other fish removal
- Changes in ecosystem attributes as a consequence of the introduction of carp or other fish or the purposes of the experiment

Searches

The search included the following databases:

- JSTOR
- Science Direct
- Web of Science
- TROVE

Websites

- Google Scholar

Scoping search results

A scoping search was conducted using a simple search string as shown below in Table 4. The search string was entered into Google Scholar resulting in 418 search returns. Relevance criteria were applied to the 418 search returns resulting in 43 relevant studies based on assessment of the title only.

Relevance criteria were then applied to the 43 search returns resulting in 31 relevant studies based on assessment of the abstract. Twelve studies were excluded from the first screening because of the lack of or use of appropriate experimental design, inability to access the full text or failure to meet the relevance criteria for the focus of the study.

Table 4. Scoping study search results

	Science Direct	JSTOR	Google Scholar
Scoping search			
"Carp removal" AND (effect OR impact OR change)	5/23	3/21	31/418

Meta data for the 43 relevant studies were stored in an electronic library using the bibliographic management software, Zotero as shown below (Figure 41).

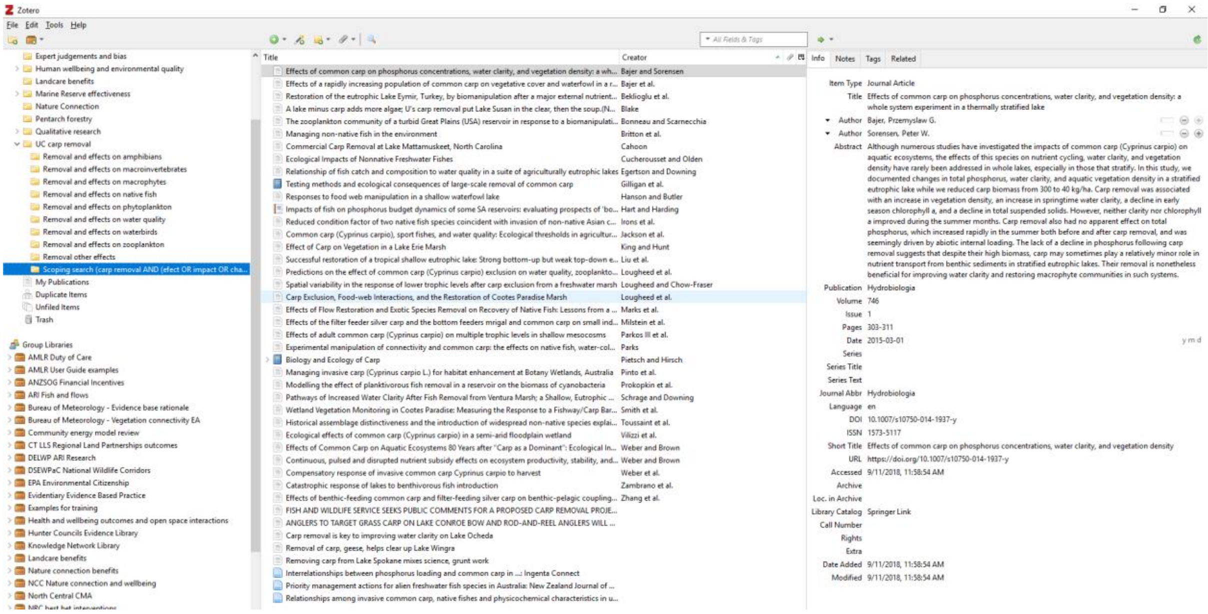


Figure 41. Scoping search results stored in Zotero

Studies found were from several countries including the USA, Canada, New Zealand, Finland, China, Turkey and Australia.

Conduct the search and document relevant search results in a structured database

The search was conducted between August 28 and September 27 using the search protocol as a guide. The search resulted in the return of approximately 30,000 potentially relevant studies primarily from the Google Scholar search (Table 5). Because a broad set of search strings was used, as opposed to a set of more specific search strings that may miss studies) the searches returned many results and that required further filtering. Primary sieving using relevance criteria applied to the study title only resulted in 228 potentially relevant studies. Secondary sieving using relevance criteria applied to the abstracts lead to the results shown in the table below. Some further, more specific searches were carried out in November in order to incorporate the terms “biomanipulation” and “extraction” as it was apparent that these were used to describe several studies previously missed. Further references were obtained from reference lists of articles. The metadata for all relevant studies was stored in the Zotero electronic library before being added to the Eco Evidence online database for later analysis using the Eco Evidence Analysis software (https://toolkit.ewater.org.au/Tools/Eco-Evidence).

Table 5. Search results and search strings used for literature searches

	Science Direct	JSTOR	TROVE	Web of Science	Google Scholar
Search (Aug-Sept)					
“Carp remov*” AND (effect OR impact OR change)	5/101	4/28	2 /37		
"freshwater fish" AND removal OR control AND "non-native" OR "non-predatory" AND (effect OR impact OR consequence OR change)				3/2,225 (first 200)	6/10,800 (first 200)
("non native" OR non-native) AND fish AND (remove OR eliminate OR reduction) AND (impact OR result OR consequence OR outcome OR change)		3/1,772 (first 200)			3/17,400 (first 200)
Freshwater AND “non-native fish” AND (removal OR control)				1/58	
Water quality only search (Nov)					
carp AND biomanipulation AND “water quality”	4/26				
carp OR fish AND (extraction OR biomanipulation) AND “water quality”	1/260	1/270			2/211,000 (first 200)

Eco Evidence weighting of evidence items

Following extraction of information from relevant studies, the evidence items concerning the hypothesized cause (in this case the removal if non-native fish) and effect (ecological response) linkages were weighted and synthesized. Each evidence item receives an evidence weight based on information about the type of study design and the number of independent control and impact sampling units (i.e., replication). The weight for an individual evidence item can range from 1 to 10, with studies that better control for confounding variables or with greater replication given higher weighting (Table 6 and). These individual weights are summed for all evidence items supporting the hypothesis and for all evidence refuting the hypothesis (Table 8). The 2 sums are compared to a threshold value (default value = 20 points), which results in 1 of 4 conclusions for that hypothesis i.e. ‘Support for a hypothesis’, ‘Insufficient evidence’, ‘Inconsistent evidence’ or ‘Support for alternative hypothesis'. When considering evidence for and against the hypothesis, the reviewer does not dismiss well-founded contrary evidence. The weightings and thresholds mean that a few high-quality studies are sufficient to support (or refute) a hypothesis, but a larger number of weaker studies are needed to reach the same conclusion (e.g., 3 studies with a weight of 7 equals 7 studies with a weight of 3).

The combination of default weights and thresholds is an implicit statement of how much evidence is considered sufficient to infer causation. Support for a hypothesis is attained with the sum ≥20 points in favour of the 'response' or 'dose response' criteria *and* <20 points refuting it (indicating 'consistency' among studies) (Table 8). The 20-point threshold was derived after trials and extensive consultation with academic researchers (see Norris et al. 2012). The Eco Evidence software produces a report that details all evidence used in the assessment, whether it supported or refuted individual hypotheses, the weightings assigned to individual studies, and the thresholds for sufficiency (see Appendix 5: Eco Evidence software reports included in this report for added transparency of the review process).

Table 6. Weights applied to study types and the number of control/reference and impact/treatment sampling units. B = before; A = after; C = control; R = reference; I = impact; M = multiple.

Study design type	**Weight**
After impact only	1
Reference/control vs impact with no before data	2
Before vs after with no reference/control location/s	2
Gradient-based designs	3
BACI or BARI MBACI or Beyond MBACI	4
Number of reference/control sampling units	
0	**0**
1	**2**
>1	**3**
Number of impact/treatment sampling units	
1	**0**
2	**2**
> 2	**3**

Table 7. Number of sampling units and weights for use with gradient-based designs

Number of sampling units used with gradient-based designs	**Weight**
3	0
4	2
5	4

≥ 6	6

Table 8. The threshold decision rules for Eco Evidence and possible outcomes depending on the evidence for a given relationship. 'Conclusions' are based on the number of summed points supporting and refuting a hypothesis, e.g., 'Support for hypothesis' is attained with the summation of ≥20 points in favour of the 'response' criteria, and <20 points refuting it; 'Inconsistent evidence' (≥20 points both support and refute the hypothesis); 'Insufficient evidence' is <20 points obtained for all criteria and no further relevant studies were found implying that one cannot reach a conclusion based on the available evidence; Support for alternative hypothesis is attained with the summation of <20 points in favour of the 'response' criteria, and ≥20 points refuting it.

Possible outcomes	**Summed evidence points - Supporting**	**Summed evidence points - Refuting**	**Conclusion**
Outcome 1	≥ 20	< 20	Support for hypothesis
Outcome 2	< 20	< 20	Insufficient evidence
Outcome 3	≥ 20	≥ 20	Inconsistent evidence
Outcome 4	< 20	≥ 20	Support for alternative hypothesis

The final stage in an Eco Evidence analysis is to consider the conclusions for each causal linkage collectively to answer the primary question developed in Step 1. An overall finding of support for the primary question does not necessarily require support for each of the individual causal linkage sub-hypotheses considered.

Rapid Evidence Synthesis Results

Of the studies identified, 32 were considered relevant to the overall question (Table 9). A total of 59 evidence items were extracted from these studies, which provided evidence supporting and refuting the hypotheses with some studies providing evidence for more than one hypothesis (Table 9). The summed weights of the studies that supported and refuted each hypothesis along with the Eco Evidence conclusions are shown in

Table 10.

There was evidence to support the 2 or the 3 hypotheses involving removal of carp and an associated improvement in water quality with 20 studies providing supporting evidence for a decrease in turbidity, and 5 of 6 studies supporting a decrease in nutrients (

Table 10). However, there was inconsistent evidence for a decrease in chlorophyll-*a*, with studies providing evidence both for and against the removal of carp being associated with decreased algal blooms and phytoplankton.

There was strong evidence to support the second and third hypotheses with a total of 10 studies providing supporting evidence that removal of an introduced fish species such as carp is associated with a recovery of macrophytes and macroinvertebrate communities (Table 9,

Table 10).

There was insufficient evidence to draw conclusions for both amphibian and fish (

Table 10).

Table 9. Causal pathways and studies used in the Eco Evidence analysis.

	Causal pathway	**References**
1	🡫 removal of carp → 🡩 water quality Where an improvement in water quality was measured as a decrease in the following attributes: ↓removal of carp → ↓ turbidity ↓removal of carp → ↓ nutrients ↓removal of carp → ↓ chlorophyll-a	(Cahoon 1953; Shapiro and Wright 1984; Sondergaard *et al.* 1990; Hanson and Butler 1994; Krienitz *et al.* 1996; King *et al.* 1997; Horppila *et al.* 1998; Meijer *et al.* 1999; Lougheed and Chow-Fraser 2001; Beklioglu *et al.* 2003; Schrage and Downing 2004; Pinto *et al.* 2005; Sondergaard *et al.* 2008; Chen *et al.* 2009; Thomasen and Chow-Fraser 2012; Lin and Wu 2013; Bajer and Sorensen 2015; Jensen *et al.* 2017; Liu *et al.* 2018; Barton *et al.* n.d)
2	🡫 removal of carp → 🡩 macrophyte abundance, cover, species richness	(Tryon 1954; King and Hunt 1967; Lougheed *et al.* 2004; Johnson and Havranek 2013; Bajer and Sorensen 2015; Bajer *et al.* 2016)
3	🡫 removal of carp → 🡩 macroinvertebrate abundance, density and richness	Bonneau and Scarnecchia (2015); Hanson and Butler (1994); Miller and Crowl (2006); Leppa *et al.* (2003); Parks (2006)

5	↓ removal of carp → ↑ amphibian abundance	(Parks 2006; Kloskowski 2009)
4	↓ removal of carp → ↑ native fish abundance and richness	(Cahoon 1953; Bunnell *et al.* 2006; Britton *et al.* 2009; Marks *et al.* 2010; Franssen *et al.* 2014)

Table 10. Results of the Eco Evidence analysis for each sub-hypothesis and the number of evidence items, the evidence scores (with number of studies that contributed to the evidence in brackets) and the conclusion based on considering the evidence for and against.

	Causal pathway	**Evidence items**	**Evidence score (& number of studies)**		**Conclusion**
			Supporting	**Refuting**	
1	↓ removal of carp → ↑ water quality				
	↓removal of carp → ↓ turbidity	20	106 (20)	4(2)	Support for hypothesis
	↓removal of carp → ↓ nutrients	6	20(5)	2(1)	Support for hypothesis
	↓removal of carp → ↓ chlorophyll-a	12	27(8)	20(4)	Inconsistent evidence
2	↓ removal of carp → ↑ macrophyte abundance, cover, species richness	8	34(5)	2(1)	Support for hypothesis
3	↓ removal of carp → ↑ macroinvertebrate abundance, density and richness	5	26(5)	0(0)	Support for hypothesis
5	↓ removal of carp → ↑ amphibian abundance	2	15(2)	0(0)	Insufficient evidence
4	↓ removal of carp → ↑ native fish abundance and richness	6	12(4)	4(2)	Insufficient evidence

Level of support

Water quality

Thirty-eight evidence items were used from 20 studies from Europe, Asia, North America and Australia. Studies were largely undertaken on lakes (31), wetlands and swamps (6) and a billabong (1). Except for two studies, all were post 1990 when biomanipulation as a restoration intervention for shallow, eutrophic lakes was gaining momentum in northern Europe.

For the studies included in this review, fish removal was either entire populations (100% removal) using agents such as Rotenone and drainage of lakes, or partially to varying extents using netting and/or electrofishing. For most studies the objective was to remove the majority of pest fish. In many studies, the removal occurred over months or years and often occurred with other complimentary intervention measures such as stocking of piscivorous fish, planting of macrophytes or control of external sources of nutrients/sediments such as sewage inputs. The duration of studies on ecosystem response ranged from two years (Shapiro and Wright 1984) to fifteen years (Krienitz *et al.* 1996; Sondergaard *et al.* 2008). The combination of these factors, plus the in-situ environmental conditions pre, during and post the study period made every study virtually unique. The influence of these contextual management and environmental variables was recognized and emphasized by the experts who contributed to the two expert elicitation process conducted by the project team.

The focus of evidence collection for the water quality attributes was turbidity (largely measured through Secchi depth and suspended sediments), nutrients (largely phosphorus) and chlorophyll *a* (including phytoplankton and cyanobacteria). These were also recognized as key water quality attributes of interest for the choice modelling team to provide information on water clarity and algal bloom risk.

The results from Eco Evidence indicate support for 2 of the 3 hypotheses.

A decrease in pest fish abundance, such as carp, leads to:

1. A decrease in turbidity (as measured by suspended sediments and Secchi depth).

2. A decrease in nutrients

The evidence is inconsistent for a similar decrease in chlorophyll-*a* concentrations.

The key findings from the literature were:

- Almost complete removal of benthivirous fish was more successful in improving water quality than partial removal
- Shallow lakes with short retention times, generally respond more effectively and rapidly to biomanipulation (i.e. fish removal)
- Lakes with initial total phosphorus concentrations < 50µg l^{-1} generally responded better to biomanipulation
- Complementary measures such as stocking with piscivorous fish and restoring macrophytes were more effective post removal
- A positive short-term (1-3 years) ‘clear water state’ was often observed but studies with longer-term monitoring suggested that this often reverted back to pre-biomanipulation states for turbidity and chlorophyll a, which in some instances was because the pest fish population recovered without continued suppression.
- Meta-analysis from a systematic review of 128 lakes that underwent biomanipulation (Bernes *et al.* 2015) showed that removal of the planktivores and benthivores led to increase water clarity (Secchi depth) and decreased chlorophyll *a* concentration during the first three years after biomanipulation.
- The short-term (1-3 years) clear-water state achieved through biomanipulation is likely to be the result of reduction in the re-suspension of sediments and nutrients after removal of benthivorous fish, which increases light penetration resulting in an increase in phytoplankton then zooplankton feeding on the phytoplankton.
- A range of contextual effect modifiers influence the effectiveness of the reduction of planktivorous and benthivorous fish on water quality in eutrophic lakes (taken from Bernes et al. 2015). These include:
    - Lake size – mean and maximum depth
    - Geographical location
    - Mean annual temperature
    - Altitude
    - Retention time

- Connectivity to other water bodies
- Lake salinity levels
- Nutrient concentrations
- Dissolved organic carbon concentration
- Stratification within the lake
- Presence of introduced species
- Degree of eradication of pest fish
- Other current or historic management factors

The rapid evidence review has provided evidence for ecosystem recovery in terms of water quality after the removal of non-native, non-predatory freshwater fish and also provided some insights into other hypothesized ecosystem effects such as hysteresis. One study suggested that a non-significant response of suspended sediments and chlorophyll *a* after biomanipulation may have been caused by hysteresis or feedback between biotic and abiotic factors (Thomasen and Chow-Fraser, 2012).

Macrophytes

Studies show that the introduction of common carp can played a key role in driving substantial reductions in macrophyte cover and richness in many lakes (Bajer et al. 2016). In predicting the recovery of macrophytes following significant decreases in carp, the experts predicted (with medium to high confidence) that macrophytes would respond in a positive way (Figure 24 and Figure 25). The results from the rapid evidence synthesis (from a total of 6 studies) support a recovery of biomass and diversity of macrophytes following the removal of carp (

Table 10).

Macroinvertebrates

Four of the five studies contributing to the synthesis of macroinvertebrate literature were undertaken in freshwater lakes, the other was conducted on three tributaries of a lake (Bonneau and Scarnecchia 2015). Four were from North America and one from Europe (Leppa *et al.* 2003). Fish were eradicated, or their numbers dramatically reduced (e.g. by 80%) by means of catching (Leppa *et al.* 2003), poisoning (Hanson and Butler 1994) or screens / exclosures (Miller and Crowl 2006; Parks 2006; Bonneau and Scarnecchia 2015). Not all studies involved the removal of carp, but they did involve removal of benthivores (Leppa *et al.* 2003; Miller and Crowl 2006). The duration of the studies ranged from weeks to years.

For the long-term, expert elicitation predicted 30-70% improvement to macroinvertebrate communities over the current situation (with confidence that ranged from low to high) if control strategies could reduce carp biomass by >70% (Figure 27). The results from the rapid evidence synthesis support a recovery in macroinvertebrate communities (increase in abundance, density and richness) following the removal of fish that feed on macroinvertebrates (

Table 10). Literature evidence suggests that in areas where submerged vegetation became established after carp removal that benthic community richness increased more than in non-vegetated fish-free areas (Bonneau and Scarnecchia 2015). Thus, even in the absence of carp other environmental factors would be important in recovery, including the presence of other benthic predators (Weber and Brown 2009).

Amphibians

Our search of relevant literature revealed two studies that showed an increase in amphibian abundance with the removal of carp, however, this was not enough evidence to draw strong conclusions regarding the recovery of amphibians following the removal of carp. Most of the studies we reviewed investigated fish removal and amphibian recovery related to the removal of trout (Hoffman *et al.* 2004;

Vredenburg 2004; Hartel *et al.* 2007; Knapp *et al.* 2007; Pope 2008). Trout studies were considered irrelevant and thus excluded from the analysis because trout eat adult frogs, which was not a causal pathway identified by expert elicitation for the effects of carp on amphibians (Figure 47). However, we note that these studies indicated that the number of amphibians or egg masses did increase concurrently with the removal of pest fish from the systems they studied.

Native fish

While the five studies reviewed (Table 9) provided insufficient evidence to draw strong conclusions on the effects of pest fish removal on native fish communities (Table 10), the literature does contain examples that corroborate some of the concerns raised during the Delphi expert elicitation process. The first of these is that it can be difficult to sustain reductions in pest species because of either reinvasion (Ellender *et al.* 2011; Weber *et al.* 2016) or compensatory population processes (e.g. decreased mortality, increased growth) among remnant populations (Weber *et al.* 2016). The literature also documents considerable variation, both among differing ecosystems (e.g. depth, connectivity) (Parks 2006; Jackson *et al.* 2010; Weber *et al.* 2016) and different species (Bunnell *et al.* 2006). Finally, Ellender *et al.* (2011) examined removal of large-mouth Bass from a headwater stream and found that a novel system developed in response, dominated by 3 introduced species. Thus, these studies eco some concerns raised by the experts we surveyed regarding the way in which other non-native species may respond to reductions in carp numbers.

Overall, the rapid evidence review has provided evidence for ecosystem recovery in terms of water quality (nutrients and turbidity), macrophytes and macroinvertebrates following the removal of non-native, non-predatory freshwater fish.

Discussion

During the expert elicitation process, experts based their judgements on their experience and expert understanding of the aquatic ecosystem attributes in question and available scientific evidence (Figure 8). The survey results clearly identified that respondents expected ecosystem attributes in different ecosystems types to vary in response to carp and that ecological responses are expected to also vary through time. The low number of estuarine experts that participated in the survey resulted in the high number of 'don't know' responses for estuaries. However, for those that did express an opinion, most considered the ecosystem attributes in estuaries would show a minor response to carp reductions. Some ecosystems, such as wetlands, were identified as being more likely to have a moderate to large response to carp reductions than others such as temporary rivers (Table 11).

Experts confidently predicted that ecosystems would change little or worsen relative to the current situation under a 'do nothing to carp control scenario', acknowledging that carp are considered an ecological problem (Table 12). Experts' comments indicated they believed that native fish populations are likely to continue to decline without management interventions to relieve the stress of both carp and other stressors such as other alien fish and catchment-wide land management practices resulting in increased erosion. Furthermore, any small reductions in carp (e.g. 25%) are considered unlikely to achieve any significant ecological outcomes.

