RESEARCH **19**

**2016-132**

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

NATIONAL CARP CONTROL PLAN

# Expected benefits and costs associated with carp control in the Murray-Darling Basin

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)

# Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin



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**in association with**

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FRDC Project No **2016-132**

**Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin**
**2016-132**

**2019**

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# Contents

## List of Tables

## List of Figures

# Acknowledgments

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# Abbreviations

| | |
|---|---|
| ACT | Australian Capital Territory |
| ASC | Alternative Specific Constants |
| AUD | Australian Dollars |
| BCR | Benefit-Cost Ratio |
| CAD | Canadian Dollars |
| Carp | Common carp (*Cyprinus carpio*) also known as European carp |
| CBA | Cost-Benefit Analysis |
| CISS | Centre for Invasive Species Solutions |
| CL | Conditional Logit |
| CM | Choice Modelling |
| CPUE | Catch Per Unit Effort |
| CRC | Cooperative Research Centre |
| CRRDC | Council of Rural Research and Development Corporations |
| CS | Compensating Surplus |
| CSIRO | Commonwealth Science and Industrial Research Organisation |
| CyHV-3 (aka Carp Virus) | Cyprinid Herpes Virus 3 |
| DELWP | Department of Environment, Land and Water Planning (Victoria) |
| DNA | Deoxyribonucleic acid |
| DO | Dissolved Oxygen |
| ERE | Environmental and Resource Economics |
| FAO | Food and Agriculture Organisation |
| FRDC | Fisheries Research and Development Corporation |
| GIS | Geospatial Information Systems |
| ha | Hectare |
| HH | Household |
| IID | Independently and Identically Distributed |
| IRR | Internal Rate of Return |
| kg | Kilogram |
| Km | Kilometre |
| LLR | Log Likelihood Ratio |
| M&E | Monitoring and Evaluation |
| MDB | Murray Darling Basin |
| MERI | Monitoring, Evaluation, Reporting and Improvement |

| | |
|---|---|
| ML | Megalitres |
| mL | Millilitres |
| n/a | Not Applicable |
| NCCP | National Carp Control Plan |
| NPV | Net Present Value |
| NSW | New South Wales |
| NSW DPI | New South Wales Department of Primary Industries |
| NTS | Non-Target Species |
| NTU | Nephelometric Turbidity Unit |
| OWG | Operations Working Group |
| p.a. | Per Annum |
| QLD | Queensland |
| RPL | Random Parameter Logit |
| RUM | Random Utility Model |
| SA | South Australia |
| SAG | Science Advisory Group |
| TAS | Tasmania |
| USA | United States of America |
| USD | US Dollars |
| VIC | Victoria |
| WA | Western Australia |
| WTP | Willingness to Pay |

# Executive Summary

**What the report is about**

This report presents the process and findings of Fisheries Research and Development Corporation (FRDC) Project 2016-132: *Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin.* The project was funded under the National Carp Control Plan (NCCP) from June 2017 to December 2019.

Project 2016-132, undertaken by Agtrans Research in association with Environmental and Resource Economics (ERE) and Gillespie Economics, investigated the current and future impact costs of European Carp in Australian waterways, particularly the Murray Darling Basin (MDB), and the costs and benefits of Carp biocontrol through the proposed release of *Cyprinid herpesvirus 3* (CyHV-3). The project aims to provide critical information on the potential costs and benefits associated with Carp and Carp biocontrol for decision-makers assessing the proposed control of Carp in Australia through the NCCP.

**Background**

Common Carp (*Cyprinus carpio*), also known as European Carp (hereafter referred to as 'Carp'), are a rapidly expanding, invasive fish species that were introduced to Australian waterways as early as the 1860s. Carp are thought to cause negative economic, environmental and social impacts predominantly through their feeding and spawning behaviour, as well as through bodily excretions. Carp now are the most significant aquatic pest fish species in Australia and are present in all Australian states and territories, except the Northern Territory.

In the late 1990s, CyHV-3 was identified as a potential viral biological control for Carp in Australian waterways, particularly the MDB. Substantial research was undertaken over the next decade to investigate the safety and efficacy of CyHV-3 as a Carp control option. However, there was no nationally coordinated approach to Carp control that could facilitate the planning, potential release and clean-up associated with the virus. Thus, in calendar 2016, a team was established within the FRDC to develop the $10.2 million NCCP.

As part of the NCCP's comprehensive research, development and extension program, the NCCP team required an improved understanding of the existing impact costs of Carp in Australia, and the likely benefits and costs of implementing the NCCP. Agtrans Research, in association with ERE and Gillespie Economics, received funding to undertake Project 2016-132 (*Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin*) to attempt to address these knowledge gaps.

**Aims/objectives**

As a result of changing NCCP information needs, data availability and changes to the overall NCCP work schedule, the objectives and schedule of Project 2016-132 were revised in May 2019.

The revised objectives of Project 2016-132 were to:

1. Quantify the current and future costs of Carp being present in Australia by sector of the community affected.
2. Calculate the likely benefits of addressing Carp impacts through the National Carp Control Plan (NCCP) (in market and non-market value terms) for two case study regions.
3. Specify the distribution of costs and benefits of different community groups for two case study regions.
4. Form strong links with the parallel NCCP risk management project (project code: 2017-054) with regard to exchange of information on risk management issues and cost and benefit information.

5. Work closely with other project teams, the NCCP operations working group, and the NCCP science advisory group to quantify costs of implementing the NCCP for the two case study regions once methods are defined; this will allow the total benefits of control to be compared with total costs of implementing the NCCP for the two case study regions.
6. Submit a draft report to the NCCP National Coordinator by 10 August 2019 that addresses the likely benefits and costs of proceeding with the NCCP for two case study regions.
7. Prepare a final report of likely benefits and costs of implementing the NCCP for two case study regions by 25 October 2019.

Further discussions between NCCP project management and the Carp cost-benefit analysis (CBA) team led to a decision in September 2019 to adjust the scope of the CBA project to address just a single case study (the Murray-Murrumbidgee system). The change was made to align the CBA project with the detailed NCCP implementation costing working conducted by Karl Mathers (The Wedge Group Pty Ltd). Further, over the course of the current project, a number of key constraints were identified that prohibited credible quantification (valuation) of some of the costs and the benefits associated with the proposed future implementation of the NCCP. A primary constraint is the complexity and diversity of highly variable and interrelated factors that are sensitive to location, year, and environmental, ecological, and social conditions. Other constraints included a lack of existing data, literature, and scientific evidence on which to base credible and robust assumptions for the estimation of some costs and benefits. Also contributing were limited resources (time and project budget) that prevented the NCCP project teams from collecting new data or conducting additional research required to fill current cost and benefit information gaps. As a result of these constraints, NCCP management and the CBA project team agreed that the CBA report would focus on identifying the range of potential costs and benefits of implementing the NCCP in the Murray-Murrumbidgee system and would describe a CBA framework that could be used to undertake a full, quantitative CBA for the implementation of the NCCP at a regional level in the future.

**Methodology**

NCCP Project 2016-132 was undertaken in four parts. First, a desktop literature review was conducted to review and summarise the available information regarding the impact costs and potential benefits of Carp in Australia. The review also included a summary of the available literature associated with Carp control, and the potential costs and benefits of biological control of Carp.

Second, Agtrans Research used the information from the literature review related to the market impact costs of Carp to develop an informal market cost pilot survey for primary water users. The pilot survey was carried out via email and phone interviews. Feedback from the informal pilot survey was then used to develop a final, comprehensive market cost survey that was distributed to 82 potential respondents (primary water users) in January of 2019. Responses from the final survey were recorded and the resulting data were used to inform the case study cost-benefit analysis for the Murray-Murrumbidgee system.

Following Parts 1 and 2, a Choice Modelling (CM) study was designed and conducted to estimate community willingness to pay (WTP) for the potential environmental outcomes of reduced Carp numbers in freshwater waterways of Australia. The goal of the study was to provide data on the non-market benefits and costs for the overall CBA. The CM questionnaire was administered between 30 November 2018 and 3 January 2019. Models were estimated using NLOGIT 4.0 (Econometric Software 2007) and results reported in terms of the mean annual household WTP for 10 years for different levels of expected environmental outcomes in 10 years' time.

Finally, data pertaining to the market and non-market impact costs and benefits of Carp in Australia (assembled through Parts 1, 2 and 3) were synthesised and summarised to inform a CBA framework for the Murray-Murrumbidgee case study region.

**Results/key findings**

1. Total, current and future impact costs of carp

The market impact cost data indicated that Carp do not impose significant costs on the market sector and that any significant damage they have caused, and still cause, are likely to be more strongly related to non-market costs via a range of causal pathways. Further, as no quantitative causal relationship between Carp biomass and turbidity levels was available, the market costs associated with the impact of Carp in Australian waterways were assumed to be low, if not negligible.

Non-market costs were calculated based on a per-household WTP for changes in particular environmental outcomes (native fish, native waterbirds, and area of healthy wetlands) over 10 years' time following Carp suppression. The range of possible total WTP calculated for Australian households was $24,372 - $2.08 billion for fish, $39,187 - $313.5 million for wetlands, and $5,422 - $601.8 million for waterbirds, with the specific values within these ranges being dependent on the extent of environmental recovery forecast after a reduction in Carp biomass.

Overall, the NCCP CBA project collected a range of highly relevant market and non-market impact cost data that may be used to estimate a total impact costs of Carp in Australian waterways. However, current knowledge of the relationship between Carp biomass and turbidity, and the relationship between Carp biomass and key environmental attributes was not adequate to allow for a credible estimate of the total impact costs of Carp to be calculated with the current project.

If future research elucidates and quantifies such key relationships associated with the impact of Carp biomasses on Australian waterways, then an overall estimate of the total impact costs of Carp, using existing market and non-market cost data provided in the current study, may be possible.

2. Costs and Benefits of Carp Control in the Murray-Murrumbidgee System (Case Study)

The CBA case study identified a suite of potential costs and benefits associated with the proposed implementation of the NCCP in the Murray-Murrumbidgee system. The report describes a CBA framework that could be used to undertake a full, quantitative CBA for the implementation of the NCCP at a regional level in the future. Such regional level CBAs could be used to demonstrate the value of the proposed NCCP investment to decision-makers and other stakeholders. Regional level CBAs, such as the Murray-Murrumbidgee case study region, also could be aggregated to estimate the total potential costs and benefits of the NCCP at a national scale (noting that this form of aggregation would not take into account economies of scale that may be achieved through implementation of the NCCP at a national level).

**Implications for relevant stakeholders**

Though the full range of current and future impact costs of Carp, and costs and benefits of Carp control could not be quantified within the scope of the current study, the report provides useful information on the likely costs and benefits associated with the NCCP that may help to inform decision-makers and stakeholders about the current impact of Carp in Australia and the potential impacts of Carp biocontrol through the release of CyHV-3 in Australian waterways.

**Recommendations**

One of the most critical information gaps identified through the CBA process was the lack of available data/scientific-evidence associated with the potential relationship between reductions in Carp biomass and the drivers of key medium- and long-term impacts such as changes in water quality (e.g. reduced turbidity) and biodiversity outcomes (e.g. increased numbers of native fish and waterbirds, and increased areas of healthy wetlands).

Any future CBA would benefit from additional research, or further elicitation of expert opinion, to quantify these relationships. Ideally, this would include information that might elucidate the relationships between Carp, other introduced species, anthropogenic impacts to Australian ecology and various environmental outcomes. This would facilitate collation of credible estimates of the likely benefits of Carp biocontrol via implementation of NCCP.


## Keywords

**Common carp, European carp, Carp, Cyprinid Herpesvirus 3, CyHV-3, Carp Virus, Carp Biocontrol, National Carp Control Plan, NCCP, Cost-Benefit Analysis, CBA, Choice Modelling, Impact Costs, Costs of Carp Control, Benefits of Carp Control, CBA Framework**

# Introduction

## Background

### Brief History of Carp in Australia

Common Carp (*Cyprinus carpio*), also known as European Carp (hereafter referred to as 'Carp'), are thought to have evolved from an Asian ancestor originating in the Caspian sea. Initially spreading into basins of the Black and Aral seas, Carp spread as far west as the Danube river and into eastern, mainland Asia approximately 8,000 to 10,000 years ago (Balon, 1995).

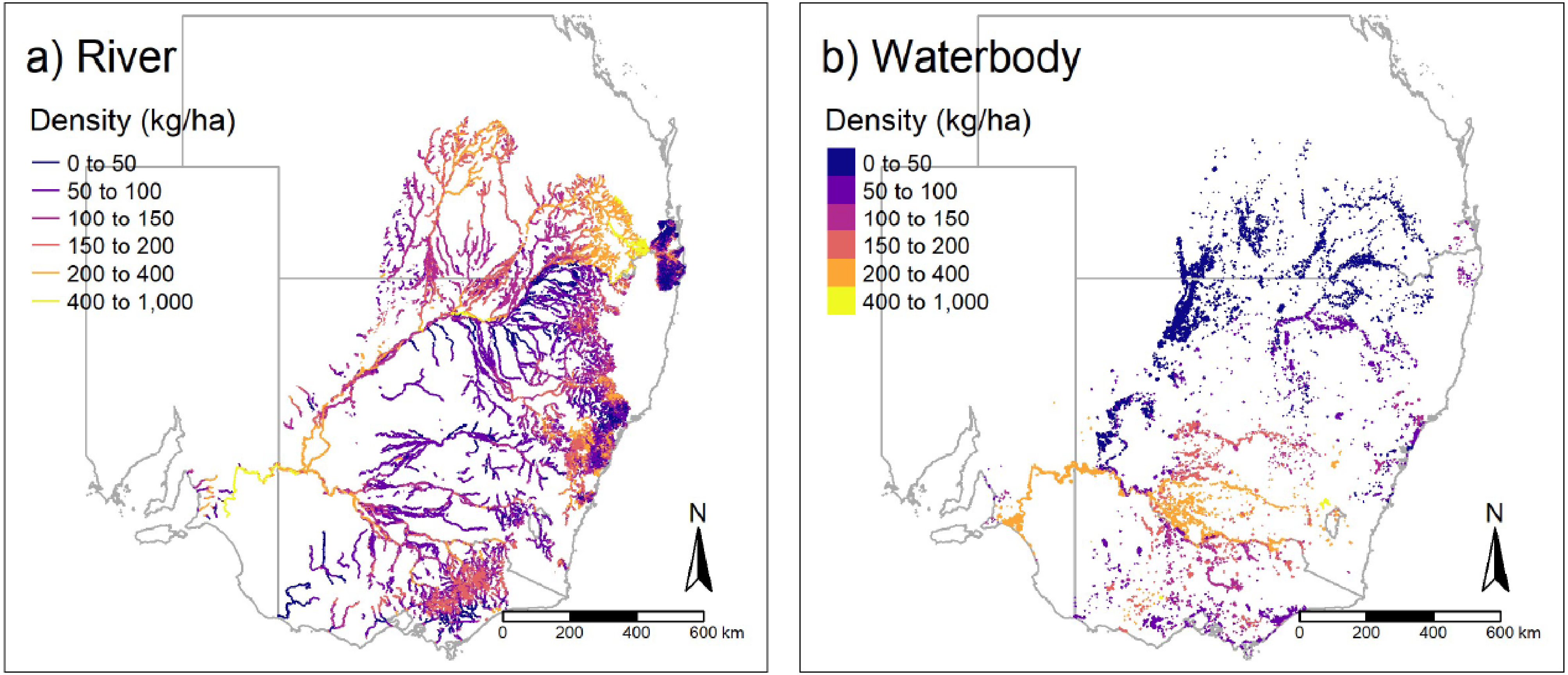
Early records indicate that Carp were present in Australia as early as the 1860s, though the exact date of introduction is uncertain. Three strains of Carp have been introduced to Australia: an ornamental strain near Sydney (~1850-60), a Singaporean strain in the Murrumbidgee (1876), and the hybrid "Boolarra" strain in Victoria (VIC) (1961) (McGrouther, 2018).

From 1964, Carp were identified as a rapidly expanding, alien fish species and by the mid-1960s Carp had been detected in three areas: Prospect Reservoir near Sydney, the canals of the Murrumbidgee Irrigation system, and in a number of dams in VIC (Shearer & Mulley, 1978). By 1968, the illegally imported Boolarra strain of Carp had made its way into the Murray River via Lake Hawthorne near Mildura. From there the species dispersed rapidly across the Murray Darling Basin (MDB) during the 1974-75 floods (Smith, 2005).

Carp are usually associated with warm, slow-flowing lowland rivers or lakes and are tolerant of a wide range of environmental conditions and able to survive in extremely low levels of dissolved oxygen (DO) (Lintermans, 2007). Carp are omnivorous and generally feed on molluscs, crustaceans, insect larvae, and seeds, usually by sucking mud from the waterway bottom to filter out food items (known as roiling or mumbling) (Gomon & Bray, n.d.).

Carp now are the most significant aquatic pest fish species in Australia and are present in all Australian states and territories, except the Northern Territory. Specifically, Carp occur in the southern half of Australia, below an altitude of 700 metres, from approximately Brisbane (Queensland (QLD)) to Perth (Western Australia (WA)), including the MDB and many coastal river systems of New South Wales (NSW) and VIC, and Lake Crescent and Lake Sorell in Tasmania (TAS) (Gomon & Bray, n.d.). Figure 1 shows a map that indicates the current distribution and density of Carp in Australia.

Figure 1: Distribution of Carp Biomass (kg/ha) Across Eastern Australia for a) River Systems, and b) Waterbodies[1]




Source: Stuart, et al. (2019)

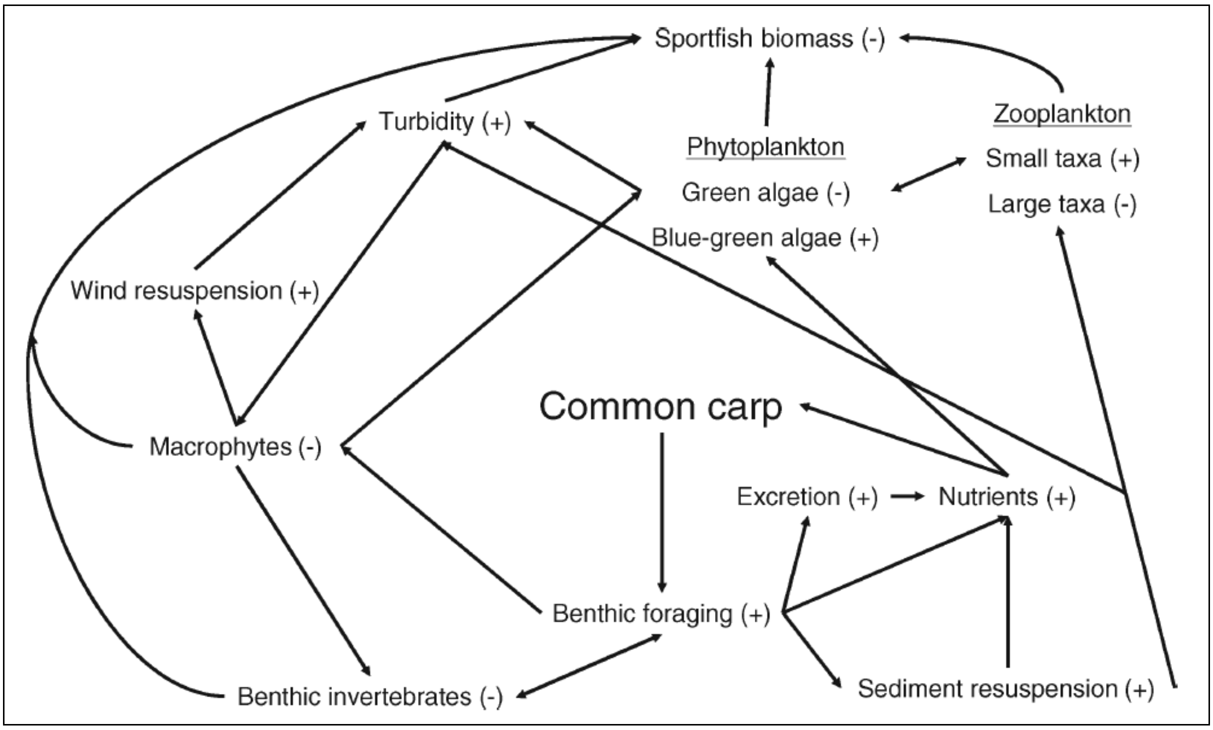
[1] 'Waterbodies' indicate wetlands, lakes, and storages and impoundments.

## Introduction to the Current Impacts of Carp

Whether Carp are a cause of environmental damage, or a symptom of the poor health of Australian inland waterways caused by other factors, has been an issue much debated by scientists and policy makers alike (Centre for Invasive Species Solutions (CISS), 2012). Generally, Carp are considered a problem species because of their perceived impacts on water quality, soft-leaved aquatic plants and native fish populations through competition and lowering habitat quality (Koehn, Brumley, & Gehrke, 2000).

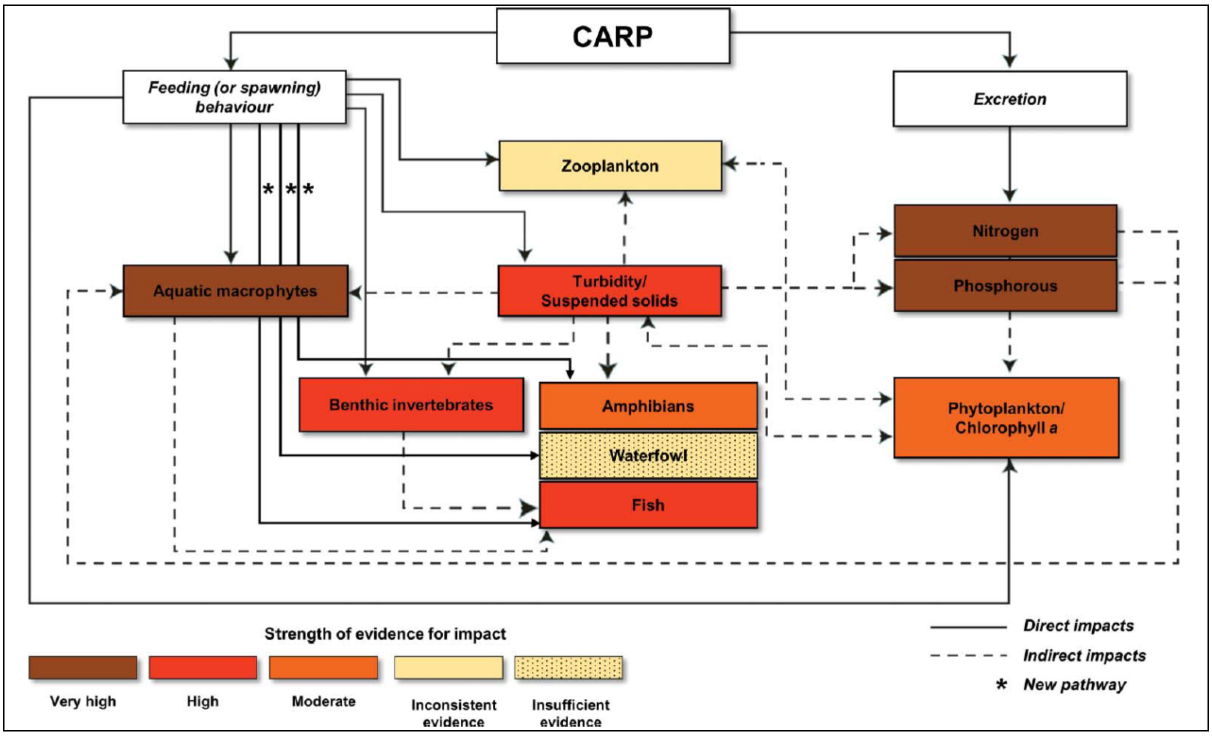
Carp are thought to cause economic, environmental and social impacts predominantly through their feeding and spawning behaviour, as well as through bodily excretions. Weber and Brown (2009) and Vilizzi, Tarkan, & Copp (2015) each provided useful, graphical representations of the effects of Carp on aquatic ecosystems. The graphics, reproduced in Figure 2 and Figure 3 below, summarise the potential direct and indirect pathways to impact of Carp in Australian.

Figure 2: Effects of Carp on Aquatic Ecosystems




Note: A positive sign (+) indicates an increase whereas a negative sign (-) indicates a decrease as an effect of Carp.
Source: Weber & Brown (2009)

Figure 3: Effects of Carp on Freshwater Ecosystems




Source: Vilizzi et al. (2015) (conceptual model updated from Koehn et al, 2000)

1. Reduced water quality

Where Carp exist in large numbers, roiling is thought to increase turbidity (increased sediment and nutrient loads), cause the disruption and re-distribution of benthic seeds and invertebrates, undermine aquatic plants, and prevent the establishment of plant seedlings resulting in reduced water quality (NSW Department of Primary Industries (NSW DPI), n.d.; Smith, 2005).

However, the contribution of Carp to increased turbidity in Australian waterways is uncertain. Early research in Canada supports the perceived impact and attributed increased turbidity to the disturbance of bottom substrates by Carp (McCrimmon, 1968). However, an Australian study by Fletcher, Morison and Hume (1985), found that populations of Carp had not caused significant increases in turbidity levels in the Lower Goulburn River Basin of VIC.

The impact of Carp on turbidity in Australian aquatic ecosystems has been obscured by the naturally high and variable turbidity existing in many inland waterways and the interaction of hydrological factors with soil type and land degradation (Arthington, 1989). Further, most of the assertions regarding the effects of Carp are speculative and based on extrapolations from observations of captive fish.

2. Erosion and increased incidence of algal blooms

Carp feeding habits may undermine riverbanks and the verges of other inland waterways, including irrigation channels. Also, it has been suggested that Carp may contribute to an increased likelihood of algal blooms by preying on animals that eat algae, stirring up or excreting excess nutrients, and eating and damaging aquatic plants. However, it is thought that Carp densities may need to be very high to significantly increase the risk of algal blooms (Gilligan & Rayner, 2007).

3. Impacts on invertebrates and aquatic plants

Carp may reduce populations of invertebrates both directly, through predation by large sub-adult and adult Carp, and indirectly through smothering and reduced light penetration caused by increased sediment and nutrient loads where Carp feed (CISS, 2012). For example, Australian studies of invertebrates in experimental ponds stocked with Carp showed that a species of cladoceran, *Daphnia carinata*, declined with the introduction of Carp (Fletcher, 1986).

Carp also have significant negative impacts on aquatic plants. Carp are known to reduce aquatic plant density and biomass through grazing and uprooting while feeding and spawning (NSW DPI, n.d.). Carp may also affect aquatic plants indirectly through reduced light penetration via their impact on turbidity.

4. Competition with endemic fish species

Inter-species competition may occur by interference or exploitation. Interference competition occurs when one fish species establishes a territory and physically excludes other fish species. Exploitation competition occurs when both species utilise a scarce resource (e.g. food) (Fletcher, 1986).

The rapid and aggressive expansion of the Carp population throughout Australia is evidence of the interference competition impact of Carp. Further, the diet of introduced Carp overlaps at various body sizes with that of several endemic Australian fishes, such as bony bream *Nematolosa erebi*, catfish *Tandanus tandanus*, silver perch *Bidyanus bidyanus*, Australian smelt *Retropinna semoni*, Carp gudgeon *Hypseleotris klunzingeri* and flat headed galaxias *rostratus* (Arthington, 1989).

Indirectly, increased turbidity may impact native fish species that rely on sight to feed. The direct and indirect competition effects associated with the introduction of invasive Carp have led to reduced numbers of native fish species in Australian waterways, particularly in the MDB.

5. Introduction of pests and diseases

Internationally, Carp have been associated with the distribution of a range of parasites and fungal, bacterial and viral diseases (NSW DPI, n.d.). There is already evidence that disease organisms have entered Australia via the aquarium trade. For example, fish introductions were responsible for importing fish parasites such as fish louse *Argulus* and anchorworm *Lernaea cyprinacea* into Australian waterways (Arthington, 1989).

However, no diseases are known to have been introduced with Carp, and their lack of close relatives in the Australian fish fauna makes this impact unlikely. Some parasites, such as the tapeworm *Bothriocephalus acheilognathi* may have been introduced to Australia with Carp and are now found on or in native species, but the impact of such parasites is unknown (CISS, 2012).

## Market and Non-Market Impacts

Carp impacts may be categorised in economic terms as either ‘market’ or ‘non-market’ impacts. Market impacts are those that may be measured through existing market mechanisms and valued using current market prices.

Other impacts of Carp, such as negative environmental impacts like biodiversity loss and reduced aesthetic and/or recreation amenity of Australian waterways, cannot be measured through conventional market mechanisms. Such impacts are non-market impacts and quantification of these impacts requires application of specific non-market valuation techniques such as benefit transfer, contingent valuation, or choice modelling (see the Glossary section for definitions of these terms).

## Carp Control in Australia

Total eradication of invasive fish species is rarely possible. However, there are a number of current and potential methods that may be used to control pest species and manage their negative impacts. Potential control methods include (Corfield, et al., 2008):

1. Physical removal

Physical removal methods include netting, trapping, line fishing, electric fishing, explosives, and water removal. These methods can be costly and often require intensive effort and repetition to be effective. Further, physical removal methods may be constrained by factors such as waterway access, water depth and velocity, aquatic plant cover and the development of avoidance behaviour by the target species.

2. Chemical toxicants

Chemicals have been used to manage vertebrate and invertebrate pests for decades. For Australian aquatic environments only a few products are available, the best known is rotenone. Other potential chemical control options for Carp include endosulfan, antimycin, acrolein, lime, chlorine or other agricultural chemicals (pesticides/insecticides/herbicides) known to be toxic to fish. However, most chemical controls that could be used to reduce invasive Carp numbers are also toxic to other aquatic invertebrates and may even be damaging to higher vertebrates (Sanger & Koehn, 1996).

3. Biological controls

Biological control options for pest fish may include the introduction of predator species, introduction of pathogens, habitat modification, immune-contraceptive control and genetic techniques (e.g. daughterless Carp[2]). Australia has had some success with biological controls in the past. For example, the combination of myxomatosis and rabbit haemorrhagic disease virus successfully reduced rabbit populations throughout the country (Schwensow, et al., 2014). Also, the moth *Cactoblastis cactorum* was introduced to control the weed known as prickly pear (*Opuntia stricta*) (Australian National University, 2019). However, there have also been examples of unsuccessful biological control, such as the introduction of the cane toad in 1935 to control cane beetles in sugarcane in northern Australia (Shanmuganathan, et al., 2009).

# Rationale

In the late 1990s, *Cyprinid herpesvirus 3* (CyHV-3) was identified as a potential viral biological control for Carp in Australian waterways (McColl, Sunarto, & Holmes, 2016). Substantial research was undertaken over the next decade to investigate the safety and efficacy of CyHV-3 as a Carp control option. However, there was no nationally coordinated approach to Carp control that could facilitate the planning, potential release and clean-up associated with the virus. Thus, in calendar 2016, a team was established within the Fisheries Research and Development Corporation (FRDC) to develop the $10.2 million National Carp Control Plan (NCCP). The objectives of the NCCP were to:

- Plan for an integrated approach to control Carp in Australia's waterways.
- Undertake research and development to address knowledge gaps, and better understand and manage risks to support the potential release of the Carp virus, subsequent clean up and recovery of native fish and ecosystems.