For all ecosystem attributes considered in this study, opinion was that the achievement of >70% reductions in carp biomass is needed to gain any significant (30-70%) improvement over the current ecological situation (with greater confidence in predictions with greater carp reductions) (Table 12), noting that complete elimination of carp was considered an unlikely scenario. However, if complete elimination of carp could be achieved, experts predicted a significant ecological response in the long-term, especially for water quality, macroinvertebrates and submerged macrophytes (albeit with a degrees of uncertainty where confidence in predictions ranged from low to high) (Table 12).

Most survey respondents believed there is a low likelihood of broad-scale ecosystem recovery following carp reductions in the medium-term (apart from perhaps macroinvertebrates) but more experts considered it a greater likelihood in the long-term (Table 13). However, experts emphasised that carp are not the only ecological stressor and without other 'non-carp' mitigation actions to address the widespread environmental problems, their confidence was not high that ecosystems could recover with carp reductions alone. Complementary actions are also considered necessary to facilitate ecological recovery. For example, likelihood of macrophyte recovery may be increased with revegetation and seed-bombing efforts and for fish, increasing chances of success might involve a program of captive breeding and restocking.

For nearly every ecosystem attribute, experts identified a range of modifying factors that are believed to influence ecosystem responses and hinder recovery. Many of the modifying factors were other stressors associated with land use and flow. For native fish, these were water quality, flow, and the presence of native fish to recolonize. Whereas for macrophytes, modifying factors such as site and seed-bank condition will influence the system's response to carp removal. Overall, the experts' responses suggest that both the effects of carp infestation and subsequent ecological responses to carp removal are likely to be influenced by the temporal (e.g. antecedent flow regime) and spatial (e.g. ecosystem type) context as well as the other prevailing stressors acting on the system.

In almost all cases, hysteresis or the development of a novel system was considered just as likely, or more likely, an outcome as was ecosystem recovery (Table 13). Experts identified the risk of both hysteresis (where a degraded system does not follow a reversal of the degradation trajectory in its recovery - meaning that the ecosystem will be harder to repair than it was to degrade) and the development of a novel system (e.g. other alien species, such as Redfin, may do better without carp and occupy the habitat more effectively than native species, creating a novel system) (Table 13).

Note that few survey responses were taken from the participants that identified as experts on the following ecosystem attributes: amphibians, algae (both phytoplankton and attached) and zooplankton. Thus, these ecosystem attributes are not featured in the tables below. Those that did contribute made similar comments regarding the ‘do nothing’ scenario and commented that the adequacy of environmental flows is a major contributing factor regarding attached algae and zooplankton responses, as is high sediment loads.

The results for waterbirds are also not added to the tables below for two reasons; 1) the low number of experts contributing to the survey results, and; 2) that the likely waterbird response to carp reductions was a potential decline in waterbirds not an increase (and as such would not be consistent with the other attributes in the table). The risk of a potential decline in waterbirds was because carp are believed to play a varyingly significant role in the diet of waterbirds. While four experts predict a minor to significant decline for piscivorous waterbirds with >70% reduction in carp, they noted it should only be short term. The likelihood of recovery in the long-term was considered medium to high. The recovery would depend on the availability of an alternative food supply (such as native fish) and thus subsequent increases in native fish abundance (which is not certain). Other factors contributing to uncertainty regarding predicted waterbird responses were that the effects of carp on herbivorous waterbird food sources is not well understood and the influence of other stressors associated with river regulation (e.g. less overbank flows in future and floodplain alienation) and uncertainty regarding adequate environmental flows.

Case study: applying the report cards

We have included this section as a guide to how the above summary and tables (report cards) below, along with other information in this report may be used and interpreted. For example, a desired ecological outcome of carp removal may be an improvement in the condition of water plant (macrophyte) communities. It is important to first ascertain that carp were the driver of the poor condition of the aquatic plants in this instance. If so, in expert opinion, a macrophyte response to reduced carp numbers is more likely to be achieved in wetlands and permanent rivers than in other ecosystem types (Table 11). To achieve this outcome, carp biomass would need to be reduced by 70-100%, which assumes a reduction of carp density below150kg/ha across the region. While achievement of this outcome is not certain, the likelihood of macrophyte recovery under favourable conditions could be medium to high (Table 13). Any efforts to improve the condition of water plant communities would need to consider modifying factors such as the starting seed-bank condition, which is likely to influence the macrophyte response to carp removal. Complementary actions, such as revegetation activities and seed-bombing, could be taken to improve the likelihood of macrophyte recovery.

Table 11. Summary of expert opinion on prediction of moderate-large and large ecosystem attribute responses to carp reductions by ecosystem type. A gradient of colour in any cell indicates the range of most common survey results.

	Ecosystems						
Ecosystem attribute	Permanent rivers	Temporary rivers	Lakes & large reservoirs	Small reservoirs	Wetlands	Floodplain habitats	Estuaries
Large-bodied native fish							
Small-bodied native fish							
Submerged macrophytes							
Macroinvertebrates							
Water quality							

Response	
Large	
moderate-large	
moderate	

Table 12. Likely response of ecosystem attributes under four different scenarios of carp reductions and the experts' level of confidence in that prediction. Scenario 1: Do nothing to reduce carp; scenario 2: 25% reduction in carp and assumes between 150kg/ha to 375kg/ha carp density; scenario 3: 70% reduction in carp and assumes below 150kg/ha carp density; scenario 4: complete elimination of carp. Response options were none = 0% response or 'gets worse'; minor = <30%; significant = <70%; proportionate = 100%; excess = >100%, noting that complete elimination of carp was considered an unlikely scenario). The gradient of colour in any cell indicates the range of most common survey results.

	Scenario			
Ecosystem attribute	Do nothing to reduce carp	25% reduction	70% reduction	100% reduction
Large-bodied native fish	M-v.H	M-H	L-M	L-H
Small-bodied native fish	M-v.H	L-H	L-M	L-H
Submerged macrophytes	M-v.H	L-H	L-M	L-H
Macroinvertebrates	M-v.H	L-H	L-H	M-H
Water quality	H-v.H	H-v.H	M-H	M-H

Response	
None = 0% response / gets worse	
Minor = <30%	
Significant = <70%	
Proportionate = 100%	
Excess = >100%)	

Confidence	Degree of confidence in being correct
v.H (Very high)	at least 9/10 chance
H (High)	~ 8/10 chance
M (Medium)	~ 5/10 chance
L (Low)	~ 2/10 chance
v.L (Very low)	<1/10 chance

Table 13. Likely ecosystem responses of ecosystem attributes to 70% reduction in carp over the long-term. The gradient of colour in any cell indicates the range of most common survey results.

	Ecosystem responses in long-term (10+ years) with 70% carp reduction			
Ecosystem attribute	Recovery	Other stressors	Hysteresis	Novel system
Large-bodied native fish				
Small-bodied native fish				
Submerged macrophytes				
Macroinvertebrates				
Water quality				

Likelihood of ecosystem responses
Low
Med
High

Rapid evidence synthesis

Will the ecosystem recover following the removal of non-native and non-predatory freshwater fish such as carp?

The syntheses of literature provided sufficient evidence in support of some degree of ecosystem recovery following pest fish removal for four of the seven sub-hypotheses related to the response of selected ecosystem attributes. Overall, the rapid evidence review has provided evidence for ecosystem recovery in terms of water quality (nutrients and turbidity), macrophytes and macroinvertebrates following the removal of non-native, non-predatory freshwater fish.

In relation to water quality, literature evidence was found supporting the hypotheses that, under the right conditions, a significant reduction in pest fish can result in decreased turbidity (as measured by suspended sediments and water clarity) and a reduction in nutrients. Whereas the evidence for the relationship between reduced pest-fish abundance and chlorophyll a was not as strong, partially because of the range of contextual variables involved and an immature understanding of feedback mechanisms between biotic and abiotic factors.

The literature provided evidence for macroinvertebrate community recovery with improved richness and abundance as a result of reduced predation and in response to enhanced macrophyte growth and water quality. In all cases of supporting literature evidence, the pest fish population was identified as the major driver of the degraded water quality or biological condition (mainly in the lake ecosystems). In studies where other factors, such as variation in water depth, were not controlled (e.g. Lougheed *et al.* 2004) recovery was often difficult to detect.

Experts predicted that if elimination of carp could be achieved, a significant long-term ecological response for submerged macrophytes. The results from the rapid evidence synthesis support a recovery of biomass and diversity of macrophytes following the removal of carp.

However, the limited evidence available from long-term ecosystem-scale studies makes predictions and generalizations difficult regarding a native fish response. It appears that native fish responses to pest fish removal are highly variable in both space and time (because of the responses of different species and in different ecosystems), and this uncertainty and variation was echoed in the of responses submitted during the expert elicitation.

Conclusion

This work collected and analysed expert views and scientific literature to better understand the likely medium- to long-term ecological responses to reduced carp populations. Experts from a wide range of disciplines were invited to participate in an online survey and workshops to predict how different levels of carp reduction would affect a variety of ecosystems (i.e. different types of lakes, rivers, wetlands) and species including native fish, water plants, macroinvertebrates (molluscs, water bugs, yabbies, shrimp), water birds, amphibians, algae, zooplankton and water quality. For many of the ecosystems and attributes there was high uncertainty regarding the long-term ecological response to carp removal. Uncertainty in generalizations resulted from the expected variation in ecosystem responses to various degrees of carp removal over both space and time. Contributing to the uncertainty and the complexity of trying to predict ecosystem responses is the likely variation in responses of different species and in different ecosystems, and the effects of other environmental stressors, including other alien fish, and the lack of long-term ecosystem-scale studies on the topic. Experts emphasised that carp are not the only ecological stressor and without other 'non-carp' mitigation actions to address the widespread environmental problems, their confidence was not high that ecosystems could recover with carp reductions alone. It is important to note that degraded systems may not return to their original state after the reduction of carp. For example, other alien species such as Redfin may do better without carp in which case Redfin would hinder native fish recovery. Furthermore, complementary actions are considered necessary to facilitate long-term ecological benefits. The results of this study need to be read with the knowledge that they are necessary simplifications of complex ecological systems where context can be critical, but the generalisations provided can nonetheless be useful to better understand where the uncertainties lie.

Experts confidently predicted that ecosystems would continue to degrade under a 'do nothing to control carp' scenario, acknowledging that carp are considered an ecological problem. Evidence from both the expert elicitation and the scientific literature, indicates that under favourable circumstances the removal of benthivorous alien fish, such as the common carp, can have positive long-term ecosystem outcomes in terms of water quality, macrophytes and macroinvertebrates providing the benthivore was the driver of the degraded environmental conditions. To achieve these ecosystem benefits, carp populations would need to be significantly reduced (70-100%) and the suppression of carp biomass would need to be sustained. Some ecosystems, such as wetlands, were identified as being more likely to show a significant response to carp reductions than others.

Implications

Note that under this project (and in compliance with Objective 4) a separate report (Choice modelling and the ecological effects of carp reductions: attributes and levels) was provided (18 September 2018) to the Market Evaluation and Risk Assessment teams to help inform modelling component of a cost-benefit analysis and inform surveys of community and stakeholder attitudes to carp biocontrol.

Recommendations

Further development

During the expert elicitation process, experts based their judgements on their expert understanding of the aquatic ecosystem attributes in question and available scientific evidence. However, the lack of relevant long-term ecological studies that was identified by both the experts and the literature search has contributed to the uncertainty that surrounded some of the ecological predictions. Note that few survey responses were taken from the participants that identified as experts on the following ecosystem attributes: waterbirds, amphibians, algae (both phytoplankton and attached) and zooplankton. Also, a low number of estuarine experts contributed to the expert elicitation. These areas may represent knowledge gaps were further research may be beneficial in helping to understand the medium to long-term ecological effects of carp reductions.

Extension and Adoption

Project outputs have been used to inform modelling component of the NCCP cost-benefit analysis project.

Australian Society for Fish Biology conference 7-11 October 2018, Melbourne. Presentation "The medium to long-term ecological effects of major carp reductions". Mark Lintermans, Susan J Nichols, Ben Gawne, Rob Richards and Ross Thompson.

Project coverage

FRDC media release 30 May 2019, 'National Carp Control Plan on track to deliver'
https://www.medianet.com.au/releases/176004/

References

Cook, C.N., Nichols, S.J., Webb, J.A., Fuller, R.A., Richards, R.M., 2017. Simplifying the selection of evidence synthesis methods to inform environmental decisions: a guide for decision makers and scientists. *Biol. Conserv*. 213, 135–145.

Hill, A.B., 1965. The environment and disease - association or causation? Proc. R. Soc. Med.-Lond. 58

MacMillan, D.C., Marshall, K., 2006. The Delphi process – an expert-based approach to ecological modelling in data-poor environments. *Animal Conservation* 9, 11–19.

Nichols, S. J., A. Webb, R. Norris, and M. Stewardson. 2011. Eco Evidence Analysis methods manual: a systematic approach to evaluate causality in environmental science. eWater Cooperative Research Centre, Canberra, Australia.

Norris, R.H., Webb, J.A., Nichols, S.J., Stewartson, M.J., Harrison, E.T., 2012. Analyzing cause and effect in environmental assessments: Using weighted evidence from the literature. *Freshwater Science*. 31, 5–21.

Vilizzi, L., Tarkan, A.S., and Copp, G.H. 2015. Experimental evidence from causal criteria analysis for the effects of common carp *Cyprinus carpio* on freshwater ecosystems: A global perspective. *Rev. Fish. Sci. Aquac.* 23(3): 253–290. doi:10.1080/23308249.2015.1051214.

Webb, J.A., Miller, K.A., de Little, S.C., Stewardson, M.J., Nichols, S.J., Wealands, S.R., (2015). An online database and desktop assessment software to simplify systematic reviews in environmental science. Environ. Model. Softw. 64, 72–79.

Weber, M.J., and Brown, M.L. 2009. Effects of common carp on aquatic ecosystems 80 years after "carp as a dominant": Ecological insights for fisheries management. Rev. Fish. Sci. 17(4): 524–537.

Zampatti, B., Gilligan, D., et al. 2018. Monitoring and evaluating ecosystem responses to release of carp virus cyprinid herpesvirus-3. Working Draft April 2018. Produced for the National Carp Control Plan.

References used in rapid synthesis

Bajer, P. G., Beck, M. W., Cross, T. K., Koch, J. D., Bartodziej, W. M., and Sorensen, P. W. (2016). Biological invasion by a benthivorous fish reduced the cover and species richness of aquatic plants in most lakes of a large North American ecoregion. *Global Change Biology* **22**, 3937-3947.

Bajer, P. G., and Sorensen, P. W. (2015). Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake. *Hydrobiologia* **746**, 303-311.

Barton, D. R., Kelton, N., and Eedy, R. I. (n.d). The effects of carp (Cyprinus carpio L.) on sediment export from a small urban impoundment 6.

Beklioglu, M., Ince, O., and Tuzun, I. (2003). Restoration of the eutrophic Lake Eymir, Turkey, by biomanipulation after a major external nutrient control I. *Hydrobiologia* **490**, 93-105.

Bernes, C., Carpenter, S. R., Gårdmark, A., Larsson, P., Persson, L., Skov, C., Speed, J. D., and Van Donk, E. (2015). What is the influence of a reduction of planktivorous and benthivorous fish on water quality in temperate eutrophic lakes? A systematic review. *Environmental Evidence* **4**.

Bonneau, J. L., and Scarnecchia, D. L. (2015). Response of benthic macroinvertebrates to Carp (Cyprinus carpio) biomanipulation in three tributaries of a eutrophic, Great Plains reservoir, USA. *Transactions of the Kansas Academy of Science* **118** 13-26.

Britton, J. R., Davies, G. D., and Brazier, M. (2009). Eradication of the invasive Pseudorasbora parva results in increased growth and production of native fishes. *Ecology of Freshwater Fish* **18**, 8-14.

Bunnell, D. B., Madenjian, C. P., and Claramunt, R. M. (2006). Long-term changes of the Lake Michigan fish community following the reduction of exotic alewife (Alosa pseudoharengus). *Canadian Journal of Fisheries and Aquatic Sciences* **63**, 2434-2446.

Cahoon, W. G. (1953). Commercial carp removal at Lake Mattamuskeet, North Carolina. *The Journal of Wildlife Management* **17**, 312-317.

Chen, K. N., Bao, C. H., and Zhou, W. P. (2009). Ecological restoration in eutrophic Lake Wuli: A large enclosure experiment. *Ecological Engineering* **35**, 1646-1655.

Ellender, B. R., Weyl, O. L. F., and Swartz, E. R. (2011). Invasion of a headwater stream by non-native fishes in the Swartkops River system, South Africa. *African Zoology* **46**, 39-46.

Franssen, N. R., Davis, J. E., Ryden, D. W., and Gido, K. B. (2014). Fish Community Responses to Mechanical Removal of - Nonnative Fishes in a Large Southwestern River. *Fisheries* **39**, 352-363.

Hanson, M. A., and Butler, M. G. (1994). Responses to Food-Web Manipulation in a Shallow Waterfowl Lake. *Hydrobiologia* **279**, 457-466.

Hartel, T., Nemes, S., Cogalniceanu, D., Ollerer, K., Schweiger, O., Moga, C. I., and Demeter, L. (2007). The effect of fish and aquatic habitat complexity on amphibians. *Hydrobiologia* **583**, 173-182.

Hoffman, R. L., Larson, G. L., and Samora, B. (2004). Responses of Ambystoma gracile to the removal of introduced nonnative fish from a mountain lake. *Journal of Herpetology* **38**, 578-585.

Horppila, J., Peltonen, H., Malinen, T., Luokkanen, E., and Kairesalo, T. (1998). Top-down or bottom-up effects by fish: Issues of concern in biomanipulation of lakes. *Restoration Ecology* **6**, 20-28.

Jackson, Z. J., Quist, M. C., Downing, J. A., and Larscheid, J. G. (2010). Common carp (Cyprinus carpio), sport fishes, and water quality: Ecological thresholds in agriculturally eutrophic lakes. *Lake and Reservoir Management* **26**, 14-22.

Jensen, M., Liu, Z. W., Zhang, X. F., Reitzel, K., and Jensen, H. S. (2017). The effect of biomanipulation on phosphorus exchange between sediment and water in shallow, tropical Huizhou West Lake, China. *Limnologica* **63**, 65-73.

Johnson, J., and Havranek, A. (2013). Effectiveness of temporary carp barriers for restoring wild rice growth in Upper Clam Lake: 2010 to 2013. Report to St. Croix Tribal Environmental Services – Natural Resources Department, Webster (WI). Freshwater Scientific Services–LLC, Maple Grove (MN). Report available for download at http://www.freshwatersci.com/fw_projects.html.

King, A. J., Robertson, A. I., and Healey, M. R. (1997). Experimental manipulations of the biomass of introduced carp (Cyprinus carpio) in billabongs .1. Impacts on water-column properties. *Marine and Freshwater Research* **48**, 435-443.

King, D. R., and Hunt, G. S. (1967). Effect of carp on vegetation in a Lake Erie Marsh. *The Journal of Wildlife Management* **31**, 181–188.

Kloskowski, J. (2009). Size-structured effects of common carp on reproduction of pond-breeding amphibians. *Hydrobiologia* **635**, 205-213.

Knapp, R. A., Boiano, D. M., and Vredenburg, V. T. (2007). Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, Rana muscosa). *Biological Conservation* **135**, 11-20.

Krienitz, L., Kasprzak, P., and Koschel, R. (1996). Long term study on the influence of eutrophication, restoration and biomanipulation on the structure and development of phytoplankton communities in Feldberger Haussee (Baltic Lake District, Germany). *Hydrobiologia* **330**, 89-110.

Leppa, M., Hamalainen, H., and Karjalainen, J. (2003). The response of benthic macroinvertebrates to whole-lake biomanipulation. *Hydrobiologia* **498**, 97-105.

Lin, Y. T., and Wu, C. H. (2013). Response of bottom sediment stability after carp removal in a small lake. *Annales De Limnologie-International Journal of Limnology* **49**, 157-168.

Liu, Z., Hu, J., Zhong, P., Zhang, X., Ning, J., Larsen, S. E., Chen, D., Gao, Y., He, H., and Jeppesen, E. (2018). Successful restoration of a tropical shallow eutrophic lake: Strong bottom-up but weak top-down effects recorded. *Water Research* **146**, 88-97.

Lougheed, V. L., and Chow-Fraser, P. (2001). Spatial variability in the response of lower trophic levels after carp exclusion from a freshwater marsh. *Journal of Aquatic Ecosystem Stress and Recovery* **9**, 21–34.

Lougheed, V. L., Theysmeyer, T. S., Smith, T., and Chow-Fraser, P. (2004). Carp exclusion, food-web interactions, and the restoration of Cootes Paradise Marsh. *Journal of Great Lakes Research* **30**, 44-57.

Marks, J. C., Haden, G. A., O'Neill, M., and Pace, C. (2010). Effects of Flow Restoration and Exotic Species Removal on Recovery of Native Fish: Lessons from a Dam Decommissioning. *Restoration Ecology* **18**, 934-943.

Meijer, M. L., de Boois, I., Scheffer, M., Portielje, R., and Hosper, H. (1999). Biomanipulation in shallow lakes in The Netherlands: an evaluation of 18 case studies. *Hydrobiologia* **408**, 13-30.

Miller, S. A., and Crowl, T. A. (2006). Effects of common carp (Cyprinus carpio) on macrophytes and invertebrate communities in a shallow lake. *Freshwater Biology* **51**, 85-94.

Nichols, S. J., Webb, A., Norris, R., and Stewardson, M. (2011). Eco Evidence Analysis methods manual: a systematic approach to evaluate causality in environmental science: ISBN 978-1-921543-43-2 eWater Cooperative Research Centre, Canberra.

Norris, R. H., Webb, J. A., Nichols, S. J., Stewardson, M. J., and Harrison, E. T. (2012). Analyzing cause and effect in environmental assessments: using weighted evidence from the literature. *Freshwater Science* **31**, 5-21.

Parks, C. R. (2006). Experimental manipulation of connectivity and common carp: the effects on native fish, water-column invertebrates, and amphibians in Delta Marsh. University of Manitoba, Winnipeg

Pinto, L., Chandrasena, N., Pera, J., Hawkins, P., Eccles, D., and Sim, R. (2005). Managing invasive carp (Cyprinus carpio L.) for habitat enhancement at Botany Wetlands, Australia. *Aquatic Conservation-Marine and Freshwater Ecosystems* **15**, 447-462.

Pope, K. L. (2008). Assessing Changes in Amphibian Population Dynamics Following Experimental Manipulations of Introduced Fish. *Conservation Biology* **22**, 1572-1581.

Schrage, L. J., and Downing, J. A. (2004). Pathways of increased water clarity after fish removal from Ventura Marsh; a shallow, eutrophic wetland. *Hydrobiologia* **511**, 215-231.

Shapiro, J., and Wright, D. I. (1984). Lake Restoration by Biomanipulation - Round Lake, Minnesota, the 1st 2 Years. *Freshwater Biology* **14**, 371-383.

Sondergaard, M., Jeppesen, E., Mortensen, E., Dall, E., Kristensen, P., and Sortkjaer, O. (1990). Phytoplankton Biomass Reduction after Planktivorous Fish Reduction in a Shallow, Eutrophic

Lake - a Combined Effect of Reduced Internal P-Loading and Increased Zooplankton Grazing. *Hydrobiologia* **200**, 229-240.

Sondergaard, M., Liboriussen, L., Pedersen, A. R., and Jeppesen, E. (2008). Lake Restoration by Fish Removal: Short- and Long-Term Effects in 36 Danish Lakes. *Ecosystems* **11**, 1291-1305.

Thomasen, S., and Chow-Fraser, P. (2012). Detecting changes in ecosystem quality following long-term restoration efforts in Cootes Paradise Marsh. *Ecological Indicators* **13**, 82-92.

Tryon, C. A. (1954). The effect of carp exclosures on growth of submerged aquatic Vegetation inPymatuning Lake, Pennsylvania. *The Journal of Wildlife Management* **18**, 251-254.

Vredenburg, V. T. (2004). Reversing introduced species effects: Experimental removal of introduced fish leads to rapid recovery of a declining frog. *Proceedings of the National Academy of Sciences of the United States of America* **101**, 7646-7650.

Weber, M. J., and Brown, M. L. (2009). Effects of common carp on aquatic ecosystems 80 years after 'carp as a dominant': ecological insights for fisheries management. *Reviews in Fisheries Science* **17**, 524–537.

Weber, M. J., Hennen, M. J., Brown, M. L., Lucchesi, D. O., and St Sauver, T. R. (2016). Compensatory response of invasive common carp Cyprinus carpio to harvest. *Fisheries Research* **179**, 168-178.

Project materials developed

All images contained within this report.

Appendices

Appendix 1: Human ethics

UNIVERSITY OF CANBERRA

Participant information form

Project Title

National Carp Control Plan - likely medium to long term ecological outcomes of major carp population reductions (FRDC project 2017-104).

Researcher

Dr Susan Nichols
Institute for Applied Ecology
University of Canberra ACT 2601
+61 (0)2 62015408
sue.nichols@canberra.edu.au

Project Aim

The aim of this research is to investigate the likely medium to long-term ecological outcomes of major carp population reductions through the planned release of the carp herpes virus.

Benefits of the Project

The information gained from the research will be have three main benefits. First, the derived information will inform the methods associated with the release, and subsequent management of the effects of the carp herpes virus, on associated ecological systems. Second, the information will inform existing and future research projects relating to the management of carp in Australian river systems. Third, the information will provide the general public with increased understanding of the likely effects of the release of the carp virus and enable government agencies to communicate with the general public in relation to the release of the carp virus.

General Outline of the Project

The potential mid-long-term ecological effects of significant population reductions of carp in Australian aquatic systems is poorly understood. Yet, such knowledge is vital for ensuring the subsequent improved health of Australian aquatic systems and informing the general public of the likely consequences. This project will, through expert elicitation, develop a suite of models intended to predict the potential mid-long-term ecological effects of significant population reductions of carp. Participants will contribute their understanding of the likely ecosystem effects of carp reductions, including, but not limited to, strength of effects, confidence in predictions, and potential for hysteresis. Individual responses will contribute to the suite of models that represent the collective knowledge of all participants.

Participant Involvement

Participants who agree to participate in the research will be asked to:

1. Complete a survey on the likely medium to long term ecological outcomes of major carp population reductions through the planned release of the carp herpes virus. The survey will likely include limited questions relating to participant expertise followed by questions relating to the likely interaction of various ecosystem attributes, given specific scenarios such as varied time horizons and carp density. Individual participant contributions will be collated to generate a suite of models that will inform the project aim.

2. Attend a follow-up workshop to refine the models and, potentially, achieve some consensus on the likely medium to long term ecological outcomes of major carp population reductions through the planned release of the carp herpes virus. Only a limited number of participants are expected to attend the workshop because of project constraints.

Participation in the research is completely voluntary and participants may, without any penalty, decline to take part or withdraw at any time without providing an explanation or refuse to answer a question.

Confidentiality

Only the researcher/s will have access to the individual information provided by participants. Privacy and confidentiality will be assured at all times. The research outcomes may be presented at conferences and written up for publication. However, in all these publications, the privacy and confidentiality of individuals will be protected.

Anonymity

All reports and publications of the research will contain no information that can identify any individual and all information will be kept in the strictest confidence.

Data Storage

The information collected will be stored securely on a password protected computer throughout the project and then stored at the University of Canberra for the required five year period after which it will be destroyed according to university protocols.

Ethics Committee Clearance

The project has been approved by the Human Research Ethics Committee of the University of Canberra (HREC – insert number here).

Queries and Concerns

Queries or concerns regarding the research can be directed to the researcher and/or supervisor. Their contact details are at the top of this form. You can also contact the University of Canberra's Research Ethics & Integrity Unit. You can either contact Mr Hendryk Flaegel via phone 02 6201 5220, Ms Maryanne Simpson via phone 02 6206 3916 or email humanethicscommittee@canberra.edu.au.

If you would like some guidance on the questions you could ask about your participation please refer to the Participants' Guide located at http://www.canberra.edu.au/ucresearch/attachments/pdf/a-m/Agreeing-to-participate-in-research.pdf

UNIVERSITY OF CANBERRA

Participant consent form

Project title: National Carp Control Plan - likely medium to long term ecological outcomes of major carp population reductions (FRDC project 2017-104).

I hereby consent to participate in a study to be undertaken by **Susan Nichols** of **University of Canberra.** I understand that the purpose of the research is to generate knowledge of the possible mid-long term ecological effects of release of the Carp herpes virus in Australian waterways. I also understand that the knowledge will be generated through expert elicitation, and that I am an expert that will be contributing my knowledge.

In giving consent I acknowledge that:

- Upon receipt, my responses will be coded, and my name and address will be kept separate to my responses, preventing association between me as an individual and my responses.
- Any information I provide will not be released in an identified form.
- Aggregated results will be used for research and policy purposes and may be presented in reports and scientific journals.
- Individual results will not be released, in a condition that could be linked to any individual participant, to any person except at my request and on my authorisation.
- I am free to withdraw my consent at any time during the study, in which event my participation in the research study will immediately cease, and any information obtained will be returned to me or destroyed at my request.

I have read and understood the information about the research. I am not aware of any condition that would prevent my participation, and I agree to participate in this project. I have had the opportunity to ask questions about my participation in the research. All questions I have asked have been answered to my satisfaction.

Please indicate whether you agree to participate in each of the following parts of the research (please indicate which parts you agree to by putting a cross in the relevant box):

UNIVERSITY OF CANBERRA

☐ Complete a survey relating to the likely medium-long term ecosystem effects of carp population reduction.

☐ Participate in a follow-up workshop to review results elicited from the survey and finalise models relating to the medium-long term effects of carp population reductions.

Name…………………………………………………………………………………………………

Signature………………………………………………………………………………

Date …………………………………

A summary of the research report can be forwarded to you when published. If you would like to receive a copy of the report, please include your mailing (or email) address below.

Name…………………………………………………………………………………………………

Address…………………………………………………………………………………………………

………

Appendix 2: Canberra workshop agenda

Workshop - Medium to long term effects of carp reductions

Agenda – Canberra Workshop, 18 July 2018

Venue: Ann Harding Conference Centre, Building 24, University Dr S, University of Canberra, BRUCE ACT 2617

Time	Activity	Who to lead
8.30	Coffee / Tea on arrival	
9.00 - 9.20	Introductions and welcome Project context within the NCCP	Sue N Matt B
9.20 – 10.00	Relevant projects • Choice modelling • Epidemiological studies • Risk Assessment	 Jeff Bennett Peter Durr Brent Henderson
10.00 – 10.15	**Format of the day**. Process and desired outcomes for the day, definitions and concepts. Process and required outputs.	Rob R
10.15 -10.30	Feedback survey results • Summary profile of responses	Ben G and Sue N
10.30-10.50	Morning tea	
10.50 -12.15	**Exercise 1. Subject specific conceptual models** • Sources of evidence • Key outcomes (Species responses) • Variance in confidence – explore • Model effect modifiers including ecosystem type	Rob R and Ben G
12.40 -1.00	Feedback from expert groups	Rob R
1.00 - 1.30	Lunch	
1.30 – 2.30	**Exercise 2**. **Senario Forecasts** • Feedback on Forecasts • Introduction to new scenarios • Assumptions for the exercise • Specific forecasts based on biomass scenarios– variance in confidence, influencing factors • General forecasts	Ben G and Rob R
2.30 – 3.00	**Exercise 4**. **Facilitated group discussion**	Rob R and Ben G

	• Review forecasts and uncertainty estimates in groups • Report back to group • Facilitated discussion o What's missing, areas of greatest uncertainty and risk. • Rapid evidence review – expert input	
3.00 – 3.20	Arvo tea	
3.20 – 4.00	Presentations on concurrent projects	Rob Gillespie, Peter Durr & Brent Henderson
4.00 - 5.00	Summary of achievements for the day and where to from here	Rob R, Ben G, Sue N, Matt B

Appendix 3: Survey comments on initial generic model

When asked to describe any significant short-comings of the model, any refinements or changes they would make to the model (e.g. to directionality of relationships), and any other comments you would like to make (e.g. are there any arrows missing, are there any nodes missing etc.), those that responded commented as follows:

There is no direct link between native fish and carp, I have evidence of direct predation by carp on native fish.
In regard to the impact of carp on freshwater fish species, the model is lacking the influence of carp on habitat availability. For instance, the model simplistically indicates the influence of carp on aquatic macrophytes and, therefore, the influence on fish (which has been identified as a direct impact of high evidence). I would suggest that the model should have represented changes in habitat structure promoted by carp. It is known that carp will influence turbidity and suspended solids as represented. That can increase siltation and, therefore, diminish the availability of rocky type substrate such as cobbles and gravel as well as change mesohabitat characteristics (such as run and riffles).
Adults also appear to predate on zooplankton at times particularly in lakes. In addition, the interaction with fish (i.e. native fish or alien) is likely to be more complex between different guilds and body sizes than primarily through macrophytes.
‘Aquatic macrophytes’ is a catch all term - carp really only impact soft stemmed submerged macrophytes. There is no link [in the model] for carp directly preying on small native fish as a food source. The conceptual model does not include a density-impact threshold for adults (i.e. 80-100/kg/ha). The conceptual model is for carp effects - not carp ecology (i.e. habitats, movement, spawning, recruitment etc), a second model would also be instructive for providing a broader context to the effects model.
There is no link either direct or indirect between carp and other fish, there is evidence of direct predation by carp on native fish, the other impact that is not included is disease and parasites such as *Lernaea cyprinacea* (Marina et al 2008).
What about competition and resource blocking? I would think that carp consuming vast amounts of invertebrates and locking that up in their own biomass would be a direct affect? For juveniles, when there are millions of small carp around after a breeding event, wouldn't they significantly affect invertebrates and zooplankton leading to less availability for native juveniles that come out later, and compete with them for food and space?
I think there is in some cases a 2-way relationship with macrophytes. I'm suggesting that (in some cases) if Carp are introduced to a structurally complex environment containing dense aquatic vegetation (which may actually be just the dense vegetation), they are less inclined to destroy existing plants, and have a reduced effect on germination and emergence. The vegetation also supports a diverse food web and hence food sources for Carp, so benthic mumbling is not as relentless. In turn, water clarity may be maintained and other subsequent processes in the model are less affected/severe. However, when Carp access recently inundated habitats they essentially preclude the development of vegetation as structure and so on, and the downward spiral continues. In essence, I'm suggesting a carp free environment may be necessary for some key components in a food web to develop and become resilient.
The effect on other fish species is not well represented e.g. use habitat (space), consumption of eggs during carp feeding. There may even be a positive effect for some species through provision of smaller carp as food (perhaps). Geomorphic and riparian effects are not represented e.g. bank undermining, consequent bank erosion.
Excretion should include egestion. Effects of carp on benthic algae are missing (negative via feeding and indirectly negative via turbidity and positive via egestion and excretion of nutrients). Flow-on from benthic algae to benthic algal consumers - benthic invertebrates, fish, amphibian larvae and turtles. Effects of carp on turtles are missing (negative via turbidity interfering with turtle feeding and indirectly via consumption and disruption of turtle foods - benthic algae, macrophytes, zooplankton and benthic invertebrates). Negative effect of zooplankton on phytoplankton should be indicated. Positive effect of P/N on macrophytes should be indicated. Negative effect of phytoplankton on macrophytes (via shading) should be indicated. Negative effect of turbidity/SS on phytoplankton, amphibians, waterbirds, fish and turtles should be indicated. Consumption of benthic invertebrates by waterbirds should be included. Link from benthic invertebrates to terrestrial consumers (via emergence) is missing. Links from aquatic macrophytes should be shown as indirect not direct.

Is there much information available on the effects of carp on amphibians? I assume there would be a direct low/inconsistent impact from Feeding/ Spawning to Amphibians (simialr to fish?).

Are there possibly feedbacks missing to aquatic macrophytes from other key drivers such as waterbirds and fish? Also, is there a potential problem for aquatic macrophytes effects of carp on substrate stability?

Misses out the single most important water quality parameter sustaining aquatic ecosystems - dissolved oxygen! Carp foraging behaviour will decrease light penetration into the water column (as noted by enhanced turbidity) - this will constrain photosynthesis. But what is totally missing is the effect of resuspending anoxic sediments - highly prevalent in soft-sediment systems. Dissolved oxygen will be consumed in oxidized a wide range of reduced species (e.g. $Fe2+$, sulfide, ammonia). this depression of DO can be severe in areas where carp proliferate.

Fails to adequately express competition with other zooplanktivorous fish or fish life stages.

Firstly, I think the model should include fauna groups that are not yet common prime management targets. This is because this is an interconnected and complex web we are dealing with, e.g. carp can have effects on other groups that then affect the management targets. E.g. turtles, snakes, water dragons/skinks, large crustaceans such as yabbies and crayfish, rakali and platypus. It is important that all primary components of the ecosystem are represented and considered, not just a few hand-picked ones - otherwise the model is biased and may miss an important interaction that just hasn't been considered to-date. Changes in invertebrate (not just benthic) and zooplankton populations or diversity can directly affect waterbirds (and amphibians) just as they do fish. In turn, changes in fish populations or diversity can directly affect waterbirds. These are missing arrows. Changes in turbidity affect prey visibility for waterbirds (indirect arrow missing). Changes in carp populations per se (especially juveniles) will directly affect waterbirds, particularly those that eat fish. It would be useful to separate impacts/roles of adult carp from those of juvenile carp. It would also be useful to separate short-term and long-term influences, and in the short-term to have some indication of how interactions and impacts change with season or timing. What about pest fish species and other pest species? In this model and in subsequent questions, the fact that waterbirds consume a range of aquatic items needs to be accounted for. I notice that on the next pages only piscivorous and herbivorous waterbirds are listed. This is too simplistic because waterbirds that consume invertebrate prey (from zooplankton to mussels to crustaceans) are also affected.

There is no node for attached algae that is affected by carp feeding (and potentially excretion) and would have flow on effects on macroinvertebrates and tadpoles. There is no link between benthic invertebrates and either waterbirds or amphibians. Several species of waterbird feed on benthic invertebrates including cormorants, ibis and egrets. Frogs also feed on emerging aquatic invertebrates, so presumably if fewer make it to emergence then there will be less food for frogs. In a similar vein, spoonbills feed on zooplankton and so there should also be a link there.

What is the purpose of the model? This does not reflect Carp ecology- if that is the question This is only about nutrients?

Without complicating any further, I believe it well sums up the main aspects. However, putting [a] northern MDB hat on where macrophytes are rare (except some off-channel habitats in perrenial streams) the strength of arrows are less so, although the direct impacts on benthic algae may be as important and in essence benthic algae essentially replaces certain aspects provided by macrophytes down south, particularly food and nutrient recycling Also shelter less important given high turbidity of northern systems.

Carp predate on small native fish but there is only anecodotal evidence to support this. I have witnessed it several times in the field.

There are some species of waterbirds that feed on zooplankton e.g. pink-eared duck. Similarly, tadpole stages feed on zooplankton.

Not clear why there is no direct arrow from carp to waterbirds - piscivores.

Benthic invertebrates can directly impact on food resource availability for some waterbird species (currently not shown), and also to amphibians when some benthic invertebrate species pupate (e.g. Chironomids) which are a food resource to frogs. Otherwise is a fair representation without making it unnecessarily too complicated (such as including aquatic reptiles and mammals, or change in temperature or DO, etc).

Impacts of carp feeding on eggs and juvenile stages of fish & amphibians

At a very general level the strength of the proposed relationships may have some support but the devil is in the detail both at a species level and water body type

Good overall representation of the main links and effects of carp. Some links seems to be missing an impact signal, e.g. - effects of phosphorus/nitrogen on aquatic macrophytes has no signal, should it be positive? - effects of phytoplankton on zooplankton needs a positive link, whereas thee ffects of zooplankton on phytoplankton on seem to need a negative link. Why are these tophic links indirect? I think that I am missing something fundamental about the depictions of such relationships. I will wait to be better informed at the workshop.

The model misses the potential and likely impacts of carp as a vector and reservoir of pathogens and parasites that affect native fish (Significant parasites includethe copepod Lernaea, and the tapeworm Bothriocephalus acheilognathi. The model also does not cover the competitive impacts of carp on native fish for things other than feeding or spawning. For example, Carp make up 80+% of fish biomass in many rivers, and so must be impacting physical habitat use by native species.

Arrows between Aquatic macrophytes and amphibian/waterbirds and fish should be dashed to indicate an indirect impact of carp on fauna? Increased Phosphorus / Nitrogen can also increase cover of floating plants such as Azolla that utilize water column nutrients. A large increase in cover of floating plants can cause a depletion in oxygen if the waterbody supports high biomass of submerged plants. Carp may be a food source for some waterbirds e.g. pelicans. So, the role of carp in food webs is worth considering in representing the impacts of carp

There is no impact of the biomass or numbers of carp imposing density impacts on native fish. Just their sheer physical presence has an impact and the greater the density the greater the physical presence impact.

I would suggest that in spawning hotspots where juveniles become highly abundant that their impact on zooplankton would be at least a medium impact on plankton. Juvenile carp consumption of zooplankton could impact upon the abundance and species composition of zooplankton, and indirectly effect phytoplankton by altering zooplankton grazing pressure. Also, I'm not sure that the current model accurately captures the carbon and nutrient resources bound up by carp that would be otherwise available to other consumers if carp were not present.

We have predicted that carp feeding will increase release of pore water in sediment. See http://www.waikato.ac.nz/__data/assets/pdf_file/0009/282690/ERI-Report-68.pdf.

1: aquatic macrophytes is not informative, as term covers a range of plant types. Change to "submerged macrophytes and seedlings", and you will capture much better what the actual dynamics are. 2: missing: a link between aqu macroFF and turbidity. The presence or absence of aqu macroFF influences turbidity (indirectly ?) through benthic sediment stabilisation. 3: Comment: a shortcoming of models such as these is that they represent causality but compress time. To fully understand the effect of carp, a series of states is needed. From perspective of aqu macroFF, carp have two principal effects: one is destructive ie loss of plants: the other is negative, ie prevents regeneration and recovery from seed bank. One is a mechanism of change; the other is a maintaining of the changed state. 4: missing. Model does not recognise the importance of submerged plants and any other macroFF with submerged plant parts as a nursery for larval or small fish, as habitat for zooplankton, as substrate for epiphytic and biofilm. Aquatic macrFF add physical and habitat and biotic diversity.

There are probably different responses for submergent and emergent macrophytes. Increased nutrients could be positive for clonal emergent species but negative for submergent species.

Potential predation on eggs and larvae Competition for space/habitat

The model, as it stands, is fine, in my opinion. But it lacks a temporal component. What I mean is that carp are long-lived and grow to quite large sizes. They also feed at quite a low trophic level. As a consequence, they lock up resources for a long time, much of which is not available to rivers and their biota in the same way that they might be for other organisms feeding at the same trophic level. In addition, the model is a food-web model, of course. And by definition does not include aspects of life history. Now, although that is only indirectly related to food webs, it does have quite a bearing on the impact of carp. Their ability to go through booms and busts in recruitment, means that they can overwhelm rivers at good times as juveniles, whereas at other times, they may tick along in considerable numbers as adults. Understanding population and recruitment dynamics and how this overlays the food-web effects, is essential, in my opinion, in appreciating the full effects of carp.