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[2] Daughterless carp gene manipulation is a genetic control method that was under development by the Invasive Animals CRC (now CISS), the MDB Authority, and CSIRO. The idea was to alter the genes of carp so that they only produce male offspring, dramatically skewing the sex ratio of the population and eventually causing the carp population in Australia to crash. For more information see: https://www.pestsmart.org.au/wp-content/uploads/2013/03/CPFS2_daughterless.pdf

- Increase community awareness of the proposal to release the Carp virus and gain an understanding of stakeholder views on the proposal through an extensive consultation program.
- Develop detailed strategies for release of the Carp virus and subsequent clean-up.
- Support national coordination on all elements of the proposal, including through the engagement of a National Coordinator to lead consultation with affected stakeholders and development of the NCCP.

As part of the NCCP's comprehensive research, development and extension program, the NCCP team required an improved understanding of the existing impact costs of Carp in Australia, and the likely benefits and costs of implementing the NCCP. Project 2016-132 (*Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin*) was funded to address this knowledge gap.

This report is structured as follows:

- Method: this section briefly describes the methods used throughout the report,
- Part 1: includes a desktop literature review that summarised previously available information regarding the impact costs and potential benefits of Carp in Australia. The review also includes a summary of the available literature associated with Carp control, and the potential costs and benefits of biological control of Carp,
- Part 2: this section includes the identification and assembly of current Carp impact costs and market costs and benefits associated with potential biocontrol of Carp,
- Part 3: describes a choice modelling study undertaken to estimate Australian households' willingness to pay for a range of key environmental outcomes that may result from the reduction of Carp biomass in Australian waterways,
- Part 4: provides a synthesis of the information outlined in Parts 1, 2 and 3.
- Case Study: this section describes the potential costs and benefits associated with implementation of the proposed NCCP in the Murray-Murrumbidgee system and outlines a framework for undertaking a full, quantitative CBA for the proposed implementation of the NCCP at a regional level,
- Discussion & Conclusion: provides a discussion and summary of key report elements and findings,
- Recommendations: describes key information gaps identified through the cost-benefit analysis process that may be addressed by future research

# Objectives

As a result of changing NCCP information needs, data availability and changes to the overall NCCP work schedule, the project objectives and schedule were revised in May 2019. The original set of objectives can be found in Appendix 1: Original Project Objectives.

The revised objectives of Project 2016-132 were to:

1. Quantify the current and future costs of Carp being present in Australia by sector of the community affected.
2. Calculate the likely benefits of addressing Carp impacts through the National Carp Control Plan (NCCP) (in market and non-market value terms) for two case study regions.
3. Specify the distribution of costs and benefits of different community groups for two case study regions.
4. Form strong links with the parallel NCCP risk management project (project code: 2017-054) with regard to exchange of information on risk management issues and cost and benefit information.
5. Work closely with other project teams, the NCCP operations working group, and the NCCP science advisory group to quantify costs of implementing the NCCP for the two case study regions once methods are defined; this will allow the total benefits of control to be compared with total costs of implementing the NCCP for the two case study regions.
6. Submit a draft report to the NCCP National Coordinator by 10 August 2019 that addresses the likely benefits and costs of proceeding with the NCCP for two case study regions.
7. Prepare a final report of likely benefits and costs of implementing the NCCP for two case study regions by 25 October 2019.

Further discussions between NCCP project management and the Carp cost-benefit analysis (CBA) team led to a decision in September 2019 to adjust the scope of the CBA project to address just a single case study (the Murray-Murrumbidgee system). The change was made to align the CBA project with the detailed NCCP implementation costing working conducted by Karl Mathers (The Wedge Group Pty Ltd). Further, over the course of the current project, a number of key constraints were identified that prohibited credible quantification (valuation) of some of the costs and the benefits associated with the proposed future implementation of the NCCP. A primary constraint is the complexity and diversity of highly variable and interrelated factors that are sensitive to location, year, and environmental, ecological, and social conditions. Other constraints included a lack of existing data, literature, and scientific evidence on which to base credible and robust assumptions for the estimation of some costs and benefits and limited resources (time and project budget) that prevented the NCCP project teams from collecting new data or conducting additional research required to fill current cost and benefit information gaps. As a result of these constraints, NCCP management and the CBA project team agreed that the CBA report would focus on identifying the range of potential costs and benefits of implementing the NCCP in the Murray-Murrumbidgee system and would described a CBA framework that could be used to undertake a full, quantitative CBA for the implementation of the NCCP at a regional level in the future.

# Method

NCCP Project 2016-132 was undertaken in four parts.

## Part 1: Desktop Literature Review

A desktop literature review was conducted to review and summarise the available information regarding the impact costs and potential benefits of Carp in Australia. The review also included a summary of the available literature associated with Carp control, and the potential costs and benefits of biological control of Carp.

The findings from the literature review were used to provide background and context for the CBA and to investigate what was already/previously known about Carp impacts to inform the assembly of market and non-market information (Parts 2 and 3) and support the assumptions required to assess the costs and benefits of the potential implementation of the NCCP in the Murray-Murrumbidgee case study region (Part 4). The full literature review can be found in Part 1: Desktop Literature Review.

## Part 2: Identification and Assembly of Carp Impact Costs and Market Costs and Benefits of Carp

Agtrans Research used the information from the literature review (Part 1) related to the market impact costs of Carp to develop an informal market cost pilot survey for primary water users. The pilot survey was carried out via email and phone interview. Approximately 20 primary water users (including irrigators, irrigation/ water authorities, and water treatment plants) were contacted across QLD, NSW, VIC, and South Australia (SA). A summary of the pilot survey and its findings can be found in Appendix 2: Pilot Survey Summary & Findings.

Feedback from the informal pilot survey was then used to develop a final, comprehensive market cost survey that was distributed to 14 irrigators, 16 irrigation/ water authorities, and 53 councils and water treatment plants (83 potential respondents) in January of 2019. Potential respondents were distributed spatially across QLD (8 potential respondents), NSW (45), VIC (20), SA (3) and other regions (7).

Responses from the final market cost survey were recorded in a Microsoft Excel spreadsheet. Results then were organised, aggregated and assessed by primary water user type and by region. The resulting data were then used to inform the CBA the Murray-Murrumbidgee case study region (Part 4). A summary of the market cost survey and its findings can be found in Appendix 3: Market Cost Survey Summary & Findings.

## Part 3: A Choice Modelling Study to Estimate the Non-Market Impact Costs of Carp and the Non-Market Benefits of Carp Control

Environmental and Resource Economics (ERE), in association with Gillespie Economics, developed a Choice Modelling (CM) study to estimate community willingness to pay (WTP) for the potential environmental outcomes of reduced Carp numbers in freshwater waterways of Australia. The goal of the study was to provide data on the non-market benefits and costs for the overall CBA (Part 4).

In a CM application, respondents are asked to make a sequence of choices in which they pick their preferred alternatives from a number of sets of options (called 'choice sets') that describe alternative future scenarios. The alternatives in the choice sets are described by a number of attributes. These attributes usually relate to the outcomes of alternative policies and one attribute will always be the cost to the respondent of the alternative they choose. This approach is based on Lancaster's 'characteristic theory of value' and it is assumed that respondent well-being is derived from the attributes of the alternative.

The alternatives in each choice set are different from each other because the 'levels' that the attributes take in each alternative will be different. The levels of the attributes are assigned across alternatives using an experimental design that ensures respondents choose between a widely and randomly spread set of alternatives. Importantly, one of the alternatives presented to respondents in every choice set is a 'status quo' or 'counterfactual' alternative. It describes the outcome of the case when no new policy initiatives are taken. It comes at no cost to the respondent and is consistent with the counterfactual used in the CBA. It therefore acts as an 'anchor' for respondents' preferences. The analysis of the choices respondents make across the choice sets relies on McFadden's Random Utility Model (RUM).

The CM questionnaire was designed using an iterative process involving the NCCP freshwater ecology team and representatives of the FRDC to establish the attributes and the range of levels to be used in the choice sets. A draft questionnaire was then tested in two focus groups conducted in Sydney, a pilot on-line survey of 100 respondents, two further Sydney focus groups and finally another pilot survey involving a further 100 respondents. Refinements to the questionnaire were made throughout the testing process.

The questionnaire was administered between 30 November 2018 and 3 January 2019 by PureProfile using a web-based survey, with two samples drawn from an existing panel of pre-stratified and registered respondents. The two samples were:

- Murray-Darling Basin (MDB) Sample - households with postcodes located within the MDB;
- Rest of Nation Sample - households across Australia excluding those in the MDB.

The drawing of the two samples allowed for the detection of differences in Carp control preferences between the populations of the MDB and the rest of Australia.

Models for each of the samples were estimated using NLOGIT 4.0 (Econometric Software, 2007) and results reported in terms of the mean annual household WTP for 10 years for different levels of expected environmental outcomes in 10 years' time. The full CM report, including method, results, and reference list, can be found in Part 3: A Choice Modelling Study to Estimate the Non-Market Impact Costs of Carp and the Non-Market Benefits of Carp Control.

## Part 4: Synthesis

Data pertaining to the market and non-market impact costs and benefits of Carp in Australia (Parts 1, 2 and 3) were synthesised and summarised to inform a CBA for the Murray-Murrumbidgee case study region (see CASE STUDY: The Murray-Murrumbidgee System – Cost-Benefit Analysis).

The Murray-Murrumbidgee river system (below the Hume Dam) represents the southern zone for potential initial deployment of CyHV-3. It was selected as the case study region for the CBA because (1) the system contains the highest Carp biomass and densities of all the case study areas reviewed by the NCCP, (2) some parts of the region have high environmental values (including the Ramsar wetlands), and (3) detailed NCCP implementation cost data were available for the Murray-Murrumbidgee system.

The planned CBA followed general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres (CRCs), State Departments of Agriculture, and some universities. The approach includes both qualitative and quantitative descriptions that are in accord with the impact assessment guidelines of the Council of Rural Research and Development Corporations (CRRDC) (CRRDC, 2018).

For the Murray-Murrumbidgee case study region, the following process was initially planned for the CBA:

1. The geographic region for the case study CBA was defined and baseline data regarding the distribution and density (biomass) of the existing Carp population was sourced from the NCCP research team.
2. Based on the baseline Carp distribution and biomass data, the current and potential future annual impact costs of Carp for the region were estimated utilising the market and non-market data obtained in Parts 1, 2 and 3.
3. Information on the most likely virus (CyHV-3) release and carcass management strategy for the region was sourced through consultation with the NCCP Operations Working Group (OWG) and other available NCCP data and reports for the case study region.
4. A comprehensive list of the potential costs associated with the likely release and clean up strategies were then estimated and provided to the CBA project team.
5. Utilising research outputs and expert opinion from the NCCP Carp ecology team and Science Advisory Group (SAG), assumptions were made about the likely impact of the Carp herpes virus on the Carp biomass within the Murray-Murrumbidgee case study region (the expected Carp ‘knock down’).
6. Following on from the estimates associated with the expected reduction in Carp biomass, further assumptions were formulated about the likely changes to Carp impacts that would result from the reduction in Carp biomass (e.g. effect on water quality, ecosystem health, and native fish populations). All assumptions were described and documented.
7. Risk factors along the pathway to impact for the potential implementation of the NCCP were then identified and estimated in consultation with the NCCP risk assessment team and other advisory groups.
8. The data, assumptions and risk factors (steps 1 to 7 above) then were compiled and entered into an Excel based economic model to estimate (quantitatively) the expected benefits and costs over time of implementation of the NCCP for the case study region (in present value terms). The model then was used to estimate other investment criteria for the case study region, including the net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR) and modified IRR (MIRR) for the NCCP investment.

Late in 2019, after in-depth discussions with NCCP personnel (including the SAG, OWG and other key members of the NCCP research team), it was decided that the scientific evidence did not exist to support credible estimates for the assumptions required for steps 6 and 7 above. Thus, the NCCP, in conjunction with the CBA project team, agreed that the expected benefits of the implementation of the NCCP in the Murray-Murrumbidgee system would not be estimated quantitatively. Instead, the potential benefits of the release of CyHV-3 in the case study region would be assessed qualitatively only. Following the qualitative assessment, a framework for the future valuation of any potential expected benefits would be described so that benefits for specific NCCP virus deployment zones could be evaluated under the next potential phase of the NCCP.

# Part 1: Desktop Literature Review

## Introduction

The following literature review has been undertaken as an input into the estimation of the costs and benefits of Carp to Australia and the CBA of potential Carp removal. The purpose of the literature review was to identify information already available on the costs and benefits of Carp and so assist in forming priorities in gathering additional information on the impacts of Carp and their potential reduction.

The review is structured into five sections. The first section identifies and describes two published studies that estimate the value of direct impacts of Carp in Australia. The first section also covers a number of studies that provide ad hoc information that relates to the costs and benefits of direct Carp impacts. Other impacts of Carp that are not addressed (or are only partially addressed) in the literature are then identified.

The second section of the review details studies that describe economic impacts and expenditure to sectors to which Carp may indirectly contribute. These include both market impacts such as increased water treatment costs and non-market impacts such as river health and amenity values. This section reviews expenditure values of some sectors to gauge the size of these sectors, as no economic surplus studies could be found.

The third section describes the currently available techniques for reducing Carp population in Australian waterways. Such techniques include both the commercial and recreational fishing effort including electrofishing, use of netting and separation cages and various combinations of these techniques. Some conclusions that appear in the literature on the effectiveness of applying such techniques are included.

The fourth section of the review contains a brief review of the impacts of controlling Carp by the potential release of a specific Carp virus (CyHV-3). This section describes some of the literature associated with the potential impacts that might flow from the release of the virus. However, the existing literature on many of the impacts are vague, while some impacts are not addressed.

The final section of the review summarises the findings and presents some implications for analysing the impacts of Carp and the benefits and costs of virus release. Of particular importance is the finding that there are gaps in the literature that need to be addressed for the purpose of undertaking a comprehensive analysis of both negative and positive, and direct and indirect, impacts of Carp and Carp removal.

# Section 1: Published Impact Studies and other Direct Impact Information

## Published Studies

### *McLeod and Norris, 2004 and McLeod, 2016*

There have been two published studies by McLeod and Norris (2004) and McLeod (2016) that estimate the value of Carp impacts in Australia. The estimates reported by these studies vary in their coverage of different impacts from Carp, their approaches to valuation of non-market impacts, and time frames covered in valuation. These variations may in part, be due to the studies being only parts of comprehensive reviews into the impacts of invasive animals in Australia, where the focus was across a number of invasive species with limited time to conduct in depth studies on individual species.

The first estimate of Carp impacts was contained within a wider review of the impacts of invasive animals in Australia (McLeod & Norris, 2004). In that study, the annual impact cost of Carp was estimated to be $15.8 million [3] [4]. This estimate took into consideration previous research and management costs, costs related to turbidity and sediment, and impacts on recreational fishing.

The impacts examined by McLeod & Norris (2004) were dominated by those associated with recreational fishing. This impact was estimated from assumptions that 0.6 million recreational fishers would have a WTP of $50 each (per annum (p.a.)) for improved recreational fishing quality. A range of $50 to $80 per fisher p.a. was generalised by the authors as indicative of the range of values based on studies in the United States of America (USA) for an improved fishing experience. The use of 'benefit transfer' to estimate a change in recreational fishing value to Australia from US studies can be problematic. There are differences between the types of experiences, the types of fishers and the extent of change evident between the US contexts and the Australian Carp context that render these transfers questionable.

McLeod & Norris (2004) assumed Carp caused an arbitrary 30% reduction in the abundance of prized native fish, although this estimate does not appear to be based on any previous study.