Adult carp prey on amphibian tadpoles directly. Adult carp have a negative influence of herbivorous waterbirds (via aquatic macrophyte removal). But juvenile carp have a strong positive influence on piscivorous waterbirds (and other piscovorous aquatic fauna) by providing an abundant food supply (adult carp are too big for anything to eat). You could split waterbirds into herbivores, planktivores and piscivores. Similarly, fish could be split into piscivores. plankitores and benthivores. At the densities at which they occur, juvenile carp are likely to have a high or medium rather than low/inconsistent influence on zooplankton.

Doesn't adequately represent the positive effect carp have in relation to waterbird foraging and carp being the dominate biomass for waterbird food in many instances.

The line between turbidity and aquatic macrophytes should be solid

Increases in turbidity affect native fish directly through a loss of visibility and the inability to see to prey. Increases in turbidity reduce light penetration and therefore can possibly decrease algal community so I'm not convinced of the direction of the arrows there. I'm not convinced that increasing turbidity through carp feeding will increase available N and P in a river system.

I believe that both adult and juvenile carp have a greater direct impact upon zooplankton than the "Low/Inconsistent" path shown. I have observed large adult carp "inhaling" Water Fleas (Cladocera) which were swarming in a recently flooded wetland. I believe the impact upon waterbirds of the loss of macrophytes is "High" rather than "Medium". Abundant Phytoplankton can also have a direct impact upon fish by reducing dissolved oxygen levels via respiration.

Freshwater mussels in the permanent rivers of the Murray-Darling drainage are large and in the potamic sections (= depositional) can be the dominant standing crop (I suspect that this has changed a lot with human alteration). They filter large amounts of water and should be a significant sink for nutrients. They consume fine organic matter and small phytoplankton and probably significantly regulate these pathways ("probably" because there has been no work in Australia that I am aware of). They can affect suspended solids by depositing "pseudo-faeces" (ss in mucous). The link might be phytoplankton -> (+) freshwater mussels (Hyriidae) -> (fine line) waterbirds and fish (+) plus Turbidity/suspended solids -> mussels (neutral; they remove it from system). Feeding (-) -> mussels (negative because small, juvenile mussels would be consumed by carp mumbling reducing recruitment. I wonder if you might use thicker lines for more important pathways like feeding -> suspended solids -> macrophytes. You have done this to some extent, but I think that you could place more emphasis on certain pathways. I do realise that mussels are benthic invertebrates, but they do behave differently than most (e.g. long life-cycle, filter feeders). Also, mussels depend on native fish to complete their life cycle (carp unsuitable) so negative impacts on native fish will impact on mussel recruitment.

There should be an arrow from the 'feeding/spawning' box to the 'Amphibian' box indicating a medium level of evidence for direct predation from carp on tadpoles.

The model is a great summary of the majority of literature to date. Well done! What about more subtle effects such as competition for space or resources particularty on native fish species? e.g. competition for space (eg snags), the model only show impact on fish mediated through macrophytes. What about something around filling a probably 'vacant niche' in MDB systems in particular as there is no or few benthivores? Im not sure i know of any data, but an opinion that ive heard is that carp have replaced the role of mussels as a benthivore. Also, should the model also show where carp affect preators? eg waterbirds or piscivorous fish? ie predators may have been positively impacted by increased carp numbers

I have a few comments on the model, which I think relate to many rivers and other wetlands in Queensland. • I am unaware of any evidence for increased nutrients in riverine ecosystems of Qld resulting from carp. Many of the Qld riverine ecosystems which are carp dominated (eg upper catchments of the Murray Darling) do not in fact have any nutrient problems. These areas are in fact light limited with most production occurring only in the small photic zone of these ecosystems. Also, there are several investigations which show the ecosystem is dominated by terrestrial energy sources and so instream production low and therefore impacts would be low. • Sediment in particular turbidity has been a problem in the Qld catchments of the Murray Darling prior to the introduction of carp. This indicates that land clearing is more likely to be having a larger and overpowering impact on turbidity than anything that carp are having. Carp could be contributing to turbidity but is most likely negligible. • Submerged macrophytes in riverine systems across all of Qld are not very common and are very patchy in their distribution. Emergent macrophytes along wetted edges are probably more common. Carp potentially impact upon these emergent vegetation types which may have some impacts. However, the high level of indirect sediment influence on macrophytes and then invertebrates and fish is probably incorrect. Also, would apply to the direct evidence on macrophytes and so on. • I think there is very little evidence of direct impacts on the invertebrates in Qld. However, we do have some information on the effects on aquatic snails. • The addition of amphibians as components in the model is a bit of a stretch. Even if carp cause increased turbidity and reduced aquatic macrophytes they are unlikely to affect amphibians as frogs are not often associated with riverine areas where carp are predominantly found. Frogs are more likely to be associated with ephemeral wetlands which are at best seasonally inundated by riverine water flooding out onto floodplains, but more likely rainfall inundated. The only exception are some wet tropics frogs which as yet are not in the current distribution areas of carp. So, any interaction is unlikely and irrelevant. • For waterbirds if there are any affects they are likely to be only locally relevant as when environmental conditions become difficult they will move away.

Comments in relation to carp in dryland intermittent rivers, such as occur in approx 40% of the catchment area of the MDB: 1) Aquatic primary production is light limited, not nutrient limited, so increased nutrients may not increase Chl a etc 2) Data suggests that in these systems with sodic floodplain and channel sediments that are clay dominated and which are naturally highly dispersive and form colloids, carp presence, abundance and biomass are not at all associated with increased turbidity. Land-use practices are the greatest driver of turbidity 3) Aquatic macrophytes are typically absent or in very low abundance of emergent taxa because of the naturally high turbidity and resulting light limitation 4) Our data suggests no impacts from carp presence, abundance or biomass on macroinvertebrate richness, abundance or assemblage composition. The only exception is the river snail Notopala which is absent from all sites with carp present and present where carp are absent. 5) Carp impacts on native fish may relate to direct predation effects but agree these are probably low/inconsistent. Probably a greater impact in these systems would be resource monopolisation of littoral benthic algal production. However, our foodweb tracer data (SI and Fatty Acids) suggest carp have a high terrestrial contribution via probably terrestrial insects. If carp were not eating this food, it seems likely other native fish would - so it is an impact on reducing native fish carrying capacity by resource monopolisation. See: a) Jardine, T. D., Woods, R., Marshall, J., Fawcett, J., Lobegeiger, J. S., Valdez, D., & Kainz, M. J. (2015). Reconciling the role of organic matter pathways in aquatic food webs by measuring multiple tracers in individuals. Ecology, 96:3257-3269. b) Woods RJ, Lobegeiger JS, Fawcett JH, Marshall JC (eds) (2012) Riverine and floodplain ecosystem responses to flooding in the lower Balonne and Border Rivers - Final Report Department of Environment and Resource Management, Queensland Government 6) Frog recruitment is strongly influenced by connectivity to rivers as fish predation is a major limitation (not just carp but fish in general). Thus, frog recruitment is largely driven by rain-fed wetlands with no fish

Phytoplankton: Increased N and P are likley to lead to 1. a shift in algal composition from small grean algae/diatom to larger more unpalatable species and increased abundance of BGA 2. loss of food quality for groups such as zooplankton 3. result in eutrophication, loss of light, which will cause a shift from macrophyte dominated systems to algal dominated systems. Zooplankton: There is a possibility that increased phytoplankton/Chl "a" 1. may lead to an increase in zooplankton abundance/density which may benefit fish (increased food availability) 2. result in a shift in zooplankton community composition

Direct benefits to predators of carp not represented. Impact on substrate/bank stability/ geomorphology not represented

Adult carp can have a direct impact on frog recruitment via consumption of eggs and tadpoles.

It doesn't seem to reflect the role carp play in the ecosystem as waterbird food. Are yabbies and shrimp, aquatic snails etc included in Benthic Inverts box? that seems unclear to me. Is another box needed to represent this food source? We have observed carp feeding on young fish also (unsure how often this happens though, might be rare). Would they also eat tadpoles? I'm interested in the Turbididty-macrophte relationship - wouldn't this be a two-way relationship? plant removal = more turbidity. which (direct feeding action or removal of macrophytes is actually the prevailing driver of turbidity change? In the Macquarie Marshes there is low turbidity in floodplain wetlands yet many carp and lots of macrophytes and emergents

Macrophytes and turbidity are often the two main cited sources of impact that carp have, but there are plenty of sites that are clear with carp and plenty that are muddy without carp, plus the original work in Victoria could only show an impact of carp on turbidity at very high densities. No doubt they have some impact on both plant and turbidity, but it is less than clear what the impacts are. I doubt there are any direct impacts of carp on native fish.

All models are wrong, but some are useful. So, while not a change to the model, I would suggest that it, like any model, the model needs to be vigorously tested.

Not clear about indirect competitive effects of carp on native fish (and perhaps amphibians); I would also specify that the model distinguish tadpole stages from adult frogs; sign needed between turbidity and P/N and I would have expected stronger pos effects from P/N to aq macrophytes; ambiguous pos/neg in arrow between chlor a and turbidity (may be better to distinguish the two pathways)

Appendix 4: Conceptual models for biotic groups

Large native fish

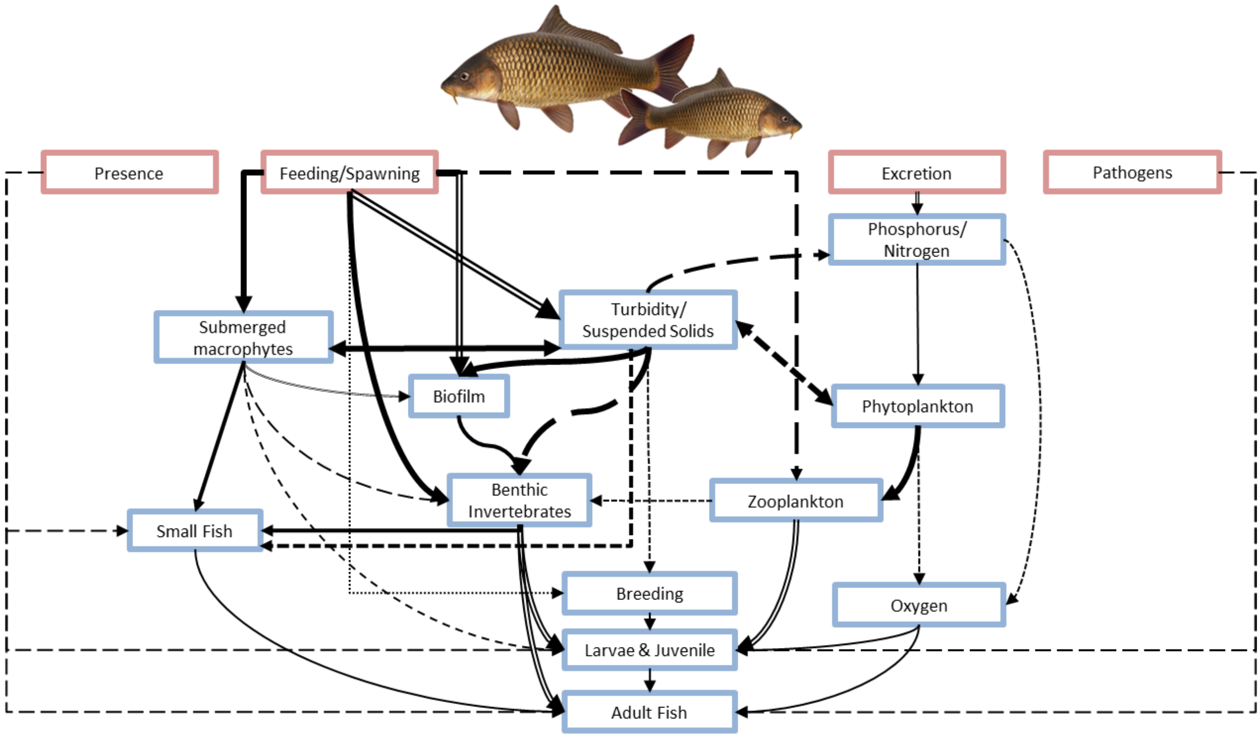


Figure 42 The conceptual model identifying the pathways by which carp influence large native fish.

Small native fish

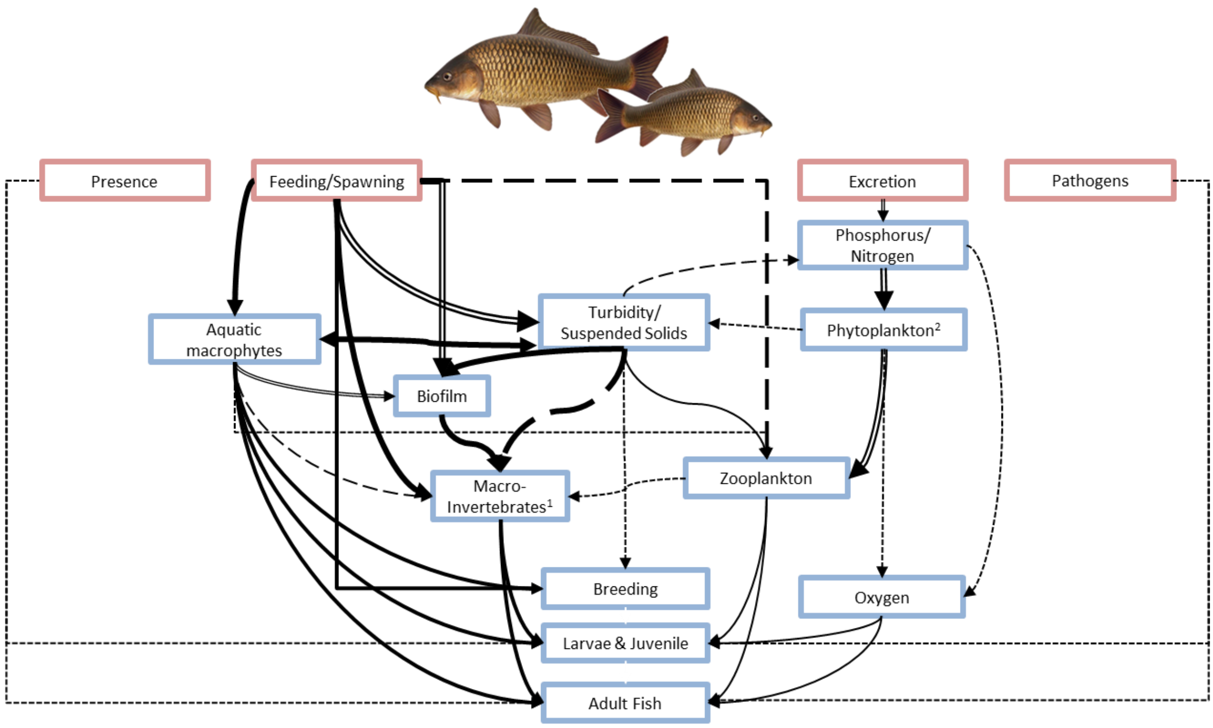


Figure 43 The conceptual model identifying the pathways by which carp influence small native fish. 1 – Macro-invertebrates includes fall-in by terrestrial invertebrates. 2 – Phytoplankton includes algal blooms.

Submerged macrophytes

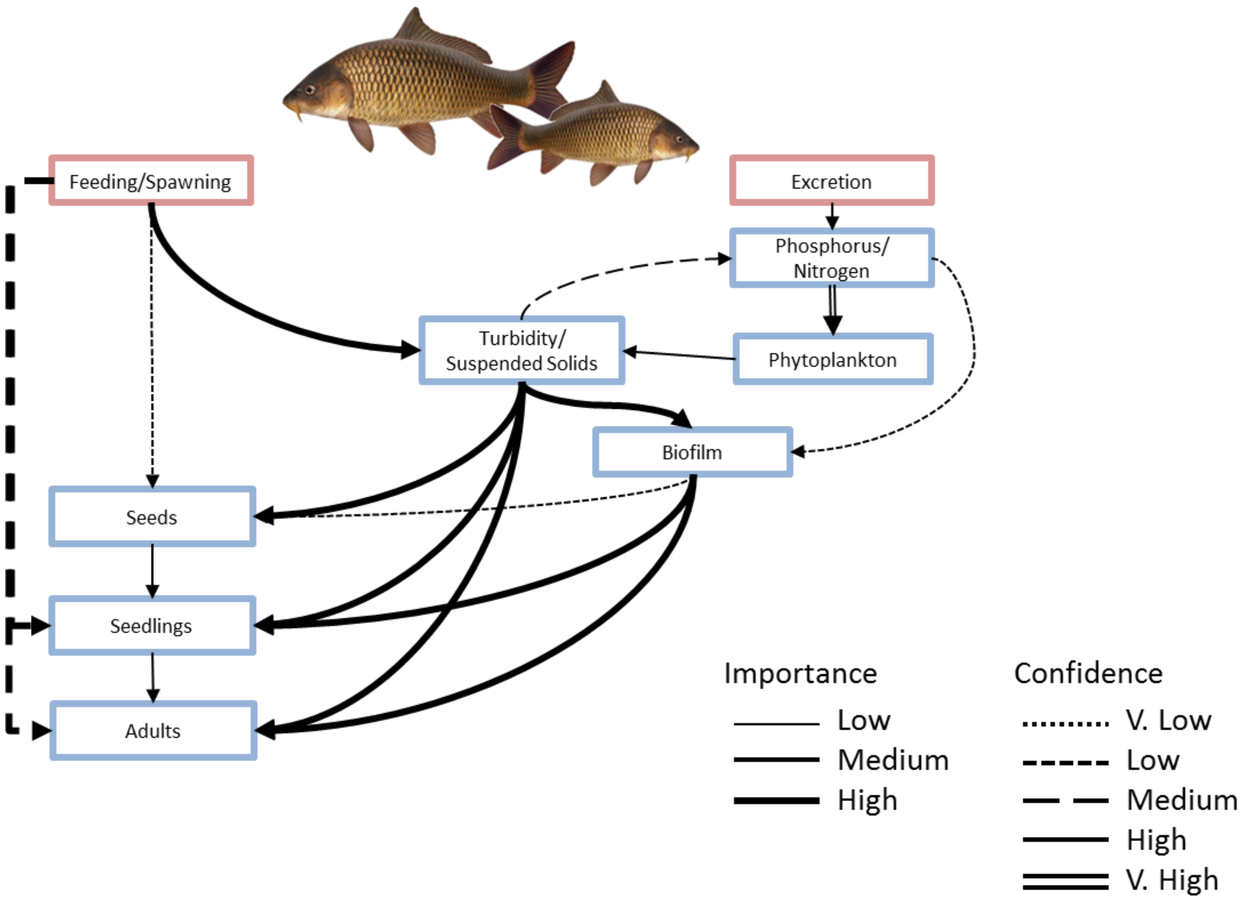


Figure 44 The conceptual model identifying the pathways by which carp influence submerged macrophytes.

Emergent macrophytes

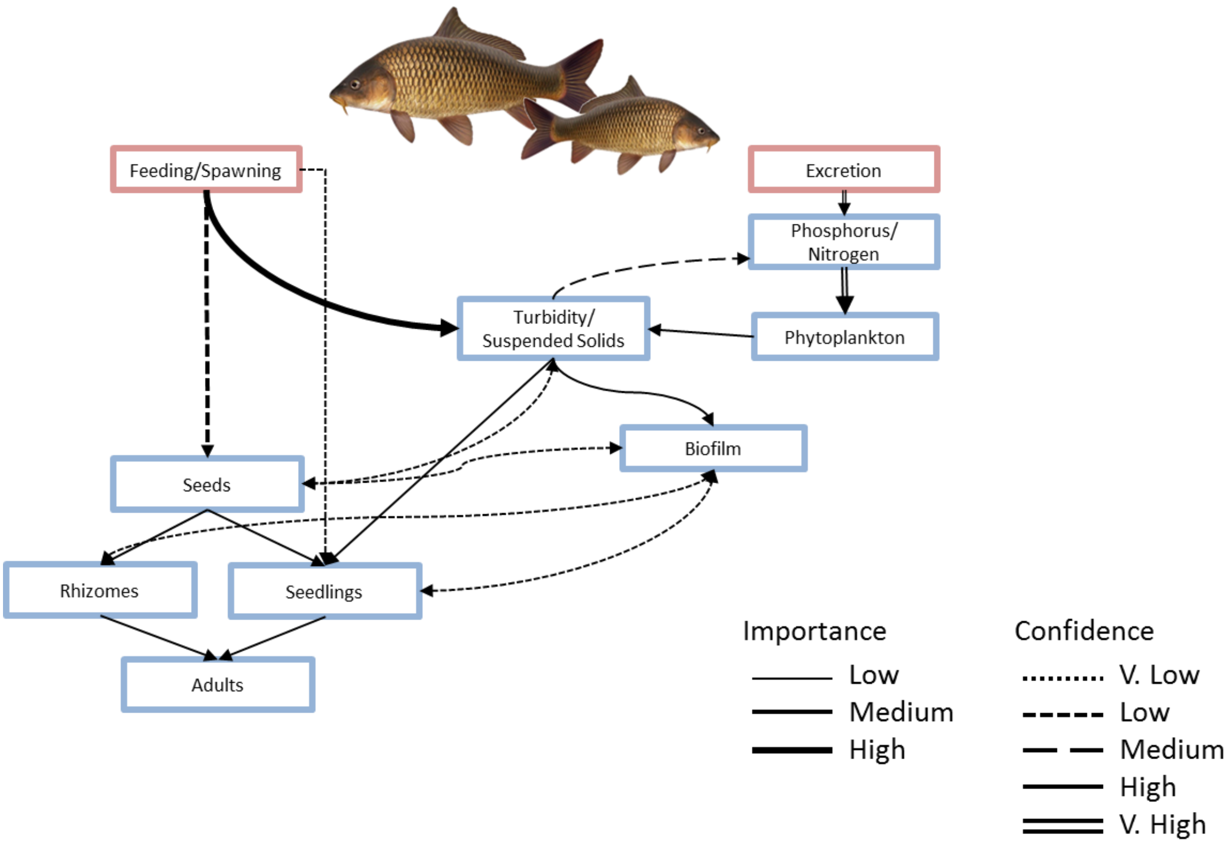


Figure 45 The conceptual model identifying the pathways by which carp influence emergent macrophytes.

Macroinvertebrates

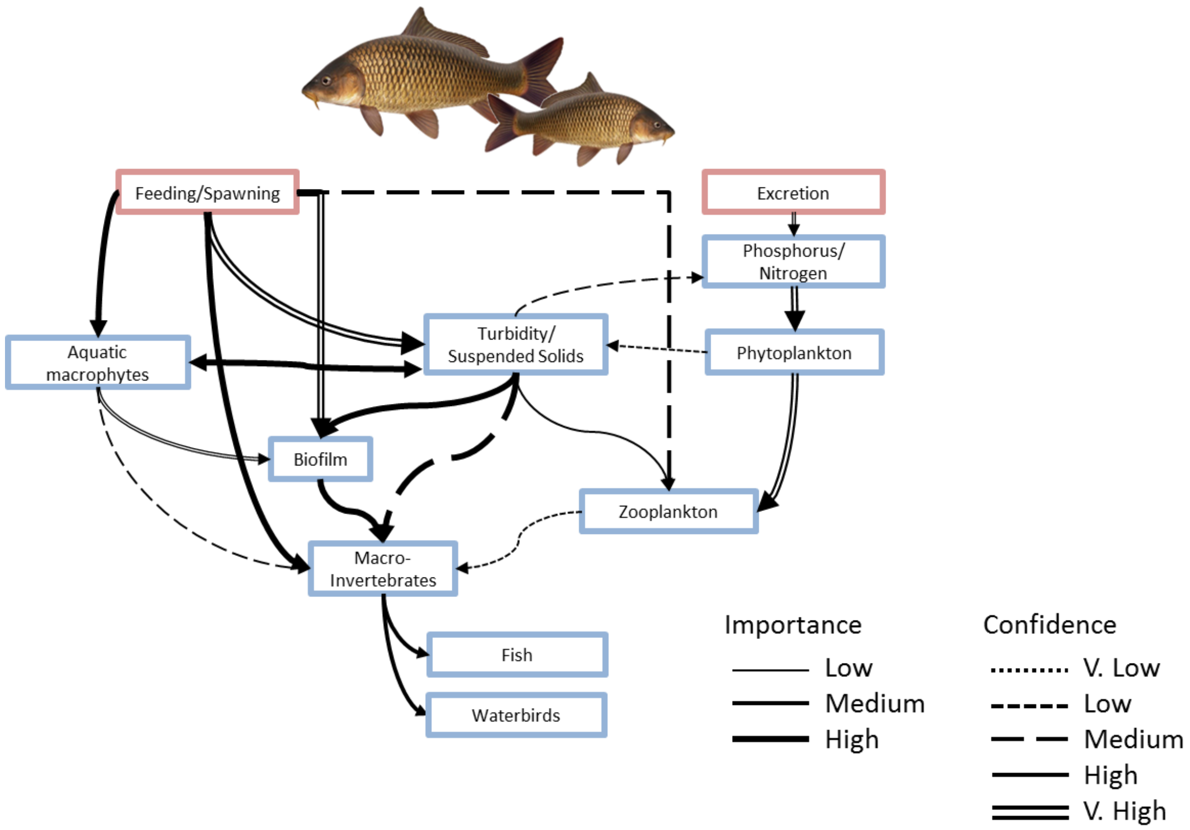


Figure 46 The conceptual model identifying the pathways by which carp influence macroinvertebrates.

Amphibians

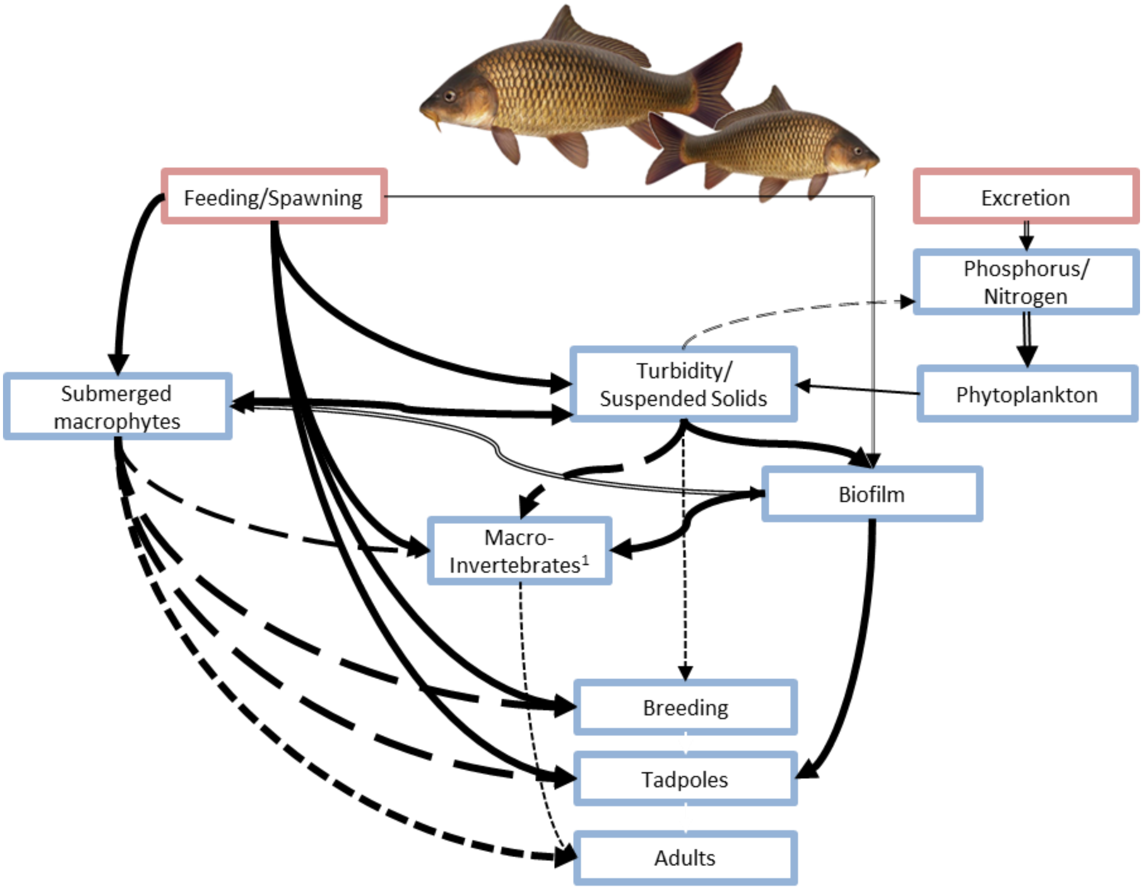


Figure 47 The conceptual model identifying the pathways by which carp influence amphibians. 1 – Macroinvertebrates includes terrestrial invertebrates

Herbivorous waterbirds

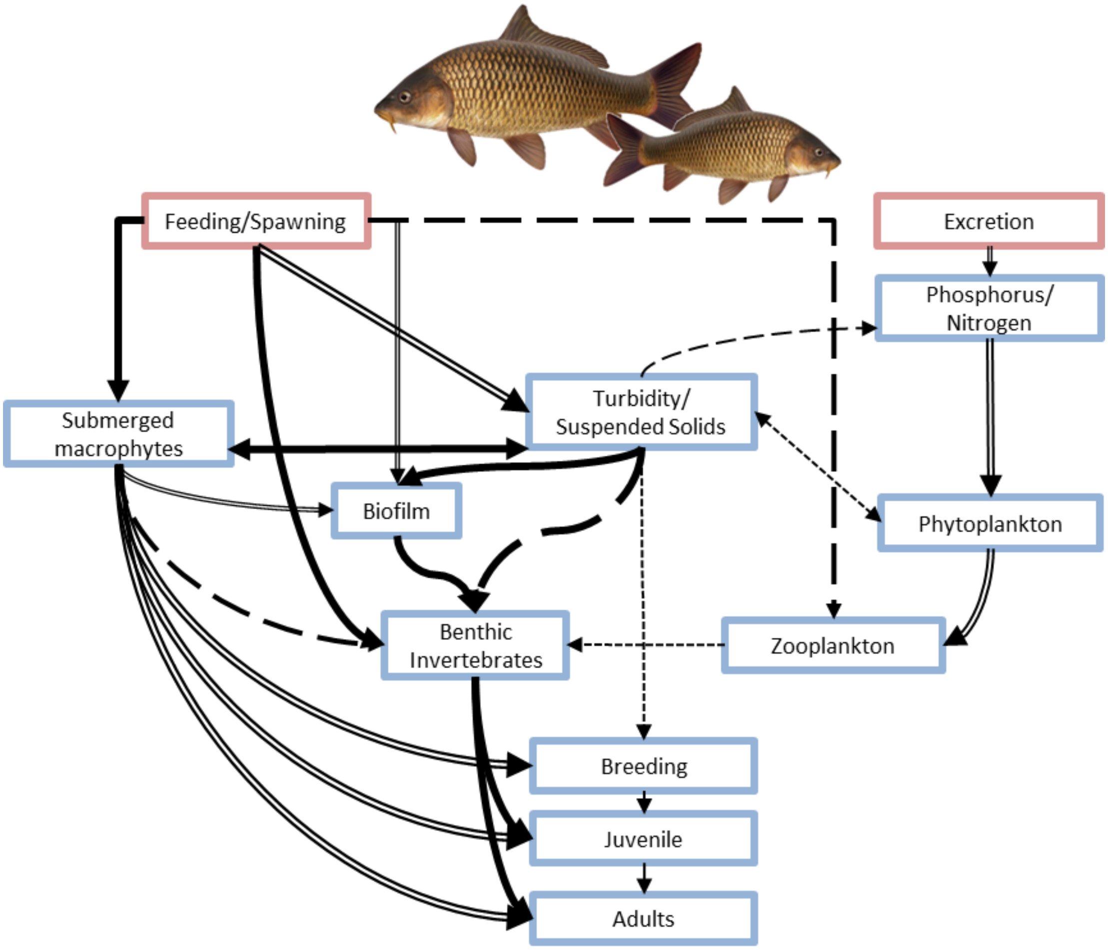


Figure 48 The conceptual model identifying the pathways by which carp influence herbivorous waterbirds

Piscivorous waterbirds

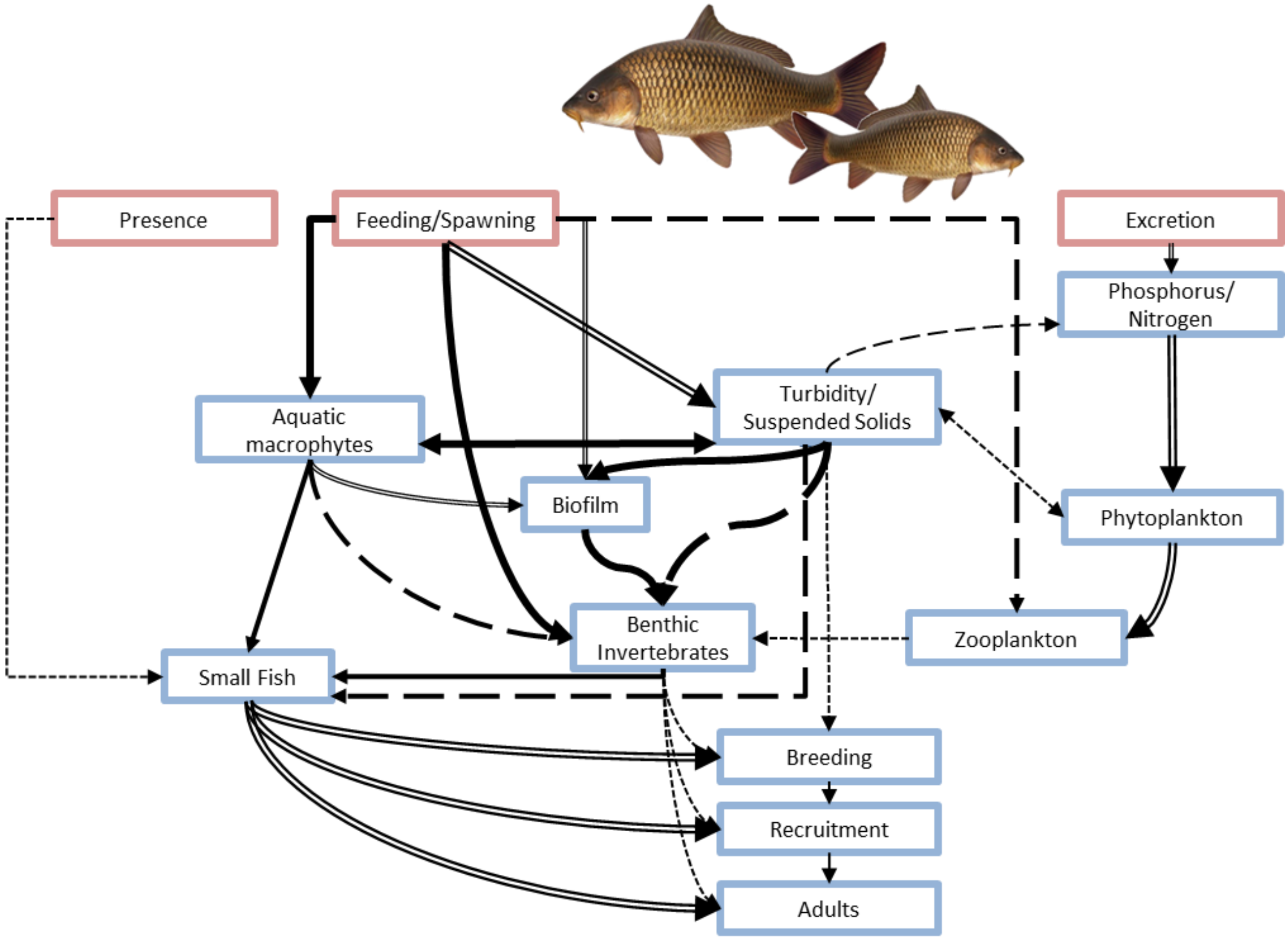


Figure 49 The conceptual model identifying the pathways by which carp influence piscivorous waterbirds

Appendix 5: Survey comments

Comments regarding recovery of large-bodied native fish

Survey participants were asked to comment on what factors represented the greatest risks or contributed most to their uncertainty. All comments provided are provided here.

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

neutral response with uncertainty due mainly to flow uncertainties (climate*management)

climate and land-use change will continue to impact into the future regardless of carp status

Relative impact of carp on large fish species versus low variability, effects of drought spells, flow regulation, water quality impairment, climate change, etc.

This is a negative <30% response. large-bodied native fish will continue to decline as a result of the other active stressors in the system (coldwater polution, other alien species, continued habitat loss; continued flow alteration). Uncertainty remains about how much effort will be directed at mitigating these other stressors, and how effective such mitigation might be

Eels will recruit but growth and survival will be restricted by competition with carp

Other factors such as restocking and habitat repair may assist large bodied native fish recovery in the absence of carp control.

other stressors; but not enough known

need more evidence of the nature of carp as stressors on native fish

Everyone is guessing by and large, but at the present time there is not great evidence that carp directly impact upon native fishes.

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

improvement may not be detectable given current level of broad-scale monitoring of fish-communities

climate and land-use clouds any future, but reduction in carp biomass could actually favour an alternate exotic (especially goldfish). Or a translocated native??

As above, but some recovery is to be expected in some ecosystem types (permanent rivers, lakes). Less recovery expected in reservoirs with fluctuating water levels, poorly developed littoral habitats, low food resources for large fish (invertebrates, samall fish).

this is a positive <30% response. other pest management approaches and experience demonstrate that you do not get much bang for buck with this level of reduction

Other large-bodied invasive fish species (cattfish, goldfish) will also proliferate

other stressors; but not enough known

need more evidence of the nature of carp as stressors on native fish and the relative roles of other stressors

Influence of other factors such as hydrology and river operations

Everyone is guessing by and large, but at the present time there is not great evidence that carp directly impact upon native fishes.

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Response from other alien fish species

Reduced densities should produce detectable benefits in processes, abundance and diversity in key monitored wetlands, lakes and river reaches

pretty much as above but all the multiple stressors will limit any true recovery. Iam in the camp that carp are so dominant because the system is screwed and not because of carp - they are (at least in part) a symptom

More likely to see recovery at this level of reduction of carp; however, other stressors may be important. Response will vary with ecosystem type.

as noted above, even acheiving a 70% carp reduction is not going to result in a massive upswing in large-bodied native fish, given the other stressors in operation.

Other large-bodied invasive fish species (cattfish, goldfish) will also proliferate

Uncertainty regarding how the ecosystem will change in response to carp reduction and whether the distribution and abundance of other pest species will increase.

Carp, because of their life history, are able to bounce back in numbers quite quickly.

other stressors; but not enough known

need more evidence of the nature of carp as stressors on native fish and the relative roles of other stressors

Everyone is guessing by and large, but at the present time there is not great evidence that carp directly impact upon native fishes.

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Response from other alien fish species and the capacity of native fish to recover

Absence of carp should produce detectable benefits in processes, abundance and diversity in key monitored wetlands, lakes and river reaches

Total removal will make some change just from taking away the sheer biomass. The problem will be what the already stressed systems will then do in response? other invaders?

Novel ecosystems are likely to develop over time in the complete absence of carp. Source populations to initiate fish population and community recovery may be stressed, limited, scattered, depending on ecosystem type. A return to original ecosystem state seems most unlikely even without carp.

the great unknown is how other stressors (see response 1) are dealt with, and whether Carp are justreplaced by an alternative non-native species such as redfin

There will be a lagged response in eel biomass increase. In our experiment in Lake Ohinewai a reduction between 2011 and 2016 from 307 to 14 kg carp/ha increased eel biomass from 9 to 42 kg/ha over the same period

Uncertainty regarding how the ecosystem will change in response to carp reduction and whether the distribution and abundance of other pest species will increase.

Elimination of carp will have profound effects on riverine ecosystems, hopefully for the better. But I suspect many of the changes will be unpredictable.

Other factors, such as water quality, sediment slugs, loss of snags, fish passage barriers, alien species (redfin in particular), general degradation of riparian zones etc will continue to exert negative pressure on large bodied native fish.

other stressors; but not enough known

need more evidence of the nature of carp as stressors on native fish and the relative roles of other stressors

What happens if redfin make a comeback? They are highly piscivorous and will decimate younger large bodied native fishes

Recovery

Not likely to recover to 1960's levels because of increase water extraction, and climate change since then

a long way to bounce back

Likely in premanent rivers and lakes if other stressors. less likely in reservoirs with fluctuating water levels that affect fish food resorces, shelter amongst macrophytes, secure spawning sites.

large, long-lived threatened species will need long time to recover, will still have other stressors present (coldwater pollution, habitat loss, nutrient loadings, barriers to fish passage,

Many other impacts on quatic ecosystem health. Carp are only one impact and many more would need to be addressed to see broadscale ecosystem recovery

As carp eradication is generally impossible the reduction of carp biomass is an ongoing cost

River regulation will still be a press disturbance with major impact.

Body condition and recruitment responses might be possible within 5-10 years. But because these species typically have older ages at sexual maturity, it will take longer for an equilibrium in populations to develop.

Native fish are severely depleted in many areas and may take many years to recover.

Will affect population of species differently but will take time

If other stressors (connectivity, habitat, flow regimes) are also managed it may be higher

Depends of flow conditions

Other stressors

Some recovery towards ecological objectives but limited by other stressors as listed.

Systems are screwed by major major stressors - to name a few flow regulation, flow diversion, barriers altered land systems, cliamte change, low natural standing stocks of breeding fish

Other stressors will limit recovery to strong recruitment levels

Removal of carp will not affect the other anthropogenic stressors mentioned above

Brown bullhead catfish and goldfish might take the place of carp

See above comments under 'recovery'

Climatic conditions may mask any carp-dependant responses. Changes in fishing pressure may confound a response.

Redfin may again become abundant and predate heavily on juvenile native species.

Other stressors already affect populations

Carp are more of a symptom than the problem. Migration cut off by weirs, cold water polluation, siltation, major water extraction all screw up native fishes more.

Hysteresis - Please provide as much detail as you wish explaining why you feel this is t...

Lag effects are to be expected, longer term response may be more akin to prior states limited by other stressors

In unknown territory here so the trajectory will almost certainly not be the opposite to what previously occured given how altered all of our aquatic ecosystems are

System is changed in so many ways that it is highly unlikely to return to its 'natural' state

Macrophytes in NZ are largely exotic so ecosystem recovery to native macrophytes is not a given and possibly unlikely

A resurgence of redfin perch may result in an alternative stable state developing.

Novel system

Carp reduction will not reverse extinctions, so by definition we are always moving into novel states

Almost certainly in the medium to long term we will have novel ecosystems with altered structure and function of aquatic ecossystems as a starting point. Further likley other invasiomns of non-native animals will occur

Novel systems seem quite likely as some fish species recover well and others do not.