Combining the extrapolated $50 WTP for improved recreational fishing by the estimated 0.6 million recreational fishers, multiplied by the 30% impact Carp were estimated to have on native fish abundance, McLeod and Norris (2004) approximated that Carp cause a social cost of $9 million p.a. to Australian recreational fishers. Therefore, the McLeod and Norris (2004) study may not have accurately represented the WTP for increased numbers of native fish, clearer water, and a more pleasant environment for fishing due to using an arbitrary impact of Carp on native fish and WTP for improved fishability.

Furthermore, the application of the 30% impact estimate potentially could be double counting because the extent of the change in fishing experience may be already embedded into the WTP estimate. It is not clear why the total WTP should be multiplied by 0.3 as this implies that a greater reduction in native fish caused by Carp means a lower WTP. These points both make the resultant $9m estimate somewhat questionable. The McLeod and Norris (2004) study did not mention what an improvement in recreational fishing would be, only that there would be an improvement. It should be noted that McLeod and Norris (2004) report was not exhaustive, as the terms of reference was to bring together existing information, not conduct primary studies (McLeod & Norris, 2004). McLeod and Norris (2004) was intended to be the first estimates on the cost of invasive animals as no previous estimates existed. In the McLeod and Norris (2004) study, costs of turbidity and sediment attributed to Carp were derived using a

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[3] All dollar values are in Australian dollars (AUD) unless otherwise stated.
[4] All figures unless expressed otherwise, are expressed in the year of publication dollar terms.

published estimate of the total annual cost of turbidity in Australia ($24 million) and sediment ($4 million) (Possingham, Ryan, Baxter, & Morton, 2002). An arbitrary proportion (10%) of this cost was then attributed to the impact of Carp. The 10% attribution to Carp was not derived from any referenced study. The resulting estimated impact of Carp from turbidity and sediment was $2.8 million p.a. The total estimated impacts included previous research costs of Carp and the cost of management of Carp at $2 million p.a. for each respectively (McLeod and Norris (2004). These estimates were derived from the costs reported in Bomford and Hart (2002) and additional known costs of control that the authors did not mention.

McLeod and Norris (2004) did not estimate any benefits of Carp due to the difficulty of determining the net benefit of Carp from commercial activities. Furthermore, the study also did not consider potential benefit value from recreational Carp fishers.

The impacts reported also excluded a potentially wide range of other costs associated with Carp, including additional management costs incurred by irrigation and water supply authorities, farmers, and the local community. It is possible that such costs may have been included in the estimates for the impact of turbidity and sediment costs, but how these figures were derived were not explained in any detail in Bomford and Hart (2002) and Possingham et al. (2002) studies.

A follow-up to the McLeod (2004) study was conducted in 2016 (McLeod, 2016). This report estimated a base case of $22.36 million p.a. for the impact costs of Carp, with a lower bound estimate of $11.18 million p.a. and a higher bound estimate of $44.72 million. The updated estimates considered only reduced recreational fishing quality from the impact of Carp and did not consider biodiversity costs, turbidity and sediment costs including those imposed on water treatment and irrigation activities, streambank and irrigation channel maintenance, or water clarity and visual amenity values associated with turbidity. McLeod (2016) used updated WTP information for recreational fishing from an Australian Choice Experiment study (Zander, Garnett, & Straton, 2010). Zander et al. (2010) assumed recreational fishers in NSW would pay $52 per fisher for an upgrade of fishing quality from 3 stars to 4 stars in tropical rivers. This assumes that the WTP for an increase in fishing quality is the same as avoiding an equivalent decrease in fishing quality. McLeod (2016) noted that a one-off payment of $52 per fisher to improve fishing quality may be an underestimate, as recreational fishers have been found to spend approximately $3,144 p.a. on recreational fishing (Ernst and Young, 2011a). The higher bound estimates were derived from doubling the WTP of recreational fishers to improve fishing, with the lower bound estimate being 50% of the base case WTP (McLeod, 2016). The use of benefit transfer in McLeod (2016) is also questionable. Upgraded fishing experience in a tropical area does not relate to a MDB experience, as well as using an upgraded fishing experience to relate a decrease in Carp. Also, using the total value of annual fishing expenditure for the WTP for a change in experience at the margin is technically inappropriate. However, it should be noted that McLeod's (2016) study was to gauge approximate estimates of the cost of all invasive animals, as an update to McLeod and Norris (2004).

While McLeod (2004) and McLeod (2016) are the only detailed published studies to date that refer to the impacts of Carp in Australia, they expose a number of gaps in knowledge that need to be filled to gain a more robust and complete understanding of the value of the impacts of Carp and of Carp removal. Furthermore, the relationship between Carp abundance and environmental outcomes is not well understood, and the positive impacts of Carp were not addressed in either study.

### *Other Negative Impact Information*

In addition to McLeod and Norris (2004) and McLeod (2016), a localised study in 1996 reported the costs of Carp in the Gippsland Lakes as being $175 million over 5 years to the local community (Koehn et al. 2000). However, it was noted that no explanation was given as to how the estimated values of the impacts identified (recreational fishing, reduced tourism, and biodiversity) were derived. For the current literature review, a published version of the Gippsland Lakes study was not located.

A figure of $500 million p.a. for the negative impacts of Carp appeared in a study by Gehrke, St Pierre, Matveev, & Clarke (2010). This figure has not been cited in subsequent literature on the impact of Carp but has appeared frequently in recent popular press. However, there is no published framework or information on how the estimate of $500 million was derived, so the estimate cannot be substantiated further, or confidently used for decision making.

The economic impacts of Carp on irrigation channels, riverbanks, and biodiversity are major gaps in the existing literature. It has been observed by Southern Rural Water (2013) that Carp cause degradation of irrigation channels, increasing costs for irrigators, resulting in the need to invest $1.9 million over eight years to repair the resulting damage assumed to be caused by Carp. However, there has so far been no robust evidence that Carp cause bank erosion (Koehn et al., 2000; Smith B. , 2004; Gilligan, et al., 2010). This cost and the relationship between Carp and degraded irrigation channels has not been explored in depth, and any further available evidence is largely anecdotal. The cost of Carp to irrigation activities is a gap in the literature that will need to be explored further.

Meta-data studies have identified environmental damage caused by Carp, such as increased turbidity, reduction in native fish abundance, reduced numbers of macroinvertebrates, increased risk of algal blooms etc. (Vilizzi, et al. 2015; Weber & Brown, 2009), but the economic implications of these relationships have not been explored in the literature reviewed.

## Potential Positive Impacts of Carp

There are numerous positive impacts associated with the presence of Carp in Australia. These include the value of recreational fishing for Carp including Carp fishing competitions, and commercial use of Carp. Each of these impacts is discussed in turn.

### *Recreational Fishing for Carp*

There is anecdotal evidence that hundreds of recreational fishers enjoy catching Carp (Leeming, 2017), but the estimated number of Carp fishers has not been verified. This number is likely to be relatively small compared to the total number of recreational fishers (both inland and coastal) in Australia, estimated to be around 3.4 million (Commonwealth of Australia, 2011). No further verifiable information was sighted on the value or size of the recreational Carp fishing industry.

### *Carp Fishing Competitions*

There are some positive impacts from Carp fishing competitions. It has been noted (though not measured) that Carp fishing competitions bring positive economic impacts to stakeholders in regional areas where they are held (Norris & Ballard, 2013). Furthermore, Norris and Ballard (2013) suggest Carp fishing competitions can raise revenue for use in other forms of Carp removal and native fish stocking. There may be local tourism impacts also, as Carp fishing competitions run over entire weekends, aiding in expenditure in the small regional towns where competitions are held. However, such measures do not represent economic surplus or benefits, as the opportunity cost (the activity that is forgone) for participants are unknown.

The Norris and Ballard (2013) study showed that having fun, spending time with family, relaxing, and socialising, were important drivers for participation in Carp fishing competitions. While these competitions show positive effects, conversely 70% of participants "want to get rid of Carp". It is possible that these competitions provide value to the participants with 98% of participants in one Carp cull at Goondiwindi stating they want to participate again (Norris & Ballard, 2013). It is unknown whether participants value the continued opportunity for Carp fishing competitions over perceived Carp impacts (or how large the gap is), whether participants place any economic value on the competitions, or to what degree they value these competitions over other activities. If Carp fishing competitions cease to exist due to a lower incentive to remove Carp following potential Carp biomass decline, and hence a reduced negative impact, there may be a limited loss of any benefits from fishing competitions, as one of the principal drivers of these events is to get rid of Carp (Norris and Ballard. 2013).

### Commercial Use of the Carp Resource

There are two significant businesses operating in Australia that involve Carp (K&C Fisheries and Charlie Carp). There are 27 commercial Carp licence holders in NSW (NSW DPI, n.d.) with 14 fishers in VIC and 25 fishers in SA (Keith Bell, pers. comm., 2018). It was reported for 2015/2016, 101 tonnes of Carp were caught in VIC (Department of Primary Industries Victoria, 2016) while 452 tonnes were caught in SA (Carlin & Morison, 2017). The commercial catch in NSW will be approximately 200 tonnes for 2017/18 (Keith Bell, pers. comm., 2018). The economic surplus provided by Carp-based products is unknown.

Export income from Carp and Carp products was approximated at $700,000 in 2003 (Lapidge, 2003) with Carp exports for 2017/18 (up to January 2018) being $247,990 (FRDC, 2018). This is above 2016/17 exports of $58,000 (FRDC, 2018). Imports of Carp products for 2016/17 were calculated at $1.87 million, there is no data yet for 2017/18 (FRDC, 2018). The profitability of fishing for Carp is unknown, as is the rate of return to the business of exporting Carp products. As Carp have an approximate average global price of $USD 1.35 per kilogram (kg) (Food and Agriculture Organisation (FAO), 2017), previous large-scale commercialisation attempts in Australia were inviable due to the low market prices of Carp (Graham, Lowry, & Walford, 2005; NSW Government, 2010).

The prospect of viable commercial Carp fisheries is dependent on several factors. The location of Carp, their density in a given location, the available infrastructure, market price and quality, will all affect the viability of any Carp fishery (Koehn et al., 2000). Roberts & Tilzey (1997) identified a relationship between Carp density and the cost of removing Carp, demonstrating that as Carp density increases, the cost of removing Carp decreases. The price elasticity for Carp also is very high. For example, it has been reported that if supply of Carp to a market (e.g. Sydney Fish Market) is above a certain level (approximately 2 tonnes per week) the price drops to an unprofitable level to continue to fish (from $2.00 per kg to $1.00 per kg for the Sydney Fish Market) (Graham et al., 2005). This lowers the incentive to catch Carp beyond a certain point, as market prices decrease to an unprofitable level.

### The Koi Carp Industry

There are ornamental Koi Carp industries in NSW and WA. The Koi Association is estimated to have approximately 2,000 members (Koi Society of Australia, 2015), but this is likely an underestimate of the size of the industry. The number of Koi Carp maintained, and their aggregate value, are unknown. There has been reported concern from the ornamental Koi industry about the potential release of a Carp herpesvirus (CyHV-3) in Australia due to the potential negative impact on ornamental Koi Carp (Le Lievre, 2016). NSW Primary Industries have stated that there are no current plans to release a vaccine for ornamental Koi if the virus is released (Le Lievre, 2016).

### Conclusion

Previously published estimates of the impact costs of Carp to Australia have not addressed all potential impact categories. Furthermore, methods of valuation for those impacts addressed have varied, with some being inappropriate to the task, and the existing estimates do not consider any of the positive impacts of Carp. This presents a gap in the existing literature, as the full economic impact of Carp in Australia (both market and non-market) is unknown. The full costs and benefits of Carp control cannot be estimated with confidence without further assembly of information associated with the economic impacts of a number of different aspects of environmental, commercial, and recreational impacts associated with Carp.

## Section 2: Studies on Impacts of Carp

Not all of the potential relationships between Carp and their likely impacts have been reported or valued in the literature covered in Section 1. There are specific economic impacts that Carp may influence to some degree, and the existing literature on these impacts is reviewed in the following section.

The McLeod reports (2004 and 2016) identify a number of Carp impacts (e.g. turbidity, sediment, recreational fishing experiences, environmental amenity values). There have been many studies that have addressed issues holistically but not necessarily with any reference to Carp.

However, Koehn et al., (2000) and later Vilizzi et al. (2015), listed several potential impacts of Carp. These range from impacts on recreational fishing, native fish abundance, and turbidity, to benthic invertebrate and phytoplankton/chlorophyll concentrations. As these biodiversity and water quality impacts may be driven by factors other than Carp, the magnitude of the Carp impacts will vary across studies depending on the region, water body, and localised biomass of Carp (Weber & Brown, 2009). However, the following review provides some starting points for valuation of Carp impacts if based on the assumption that Carp contribute to these impacts to some degree.

### Recreational Fishing

The following estimates are associated with recreational fishing expenditures. These provide information on the magnitude of the sector but do not relate to economic surplus estimates that can be used in CBA as a measure of societal well-being.

Recreational fishing is a popular leisure activity within Australia (including the MDB). The recreational fishing sector was estimated to have a gross market value of $2.56 billion in Australia in 2013 (Colquhoun, 2015). This estimate was derived from the market price of catch and expenditure on goods for recreational fishing. It should be noted that the gross market value of recreational fishing is neither a WTP estimate or an estimate of economic surplus.

Morrison & Bennett (2004) showed that there is a WTP for improved recreational fishing experience. For an improved recreational fishing experience in the Bega, Clarence, Georges, Gwydir, and Murrumbidgee rivers there was a WTP range of $45.26 to $54.16 per household (one-off payment) estimated for improved fishability across these rivers for 'within catchment' residents, while WTP estimates of $28.75 to $29.93 were reported for improved fishability for 'outside catchment' residents (Morrison & Bennett, 2004). The study did not gauge the extent of improvement in fishability, just that improved fishability would take place.

As the MDB is the largest inland river system in Australia, it represents a high proportion of Australian freshwater fishing activity. However, this review identified only one comprehensive study of recreational fishing specifically targeting the MDB and focusing on the market value of recreational fishing in that water body (Ernst and Young, 2011a).

In the same study, spending per trip per fisher was estimated at $262 in 2010 dollars (Ernst and Young, 2011a). McIlgorm & Pepperell (2013) reported an estimated expenditure of $225.24 per trip for NSW fishers. In the recommendations of the Ernst and Young (2011a) report, it was suggested that a study using other methods (WTP etc.) be carried out on recreational fishing in the MDB, to capture non-market benefits of recreational fishing, and the opportunity cost of recreational fishing. To our knowledge, no such study has been carried out to date. Expenditure on freshwater fishing in NSW has been estimated at $231 million per year but this was dwarfed by saltwater fishing expenditure of $1.415 billion per year (McIlgorm & Pepperell, 2013). The McIlgorm and Pepperell (2013) report on NSW fishing estimated the value added by inland fishers to be $149.85 million per year. This estimate was derived from assumptions related to recreational fisher locations and where recreational fishers spent their recreational fishing time. The McIlgorm & Pepperell (2013) made no mention of Carp.

## Native Fish

In contrast to the recreational fishing studies, native fish studies differ significantly in both methodology and usage. These studies address the marginal gains from native fish improvement (i.e. the economic impact), and society's WTP for these improvements.

An initial study on non-market values of VIC river health using CM provided various WTP estimates for certain improvements in riverside vegetation, native fish, birds, and recreational water quality for the Gellibrand, Moorabool, and Goulburn rivers in the MDB (Bennett, et al., 2008). The range of WTP value estimated for a one percent increase in native fish numbers was between $2.19 and $5.34 per household, one-off payment (significant at 5%), depending on the location of the area being improved.

The CM study by Morrison & Bennett (2004) looked at pooled models for benefit transfer and found varying estimates of WTP for native fish restoration in the Bega, Clarence, Georges, Gwydir, and Murrumbidgee rivers. For native fish restoration, significant values between $2.12 and $7.23 per household per species present in the catchment, and between $3.51 and $4.05 per household per species present for outside catchment residents were estimated; both estimates were one-off payments. These studies do not address how these improvements would be achieved.