Other alien species may take over (e.g. redfin perch in southern MDB)

At least an ecosystem not seen before European colonisation

It is highly likely that what will result will be largely unpredictable. It may be that another alien species will expand its distribution and increase hugely in number.

Redfin may again become abundant and predate heavily on juvenile native species.

Comments regarding recovery of small-bodied native fish

Scenario One: Do nothing to reduce carp

Relative impact of carp versus natural environmental factors and stressors on small native fish. Improved e-flows could generate increased native fish recruitment, and this could outweigh impact of carp on fish popoulations and community structures.

This is a negative <30% response. Small-bodied native fish will continue to decline as a result of the other active stressors in the system (coldwater pollution, other alien species, continued habitat loss; continued flow alteration, floodplain alienation, wetland darainage). Uncertainty remains about how much effort will be directed at mitigating these other stressors, and how effective such mitigation might be. Captive breeding and stocking of smallbodied species is more likely to yield results than for large-bodied species, but capacity (hatcheries, funding) is severely limited

There would be a decline in galaxias numbers if nothing was done to reduce the number of carp. Main factor would be competition for prey, but possibly deterioration in water quality from algal blooms.30% decline.

Carp plus other stressors

I don't see evidence for much ongoing decline of smaller natives that could be connected with carp, thus I don't see much change with the status quo.

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

As above but reduced carp impacts could generate better response of native fish

this is a positive <30% response. other pest management approaches and experience demonstrate that you do not get much bang for buck with this level of reduction

Not sure if a small reduction in carp will have any effect. And carp can recover quickly because of their life history strategy.

Stressors other than those related to carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

This level of carp reduction can be expected to generate greater levels of recovery of native fish species. Can expect different benefits for various fish species (e.g. related to guild affiliations).

as noted above, even acheiving a 70% carp reduction is not going to result in a massive upswing in small-bodied native fish, given the other stressors in operation. The greatest uncertainty is how much attention will be given to mitigating other stressors. Without other non-carp mitigation actions, there is little confidence that native fish communities will significantly respond

Uncertainty regarding how the ecosystem will change in response to carp reduction and whether the distribution and abundance of other pest species and of generalist small-bodied species will increase.

Again, there may be a short-term effect, but recovery of carp is likely to be fairly rapid, and the effects will then persist.

Stressors other than those related to carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Would expect novel ecosystem structures to emerge over time. How different to pre-carp will depend on the ecosystem type, other stressors on the ecosystem, and probably effects of climatic shifts.

as above, the great unknown is how other stressors (see scenario 1 and 3) are dealt with, and whether Carp are just replaced by an alternative non-native species such as redfin, goldfish, gambusia, weatherloach

Uncertainty regarding how the ecosystem will change in response to carp reduction and whether the distribution and abundance of other pest species and of generalist small-bodied species will increase.

It is likely that if all carp are eliminated, small native fish will benefit for reasons mentioned previously. But it is likely that other factors, such as other alien species, or other stressors will continue to have negative effects.

Alien species such as redfin, gambusia and Weatherloach may proliferate and occupy the habitat more effectively than native species.

Stressors other than those related to carp

If redfin come back then what little native fishes are still here will be in worse trouble.

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

Some already extinct. No breeding program for any small bodied and many non extinct are fragmented so can't come back without assistance such as breeding and release program

Sgort life cycles, potentialfor rapid recovery of small fish populations in suitable habitats.

species will need long time to recover, will still have other stressors present (coldwater pollution, habitat loss, nutrient loadings, floodplain alienation, barriers to fish passage, other alien species

Other stressors, such as river regulation and other alien species will remain.

Macrophyte communities need to recover before small bodied native fish can recover so there will be a lag in response.

Unsure the relative contribution of carp-related stressors and other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

Other stressors may limit recovery of small fish species even in absence of carp, but more likelyhood of recovery over longer time periods

removal of carp will not affect the other anthropogenic stressors mentioned above

Climatic conditions may mask any carp-dependant responses. Changes in fishing pressure may confound a response.

Redfin may also increase and exert predation pressure on small bodied native fish.

likely to be more significant than carp

Carp aren't the major problem, fragmentation, loss of floodplain habitats, introduced predatory fishes (Gambusia, Redfin) are much bigger problems.

Hysteresis - Please provide as much detail as you wish explaining why you feel this is the case

Don't know

system is changed in so many ways that it is highly unlikely to return to its 'natural' state

Many populations of small bodied native species are locally extinct. Natural recolonisation may be unlikely over large areas.

Novel system - Please provide as much detail as you wish explaining why you feel this is the case

Would expect some chnage in fish community composition, possibky to extent of novel ecosystems developing over time

other alien species may take over (e.g. goldfish, eastern gambusia, weatherloach in wetland/floodplain systems, redfin perch in southern MDB (both wetland/floodplain and riverine systems)

I think it likely that, especially long-term effects, will be unpredictable

Comments regarding recovery of fish 'other'

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

total recovery unlikley due to EHN disease now being prevalent in redfin populations

Dont know of any evidence that carp reductions will give native fish better chances of recruitment than any other alien species in the system. I think we need to be aware of implications of all carp impacts on other alien species, and possibly also translocated species...

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

some recovery, but limited by EHN mortality

Other stressors may creat conditions that favor alien species which may fare better than native species even when carp are removed

If redfin increase in abundance we are all doomed!

Novel system - Please provide as much detail as you wish explaining why you feel this is the case

Possible. Reduced invertebrate food resources /shifts in composition of invert and zooplankton communities may influence the success of alien species relative to native species and produce novel configurations of species after carp removal.

Comments regarding recovery of macrophytes emergent

Scenario One: Do nothing to reduce carp

See response for submerged plants

there should be no change

As per previous options, I don't understand this part of the survey

water availbility/climate

Scenario Two: 25% reduction in carp -

Carp numbers will recover quickly so there will probably be very little response

water availbility/climate

Scenario Three: 70% reduction in carp -

There may be minor changes in the short-term but carp numbers will recover.

water availbility/climate

Scenario Four: Complete elimination of carp -

Emergent plants are more robust than submergents so they are probably not impacted by carp to the same degree

Other factors such as cattle grazing may also be preventing the recovery of emergent amphibious plants.

water availbility/climate

Recovery - Please provide as much detail as you wish

Similar to submerged plants. Recovery is linked to the availability of propagules and the ability to disperse. Will be slow initially and will depend on the condition of a site prior to carp removal. Likely to be fairly site specific. Facilitating recovery (revegetation, seed bombing) is likely to help

Other factors influence abundance, other mechanism influence establishment dispersal

No data is available from before carp invaded so there is no way to tell

reduced distrubance

Other stressors - Please provide as much detail as you wish

Plants are affected by numerous other stressors: flow modification, connectivity, fragmentation, habitat modification, climate change, other disturbances e.g. pigs, cattle, horses, sheep, waterbirds, landuse, runoff

No data is available from before carp invaded so there is no way to tell

water availbility/climate

Hysteresis - Please provide as much detail as you wish

don't know

No data is available from before carp invaded so there is no way to tell

Novel system - Please provide as much detail as you wish

don't know
No data is available from before carp invaded so there is no way to tell
some species may not come back

Other

No data is available from before carp invaded so there is no way to tell

Comments regarding recovery of macrophytes submerged

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your un...

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?
further declines possible due to other stresses
No change, changes in submergent vegetation will be due to other factors
Already plenty of evidence of recovery of submerged aquatic plants in rivers and lakes following the Millenium drought. Unclear if that was due to a reduction in carp numbers or other hydrologic factors such as low flows, warmer waters etc.
water availability

Scenario Two: 25% reduction in carp

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?
response are likely to be patchy across the landscape depending on initial abundance of submerged veg and proximity of propagule sources and type and severity of other threats and climate conditions over the period. There is also the potential that carp control results in severe depletion in DO and this may also cause the local extinction of submerged plant and seed banks. There is also the risk of hysteresis from low DO with the release of nutrient from sediments
Probably will not change much, carp populations will probably be at historical levels in a short time
water availability

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?
Need a large reduction to get a response . As above
There will probably be a response in the short-term but it may not be long lasting because the carp populations will recover
water availability

Scenario Four: Complete elimination of carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

As above

Spatial averaging, as required by these scenarios is pretty challenging to deal with and make assessments.

I think there will be a response but what I'm just not sure of

Numerous species of alien submerged aquatic plant may occupy the habitat more effectively than native species.

water availability

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

Need seed / propagule sources to be available or dispersed throughout the system. The required connectivity maynot exist in some areas and the timeframes will be long. The ability to recover will vary significantly across river-floodplain systems. Comments are based on a large spatial scale in general. The opportunities for recovery on small spatial scales are likely to be high.

Rates of recovery will depend on colonisation rates which may be slow in fragmented systems

There is not any data from before carp infestation to compare so I cannot say

Alien species of submerged aquatic plants (eg Elodea) may expand to occupy the habitat more effectively than native species.

already patchy and uncommon

inproved water quality should rpomote germination and growth

Other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

Flow modification, connectivity, weed species, fragmentation, habitat modification, impacts of other grazing/disturbing animals (e.g. pigs, cattle, horses, sheep, waterbirds)

nutrients and altered water regime will persist and constrain recovery

There is not any data from before carp infestation to compare so I cannot say

already patchy and uncommon

flows/climate may inhibit respocovery

Hysteresis

Hysteresis - Please provide as much detail as you wish explaining why you feel this is the case

If substantial deleption of DO occurs this will result in loss of exant population and potially the loss of soil seed banks. DO depletion can also release P from sediment and increase phytoplanton. This may lead to a shift toward phytoplankton dominance

There is not any data from before carp infestation to compare so I cannot say

Alien species of submerged aquatic plants (eg Elodea) may expand to occupy the habitat more effectively than native species.

already patchy and uncommon

may not shift back

Novel system

Novel system - Please provide as much detail as you wish explaining why you feel this is the case

No sure really

Factors determining regeneration (incl germination, dispersal, sources of prpoagules, availability) have changed and these will control what develops and which species will be favoured: especially under situation of altered hydrology and warmer conditions (climate change). This affects all preceding possibilities.

There is not any data from before carp infestation to compare so I cannot say

already patchy and uncommon

some species my not return

Other

Other - Please provide as much detail as you wish explaining why you feel this is the case

There is not any data from before carp infestation to compare so I cannot say

already patchy and uncommon

Comments regarding recovery of macroinvertebrates

Scenario One: Do nothing to reduce carp

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Unsure of the relative impact of carp versus flow variability, drought cycles, water quality impairment, feeding by native fishes, etc, on invertebrates.

Sources of sediment from catchment.

the system is not likely to be stable due to the range of stressors already acting on it.

No change in stressor

I think most of the impacts have probably already occurred

Scenario Two: 25% reduction in carp

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Potential changes in size composition of carp

As above

as in do nothing

data suggest carp presence, irrespective of carp density, extirpate Notopala

Unlikely to be detectable or significant

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Effects of other invasive species Changes in size composition of carp

More likely to see recovery at this level of e reduction of carp; however, other stressors may be important. Response will vary with ecosystem type.

as in do nothing

data suggest carp presence, irrespective of carp density, extirpate Notopala

Still a bit unclear but if sustained decline of 70%, then I would expect some sort of response

Scenario Four: Complete elimination of carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Effects of other invasive species

Other impacts in catchment (increased diffuse inputs, land use changes, agricultural intensification)

Novel ecosystems are likely to develop over time in the complete absence of carp. Source populations to initiate recovery may be stressed, limited, scattered, depending on ecosystem type.

as in do nothing Aquatic snails may have the capacity to bounce back with complete removal, but the population of some species may already be extinct

Recovery of Notopala would require active reintroductions as have very restricted dispersal capacity based on life history and genetics studies

I think there will be a strong recovery; whether it would be 100% is hard to say but I feel reasonably confident it would be substantial

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

Medium to long-term recovery in permanenet rivers and large lakes with no other stressors. Recovery hard to predict intemporary rives. If capr were mainly confined to isolated pools/waterholes in dry times, their impoAct could be hihg and recovery after removal also high. However, theinflunece of variable flow regime and marked boom andbust cycles may be a more important factor in the recovery even if carp are removed.

Carp are not the only stressor in the system. Multiple other impacts from agriculture and urban development. Likely reductions in cape will not result in major changes part from smaller lentil water bodies.

Populations may take many years to recover.

not likely to be having a large effect

stressor for Notopala unlikely removed unless carp eliminated based on available data

I think that most Aust macroinverts disperse fast and will recolonise quickly

Other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

Reservoirs with fluctuating water levels may have limited/patchy/variable littoral macrophyte communities, few source populations of invertebrates, variable invertebrate community structures, low recovery at first, possibly medium recovery >10 years.

Hard to judge - this is ambiguous

Hysteresis

Hysteresis - Please provide as much detail as you wish explaining why you feel this is the case

Notopala recovery would require active intervention as have very limited dispersal ability demonstrated by genetics studies

Recovery trajectory depends on colonisation sequence

Novel system

Novel system - Please provide as much detail as you wish explaining why you feel this is the case

Full recovery to former ecosystem state may never occur after decades of carp impacts, even over 5-10years or >10 years. This could be the most most likely outcome for all ecosystem types.

Very likely to return to close to what it was

Comments regarding recovery of water quality

Scenario One: Do nothing to reduce carp

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

it probably gets worse because of confounding effects of other stressors, but see my comments in the next box

Ecosystem has adjusted and stabilised to the current levels of carp

other complementary management in the system

catchment soil properties, landuse, history, suspended sediment residence time

Scenario Two: 25% reduction in carp

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

OK, so I don't understand what I'm being asked to do here. I have defined 3 causal links between water quality attributes and carp. One I am not sure of the lreationship, the second is a positive relationship and the third is a negative relationship. Integrating these I get no relationship. Do I modify this???

Carp numbers will still be very high, and their impacts will be similar to a higher population (asymptotic response)

Other stressors
other complimentary management in the system
catchment soil properties, landuse, history, suspended sediment residence time

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?
Other stressors like severe flow modification and disintegrating river banks, bank erosion due to grazing pressure will contribute significant suspended solids and nutrient inputs. response will be larger in Barwon-Darling and lower reaches of tribs.
Other stressors
other complimentary management in the system
catchment soil properties, landuse, history, suspended sediment residence time

Scenario Four: Complete elimination of carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?
Influence of factors other than carp, especially intensification of water use/abstraction
General catchment erosion is also a powerful influence on water quality (turbidity) and is likely to continue to exert a strong influence even in the absence of carp.
For the reasons given above I would expect less than a proportionate response
Other stressors
other complimentary management in the system
catchment soil properties, landuse, history, suspended sediment residence time

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case
other stressors will limit the recovery
It may take many years for macrophyte communities to recover and stabilise the sediements.
Only in lower sections of rivers; irrigation transfer zones are medium
as explained previously - turbidity was already high prior to carp introduction

Other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case
This question is confusing.
In highly flow regulated sections and cropped agriculture, suspended solids may remain high but in the Barwon-Darling and lower sections of tribs other stressors should have less effect

Catchment sources provide long term increased nutrient and sediment concentrations so impact of carp removal in many cases may be limited.

clearing in the landscape is more likely to be increasing turbidity

high turbidity not due to carp

Hysteresis

Hysteresis - Please provide as much detail as you wish explaining why you feel this is the case

altered channel morphology and loss of macrophytes may affect recovery trajectory

Suspended sediment residence time is 1000s of years

Novel system

Novel system - Please provide as much detail as you wish explaining why you feel this is the case

nutrients may remain high due to agricultural and township inputs

Comments regarding recovery of herbivorous waterbirds

Scenario One: Do nothing to reduce carp

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Environmental flows

actual impact of carp on herb bird food sources.

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

River regulation stressors - less overbank flows and floodplain alienation

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

Other stressors affect recovery

Other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

River regulation

Comments regarding recovery of piscivorous waterbirds

Scenario One: Do nothing to reduce carp

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Only short term though.

Scenario Two: 25% reduction in carp

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Only short term though.

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

Depends on increase in native fish abundances

Only short term though.

Scenario Four: Complete elimination of carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

As above but depends on increase in native fish abunances

Only short term though.

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

Decline in waterbirds unless native fish abundance increases

lag in alternative food supply

Short term hit to food resources will hpoefully be quickyl remedied by increased native fish abundance

Other stressors

Other stressors - Please provide as much detail as you wish explaining why you feel this is the case

River regulation and barriers

Comments regarding recovery of amphibians

Scenario One: Do nothing to reduce carp

Scenario One: Do nothing to reduce carp - What factors represent the greatest risks or contribute the most to your uncertainty?

does not affect them

lack of experimental data

Scenario Two: 25% reduction in carp

Scenario Two: 25% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

does not affect them

The impacts of carp impact amphibian species differently. Threshold impacts are likely to be significant species some species, others may exhibit a more linear response to decreasing carp abundance .

Scenario Three: 70% reduction in carp

Scenario Three: 70% reduction in carp - What factors represent the greatest risks or contribute the most to your uncertainty?

does not affect them

The impacts of carp impact amphibian species differently. Threshold impacts are likely to be significant species some species, others may exhibit a more linear response to decreasing carp abundance .

Scenario Four: Complete elimination of carp

Scenario Four: Complete elimination of carp - What factors represent the greatest risks or contribute the most to your uncertainty?

does not affect them

based on carp exclusion trails we could expect signification recover of most frog species, but there are other exotic fish in the systems that might influence recovery for some species

Recovery

Recovery - Please provide as much detail as you wish explaining why you feel this is the case

I have extensive observations of systems without carp, or the change in the system with the invation of carp.

evidence from carp exclusion trails in wetlands show large increases in tadpoles and adults over short time frames. Biomass of tadpoles can equal biomass previously recorded for juvenile carp

Appendix 5: Eco Evidence software reports

Eco Evidence: Analysis report – Water Quality

Problem

See text in main document

Question

Will the ecosystem recover following the removal of non-native and non-predatory freshwater fish, such as common carp?

Context

See text in main document

Conceptual model

See conceptual models in main document. Ecosystem recovery was measured as: • An improvement in water quality (increased clarity, decreased turbidity, decrease in nutrients, decrease in chlorophyll-a, fewer algal blooms) • An increase in macrophyte biomass, abundance and taxa richness • An increase in macroinvertebrate abundance, density and richness • An increase in amphibian abundance • An increase in native fish abundance and richness

Literature review

Search strategy

See text in main document

Table 1: Results

The evidence according to the 3 major causal criteria shows whether the analysis provides enough support for a causal relationship between the hypothesised effect-cause linkages or alternatively whether there is no support, insufficient evidence or inconsistent evidence for the causal relationship. The minimum requirement for demonstration of a causal relationship is either "Response" or "Dose-response" to be HIGH, and also "Consistency" needs to be HIGH. Also shown are the number of studies and citations contributing to the analysis of each linkage.

Linkage	Conclusion regarding the level of support for the hypothesised linkage	Level of support for each criterion (sum of weights) *			Item counts		Number of studies reporting signs of causal agent in the biota
		Response	Dose-response	Consistency	Evidence items **	Citations	
↓ fish → ↓ water quality (turbidity)	Support for hypothesis	High (106)	No evidence (0)	High (4)	25	20	0
↓ fish → ↓ water quality (nutrients)	Support for hypothesis	High (20)	No evidence (0)	High (2)	6	6	0
↓ fish → ↓ water quality	Inconsistent evidence	High (27)	No evidence (0)	Low (20)	12	12	0
Total number of evidence items and citations contributing to causal analysis					43	38	0

* Summed study weights for the different causal criteria. For "Response" and "Dose-response" criteria, if the summed study weight is less than 20 then the level of support is LOW, otherwise it is HIGH. For "Consistency" criteria, if the summed study weight is less than 20 then the level of support is HIGH, otherwise it is LOW.
** The number of relevant evidence items contributing to the analysis. Relevance is determined (and documented) by the user. For evidence to be included, the study must also conduct an appropriate analysis/interpretation. The project file contains the justification for including or excluding each evidence item.

Appendix

Table 2: Evidence relating to each cause-effect linkage

↓ fish → ↓ water quality (turbidity)

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
Removal of carp from a lake from 1940 - 1952	Decrease	In this case water quality is defined as water clarity. Water visibility increased from six inches in 1948 to three and four feet in 1952	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Cahoon, W. G. (1953)
The densities of carp were manipulated to establish high- and low-carp biomass treatments in two billabongs (B1 and B2) in NSW in Jan - July 1995. Final standing stocks of carp in the high- and low-carp treatments of each billabong were 1181 and 101 kg ha-1 , and 669 and 348 kg ha-1 , respectively.	Decrease	Turbidity ranged from 55 to 550 NTU in B1 and 5 to 267 NTU in B2, and on any one date was higher in B1 than in B2. In each billabong, turbidity was significantly higher in the high-carp	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 2 (control); 2 (impacted)	9	King A. J., Robertson A. I. and Healey M. R. (1997)

↓ fish → ↓ water quality (turbidity)

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		treatment. Manipulations of carp biomass explained 60% of the total variation in turbidity in B1 but only 2% of the total variation in B2. In B1, turbidity increased with time in the high-carp treatment (r = 0·33, P < 0·01) but decreased in the low-carp treatment (r = –0·37, P < 0·01), whereas in B2 turbidity decreased with time in both treatments (r = –0·53, P < 0·001 and r = –0·53, P < 0·001)					
Elimination of carp from one of three reservoirs in Ontario, Canada. Removal of about 480 kg ha1 of carp from one reservoir (almost all the population) in spring 1999	Decrease	Carp removal resulted in a significant reduction concentration of suspended solids at the outflow. This suggests that bioturbation by carp was the primary cause of elevated sediment export from LL, and probably the other impoundments on Laurel Creek. Suspended inorganic sediment concentrations at the outflow of LL were significantly lower (t = 10.910, p < 0.001) than at the inflow.	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 2 (control); 1 (impacted)	7	Barton et al (2000)
Rotenone applied to lake in 1980 to eliminate predominantly planktivorous and benthivorous fish to small lake in Minnesota	Decrease	In this case an increase in water quality is associated with an increase in clarity as	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Shapiro and Wright (1984)

↓ fish → ↓ water quality (turbidity)								
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
		measured by Secchi depth. In 1981 the mean transparency was 4.8m, a significant increase over 1980 (pre biomanipulation) (P<0.001, t-test with unequal variances). Increased transparency persisted during the summer of 1982 with the mean at 4.7m which was also significant (P<0.001).					
In order to improve lake water quality by means of biomanipulation, a total of 2.5 tons of bream (Abramis brama) and roach (Rutilus rutilus) was removed during 1986 and the spring of 1987. The planktivorous/benthivorous fish biomass was thereby reduced by approximately 50 %, from 30 to 15 g WW m -2	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. Secchi depth increased from a mean summer level of 0.6 m in 1986 to 1.0 m in 1987 and 1.3 m in 1988.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Søndergaard et al (1990)
Application of rotenone in 2000 killed approx 75% of the carp population in the wetland.	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. Secchi disk transparency was generally quite low in the marsh (~0.35 m) but was signi?cantly higher following FK3 (BACI, p <0.05). The highest Secchi disk transparency of 1.0 m was recorded on 13 July 2000, 6 weeks after FK3.	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 2 (impacted)	8	Schrage and Downing (2004)

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
Removal of a substantial amount of plankti-benthivorous ?sh was followed by planting of submerged macrophytes and stocking of piscivorous ?sh. We found strong and relatively long-lasting effects of the restoration initiative in the form of substantial improvements in water clarity and major reductions in nutrient concentrations, particularly total phosphorus, phytoplankton and turbidity	Decrease	A major reduction in TSS was observed upon restoration. Thus, annual mean values were constantly lower than 5 mg L ,which is much lower than both before restoration (annual mean values > 21 mg L) and in the reference lake (annual mean values > 30 mg L) (BACIP, t ¼ 7.99, df ¼ 23.2, p < 0.0001). ISS in the restored site followed the TSS pattern observed in the reference lake, and compared to CLake the differences in ISS were significant (BACIP, t ¼ 2.65, df ¼ 45, p < 0.012). The percentage of ISS to TSS also decreased significantly (BACIP, t ¼ 2.4, df ¼ 45, p < 0.021).	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Liu et al (2018)
Removal of all fish from a 10 ha enclosure within a lake by trawl netting and continuous removal using nets	Decrease	In this case water quality is defined as water clarity measured by Secchi depth. Mean Secchi depth was 0.40 m outside and 0.75 m inside the enclosure, and the mean differences were significant (p < 0.001).	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Chen et al (2009)
Removal of all fish from a 10 ha enclosure within a lake by trawl netting in March 2004 and continuous removal using nets	Decrease	The mean concentrations of TN and TP inside the enclosure from May 2004 to May 2008 were 22.2% and	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Chen et al (2009)

↓ fish → ↓ water quality (turbidity)

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		26.0% of those outside, respectively. Compared with outside, the mean concentrations of TN and TP inside the enclosure were significantly lower ($p < 0.01$).					
Large-scale biomanipulation trial was carried out on Lake Vesijärvi in Finland during 1989–1993. Roach removal resulted in biomass from 178 kg/ha to 39 kg/ha and smelt 75 kg/ha to 12 kg/ha	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. The summertime transparency of the water increased from 1.5m in 1989 to 3.5 m in 1995.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Horppila et al (1998)
In 2004 200 kg fish ha was removed from Bio 1 and in 2007 286 kg fish ha was removed from Bio 2. The removed species were tilapia (Oreochromis niloticus), silver carp (Hypoph-almcihthys molitrix), common carp (Cyprinus carpio) and mud carp Cyprinus molitorella), and in addition, crucian carp (Crassius auratus) and bighead carp (Hypophthalmcihthys nobilis) were removed from Bio 1.	Decrease	In 2013 SS (mg l -1) Bio1 was 3.73 Bio2 4.81 and Control 33.8	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 2 (impacted)	8	Jensen et al (2017)
In 2004 200 kg fish ha was removed from Bio 1 and in 2007 286 kg fish ha was removed from Bio 2. The removed species were tilapia (Oreochromis niloticus), silver carp (Hypoph-almcihthys molitrix), common carp (Cyprinus carpio) and mud carp Cyprinus molitorella), and in addition, crucian carp (Crassius auratus) and bighead carp (Hypophthalmcihthys nobilis) were removed from Bio 1.	Decrease	In this case an increase in water quality in associated with an increase in water clarity. In 2013 (Post fish removal) Bio1 clarity was to bottom, Bio2 was to bottom and Control to 23 cm.	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 2 (impacted)	8	Jensen et al (2017)
Using electrofishing and gill netting, 4073 carp and 261 gold?sh, amounting to	Decrease	In this case water quality increase is	Decrease	Yes	Before v. after (no reference/control)	4	Pinto L., Chandrasena N., Pera J.,

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
10 117 kg of cyprinid biomass were removed between 1996 and 2004 from the Botany wetlands near Sydney.		associated with an increase in water clarity as measured by Secchi depth. After 8 yr of removal the Secchi disc transparency increased by 20%.			0 (control); 2 (impacted)		Hawkins P., Eccles D. and Sim R. (2005)
The long-term effects obtained after the removal of 41-1360 kg fish ha -1 in 36 mainly shallow and eutrophic lakes in Denmark.	Decrease	In lakes in which less than 200 kg fish ha-1 were removed within a 3 -year period only minor effects were observed, but at higher removal rates both chemical and biological variables were markedly affected. The concentrations of chlorophyll a (Chla), total phosphorus (TP), total nitrogen (TN), and suspended solids (SS) decreased to 50-70% of the level prior to removal. The most significant and long-lasting effects were found for SS and Secchi depth, whereas the most modest effects were seen for Chla. a. Total algal biomass also declined after fish removal, particularly that of cyanobacteria, whereas the biomass of cryptophytes increased.	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 10 (control); 27 (impacted)	10	Søndergaard et al (2008)
Removal of carp (reduction in abundance from 4,181 (2008) to 281 (2011)) from a stratified eutrophic lake in Minnesota, USA	Decrease	A decline in total suspended solids (removal caused a decrease in TSS throughout	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bajer, P.G., Sorensen, P.W (2015)

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		the entire season, but particularly in the summer)(F = 11.84, df = 3 P = 1.62 x 10 - 4)					
Removal of all fish using rotenone (including benthivores) from a shallow eutrophic lake in Minnesota, USA in October 1987	Decrease	In this case improved water quality is defined as improved water clarity as measured by Secchi depth. Before fish removal, water clarity declined quickly after ice-out and remained low (Secchi disk transparency 30-40 cm) notable changes in water transparency followed fish removal. First, a spring clear-water phase developed during May-June 1988 and again briefly during May 1989. Second, dramatic improvements in transparency began during August 1989 and persisted through October 1990. Secchi disk transparency exceeded 1 m throughout the ice-free period in 1990.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Mark A. Hanson & Malcolm G. Butler (1994)
51% of carp removed (from 351 to 172 kg.ha) in 2008/09 in a lake in Wisconsin, USA. bottom sediments. The carp exclosure was removed in September 2008. During the winters of 2007–2008 and 2008–2009, the Wisconsin Department of Natural Resources attempted to remove carp from Lake Wingra. Nearly	Decrease	In this case an increase in water quality is defined as an increase in water clarity as measured by Secchi depth. Averaged Secchi depth during 2008–2010 was more than that during	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Lin and Wu (2013)

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
7000 carp were captured and taken out of the lake. According to the mark-recapture estimates, carp density in the lake declined by 51% (from 351 to 172 kg.ha x1).		1996–2007, i.e., water became clearer after the removal of carp during the winters of 2008 and 2009. Improved water quality could be attributed to the reduction of sediment resuspension and algae growth. The removal of carp led to the abundance of submerged macrophytes and consolidation of sediment bottoms especially in deep water. In short, the ?u?y sediment layer because of carp activities may be the main source for suspended sediments to deteriorate water quality. Removal of carp is crucial for stabilizing bottom sediment and improving water clarity in this small lake.					
Baltic lake (Germany). Intensive removal of planktivorous and benthivorous fish by means of beach seining. Lake restoration was from 1980-1994. The paper reports on the period 1984-1995. With the exception of 1991 we performed fish removal 14-20 times per year, and treated 50-75% of the lake area each year.	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. Secchi readings less than 1 m were typical between 1973-1982 . During the second half of the 1980s, after biomanipulation had been initiated, the values were 1.30-1 .75 m. At	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Krienitz et al (1996)

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
		the beginning of the 1990s, the Secchi transparency decreased to 0 .65-0 .85 m, and this coincided with a chlorophyll a concentration maximum of 0.059 mg 1 -1 in 1992 (Figure lb). The 1994 average of 1 .80 m was the highest transparency since the 1960s .					
Removal of carp and plankitvorous tench from a shallow lake in Turkey from Aug 1998 to Dec 2000	Decrease	Fish removal resulted in 4 fold reductions in the concentration of suspended solids from 38 ± 18 before carp were removed to 9.4 ± 6 (F:22 p0.000)	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Beklioglu et al (2003)
Removal of carp and plankitvorous tench from a shallow lake in Turkey from Aug 1998 to Dec 1999	Decrease	In this case water quality is defined as water clarity measured using Secchi depth. 2.5-fold increase in Secchi disk transparency from 101 ± 43 before fish removal to 262 ± 14 (F:20, p:0.000 99-***-93_95 & 97) during biomanipulation	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Beklioglu et al (2003)
Removal of carp and plankitvorous tench from a shallow lake in Turkey from Aug 1998 to Dec 2002	Decrease	Significance of differences was tested using one-way ANOVA and Tukey's honestly significant difference (HSD) test. The in-lake concentration of TP and soluable reactive phosphate	Increase	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Beklioglu et al (2003)

↓ fish → ↓ water quality (turbidity)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
		(SRP) increased during the fish removal in 1999 (381 ± 22 µg l1 and 284 ± 18 µg l1, respectively). TP before fish were removed 324 ± 31 to 381 ± 21 (F:12 p:0.000, 93_95-***–97, 99; 97-**-99) during biomanipulation.					
Exclusion of common carp (Cyprinus carpio) via construction of the Cootes Paradise Fishway (Lake Ontario) that became operational in 1997.	Decrease	Mean turbidity following exclusion (33.7 ± 4.3 NTU, 1998–2008) decreased by almost half of its original value during the pre exclusion years (60.7 ± 4.3 NTU, 1993-1996). This was significant change r2=0.6 and p=0.04	Decrease	Yes	Reference/control vs. impact (no before) 0 (control); 1 (impacted)	2	Thomasen and Chow-Fraser (2012)
Exclusion of common carp (Cyprinus carpio) via construction of the Cootes Paradise Fishway (Lake Ontario) that became operational in 1997.	Decrease	TSS (mg/L) over the period 1993 to 2008 r2=0.24 p=0.26. Not significant	No change	No	Reference/control vs. impact (no before) 0 (control); 1 (impacted)	2	Thomasen and Chow-Fraser (2012)
Eighteen shallow lakes in The Netherlands were subjected to biomanipulation, i.e. drastic reduction of the ?sh stock, for the purpose of lake restoration. In some lakes biomanipulation was accompanied by reduction of the phosphorus loading.	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. In all but two lakes (16 lakes), the Secchi disk transparency increased after the ?sh removal. Eight lakes (no phosphorus loading reduction, except for one lake) showed a strong and quick response to the measures: the bottom of the lake became	Decrease	Yes	Before v. after (no reference/control) 0 (control); 18 (impacted)	5	Meijer et al (1999)

↓ fish → ↓ water quality (turbidity)

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		visible ('lake bottom view). In eight other lakes the water transparency increased, but lake bottom view was not obtained. The critical factor for obtaining clear water was the extent of the fish reduction in winter. Significant effects were observed only after >75% fish reduction.					
Large common carp (Cyprinus carpio >30 cm) were excluded from a turbid, eutrophic coastal marsh of Lake Ontario with the construction of a ?shway at the outlet. We present water turbidity data collected for 3 years prior to carp exclusion (1993–94, 1996) and 4 years following exclusion (1997–2000) to illustrate long term trends in water clarity (NOTE: there was no monitoring program in 1995).	Decrease	In the first year after carp exclusion, mean seasonal water turbidity decreased at all sites by 49–80%. Water clarity and macrophyte growth improved most in those areas of the marsh that were least degraded (i.e. areas with emergent vegetation), whereas the other sites remained relatively turbid and devoid of vegetation or only exhibited temporary changes in water clarity	Decrease	Yes	Before v. after (no reference/control) 1 (control); 3 (impacted)	7	Lougheed and Chow-Fraser (2001)

↓ fish → ↓ water quality (nutrients)

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
In order to improve lake water quality by means of biomanipulation, a total of 2.5 tons of bream (Abramis brama) and roach (Rutilus rutilus) was removed during 1986 and the spring of 1987. The planktivorous/benthivorous fish biomass was thereby reduced by	Decrease	Phosphorus declined from a mean summer of 157 µg tot-P l^{-1} in 1986 to 87 µg tot-P l^{-1} in 1988.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Søndergaard et al (1990)

↓ fish → ↓ water quality (nutrients)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weigh t**	**Citation**
approximately 50 %, from 30 to 15 g WW m -2							
Application of rotenone in 2000 killed approx 75% of the carp population in the wetland.	Decrease	Total phosphorus concentrations were somewhat reduced in the period following FK3 compared to the pre-manipulation and the post-FK1 periods (BACI, p <0.058). In the pre-manipulation and the post-FK1 periods, the total phosphorus of Ventura Marsh was, on average, 147 and 216 µg l1 , respectively, higher than the total phosphorus concentration of the reference system, whereas in the clear-water phase, the average difference was only 32 µgl1 . By inference, therefore, carp removal resulted in a 115–184 µgl1 reduction in total phosphorus concentration in the marsh.	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 2 (impacted)	8	Schrage and Downing (2004)
Biomanipulation of fish, including benthivorous fish in one of two basins, CLake the control and RLake the restored basin in Chinese Huizhou West Lake	Decrease	After restoration TP dropped markedly in the restored site, frequently reaching values lower than 50 mgL , while the concentrations in CLake remained	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Liu et al (2018)

↓ fish → ↓ water quality (nutrients)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
		within the range of 52-340 mgL. Accordingly, the BACIP analysis revealed a signi?cant drop in TP in the restored site (t ¼ 4.24, df ¼ 51, p < 0.0001).					
Large-scale biomanipulation trial was carried out on Lake Vesijärvi in Finland during 1989–1993. Roach removal resulted in biomass from 178 kg/ha to 39 kg/ha and smelt 75 kg/ha to 12 kg/ha	Decrease	Following the mass removal of coarse fish (roach and smelt) the total phosphorus concentration declined from 45 mg/L to 30 mg/L.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Horppila et al (1998)
Removal of carp (reduction in abundance from 4,181 (2008) to 281 (2011)) from a stratified eutrophic lake in Minnesota, USA	Decrease	Mean TP concentrations before and after carp removal were 69.4 and 75.3 lg/L, respectively (not significant). Carp removal had no apparent effect on total phosphorus.	No change	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bajer, P.G., Sorensen, P.W (2015)
Baltic lake (Germany). Intensive removal of planktivorous and benthivorous fish by means of beach seining. Lake restoration was from 1980-1994. The paper reports on the period 1984-1995. With the exception of 1991 we performed fish removal 14-20 times per year, and treated 50-75% of the lake area each year.	Decrease	From 1980-1986 the spring maximum of TP was 1 .2-1 .4 mg l -1 while annual mean P04-P varied between 0 .650.93 mg 1 -1 . From the mid-1980s the concentration of TP and P04-P decreased continuously	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Krienitz et al (1996)

↓ fish → ↓ water quality (chlorophyll-a)							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**

Rotenone applied to lake in 1980 to eliminate predominantly planktivorous and benthivorous fish to small lake in Minnesota	Decrease	In this case decreased water quality is associated with chlorophyll a concentration. In 1981 the concentration of chlorophyll a were lower than the comparable dates in 1980 and the average concentration for all dates was significantly less (P<0.001). By September 1982 the concentration levels were back to pre-biomanipulation levels.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Shapiro and Wright (1984)
In order to improve lake water quality by means of biomanipulation, a total of 2.5 tons of bream (Abramis brama) and roach (Rutilus rutilus) was removed during 1986 and the spring of 1987. The planktivorous/benthivorous fish biomass was thereby reduced by approximately 50 %, from 30 to 15 g WW m -2	Decrease	In this case decreased water quality is associated with increased phytoplankton biomass. Phytoplankton biomass decreased from a mean summer level of 25 mm3 -1 in 1986 to 12 in 1987 and to 7 mm3 -1 in 1988.	Increase	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Søndergaard et al (1990)
Removal of all fish from a 10 ha enclosure within a lake by trawl netting in March 2004 and continuous removal using nets	Decrease	In this case water quality decrease is defined as an increase in phytoplankton biomass. Phytoplankton biomass, especially cyanobacterial biomass, signifcantly increased from July 2004 to September 2004 (p < 0.001), compared with outside.	Increase	No	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Chen et al (2009)
Large-scale biomanipulation trial was carried out on Lake	Decrease	In this case an improvement in water quality is	Decrease	Yes	Reference/control vs. impact (no before)	2	Horppila et al (1998)

Vesijärvi in Finland during 1989–1993. Roach removal resulted in biomass from 178 kg/ha to 39 kg/ha and smelt 75 kg/ha to 12 kg/ha		associated with a decrease in phytoplankton. Following the mass removal of coarse fish (roach and smelt) the biomass of cyanobacteria collapsed from 1.4 g/m -3 to below 0.4 g/m -3. No harmful blooms of cyanobacteria have occurred since 1989.			0 (control); 1 (impacted)		
In 2004 200 kg fish ha was removed from Bio 1 and in 2007 286 kg fish ha was removed from Bio 2. The removed species were tilapia (Oreochromis niloticus), silver carp (Hypoph-almcihthys molitrix), common carp (Cyprinus carpio) and mud carp Cyprinus molitorella), and in addition, crucian carp (Crassius auratus) and bighead carp (Hypophthalmcihthys nobilis) were removed from Bio 1.	Decrease	In this case increased water quality is associated with decreased concentration of chlorophyll a. In 2013 (post fish removal) Chl.a. (g l-1) Bio1 was 8.08 and Bio2 5.29 and Control 35.5	Decrease	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 2 (impacted)	8	Jensen et al (2017)
Using electrofishing and gill netting, 4073 carp and 261 gold?sh, amounting to 10 117 kg of cyprinid biomass were removed between 1996 and 2004 from the Botany wetlands near Sydney.	Decrease	In this case water quality decrease is defined by the concentration of cyanobacteria. After 8 yr of removal, a 10-fold decrease occurred in cyanobacterial counts.	Decrease	Yes	Before v. after (no reference/control) 0 (control); 2 (impacted)	4	Pinto L., Chandrasena N., Pera J., Hawkins P., Eccles D. and Sim R. (2005)
The long-term effects obtained after the removal of 41-1360 kg fish ha -1 in 36 mainly shallow and eutrophic lakes in Denmark.	Decrease	In this case an increase in water quality is associated with an increase in water clarity as measured by Secchi depth. Secchi depth almost doubled during the first 8-10 years after the initiation of removal. Despite large variations among lakes effect was observed in more than 75% of the lakes	Increase	No	BACI or BARI MBACI or Beyond MBACI 10 (control); 27 (impacted)	10	Søndergaard et al (2008)

		and it remained statistically significant for several years. Most variables differed from the pre-situation during the first 6-8 years after the removal, but after approximately 10 years all variables, excluding Secchi depth and partly also SS, exhibited a tendency to return to pre-removal conditions. However, this tendency is based on data from a limited number of lakes. After 14 years SS and Secchi depth also returned to pre removal conditions, but data are only available for 1-3 lakes.					
Removal of carp (reduction in abundance from 4,181 (2008) to 281 (2011)) from a stratified eutrophic lake in Minnesota, USA	Decrease	A decline in chlorophyll-a contributes to improved water quality. a decline in early season chlorophyll a (ChlA was consistently lower during May and early June (days 120–160) following carp removal) ($F = 0.48$, $df = 5$, $P = 0.78$)	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bajer, P.G., Sorensen, P.W (2015)
Removal of all fish using rotenone (including benthivores) from a shallow eutrophic lake in Minnesota, USA in October 1987	Decrease	In this case an improvement in water quality is associated with a decrease in the concentration of Chlorophyll-a. Seasonal patterns of phytoplankton biomass Chlorophyll-a (ugl- ') , varied pre- and post-	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Mark A. Hanson & Malcolm G. Butler (1994)

		treatment. In 1987 (pre-treatment), mean chlorophyll-a increased to peak at 45-65 g 1- during June-October. In all 3 post treatment years, chlorophyll-a concentration was high shortly after ice-out but subsequently decreased to lower levels until late summer. The late summer to fall levels of chlorophyll-a decreased each succeeding post treatment year (1988, (35.1), 1989 (28.2), 1990 (11.1)) .					
Removal of carp and plankitvorous tench from a shallow lake in Turkey from Aug 1998 to Dec 2001	Decrease	In this case water quality is defined as concentration of chlorphyll-a. Fish removal resulted 1.7-fold reductions in the concentration of chlorophyll-a from 27 ± 7 before fish were removed to 11.4 ± 2.6 (F:4.6, p:0.016, 99-*-93_95 & 97) during biomanipulation	Decrease	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Beklioglu et al (2003)
Exclusion of common carp (Cyprinus carpio) via construction of the Cootes Paradise Fishway (Lake Ontario) that became operational in 1997.	Decrease	In this case water quality is associated with concentration of Chl a. Chl a (ug/L) over the period 1993 to 2008 r2 = 0.05 p=0.65. Not significant.	No change	No	Reference/control vs. impact (no before) 0 (control); 1 (impacted)	2	Thomasen and Chow-Fraser (2012)
Eighteen shallow lakes in The Netherlands were subjected to biomanipulation, i.e. drastic reduction of the ?sh stock, for the purpose of lake restoration. In	Decrease	In the biomanipulation cases a significantly stronger decrease in concentrations	Decrease	Yes	Reference/control vs. impact (no before) 0 (control); 18 (impacted)	5	Meijer et al (1999)

some lakes biomanipulation was accompanied by reduction of the phosphorus loading.		of chlorophyll a ($P < 0.05$) was found compared to the general trend occurring in lakes where no specific measures In 13 out of 18 lakes the chlorophyll a concentration decreased. In lakes with bottom-view the summer average chlorophyll a concentration generally became lower than 15 g l-1. In the lakes where the Secchi depth improved without lake bottom view the chlorophyll a concentration was often low in spring (May–June) but increased from July onwards.					