A CM study for the River Murray gave estimates of a WTP between $1.71 and $3.58 (dependent on location) per household every year for 10 years for a 1% improvement in native fish numbers (MacDonald, Morrison, Rose, & Boyle, 2011). When extrapolated over 10 years by location and discounted by 28%[5], the study reported a WTP for a 1% improvement of native fish numbers of $51.6 million.

Morrison & Hatton MacDonald (2010) aggregated values of WTP for a 1% increase in native fish across a number of studies for the MDB. There was a range between $0.46 - $12.80 for a one-off payment per household for a 1% increase in native fish depending on the MDB region. Morrison and Hatton MacDonald (2010) used existing studies to aggregate these figures to a one-off payment, using benefit transfer and other aggregation methods.

The studies above provide robust evidence of the WTP by communities for native fish restoration. However, the extent of improvements on which estimates are based are generalised such as the number of native fish numbers, native fish species present, and improved fishability.

There is global evidence that Carp have been shown to affect native fish populations (Vilizzi et al., 2015) but the size of relationship by scale and fish type is not known in the MDB and Australian context. The review found only one study that addressed native fish recovery from direct Carp removal. Gehrke et al., (2010) showed a reduction of 30 kg per hectare (ha) of Carp increased native fish by 90 kg per ha but referred only to lagoons in the Condamine and Macintyre river catchments, with native fish recovering being bony herring and gudgeons. There may be a WTP to reduce Carp if reduction leads to an increase in native fish populations. Given the lack of quantitative relationships in the literature, this relationship needs to be explored further if the value of any Carp reduction effort is to be estimated.

## Water Quality

Water quality can affect both the market and non-market values of water in rivers and water extracted from rivers. Some literature on water quality impacts is reviewed in the following.

[5] A 28% discount rate was used as well as a 5% p.a. discount rate so the resulting value could be compared to other one-shot payment studies.

### *Amenity aspects*

There have been some WTP estimates using techniques to capture the marginal benefit and economic surplus for improved visual aspects of water quality. Bennett et al. (2008) estimated a WTP between \$1.64 and \$2.12 (one-off payment) per household for a 1% increase in the length of the river subject to improved water quality. This applied to the Goulburn River in VIC for residents in the Goulburn and Melbourne catchments. For NSW Rivers, CM was used to estimate the WTP for improved water quality for different recreational activities, such as swimming, boating, and fishing on the Bega, Clarence, Georges, Gwydir, and Murrumbidgee Rivers (Morrison & Bennett, 2004). Using a pooled model, the results showed a one-off WTP, dependent on the catchment area, of between \$59.98 to \$104.07 for rivers in NSW to be swimmable throughout the entire river. The study did not gauge the extent of improvement in swimmable rivers, just that the activity would be able to be undertaken.

### *Water treatment (sediment removal)*

Water treatment authorities must treat all drinking water for turbidity before use by the end consumer, according to the Australian Drinking Water Guidelines (National Health and Medical Research Council, 2011). According to the Australian Drinking Water Guidelines, an acceptable level for consumption is under 0.2 Nephelometric Turbidity Unit (NTU) with aesthetically pleasing water being < 5 NTU. There is not a wide range of literature on whether more turbid source water increases costs of treatment, but water treatment authorities do make additional investments to manage turbidity and use measurements of turbidity as a water treatment measure in general (Francis, 2015). One study was found on water treatment costs for different levels of turbidity. A study from Texas, in the United States, using a treatment cost model, showed a 1% increase in turbidity lead to a 0.25% increase in chemical costs (Dearmont, McCarl, & Tolman, 1998).

Water treatment coagulants used for treating turbidity at water treatment plants can range from approximately \$450 per tonne for alum to \$2,800 per tonne for aluminium chloralhydrate (Gebbie, 2006).

There is strong evidence of a positive relationship between Carp biomass and turbidity (Vilizzi et al., 2015; Weber & Brown, 2009). The exact functional relationship between Carp biomass and turbidity is not clear from the literature with estimates varying widely from 50kg/ha -100 kg/ha for noticeable difference in turbidity up to 500kg/ha for large shifts in turbid water states (Department of Environment, Land and Water Planning Victoria, 2017; Vilizzi et al., 2015; Brown & Gilligan, 2014; Weber & Brown, 2009). Vilizzi et al (2015) reported that specifying any critical Carp biomass that impacts on turbidity have been problematic due to the differing nature of the experiments carried out. However, Carp were shown to affect turbidity at different biomasses, dependent on location and waterbody type. The increase in turbidity caused by Carp may reduce amenity values as well as increase water treatment costs as well as costs associated with the maintenance of irrigation channels, pipes, and pump maintenance.

Carp may be associated with an increased cost to irrigation authorities and irrigators through their contribution to greater turbidity and erosion of irrigation channels (leading to pipe corrosion and increased maintenance costs of irrigation channels) (Southern Rural Water, 2013). This relationship needs to be confirmed and further explored to establish the costs of Carp to both irrigation authorities and irrigators. The review has found no literature to confirm this relationship.

It has been suggested that turbidity causes blocked irrigation pumps through clay and organic material (NSW Government, 2014) increasing costs for irrigators (NSW Government, 2014; Lymbery & Nancarrow, 2017). Further research regarding Carp and irrigator costs has been suggested in the past (McLeod & Norris, 2004; McLeod, 2016), but currently there is no authoritative information in the literature on these relationships. Further information from irrigators, irrigation authorities, and water treatment managers is required to ascertain the validity and extent of any relationship.

### *Algal blooms*

Algal blooms create a multitude of negative impacts. These include direct impacts such as biodiversity loss, amenity loss (smell and visual) and loss of recreational opportunities (Atech Group, 2000). Impacts of algal blooms also can include increased water treatment costs and restricted use of water for irrigation and livestock (Atech Group, 2000). Algal blooms may also affect growth rates of irrigated crops as irrigators are allowed to use water affected by algal blooms for irrigation (NSW Government, 2014).

In 1999, it was estimated that the total costs of algal blooms may be between $185 million and $250 million in Australia per year (Atech Group, 2000). The Atech report considered the additional costs of sewage, stormwater, and agricultural and industrial wastewater management, as well as the costs of rehabilitating land and water resources. Some of these costs are associated with the management of factors that affect the frequency and severity of algal blooms (e.g. sewage runoff, land clearing, chemical runoff). The added costs of monitoring, contingency planning, and use of algal bloom water were estimated at $8.7 million per year. A further $9.5 million per year was attributed to water authorities in one-off costs and ongoing costs of monitoring and preparing for algal blooms. The costs to farmers and irrigators from algal blooms in irrigation channels and rivers was estimated at $15 million per year for both irrigators and dryland farmers. For non-market costs, an estimate of $76 million to $136 million per year was estimated, but the study noted that the non-market costs may be even larger, as the Atech study was not specific on what non-market costs were covered.

Ernst and Young (Ernst and Young, 2011b) reported that the MDB Authority's main concerns from the effects of algal blooms are for livestock that drink from the river, and water treatment plants. The costs to water treatment and water supply organisations are mainly through interruptions in the water supply, monitoring for algal blooms, and additional capital costs for equipment to treat algal blooms (Atech Group, 2000). These costs may now be lower as the later report by Ernst and Young (2011b) reported that algal blooms did not involve large costs for either water authorities or irrigators, and that other issues are more important than algal blooms.

However, the Ernst and Young report (2011b) did not consult farmers or smaller irrigators and did not contact all water treatment plants, due to water treatment being only one aspect of the report. This was the only study identified that addressed the economic impacts of algal blooms in the MDB.

An ex-post study on algal blooms showed a potentially lower consumer surplus for potential visitors to Lake Hume when algal blooms were present. Consumer surplus was calculated for a base scenario (defined as the water level at during the survey), for a water level at 50% base water level at 10% base, and for an algal alert scenario. Consumer surplus with the algal alert was $20 per visit, lower than the base water level scenario at $33 per visit. The consumer surplus for the algal alert level was equal with the lake having 50% of the base scenario capacity water levels, but higher than if the lake had only 10% of the base water levels at $16 per visit (Crase & Gillespie, 2006).

Not all of the estimated $185 million - $250 million Australian cost of algal blooms p.a. can be attributed to Carp, but Carp may well be one of the contributing factors. The current relationship between Carp and algal bloom frequency, severity, and longevity is not well understood. Many factors are relevant in the relationship between Carp and algal blooms. Carp feeding on zooplankton decrease the zooplankton ability to feed on algae (Koehn et al., 2000; Vilizzi et al., 2015; Weber & Brown, 2009). Also, Carp release a higher level of nutrients into the aquatic environment, such as nitrogen and phosphorus, that are known to contribute to the occurrence of algal blooms (KCI Associates of Ohio PA, 2016). On the other hand, the increased turbidity caused by Carp decreases algal growth (Ernst and Young, 2011b). Therefore, the relationship between Carp and algal blooms will need to consider and integrate these different pathways to value the contribution of Carp to any algal bloom impact.

## Biodiversity

Due to their feeding behaviour, Carp can impact negatively on native fauna (including macroinvertebrates) and flora (Vilizzi et al., 2015; Weber & Brown, 2009). Declines in aquatic vegetation have been observed to start to occur from Carp densities ranging from 68 kg/ha to 450 kg/ha (DELWP, 2017). Carp have a multitude of effects on biodiversity through their feeding habits, and indirectly through the food web, that also impact native fish (Gehrke et al., 2010). These complex relationships will need to be further informed if any attempt is made to value the current impact of Carp on the different aspects of biodiversity in Australia.

There have previously been CM studies on the value of biodiversity within Australian rivers, for example, healthy river vegetation in the MDB. For households across Australia, a WTP for a 1% increase in healthy vegetation of $2.87 to $4.42 per household per year for 10 years for the Murray and Coorong Rivers was reported (MacDonald et al., 2011). Bennett, et al. (2008) also found a WTP for a 1% increase in healthy river vegetation in VIC Rivers between $2.91 and $5.56 per household. The studies above address riverside vegetation and other biodiversity aspects, but do not include macroinvertebrates explicitly. This is an area that may need to be further explored by ecologists as it is unknown how society may value an increase in macroinvertebrates in river systems if Carp are reduced.

An aggregate study estimated the range of a household’s one-off payment for a 1% increase in healthy native vegetation in the MDB ranges from $2.19 to $13.72 for different MDB regions (Morrison and Hatton MacDonald, 2010).

## Tourism

Tourists visit the MDB and other river habitats throughout Australia for a variety of reasons. For example, in Albury, people visit for riverside recreation, to have food and wine experiences, to visit friends and relatives, and for cultural activities  (Tourism Research Australia, 2013).

The breakdown of recreational activities by tourists who visit the MDB and other rivers where Carp are present is not available. There is information available on the number of nights international visitors spend in the MDB region(s), but the information does not specify the activities undertaken by visitors or the reasons for their visits. An estimated 324,000 nights are spent annually by international tourists in the Murray River region. For the Goulburn River Region, an estimated 659,000 nights were spent by all tourists, with an average spend in the Goulburn region per international tourist of $2,081 per visit (Tourism Research Australia, 2017).

There was no literature found on Carp’s direct impact on tourism in this review, but there may be indirect influences of Carp via various attributes of water quality, biodiversity, and other amenity values as reported earlier.

# Section 3: Reducing the Carp Population

## Introduction

There has been no direct valuation identified in the literature of what the Australian community is willing to pay to reduce Carp populations. Many commentators have hypothesised that the Australian population would like to see Carp removed, as Carp are an invasive species and have been shown to cause environmental degradation (Norris & Ballard, 2013; Wallis, Kelly, Salzmann, Gilligan, & Hartewll, 2009). This view is supported by the existence of 'Carp out' events attended by recreational fishers for the purpose of reducing Carp numbers. A survey response on the reasons why participants enter Carp out events showed "getting rid of Carp" as the second most selected option for participating at 21%, while approximately 70% stated getting rid of Carp was one of the reasons for participating (Norris & Ballard, 2013). While these studies do not elicit values for society's WTP, they provide anecdotal evidence that there is a general attitude of supporting a reduction in Carp numbers, and that at least some section of society is willing to pay for it. This is not conclusive, as these events are subject to bias from members of society who want to see Carp reduced. There is currently no evidence on the attitude of the Australian populations attitude towards Carp and their removal, society's WTP for the reduction of Carp, and the benefits that a potential reduction in Carp may bring.

A brief summary of some of the methods for reducing Carp populations follows.

## Commercial Fishing (no specific method)

Commercial fishing pressure has been shown to be unable to knock Carp numbers down to a level where they can be adequately controlled (Brown and Gilligan, 2014). For example, even in a closed system (Lake Cargill), commercial fishing did not reduce Carp numbers to levels that were necessary to avoid environmental damage (Koehn, et al., 2016). In 2014, 40 tonnes of Carp were removed from Lake Moira by commercial fishing. An issue identified for possible large-scale reduction, was the *ad hoc* nature of the removal. The necessity of *ad hoc* removal of Carp from commercial operations is due to problems accessing the site, making year-round removal impossible (Koehn et al., 2016).

There have been attempts at commercialising Carp fishing in the Mississippi River in the United States. Despite having a larger human population, and more appropriate infrastructure, the commercial Carp industry is still small, requiring government subsidies (Lepeska, 2011). If the experience is translated to Australia, any commercialisation strategy would be unlikely to present a significant knockdown of Carp.

A large scale commercial Carp industry has been attempted in NSW in the past, supported by the NSW Government, but appeared not to be commercially viable on a large scale due to low market returns and uncertainty over biomass of Carp in locations suitable for capture (NSW Government, 2010). As referred to earlier, the commercial domestic market for Carp can take only approximately 2 tonnes per week before fishing becomes unprofitable due to lower prices.

### *The global production of Carp*

Global aquaculture production of Carp is approximately 4.33 million tonnes p.a., with a gross monetary value of approximately $USD 5.9 billion (FAO, 2017). There is a wild catch industry of approximately 1.52 million tonnes for all types of Carp (FAO, 2017). Globally, Carp is not widely exported, with the export price of Carp being $USD 2.51 per kg with only 0.20% of global production exported.

## Electrofishing

Electrofishing has been shown to have the highest catch per unit effort (CPUE) compared to other fishing methods (Gehrke et al., 2010). Through electrofishing, approximately 13% of a localised Carp population can be removed (Norris & Chilcott, 2013). Electrofishing has been shown to be relatively expensive to implement, but it has also been shown to be more effective per labour hour than recreational fishing hour. Per day, electrofishing costs approximately $2,500. Also, while electrofishing may be effective, it cannot be used in certain environments. For example, the boats cannot be used in waters deeper than 4 m, it is not effective in high flow environments, and it is not effective in areas with snags.

In terms of control, there may also be a selection bias, with Carp avoiding the electronic currents/swimming away (Gehrke et al., 2010). This may enhance genetic traits that may render electrofishing less effective into the future (Gehrke et al., 2010).

While the reductions through electrofishing are significant, they are not enough to stop recruitment or migration of Carp from other areas, and only provide respite to a localised area from Carp for a period of time.

## Recreational Fishing

Recreational fishers have been reported to believe that recreational fishing may be an effective Carp control technique behind electrofishing and commercial fishing (Wallis et al., 2009). Recreational fishing for Carp control, while important for promoting Carp control and the negative impacts of Carp, has been shown not to be an effective Carp control technique. During a study on the effectiveness of Carp control competitions in QLD, Norris and Chilcott (2013) found the amount of Carp removed from the localised system was approximately 1.3% of the biomass present in the water bodies where the competitions took place. As identified by Brown and Gilligan (2014), recreational fishing pressure is nowhere near a level to reduce Carp biomass to a level where Carp will not have negative environmental effects. Also, the CPUE of recreational fishing is lower than electrofishing with angling effort ranging from 0.031 to 0.058 Carp per angling hour (Norris and Chilcott, 2013).

## Netting

Fyke nets have been found to be the second most cost-effective removal mechanism after electrofishing (in terms of fishing methods) (Gehrke et al., 2010). For example, the total amount of Carp removed by netting was significantly lower than for electrofishing in the Rainbow and Warren Lagoon study (Gehrke et al., 2010). While not effective for large-scale removal, netting is a low-cost method of removal (Gilligan, Gehrke, & Schiller, 2005). Fyke nets are approximately $800 each and were recommended for use by community groups (Gilligan et al., 2005). Despite the low cost, the removal rates through use of the nets are low and, for effective control of Carp, are dependent on where the nets are set up (Gehrke et al., 2010).

## Separation Cages

Williams separation cages have been used to keep Carp out of wetlands across the MDB. The capital cost of a cage is approximately $USD5,000 (Stuart, McKenzie, Williams, & Holt, 2003). Other publications report Williams cage costs at $63,278 for one cage (including installation and other capital costs but excluding operational and in-kind costs) (Gilligan et al., 2010; Koehn et al., 2016).

## Use of Multiple Measures: Tasmania Removal

In TAS, there was large-scale removal of Carp from Lake Sorell and Lake Crescent over the period 1995 to 2013 with an overall monetary cost of removal of approximately $9.6 million (Pestsmart, 2014). This was only possible due to Carp populations being located within a closed Lake system. The removal was achieved through multiple methods such as public closure of the lakes, fish screens to stop movement between lakes, netting, and Carp tracking.

## Strategy for Knockdown using Existing Methods

It has been reported that the current fishing pressure on Carp is not at the level required to make any significant impact on reducing the current level of Carp biomass (Norris, Hutchison, Chilcott, & Stewart, 2014; Norris & Chilcott, 2013). It has been stated that for an effective knockdown of Carp, a mechanism such as a virus release may be needed to be compared to existing measures (Brown & Gilligan, 2014). To stop Carp populations rebounding, there would need to be an initial knockdown of 70% - 90% (Brown & Gilligan, 2014).

From the evidence stated above, the removal of Carp via existing methods will not be enough to reduce Carp numbers to a level where environmental degradation due to Carp will be reversed. The literature review has not identified any studies on the cost-effectiveness of existing removal methods if such methods were scaled up to a level needed to reduce the negative impacts of Carp.

From the literature, no physical removal method would seem to be cost effective due to the relatively low proportion of the population that could be caught. From Brown and Gilligan (2014), the combination of different control mechanisms would not achieve the required 70%-90% reduction in biomass over the long term to reduce the negative impacts of Carp in the Lachlan River (excluding methods such as Daughterless Carp and the virus CyHV-3).

# Section 4: Potential Impacts of Biocontrol via Release of CyHV-3

## Introduction

The literature associated with the prospective benefits and costs of releasing CyHV-3 is limited. The following addresses some relevant literature discovered in this domain. Some of the literature already reviewed (related to the costs of Carp) also is relevant to the removal of Carp. However, relationships are not necessarily symmetrical in that an additional cost of Carp being present may not be removed according to a linear relationship with the proportion of Carp removed.

Therefore, this review addresses only a few selected subject areas of virus release impacts and is limited to where some useful literature has been identified.

## Potential Benefits

It is predicted that a CyHV-3 release will potentially knock down current Carp populations by 70% - 90%, depending on the initial knockdown rate and the continuing knockdown rate (Brown & Gilligan, 2014). The relationships between biomass of Carp, environmental damage, loss of amenity value and additional costs are unknown as well as the potential reduction of Carp on these factors. As well as the Carp knockdown impact, the ecosystem response to the knockdown will be critical to the valuation of benefits and a range of assumptions will need to be explored and developed.

### *Water Turbidity and Algal Bloom Presence*

Reducing Carp populations may provide benefits for a number of water sectors, but the economic benefits of reducing Carp numbers via water quality improvements are unknown.

Carp have been identified in a number of studies to increase turbidity and frequency and severity algal blooms in a number of different international and Australian water bodies (Vilizzi et al., 2015). There are a wide variety of estimates on when Carp affect turbidity including a Carp population density of at least 68 kg/ha after which there is a noticeable turbid water increase (Vilizzi, Thwaites, Smith, Nicol, & Madden, 2014). Other literature mentions a variety of higher threshold densities (100-500 kg/ha) for when Carp have an effect on turbidity levels (Brown & Gilligan, 2014). Carp population densities will need to be established in different regions and water bodies for the current turbidity impacts from Carp to be estimated.

A reduction in turbidity may reduce costs for water treatment plants and irrigators through reduced treatment costs and pump blockages, but these cost reductions will depend on the amount Carp biomass may be reduced, the effect of this reduction on turbidity, and the turbid state of source water after Carp populations are reduced.

For algal blooms, there may be decreased costs for water treatment and farmers, and an increase in biodiversity and amenity values. As there is a relationship between Carp and algal blooms (Vilizzi et al., 2015), the removal of Carp should decrease the likelihood of algal blooms (Sierp, Qin, & Recknagel, 2009). However, the functional relationship is not specific enough to inform the CBA. Hence, further expert input will be required to inform assumptions regarding any impact Carp biomass reductions may have on the frequency and severity of algal blooms.

### *Biodiversity*

There is ample evidence to suggest that by removing Carp there will be some increase in water quality, increased macrophytes, and an increase in native fish abundance (Vilizzi et al., 2015). However, relationships between different levels of Carp knockdown and these impacts have yet to be quantified and will need to be explored further and associated assumptions made if estimates of benefits are to be made from the release of the CyHV-3 virus.

### *Native Fish*

There is evidence to suggest that Carp have reduced native fish numbers through reducing habitat and food sources (Gehrke et al., 2010; Vilizzi et al., 2015; Weber & Brown, 2009), and other studies have shown that some native fish have increased due to removal of Carp (Gehrke et al., 2010; Weber & Brown, 2009). In Rainbow Lagoon and Warra Lagoon, QLD, reducing Carp biomass by 33% and 41% lead to an increase of bony herring by 240%-1,130% and Carp gudgeons by 1,600% (Gehrke et al., 2010).

To date, there have been no studies that have been found on the WTP by any Australian population to reduce the population of Carp (or reduce Carp populations in relation to native fish). It is known that recreational fishers value catching native fish and associate Carp with their decline (Norris & Ballard, 2013) and that the public does value increasing the abundance of native fish. This may imply that if there is a WTP to increase native fish abundance, and therefore there may be a WTP to decrease Carp populations.

However, this relationship has not been quantified or estimated and constitutes a gap in the literature that needs to be filled. Also, information on the inverse relationship is required (e.g. if Carp numbers are reduced by different amounts, what species and quantities of native fish populations will respond and how). It is unknown what effect reducing Carp populations may have on angler catches (McLeod & Norris, 2004) and the types of fish that will be caught or increase due to a reduction in the Carp population.

### *Recreational Fishing*

If there is a reduction in Carp populations in the MDB, it is possible that it may lead to an improvement in the freshwater recreational fishing experience.

An associated issue raised by McIlgorm and Pepperell (2013) is whether there may be substitution between fresh and saltwater recreational fishing. For example, if an increase in native fish biomass increases the MDB fishing experience, would some recreational fishers substitute freshwater fishing for saltwater fishing (McIlgorm & Pepperell, 2013)?

The studies outlined in Section 2 have addressed non-market valuation of recreational fishing in conjunction with changes in associated variables including native fish abundance, recreational values, and environmental impacts. None of these studies relate directly to Carp but may be relevant in assessing the value of Carp removal if the removal can be assumed to lead to an improved recreational fishing experience.

### *Tourism*

There was no literature found that addressed the question of whether Carp have reduced tourism in the MDB and other areas where they are present. However, it is possible that there may be a reduced tourism impact due to Carp lowering water clarity and associated amenity value, as well as reducing recreational fishing experience.

While Carp may have a significant detrimental effect on tourism in the MDB, this necessarily may not constitute a net economic (market) loss to Australia, as deterred domestic tourists may substitute by visiting and make expenditure in other areas in Australia.

It is unknown whether the rationale for international tourists visiting the MDB region is based on the MDB rivers (and associated waterways) as a central driver. The literature review found no data or studies that have explored this area and it is a gap in the literature that could be filled.

From the literature covered in Section 2, there were no studies identified that related to factors affecting potential substitution between Australian tourist destinations by Australian tourists.

## Potential Costs

There may be some negative impacts, and hence costs, associated with the successful knockdown of the Carp population after release of the virus. These impacts may include native fish kills due to low oxygen water, the smell of dead Carp, any carcass management or clean-up costs (including carcass disposal) deemed necessary, and an increased risk of algal blooms and blackwater events.

### *Clean-up Strategies*

No literature pertaining to the cost of carcase management and clean-up strategies of Carp from other countries where the CyHV-3 is present was found for this review. The NCCP states *"Considerable knowledge and experience of appropriate clean-up methodologies, therefore, exists both within Australia and overseas, but has not been collated or synthesized and is sometimes difficult to access*" (NCCP, 2017). Another NCCP project is exploring potential carcass management and clean-up strategies and has also recognised that there is little information on the costs and benefits of such strategies. However, there is literature on methods of fish kill clean up. Silva, Bell, & Baumgartner (2017) summarised the literature on fish kills, with most clean-up being done by nets, and in response to unplanned fish kill events.

Clean-up strategies have been identified including hand-picking, dip netting, seine netting, boar trawls, water vacuum, excavator tractors, and barges with automatic collectors (Silva et al., 2017). It is beyond the scope of the CBA to determine the most cost effective clean up method.

### *Costs of Clean-up*

If there are large Carp kills due to a virus release, the costs of cleaning up dead Carp will have to be addressed. This need will be due to dead Carp potentially causing environmental problems, such as lower oxygen levels in water and a higher probability of blue-green algae outbreaks, including an increased probability of blackwater events. The costs of clean- up will rely on mechanisms used, the distribution of dead Carp, availability of access to the location of Carp, and availability of mobile clean-up resources. There may be opportunity costs with recreational users not being able to use waterways for a period due to Carp deaths. Subsequent literature from another NCCP Project 2016-158 reported some references to clean-up costs. There were two examples in VIC of Carp clean up. The costs were $35,420 for 12 tonnes in 2000 for the Mitchell River and $15,980 for 5 tonnes in 2006 for the Nicholson River (Silva et al., 2017).

These examples may not be comparable to the CyHV-3 virus release as the fish deaths were unplanned, and the scale may be very small compared to the potential number of deaths due to CyHV-3. Location is also relevant, with the two case studies covering only a lake and a section of a river. There was no large-scale clean up (equivalent to the MDB) literature or examples reported in Silva et al. (2017).

### *Disposal and Utilisation of Dead Carp*

The method of disposal of the Carp carcasses may be problematic due to environmental legislation. It is possible that some of the costs of the clean-up and disposal may be offset by potential product development through the utilisation of dead Carp. A separate NCCP project is exploring the potential for such commercial utilisation of the dead Carp. This will fill a gap in the knowledge whether a mass mortality of Carp can be utilised profitably as a commercial product, given the short time frame for harvesting dead Carp and the operational logistics of transport, storage and processing. This subject matter has not been addressed in this review as there is little relevant literature available.

### *Smell*

If the virus is released, there is a potential negative externality for regional communities due to the smell of the dead Carp, if carcasses are not collected rapidly. From the literature reviewed to date, there is a lack of studies on the negative externality of dead fish smell.

However, there have been studies on the WTP to reduce smell. For example, residents in Hamilton, Canada were found to have a WTP of about $CAD13.10 to reduce the frequency of unpleasant smell days caused by air pollution from 4 days to 3 days per month (Diener, Muller, & Robb, 1997). There are Australian regulations across different states regarding odour, with legislation in place to prevent unreasonable odour exposure to community populations (Department of Environment and Conservation NSW, 2006). No studies have been found in this literature review specifically concerning the smell of dead fish to river and lake communities.

### *Algal Blooms and Blackwater Events*

Apart from smell, there may be further negative impacts due to decomposing Carp biomass within rivers if not cleaned up properly. This includes increased frequency and severity of algal blooms and blackwater events that may in turn impact on amenity values, biodiversity, native fish populations, communities, and recreational fishing values. If there are native fish killed due to the impact of dead Carp, there may further negative impacts to the recreational fishing sector, tourism, and biodiversity.

There is little literature on these potential impacts specifically for Carp. However, there are two NCCP projects exploring the relationships between Carp deaths and algal blooms/ blackwater events. These projects could provide useful information. The assumptions for the CBA regarding these relationships will depend on the release and carcass management strategies of the NCCP and the results of these other NCCP projects.

## Section 5: Conclusion

The impact costs of Carp are largely uncertain. Previously published estimates have varied between \$15.8 to \$22.4 million per year. These studies have not addressed all relevant negative Carp impacts and have used methods of valuation that cannot be viewed with a high level of confidence. Also, no attempt has been made in previous studies to value the positive impacts of Carp.

In the limited economic studies undertaken to date, the non-market impact costs of Carp have dominated compared to market costs. However, non-market impacts are difficult to value, and such costs are likely to vary significantly between different communities of interest.

Current estimates of the impact of Carp on the MDB and other Australian waterways where Carp are present are somewhat speculative and there are no comprehensive studies providing robust and verifiable estimates.

A major weakness in attempting to make an improved estimate of the net impact of Carp is the lack of information on the specific scale and location relationships between Carp and various river health and water quality attributes. This is because many of the potential impact types are also influenced by other land use, river and water management issues.

Understanding the true extent of Carp's impact on water quality issues such as turbidity, native fish populations, algal blooms, native vegetation, riverbank erosion, and amenity values, will constitute a key knowledge resource for estimating the market and non-market impacts of Carp in Australia. In particular, to confidently estimate the non-market values of the impact of releasing CyHV-3 will require the development of best-bet assumptions on the various ecological impacts associated with Carp biomass reduction.

# Part 2: Identification and Assembly of Carp Impact Costs and Market Costs and Benefits of Carp

## Overview

Carp are thought to be associated with a number of impacts in Australia (see Introduction to the Current Impacts of Carp, and Figure 2 and Figure 3). Objective 1 of the current project (2016-132) was to quantify the current and future costs of Carp being present in Australia by sector of the community affected.

The following section identifies and describes: (1) the potential economic, environmental and social costs and potential benefits that may be related to the impacts of Carp in Australian waterways; (2) impact costs that may be estimated using available market data (market costs); (3) a Carp market cost survey that was used to obtain up-to-date data on the market impact costs of Carp across Australia; and (4) valuation data from past studies on the existing market impact costs and benefits of Carp, as well as on the potential costs and benefits of Carp control in Australian waterways. This section does not consider the impact costs associated with the potential release of the CyHV-3 virus as these impacts are considered in the Murray-Murrumbidgee case study CBA of the implementation of the NCCP (see Part 4: Synthesis).

## Identification of Current Impact Costs of Carp in Australian Waterways (Market and Non-Market)

### 1. Costs Associated with Reduced Water Quality

The increased sediment and nutrient loads (increased turbidity) in Australian waterways, potentially caused by the presence and feeding behaviour of Carp, was thought potentially to be associated with the following impact costs:

1.1 Increased costs of water treatment in terms of chemical use and treatment processes,

1.2 Increased maintenance costs for some primary water users (e.g. irrigators) through blockages and increased wear and tear of infrastructure (e.g. water pumps and irrigation channels),

1.3 Reduced ecosystem health in Australian waterways as a result of increased sediment and nutrient loads negatively impacting water quality (Huang, Wen, Cai, Cai, & Sun, 2010),

1.4 Reduced tourism revenue because of the diminished amenity of Carp infested waterways, and

1.5 Some contribution to reduced amenity of key fishing waterways for recreational fishers.

### 2. Costs Associated with Erosion and Increased Incidence of Algal Blooms

The following potential impact costs were identified as being associated with accelerated erosion of riverbanks, degradation of waterway verges and irrigation channels, and the potential for increased incidence of algal blooms associated with Carp feeding, spawning and excretion:

2.1 Increased maintenance costs for some primary water users (e.g. irrigators) because of damage to irrigation channels,

2.2 Biodiversity loss (e.g. native fish and other aquatic species),

2.3 Reduced ecosystem health in Australian waterways as a result of erosion and increased incidence of algal blooms negatively impacting habitats of native animal and plant species and causing biodiversity loss,

2.4 Reduced amenity of waterways for recreational fishers, tourists and local residents,

2.5 Increased costs of water treatment in terms of chemical use and treatment processes,

2.6 Additional costs of planning, monitoring, management and rehabilitation of affected land and water resources, and

2.7 Secondary impacts associated with productivity losses for primary producers who utilise affected water for irrigation of crops and livestock.