Citations

Bajer, P.G., Sorensen, P.W (2015) *Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake*. Hydrobiologia

Barton et al (2000) *The effects of carp (Cyprinus carpio L.) on sediment export from a small urban impoundment*. Journal of Aquatic Ecosystem Stress and Recovery

Beklioglu et al (2003) *Restoration of the eutrophic Lake Eymir, Turkey, by biomanipulation after a major external nutrient control*. Hydrobiologia

Cahoon, W. G. (1953) *Commercial carp removal at Lake Mattamuskeet, North Carolina*. The Journal of Wildlife Management

Chen et al (2009) *Ecological restoration in eutrophic Lake Wuli: A large enclosure experiment*. Ecological Engineering

Horppila et al (1998) *Top-down or Bottom-up Effects by Fish: Issues of Concern in Biomanipulation of Lakes*. Restoration Ecology

Jensen et al (2017) *The effect of biomanipulation on phosphorus exchange between sediment and water in shallow, tropical Huizhou West Lake, China*. Limnologica

King A. J., Robertson A. I. and Healey M. R. (1997) *Experimental manipulations of the biomass of introduced carp (Cyprinus carpio) in billabongs .1. Impacts on water-column properties*. Marine and Freshwater Research

Krienitz et al (1996) *Long term study on the influence of eutrophication, restoration and biomanipulation on the structure and development of phytoplankton communities in Feldberger Haussee (Baltic Lake District, Germany)*. Hydrobiologia

Lin and Wu (2013) *Response of bottom sediment stability after carp removal in a small lake*. Annales de Limnologie - International Journal of Limnology

Liu et al (2018) *Successful restoration of a tropical shallow eutrophic lake: Strong bottom-up but weak top-down effects recorded*. Water Research

Lougheed and Chow-Fraser (2001) *Spatial variability in the response of lower trophic levels after carp exclusion from a freshwater marsh*. Journal of Aquatic Ecosystem Stress and Recovery

Mark A. Hanson & Malcolm G. Butler (1994) *Responses to food web manipulation in a shallow waterfowl lake*. Hydrobiologia

Meijer et al (1999) *Biomanipulation in shallow lakes in The Netherlands: an evaluation of 18 case studies*. Hydrobiologia

Pinto L., Chandrasena N., Pera J., Hawkins P., Eccles D. and Sim R. (2005) *Managing invasive carp (Cyprinus carpio L.) for habitat enhancement at Botany Wetlands, Australia*. Aquatic Conservation-Marine and Freshwater Ecosystems

Schrage and Downing (2004) *Pathways of Increased Water Clarity After Fish Removal from Ventura Marsh; a Shallow, Eutrophic Wetland*. Hydrobiologia

Shapiro and Wright (1984) *Lake restoration by biomanipulation: Round Lake, Minnesota, the first two years*. Freshwater Biology
Søndergaard et al (1990) *Phytoplankton biomass reduction after planktivorous fish reduction in a shallow, eutrophic lake: a combined effect of reduced internal P-loading and increased zooplankton grazing*. Hydrobiologia
Søndergaard et al (2008) *Lake Restoration by Fish Removal: Short- and Long-Term Effects in 36 Danish Lakes*. Ecosystems
Thomasen and Chow-Fraser (2012) *Detecting changes in ecosystem quality following long-term restoration efforts in Cootes Paradise Marsh*. Ecological Indicators

Table 3. Weights applied in this analysis

Study design type	Weight
BACI or BARI MBACI or Beyond MBACI	4
Gradient response model	3
Before v. after (no reference/control)	2
Reference/control vs. impact (no before)	2
After impact only	1
Number of independent control locations	**Weight**
No control locations	0
One control location	2
More than one control location	3
Number of independent impact locations	**Weight**
One impacted location	0
Two impacted locations	2
More than two impacted locations	3
Number of locations for gradient response model	**Weight**
3 independent locations	0
4 independent locations	2
5 independent locations	4
More than 5 independent locations	6

Eco Evidence: Analysis report – response of macrophytes, macroinvertebrates, amphibians, fish

Problem

See text in main document

Question

Will the ecosystem recover following the removal of non-native and non-predatory freshwater fish, such as common carp?

Context

see text in main document

Conceptual model

See conceptual models in main document. Ecosystem recovery was measured as: • An improvement in water quality (increased clarity, decreased turbidity, decrease in nutrients, decrease in chlorophyll-a, fewer algal blooms) • An increase in macrophyte biomass, abundance and taxa richness • An increase in macroinvertebrate abundance, density and richness • An increase in amphibian abundance • An increase in native fish abundance and richness

Revisions

see text in main document

Literature review

Table 1: Results

The evidence according to the 3 major causal criteria shows whether the analysis provides enough support for a causal relationship between the hypothesised effect-cause linkages or alternatively whether there is no support, insufficient evidence or inconsistent evidence for the causal relationship. The minimum requirement for demonstration of a causal relationship is either "Response" or "Dose-response" to be HIGH, and also "Consistency" needs to be HIGH. Also shown are the number of studies and citations contributing to the analysis of each linkage.

Linkage	Conclusion regarding the level of support for the hypothesised linkage	Level of support for each criterion (sum of weights) *			Item counts		Number of studies reporting signs of causal agent in the biota
		Response	Dose-response	Consistency	Evidence items **	Citations	
↓ fish → ↑ vegetation	Support for hypothesis	High (34)	Low (18)	High (2)	8	6	0
↓ fish → ↑ invertebrates	Support for hypothesis	High (26)	No evidence (0)	High (0)	5	5	0
↓ fish → ↑ amphibians	Insufficient evidence	Low (15)	No evidence (0)	High (0)	2	2	0
↓ fish → ↑ fish	Insufficient evidence	Low (12)	No evidence (0)	High (4)	6	5	0
Total number of evidence items and citations contributing to causal analysis					21	18	0

* Summed study weights for the different causal criteria. For "Response" and "Dose-response" criteria, if the summed study weight is less than 20 then the level of support is LOW, otherwise it is HIGH. For "Consistency" criteria, if the summed study weight is less than 20 then the level of support is HIGH, otherwise it is LOW.
** The number of relevant evidence items contributing to the analysis. Relevance is determined (and documented) by the user. For evidence to be included, the study must also conduct an appropriate analysis/interpretation. The project file contains the justification for including or excluding each evidence item.

Conclusion

see text in main document

Appendix

Table 2: Evidence relating to each cause-effect linkage

↓ fish → ↑ vegetation							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
removal of common carp	Decrease	Increased plant biomass	Increase	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	King, D. R., and Hunt, G. S. (1967)
Removal of carp. The restoration of Cootes Paradise Marsh was designed to restore aquatic vegetation, and thereby improve habitat values, by reducing carp biomass to 50 kg/ha through a carp exclusion strategy. Barriers prevented large carp (> 40 cm) from entering the marsh.	Decrease	Submergent plant stem density (stems/ha) was surveyed along transects in three in vegetated, sheltered bays (~0.5 m deep), June 1996 through 2000. Increased growth of submergent plants peaked in 1998 at an average of 32,000 stems/ha.	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Lougheed V. L., Theysmeyer T. S., Smith T. and Chow-Fraser P. (2004)
Removal of carp. The restoration of Cootes Paradise Marsh was designed to restore aquatic vegetation, and thereby improve habitat values, by reducing carp biomass to 50 kg/ha through a carp exclusion strategy. Barriers prevented large carp (> 40 cm) from entering the marsh.	Decrease	Submergent plant stem density (stems/ha) was surveyed along transects in three open water areas, June 1996 through 2000. The open water areas of the marsh remained largely plantless throughout the study period.	No change	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Lougheed V. L., Theysmeyer T. S., Smith T. and Chow-Fraser P. (2004)
Most adult carp (approximately 80% of the population) were removed from the lake in March 2009	Decrease	Following carp removal, vegetation density increased from approximately 5% cover to over 45% cover (t test; t =	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bajer, P.G., Sorensen, P.W (2015)

↓ fish → ↑ vegetation							
Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		10.13; df = 38; P\0.01).					
Reduction of number and biomass of carp	Decrease	Visual estimates of percent plant cover (nearest 10%); only submersed plants and macroalgae (Chara sp.) were included. Plant cover was negatively influenced by carp biomass. Overall (pre- and postremoval data combined), carp biomass explained 87% of variance in plant cover (plant cover = 10(2.08–0.0056• carp biomass),P < 0.001)	Increase	Yes	Gradient response model 6 (independent)	9	Bajer, P. G., Beck, M. W., Cross, T. K., Koch, J. D., Bartodziej, W. M., and Sorensen, P. W. (2016)
Reduction of number and biomass of carp	Decrease	Presence of plant species recoded; only submersed plants and macroalgae (Chara sp.) were included.Plant species richness was negatively influenced by carp biomass. Overall (pre- and postremoval data combined), carp biomass explained 68% of variance in plant species richness (plant species = 15.91–4.52 • log10 (carp biomass +1); P < 0.001).	Increase	Yes	Gradient response model 6 (independent)	9	Bajer, P. G., Beck, M. W., Cross, T. K., Koch, J. D., Bartodziej, W. M., and Sorensen, P. W. (2016)
exclusion of carp	Decrease	Increased plant biomass	Increase	Yes	Reference/control vs. impact (no before) 1 (control); 1 (impacted)	4	Tryon, C. A. (1954)
exclusion of carp from lake section	Decrease	the 2011 and 2012 surveys sampled wild rice growth over the entire bay. In 2012, after 2 summers of carp exclusion, we observed a dramatic increase in the mean density of rice growth throughout the bay (Fig 3), increasing from 1.2 ±0.4 stems/m2 in 2011 to 53 ±10 stems/m2 in 2012 (p <0.001; mean	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Johnson JA, Havranek AJ. (2013)

↓ fish → ↑ vegetation

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
		±2SE). This trend continued between 2012 and 2013, with mean stem density increasing further to 85 ±14 stems/m2 in 2013 (p = 0.006).					

↓ fish → ↑ invertebrates

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
From 1993 to 1997, over 200 kg ha(-1) of fish, mainly roach (Rutilus rutilus (L.)) and bream (Abramis brama (L.)) were caught and the fish biomass was reduced by nearly 80%.	Decrease	Higher biomass and density of all major groups of benthic invertebrates during the early years of fish removal.	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Leppa, M. Hamalainen, H. Karjalainen, J. (2003)
Fish exclusion	Decrease	Changed invertebrate assemblage associated with ponds with and without fish	Increase	Yes	Reference/control vs. impact (no before) 6 (control); 4 (impacted)	8	Parks, C. R. (2006)
Exclusion of carp	Decrease	Total benthic macroinvertebrate diversity	Increase	Yes	Reference/control vs. impact (no before) 1 (control); 1 (impacted)	4	Miller, S. A. and T. A. Crowl (2006)
fish removal from a large, shallow lake	Decrease	Densities of invertebrates	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Mark A. Hanson & Malcolm G. Butler (1994)
Eradication of benthic omnivorous fish species. Fish were eradicated with rotenone from the lower sections of each tributary.	Decrease	After fish eradication in two successive years, chironomid densities increased up to 50-fold in the fish-free areas but remained low elsewhere	Increase	Yes	BACI or BARI MBACI or Beyond MBACI 3 (control); 3 (impacted)	10	Joseph L. Bonneau and Dennis L. Scarnecchia (2015)

↓ fish → ↑ amphibians

Cause (and trajectory)		Effect (and trajectory)		Supports linkage?	Study details	Weight	Citation
Fish exclusion	Decrease	increased numbers of amphibians associated with ponds screened to exclude adult carp	Increase	Yes	Reference/control vs. impact (no before)	7	Parks, C. R. (2006)

↓ fish → ↑ amphibians							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
					6 (control); 2 (impacted)		
Adult carp excluded from ponds	Decrease	Abundance of larvae significantly greater in carp-free ponds compared to ponds with carp of ages 1+ and 2+	Increase	Yes	Reference/control vs. impact (no before) 56 (control); 7 (impacted)	8	Kloskowski J (2009)

↓ Pest fish → ↑ native fish							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
carp reduction, through seines	Decrease	game fish increased (commercial catch data) along with water quality and macrophytes	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Cahoon, W. G. (1953)
suppression of non-native Channel Catfish and Common Carp densities through removal via electro-fishing resulting in declines in carp densities, variable reductions in channel catfish	Decrease	Responses of native fishes to removal were not evident in most species and size classes. However, juvenile Flannelmouth Sucker densities did increase over time at the upper reach	No change	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Franssen, N. R., Davis, J. E., Ryden, D. W., and Gido, K. B. (2014)
flow restoration and exotic fish removal	Decrease	Native fish increase in abundance. 4 species increased. Speckled dace, Roundtail Chub, Desert sucker, Sonoran sucker. They show that removal of exotic fish dramatically increased native fish abundance. Flow restoration also increased native fish abundance, but the effect was smaller than that from removing exotics.	Increase	Yes	BACI or BARI MBACI or Beyond MBACI 1 (control); 1 (impacted)	6	Marks, J. C., Haden, G. A., O'Neill, M., and Pace, C. (2010)
eradication of invasive topmouth gudgeon	Decrease	the abundance, somatic growth rate and production of roach Rutilus rutilus and common bream Abramis brama (natives) have increased significantly	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Britton, J. R., Davies, G. D., and Brazier, M. (2009)
reduced abundance of introduced alewife through biological control	Decrease	recovery of native burbot (Lota lota), deepwater sculpin (Myoxocephalus thompsonii), and yellow perch (Perca flavescens) was partially or fully aided by the alewife reduction. However, as emerald shiner (Notropis atherinioides), cisco (Coregonus artedii), and	Increase	Yes	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bunnell, D. B., Madenjian, C. P., and Claramunt, R. M. (2006)

↓ Pest fish → ↑ native fish							
Cause (and trajectory)		**Effect (and trajectory)**		**Supports linkage?**	**Study details**	**Weight**	**Citation**
		lake trout (Salvelinus namaycush) have yet to demonstrate recovery					
reduced abundance of introduced alewife through biological control	Decrease	Recovery of native burbot (Lota lota), deepwater sculpin (Myoxocephalus thompsonii), and yellow perch (Perca flavescens) was partially or fully aided by the alewife reduction. However, others such as emerald shiner (Notropis atherinioides), cisco (Coregonus artedii), and lake trout (Salvelinus namaycush) have yet to demonstrate recovery	No change	No	Before v. after (no reference/control) 0 (control); 1 (impacted)	2	Bunnell, D. B., Madenjian, C. P., and Claramunt, R. M. (2006)

Citations

Bajer, P. G., Beck, M. W., Cross, T. K., Koch, J. D., Bartodziej, W. M., and Sorensen, P. W. (2016) *Biological invasion by a benthivorous fish reduced the cover and species richness of aquatic plants in most lakes of a large North American ecoregion*. Global Change Biology

Bajer, P.G., Sorensen, P.W (2015) *Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake*. Hydrobiologia

Bonneau, J.L., Scarnecchia, D.L. (2014) *The zooplankton community of a turbid Great Plains (USA) reservoir in response to a biomanipulation with common carp (Cyprinus carpio)*. Transactions of the Kansas Academy of Science

Britton, J. R., Davies, G. D., and Brazier, M. (2009) *Eradication of the invasive Pseudorasbora parva results in increased growth and production of native fishes*. Ecology of Freshwater Fish

Bunnell, D. B., Madenjian, C. P., and Claramunt, R. M. (2006) *Long-term changes of the Lake Michigan fish community following the reduction of exotic alewife (Alosa pseudoharengus)*. Canadian Journal of Fisheries and Aquatic Sciences

Cahoon, W. G. (1953) *Commercial carp removal at Lake Mattamuskeet, North Carolina*. The Journal of Wildlife Management

Franssen, N. R., Davis, J. E., Ryden, D. W., and Gido, K. B. (2014) *Fish Community Responses to Mechanical Removal of Nonnative Fishes in a Large Southwestern River*. Fisheries

Johnson JA, Havranek AJ. (2013) *Effectiveness of temporary carp barriers for restoring wild rice growth in Upper Clam Lake: 2010 to 2013*. Report to St. Croix Tribal Environmental Services – Natural Resources Department, Webster (WI). Freshwater Scientific Services–LLC, Maple Grove (MN). 8 pp. Report available for download at http://www.freshwatersci.com/fw_projects.html

Joseph L. Bonneau and Dennis L. Scarnecchia (2015) *Response of benthic macroinvertebrates to carp (Cyprinus carpio) biomanipulation in three tributaries of a eutrophic, Great Plains reservoir, USA*. Transactions of the Kansas Academy of Science

King, D. R., and Hunt, G. S. (1967) *Effect of carp on vegetation in a Lake Erie Marsh*. The Journal of Wildlife Management

Kloskowski J (2009) *Size-structured effects of common carp on reproduction of pond breeding amphibians*. Hydrobiologia

Leppa, M. Hamalainen, H. Karjalainen, J. (2003) *The response of benthic macroinvertebrates to whole-lake biomanipulation*. Hydrobiologia

Lougheed V. L., Theysmeyer T. S., Smith T. and Chow-Fraser P. (2004) *Carp exclusion, food-web interactions, and the restoration of Cootes Paradise Marsh*. Journal of Great Lakes Research

Lougheed, V. L. Crosbie, B. Chow-Fraser, P. (1998) *Predictions on the effect of common carp (Cyprinus carpio) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland*. Canadian Journal of Fisheries and Aquatic Sciences

Mark A. Hanson & Malcolm G. Butler (1994) *Responses to food web manipulation in a shallow waterfowl lake*. Hydrobiologia

Marks, J. C., Haden, G. A., O'Neill, M., and Pace, C. (2010) *Effects of Flow Restoration and Exotic Species Removal on Recovery of Native Fish: Lessons from a Dam Decommissioning*. Restoration Ecology

Miller, S. A. and T. A. Crowl (2006) *Effects of common carp (Cyprinus carpio) on macrophytes and invertebrate communities in a shallow lake*. Freshwater Biology

Parks, C. R. (2006) *Experimental manipulation of connectivity and common carp: the effects on native fish, water-column invertebrates, and amphibians in Delta Marsh*. Masters Thesis

Tryon, C. A. (1954) *The effect of carp exclosures on growth of submerged aquatic Vegetation in Pymatuning Lake, Pennsylvania*. The Journal of Wildlife Management

Table 3. Weights applied in this analysis

Study design type	**Weight**
BACI or BARI MBACI or Beyond MBACI	4
Gradient response model	3
Before v. after (no reference/control)	2
Reference/control vs. impact (no before)	2
After impact only	1
Number of independent control locations	**Weight**
No control locations	0
One control location	2
More than one control location	3
Number of independent impact locations	**Weight**
One impacted location	0
Two impacted locations	2
More than two impacted locations	3
Number of locations for gradient response model	**Weight**
3 independent locations	0
4 independent locations	2
5 independent locations	4
More than 5 independent locations	6

FRDC FINAL REPORT CHECKLIST

Project Title:			
Principal Investigators:	XXXX (include all recognised authors -)		
Project Number:	XXXX/XXX		
Description:	Brief one/two paragraph overview of what the project did and achieved.		
Published Date:	XX/XX/XXXX (if applicable)	**Year:**	XXXX
ISBN:	XXXXX (if applicable)	**ISSN:**	XXXXXXXXXXXXX (if applicable)
Key Words:	Needs to include key subject areas and species name (see www.fishnames.com.au)		

Please use this checklist to self-assess your report before submitting to FRDC. Checklist should accompany the report.

	Is it included (Y/N)	**Comments**
Foreword (optional)		
Acknowledgments		
Abbreviations		
Executive Summary		
– **What the report is about**		
– **Background – why project was undertaken**		
– **Aims/objectives – what you wanted to achieve at the beginning**		
– **Methodology – outline how you did the project**		
– **Results/key findings – this should outline what you found or key results**		
– **Implications for relevant stakeholders**		
– **Recommendations**		
Introduction		
Objectives		
Methodology		
Results		
Discussion		
Conclusion		
Implications		
Recommendations		
Further development		
Extension and Adoption		
Project coverage		
Glossary		
Project materials developed		

Appendices		

NATIONAL CARP CONTROL PLAN

The National Carp Control Plan is managed by the
Fisheries Research and Development Corporation

Tel: 02 6285 0400
Post: Locked Bag 222, Deakin West ACT 2600

www.carp.gov.au