### 3. Costs Associated with Impacts on Invertebrates and Aquatic Plants

The direct and indirect impacts of Carp on invertebrate populations and aquatic plants may include:

3.1 Biodiversity loss through predation and the impacts of Carp feeding and/or spawning behaviours (including indirect biodiversity loss such as reduced bird populations),

3.2 Reduced ecosystem health in Australian waterways, and

3.3 Reduced amenity (both aesthetic and recreational) of Australian waterways and related, non-aquatic environments,

### 4. Costs Associated with Competition with Endemic (Native) Fish Species

Interference or exploitation competition between Carp and endemic Australian fish species is likely to be associated with the following impact costs.

4.1 Direct and indirect biodiversity loss specifically in the form of reduced populations of native fish species,

4.2 Secondary biodiversity loss of associated species that feed on native fish species (e.g. native birds),

4.3 Reduced ecosystem health in Australian waterways as a result of biodiversity loss, and

4.4 Reduced amenity of key fishing waterways for recreational fishers.

### 5. Costs Associated with the Introduction of Pests and Diseases

Given that no diseases are known to have been introduced with Carp, and that the lack of close Carp relatives in the Australian fish fauna makes this impact unlikely, no specific impact costs are currently recorded as being associated with pests and diseases potentially associated with the introduction of Carp to Australian waterways.

## Potential Positive Impacts of Carp

There is evidence that Carp provide some positive impacts in Australia. For example, there is anecdotal evidence that a small proportion of recreational fishers enjoy catching Carp (Leeming, 2017); also, there may be economic, environmental and social benefits stemming from regional Carp fishing competitions.

Most notably, there are two significant commercial Carp businesses operating in Australia (K&C Fisheries and Charlie Carp) as well as between 44 and 66 fishers with commercial Carp fishing licences across NSW, VIC and SA (Schirmer, Clayton, & Dare, 2019; see also Part 1: Desktop Literature Review). Current commercial use of Carp in Australia ranges from sale of Carp products for human consumption to the production of pet food and production of other associated products such as fertiliser and leather. For those engaged in commercial Carp fishing, dependence on income earned from Carp fishing varies, with most commercial Carp fishers having a relatively small proportion of household income derived from Carp (Schirmer et al., 2019). Commercial Carp enterprises also are estimated to be worth between $50,000 and $700,000 p.a. in Australian Carp exports, however these positive values are likely to be small relative to the negative impact costs associated with Carp.

More detail about the potential positive impacts of Carp can be found in the literature review accompanying this report (Part 1: Desktop Literature Review).

## Existing Data on the Estimated Value of Potential Carp Impacts

A number of published reports/studies have made some attempt to quantify, in monetary terms, economic, environmental and/or social impacts related to the direct impacts of Carp or where Carp may be a contributing factor. Table 1 presents a summary of the various estimates of the value of negative impacts (both market and non-market) and which are, either directly or indirectly, linked to the presence of Carp in Australian waterways.

Table 1: Existing Estimates of the Value of Impacts where Carp may Contribute to the Impact in Australian Waterways

| Impact Type | Estimated Value[(a)(b)] | Source | Spatial Application |
|---|---|---|---|
| **Estimates associated directly with the impact costs of Carp** | | | |
| Aggregate impact of Carp | $15.8 million p.a. | McLeod & Norris, 2004 | Australia wide |
| | $22.36 million p.a. (base case)<br><br>$11.18 million p.a. (lower bound)<br><br>$44.72 million p.a. (upper bound) | McLeod, 2016 | Australia wide (with a focus on NSW) |
| | $175 million over 5-years | Koehn & Gehrke, 2000 | Gippsland Lakes, VIC |
| | $500 million p.a. | Gehrke, St Pierre, Matveev, & Clarke, 2010 | Unclear/ unsubstantiated |
| **Estimates of the value of impacts where Carp may be a contributing factor** | | | |
| Erosion | $1.9 million over 8-years (irrigation channel repairs) | Southern Rural Water, 2013 | VIC (Maffra, Bacchus Marsh and Werribee irrigation districts) |
| Reduced amenity for recreational fishers | $45.26 to $54.16 per household (one-off payment) for improved fishability for 'within catchment' residents<br><br>$28.75 to $29.93 per household (one-off payment) for improved fishability for 'outside catchment' residents | Morrison & Bennett, 2004 | MDB, NSW: Bega, Clarence, Georges, Gwydir, and Murrumbidgee rivers |
| Biodiversity – native fish species | $2.19 to $5.34 per household (one-off payment) for a 1% increase in native fish numbers | Bennett, et al., 2008 | VIC |
| | $2.12 to $7.23 per household per species present (one-off payment, 'within catchment' residents)<br><br>$3.51 to $4.05 per household per species present (one-off payment, 'outside catchment' residents) | Morrison & Bennett, 2004 | MDB, NSW: Bega, Clarence, Georges, Gwydir, and Murrumbidgee rivers |
| | $1.71 to $3.58 per household p.a. for 10 years | MacDonald, Morrison, Rose, & Boyle, 2011 | River Murray |

| | | | |
|---|---|---|---|
| | for a 1% improvement in native fish numbers<br><br>$51.6 million aggregate WTP for a 1% increase in native fish numbers over 10 years | | |
| | $0.46 to $12.80 per household (one-off payment) for a 1% increase in native fish | Morrison & MacDonald, 2010 | MDB |
| Biodiversity – other plant and animal species | $2.87 to $4.42 per household p.a. for 10 years for a 1% increase in healthy vegetation | MacDonald et al., 2011 | Murray and Coorong Rivers |
| | $2.91 to $5.56 per household (one-off payment) for a 1% increase in healthy river vegetation | Bennett, et al., 2008 | VIC |
| | $2.19 to $13.72 per household (one-off payment) for a 1% increase in healthy native vegetation | Morrison & MacDonald, 2010 | MDB |
| Water quality – amenity | $1.64 to $2.12 per household (one-off payment) for a 1% increase in the length of the river subject to improved water quality | Bennett, et al., 2008 | Goulburn River, VIC |
| | $59.97 to $104.07 per household (one-off payment) for rivers to be swimmable throughout the entire length | Morrison & Bennett, 2004 | MDB NSW: Bega, Clarence, Georges, Gwydir, and Murrumbidgee rivers |
| Water quality – turbidity | 0.25% increase in chemical costs due to a 1% increase in turbidity | Dearmont, McCarl, & Tolman, 1998 | Texas, USA |
| Algal blooms | $185 million to $250 million p.a. | Atech Group, 2000 | Australia wide |
| | Potential loss of consumer surplus of approximately $13 per visit to Lake Hume as a result of an algal bloom alert | Crase & Gillespie, 2006 | Lake Hume, NSW-VIC border |

(a) All values are in AUD unless otherwise stated.
(b) All values are expressed in the dollar terms of the year of publication unless otherwise stated.

The estimates summarised in Table 1 were sourced from a wide range of studies/reports with different scopes, methodologies and limitations. More information on the specific details of the studies listed can be found in the desktop literature review in Part 1 of the current report.

# Carp Impacts – Market Costs

## Market Impact Costs of Carp: Summary

A number of the Carp impact costs identified may be categorised in economic terms as 'market costs'. That is, the impact may be measured through existing market mechanisms and valued using current market prices. The market costs associated with the impacts of Carp in Australian waterways are likely to include:

1. Increased costs of water treatment in terms of chemical use and treatment processes,
2. Increased maintenance costs for some primary water users because of pump and pipe blockages and increased wear and tear of infrastructure,
3. Additional costs of planning, monitoring, management and rehabilitation of affected land and water resources,
4. Reduced tourism revenue because of the diminished amenity of Carp infested waterways, and
5. Secondary impacts associated with productivity losses for primary producers who utilise affected water for irrigation of crops and livestock.

## Market Impact Cost Survey

To ensure a comprehensive and current estimate of the total impact costs of Carp in Australia, Agtrans Research undertook a survey process to obtain current data to estimate the market costs associated with existing Carp impacts. These data were then supplemented by information collected earlier as part of the desktop literature review (see Part 1: Desktop Literature Review) and the non-market CM study (see Part 3: A Choice Modelling Study) and used to inform the CBA for the Murray-Murrumbidgee case study region (Part 4: Synthesis).

### *Pilot Market Cost Survey*

Agtrans Research used the information from the literature review (Part 1: Desktop Literature Review) related to the market impact costs of Carp to develop an informal market cost pilot survey for primary water users. The pilot survey was carried out using both email and phone interviews.

Approximately 20 primary water users (including irrigators, irrigation/ water authorities, and water treatment plants) were contacted across QLD, NSW, VIC, and SA. A summary of the pilot survey and its findings can be found in Appendix 2: Pilot Survey Summary & Findings.

### *Full Market Cost Survey*

Feedback from the informal pilot survey was used to develop a final, comprehensive market cost survey that was distributed in January of 2019 to a total of 82 potential respondents (14 irrigators, 16 irrigation/ water authorities, and 52 water treatment plants). Potential respondents were distributed spatially across QLD (8 potential respondents), NSW (46), VIC (20), SA (3) and other regions (5).

Responses from the final market cost survey were recorded in a Microsoft Excel® spreadsheet. Results then were organised, aggregated and assessed by primary water user type and by region. The resulting data were then used to inform the CBA for the Murray-Murrumbidgee case study (Part 4: Synthesis). A summary of the market cost survey and its findings can be found in Appendix 3: Market Cost Survey Summary & Findings.

### *Key Findings*

The informal pilot survey found that irrigation/ water authorities and irrigators/primary producers did not perceive Carp to be a notable problem. All respondents indicated that Carp either did not have a direct effect on irrigation operations or that their impact was negligible.

Water treatment plants were more likely to be affected by Carp. However, pilot survey respondents indicated that, given the underlying conditions in various water sources, it was unlikely that Carp contribute to turbidity is such a way as to significantly impact water treatment costs.

The formal market impact costs of Carp survey found that the existing Carp biomass was reported to have negligible direct impacts on costs for primary water users. Turbidity and sediment loads in source water for water treatment plants were found to have an effect on water treatment costs. Based on the data collected, the average quantity of water treated across 101 water treatment plants in NSW and VIC was 1,047 megalitres (ML) p.a. at an average cost of $808 per ML (total annual cost of $845,976) however treatment costs varied significantly between water treatment plants. On average, the water treatment facilities surveyed indicated that 25% of their water treatment costs could be attributed to treating turbidity/ sediment. Therefore, it is estimated that the treatment of source water for turbidity/ sediment costs, on average, $211,494 per treatment plant per year. However, the existing literature, supported by survey responses, indicated that it was unlikely that Carp activities contributed significantly to source water turbidity levels.

Overall, the survey data were interpreted as indicating that Carp do not impose significant costs on the market sector and that any significant damage they have caused, and still cause, are likely to be more strongly related to non-market costs via a range of causal pathways.

# Part 3: A Choice Modelling Study to Estimate the Non-Market Impact Costs of Carp and the Non-Market Benefits of Carp Control

## 1. Introduction

European Carp (*Cyprinus Carpio*) - hereafter referred to as Carp – is a species of freshwater fish that live in Australia's freshwater rivers, wetlands and lakes. Since the 1960s Carp have become a dominant pest species in Australia. At the request of the Australian Government, a team has been established within FRDC to investigate the potential release of CyHV-3 to control Carp numbers. Under the banner of the NCCP the FRDC is coordinating a program of research and consultation to carry out that investigation.

As part of the NCCP programme of research, the FRDC has commissioned a CBA of the release of the Carp Virus. The CBA is being conducted by Agtrans and ERE in association with Gillespie Economics. The CBA requires estimation of the full range of costs and benefits brought about by the release of the Carp Virus. Some of these costs and benefits are financial in nature and can be estimated using market data. However, the values held by the community for potential environmental outcomes are not associated with any market transactions and their estimation requires the use of nonmarket valuation methods.

This part of the report sets out the details of a study that is a component of the CBA of the release of the Carp Virus. It involves the application of a non-market valuation technique - CM - to estimate community WTP for the potential environmental outcomes of reduced Carp numbers in the freshwater waterways of Australia. As such, its goal is to provide a sub-set of the benefit estimates required to conduct the CBA of the Carp Virus release.

This report is structured as follows. Section 2 introduces the CM method. Section 3 summarises the Carp problem and the potential environmental benefits of a reduction in their population. Section 4 discusses the design and implementation of the nation-wide survey that was conducted to implement the CM method. The results of the econometric analysis of the CM survey data are reported in Section 5. The application of the results in the context of the CBA is set out in Section 6, including a reference table that provides value estimates across a range of potential different virus release strategies and outcomes. Some conclusions are drawn in Section 7.

## 2. Choice Modelling

The economic benefits of a good or service are defined in terms of people's WTP for them. Where benefits relate to goods and services that are bought and sold in markets, it is possible to observe the patterns of peoples' purchases and infer from them the values they hold. However, where the relevant goods and services are not marketed, people's WTP can only be determined using revealed or stated preference methods. Revealed preference methods rely on the observation of people's behaviour in markets for goods and services that are related to the values of interest. For instance, peoples' values for a recreational site that has open access to the public and is thus not priced can be inferred from their WTP for the costs of travelling to the site. Where no such relationships exist, stated preference valuation methods are required. These methods involve a sample of the people who are likely to be affected by a change being asked either directly or indirectly about their WTP for the change.

CM is one such stated preference method that has undergone considerable development since its first application to environmental management issues in the 1980's. It has a number of advantages over other non-market valuation methods, particularly in terms of its flexibility to estimate a range of values from a single application. WTP values (known as 'implicit prices') from a CM application can be used across a range of potential policy options. Hence, a CM study can be commissioned prior to the determination of an exact policy specification. Having this value information earlier in the policy development process is useful in so far as it can assist policy makers to decide which policy formulation is most appropriate. In the context of the Carp CBA, being able to estimate the values of a range of Carp population reduction scenarios allows for the assessment of what level of Carp Virus release effort is most efficient.

In a CM application, respondents are asked to make a sequence of choices in which they pick their preferred alternatives from a number of sets of options (called 'choice sets') that describe alternative future scenarios (Bennett & Blamey, 2001). The alternatives in the choice sets are described by a number of attributes. These attributes usually relate to the outcomes of alternative policies and one attribute will always be the cost to the respondent of the alternative they choose. This approach is based on Lancaster's 'characteristic theory of value' (Lancaster, 1966) and it is assumed that respondent well-being is derived from the attributes of the alternative (Amaya-Amaya, 2008). The alternatives in each choice set are different from each other because the 'levels' that the attributes take in each alternative will be different. The levels of the attributes are assigned across alternatives using an experimental design that ensures respondents choose between a widely and randomly spread set of alternatives. Importantly, one of the alternatives presented to respondents in every choice set is a 'status quo' or 'counterfactual' alternative. It describes the outcome of the case when no new policy initiatives are taken. It comes at no cost to the respondent and is consistent with the counterfactual used in the CBA. It therefore acts as an 'anchor' for respondents' preferences.

The analysis of the choices that respondents make across the choice sets relies on McFadden's (1974) RUM. In this model of individual choice, alternative *i* will be chosen from a choice set if, and only if, the utility derived from that option is greater than the utility derived from any other alternative. Hence, the probability of a respondent choosing a particular option *i* from a choice set is greater if that option has a higher level of the desirable attributes. Thus, the relative utility (U) that a respondent derives from an alternative *i* comprises:

- a component ($V_i$) that is observable and normally specified as a linear, additive function of a vector ($X_i$) of explanatory variables that can include the attributes that describe the alternatives, socio-demographic characteristics of the respondent, information on the decision context and features of the choice task (Hensher & Greene, 2003); and
- a component that is unobservable ($\varepsilon_i$) which represents variations in choice due to within – and between – individual variance, omitted or unobserved influences on individual choice, measurement errors and functional specifications (Batsell & Louviere, 1991).

It is generally assumed "that these two components of relative utility are independent and additive" (Hensher, Rose, & Greene, p.75, 2005) and that $\varepsilon_i$ is independently and identically distributed (IID) across utilities, with a type I extreme-value (Weibull) distribution. This assumption allows the estimation of a conditional logit (CL) functional specification of the utility function:

$$U_i = V_i + \varepsilon_i = \beta X_i + \varepsilon_i \quad (1)$$

The CL functional specification is the standard starting point for CM modelling, with modelling progressing to other specifications, if required. By including a monetary cost as one of the attributes used to describe the alternatives it is possible to use the CL estimation of utility to estimate the marginal rate of substitution between changes in the levels of individual attributes and changes in cost. Put simply, the CL model allows the analyst to calculate how much cost the average respondent is willing to pay in order to have an extra unit of each of the other, non-marketed attributes. These are the respondents' WTPs, or implicit prices, for changes in the levels of individual attributes (Hanley et al., 1998). Alternative specific constants (ASC) are included in $X_i$ to measure any systematic, but unobserved differences in utilities between alternatives that are not explained by the other parameters in the utility function specification.

A random parameter logit (RPL) specification of the utility function, allows for the relaxation of the IID assumption of the CL specification. It allows for heterogeneity of preferences across individuals (Hensher et al., 2005) and across alternatives (Greene & Hensher, 2007) by specifying the coefficients of the non-monetary attribute variables in the utility function as random parameters (with a pre-specified distribution) instead of fixed parameters as is the case in the CL model formulation. It can also account for correlations in unobserved factors over repeated choices by each individual (Revelt & Train, 1998).

The RPL specification is the same as the CL specification set out in equation 1 except one or more of the parameter estimates are represented as:

$$\beta_{nk} = \beta_k + \eta_k z_{nsjk} \qquad (2)$$

where $\beta_k$ is the mean marginal utility in the sampled population (estimated coefficient) for attribute k and $\eta$ is the deviation of the mean marginal utility held by respondent $n$ for attribute $k$ belonging to alternative $j$ in choice set $s$. $z_{nsjk}$ represents some underlying distribution such as normal, triangular or lognormal distributions (Rose & Hensher, 2010).

Both the CL and RPL models are estimated using simulated maximum likelihood methods (McFadden & Train, 2000).

In addition to the initial CL models, RPL models that allow for heterogeneity of preferences across individuals including a latent error component term to account for heterogeneity across alternatives and a panel data specification are reported in this study. The RPL form of model allows for greater flexibility in the underlying assumptions of preferences and so is not limited by the specifics of the preferences under investigation.

Whichever modelling approach is used, the validity of a statistical model can be assessed by examining:

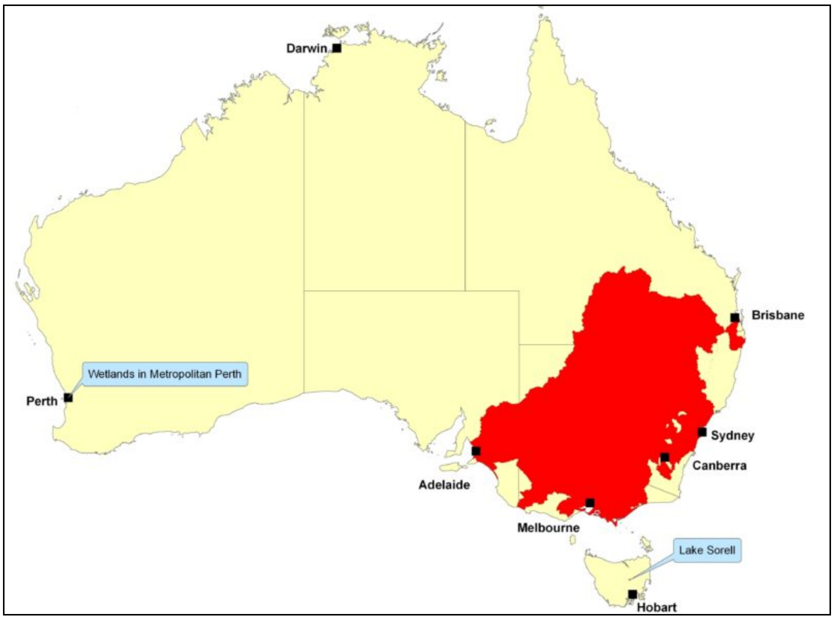
- the statistical significance of the coefficients for the attributes and socio-demographic variables;
- that the coefficients of attributes and socio-demographic variables have the sign predicted by theory. The sign of the coefficients gives the direction of the relationship between the attribute or variable and the wellbeing of the respondent;
- the statistical significance of the model through a comparison of the log likelihood function of the model to that of the base model - a log likelihood ratio (LLR) test. If the LLR test statistic exceeds the critical Chi-squared value with degrees of freedom equal to the difference in the number of parameters estimated for the two models then the model is considered statistically superior to the base model (Hensher et al. 2005); and
- the statistical power of the model in predicting respondents choices as indicated by the McFaddens pseudo R-squared: values of 0.15 to 0.4 are considered to be of acceptable statistical power (Hensher et al. 2005).

# 3. Carp and The National Carp Control Plan[6]

## Introduction

Carp are a freshwater fish that live in rivers, wetlands and lakes. They were introduced to Australia from Europe in the mid-1800s but only became well established in Australia in the early 1960s when a new type of Carp was imported for fish farming. These Carp were stocked in reservoirs and farm dams and soon spread along the Murray and Darling Rivers, assisted by widespread flooding in the mid-1970s and early 1990s. Most Carp live in the rivers and wetlands of the MDB (see Figure 4).

Figure 4: Location of Carp in Australia




Carp have become a dominant pest in Australia. This is because Carp eat almost anything, grow quickly, produce millions of eggs and do well in a wide variety of Australian conditions.

They also initially spread through the MDB at a time when native fish numbers were significantly reduced due to a range of factors including commercial fishing, clearing of habitat and construction of dams and other barriers that prevented fish migration for breeding.

Environmental impacts of Carp include:

- competing with native fish for food and space, smothering native fish eggs with sediment and eating native fish, eggs and larvae;
- reducing water quality in rivers and lakes by stirring up silt and mud during feeding, as well as releasing nutrients trapped in the silt and mud;
- degrading wetlands by uprooting and eating aquatic vegetation; and
- eating the food of native waterbirds i.e. aquatic vegetation, yabbies, worms, insects.

For more information see: http://www.Carp.gov.au/The-Carp-Problem

[6] The information presented in this section serves as background to the context of the Carp Virus case. It was, in the main, also used in the CM questionnaire to inform respondents of the issue at hand.

There is some recreational fishing for Carp in Australia, however very few Carp that are caught by recreational fishers are eaten because of their 'muddy' taste and bones. There is also some commercial fishing of wild Carp in Australia. The caught fish are either exported to Asia and Europe for eating, or used in Australia for rock lobster bait, pet food or fertilizer.

## Carp Control

A number of ways of controlling Carp numbers have been tried in the past: commercial Carp fishing for eating, bait, fertiliser and fish food, and manual removal via trapping. However, these have been unable to control Carp numbers, except in localised areas.

Research has also been done into ways to alter Carp genetically to produce offspring of a single sex. However, because Carp have a lifespan of 35 years it would take more than a century using this approach alone to reduce the population significantly.

The Commonwealth Government is considering the introduction into Australia of a virus that kills Carp. The Carp Virus (CyHV-3) occurs in over 33 countries. It has not yet been found in Australian waterways. It was first observed to occur naturally in the environment and kill large numbers of Carp in 1997 in Germany, and then in Israel and the USA in 1998.

The Carp Virus is contagious for Carp and is mostly transferred through Carp-to-Carp contact. Carp may also become infected by the virus simply by swimming in the same waterbody as fish that are already infected (this is being investigated under another NCCP research project). Once infected, most Carp die within 3 to 4 days. The virus typically survives in water without a host for around 3 days.

A literature review focused on the interactions of humans with the virus, conducted under the NCCP, concluded that humans are not affected by the virus. Research conducted by the Commonwealth Science and Industrial Research Organisation (CSIRO) indicated that the virus is species-specific. A further review is being undertaken by the NCCP to establish best practice in non-target species (NTS) testing, and to make recommendations regarding future NTS testing for Australian fishes.

The virus has a very large, double-stranded DNA, making it particularly stable among viruses, and has a low risk of undergoing genetic changes that would make it an increased risk to Australian native species. However, the virus has never been used to control Carp populations in freshwater waterways.

For more information see: http://www.Carp.gov.au/FAQ/Fact-sheet

## Impacts of Releasing the Carp Virus

The impacts of releasing the Carp Virus in Australia are not known with certainty. As part of the NCCP, a number of studies have been commissioned to investigate the potential spread of the virus, its impacts on the Carp population and the changes that reduced Carp numbers would have on the Australian environment.

The projected impacts on the environment are of specific importance to the CM study because these impacts are what are important to the well-being of the Australian community. They are the sources of benefits and hence are the attributes that can be used to describe the outcomes of alternative Carp reduction strategies in a choice set. Hence, for the CM study, information on what aspects of the environment will be affected by the Carp Virus release (the attributes) and the extent of the changes that are likely (the levels of the attributes) is of critical importance.

The research team commissioned by FRDC to predict the type and extent of environmental changes caused by reduced Carp numbers employed a Delphi approach to this task. The Delphi approach is used in contexts where information regarding future outcomes is lacking and where judgement rather than statistical inference is more appropriate to the task of prediction. In this application, experts in freshwater ecology from around Australia were contacted to provide their best estimates of likely impacts. The results of that survey were collated and presented back to the experts so that they could re-assess their initial judgements. Workshops were held so that the panel of experts could debate the merits of the judgements made, and a final set of predictions drawn[7].

To broadly summarise the findings of the expert elicitation exercise, with fewer Carp in freshwater rivers, lakes and wetlands, there would be more native fish, more healthy wetlands and more native waterbirds. These potential environmental outcomes were used as the non-market environmental attributes for the CM study. In addition, the ecology research team provided metrics that are appropriate to the measurement of these attributes. These were chosen on the basis of ease of understanding for the lay public and ability to refer to the established literature to determine the levels these attributes currently take. For native fish, the metric chosen was the number of native fish per kilometre (km) of river, for wetlands it was area free of Carp, and for water birds, total number was used.

Importantly, the freshwater ecology research team concluded that there was significant uncertainty surrounding the predictions made. The levels of the three environmental attributes in ten years' time that were predicted by the team under three different scenarios – the 'do nothing' counterfactual case, the worst case if the Carp Virus was released and the best case if the Carp Virus was released – were therefore given as ranges with associated 'levels of confidence'. The 'level of confidence' is the probability that the prediction will come to be. This probability was used as a fourth attribute in the choice sets, reflecting the observation that people hold preferences not only for outcomes but also the chance that those outcomes will occur.

It was also noted that a temporary and short-term impact of the Carp Virus release is likely to be that dead Carp would be found in waterways when and where the Virus is released. A carcass management plan is being developed to manage dead Carp in a way that will minimise impacts on water quality, people, livestock and native species. This will be detailed in the NCCP Operations Management Plan.

Because of the short-term nature of the negative fish kill impacts and the potential remediation provided by the methods of management, these impacts were not included as attributes in the CM study.

[7] For more details regarding the results of the Delphi study, see Nichols SJ, Gawne B, Richards R, Lintermans M, and Thompson R (2018). "NCCP: The likely medium- to long-term ecological outcomes of major carp population reductions". Progress Report. Prepared by the Institute for Applied Ecology, University of Canberra for FRDC, ACT and a subsequent briefing paper from the same group of freshwater ecology experts entitled "Choice modelling and the ecological effects of carp reductions: attributes and levels"

# 4. Questionnaire Design and Implementation

## Questionnaire Design

The CM questionnaire was designed using an iterative process involving the freshwater ecology team and representatives of the FRDC to establish the attributes and the range of levels to be used in the choice sets. A draft questionnaire was then tested in two focus groups conducted in Sydney, a pilot on-line survey of 100 respondents, two further Sydney focus groups and finally another pilot survey involving a further 100 respondents. Refinements to the questionnaire were made throughout the testing process.

The attributes and their metrics used to describe the potential alternatives arising from the release of the virus were developed with advice from the freshwater ecology research team and FRDC. The potential levels taken by these attributes in 10 years' time "with" and "without" Virus release strategies were also predicted to inform the change and counterfactual alternatives. A 10-year time frame was used because a programme of virus release would take a number of years to implement and the environmental outcomes arising from the programme would also take time to eventuate. As outlined in the previous section, the probabilities associated with outcomes were also predicted so that respondents could choose between different potential environmental outcomes with differing likelihoods of occurrence.

The 'frame' or context developed for the questionnaire was the introduction of virus release strategies to reduce the impact of Carp on freshwater inland rivers. These virus release strategies were explained to involve different locations, timings and methods of release. So that a full range of possible outcomes would be considered plausible by respondents, other water management actions, such as changing the amount and timing of water released from dams into rivers and protecting riverbanks from stock grazing, and clean-up of dead Carp were also introduced as being part of the Carp control process.

The CM method requires one attribute in the choice sets to be a monetary impact so as to establish the trade-off respondents are willing to make between a monetary cost and an environmental benefit. The cost attribute defined for the CM questionnaire was an EXTRA payment to be made by all Australian households in the form of an environmental levy collected via Council rates to be used to fund the Carp control programme. For respondents who rent their residence and hence do not pay rates directly, it was proposed in the questionnaire that the so-increased Council rates would be completely passed onto renters by their landlords. The time-frame for payments was annually for 10 years.

A strong finding in the CM literature is that for results to be accurate reflection of respondents' true values, they must consider the questionnaire to be 'consequential' (Johnston et al., 2018). Put simply, that means respondents need to take the survey seriously and believe that the answers they give will have consequences for them both in terms of the environmental outcomes to be received and the cost to be paid. A key element of that consequentiality requirement is that the questionnaire provides respondents with a rule regarding how their answers will affect the decision that is to be made. This is known as a 'provision rule'. Most importantly, the cost attribute must involve compulsory payment across the whole of the community if the provision rule is satisfied. These measures ensure that the questionnaire is 'incentive compatible'. In other words, the questionnaire provides respondents with an incentive to answer the questions honestly and not to try and 'game the system' by falsely representing their preferences.

To meet these requirements, the final questionnaire included a consequentiality statement and a provision rule as follows:

*The results from this survey will be used by the Australian Government to decide if the Carp Virus should be released, and if so, how it should be released.*

*A virus release strategy will only be implemented if more than 50% of households in Australia are willing to pay for it. If implemented, a levy based on the most popular option, would be compulsory for all households.*

The attributes, metrics and levels used in the questionnaire are set out in Table 2.

Table 2: Attributes, metrics and levels

| **Attribute** | **Metrics** | **Current level** | **Levels in 10 years' time*** |
|---|---|---|---|
| Cost to your household every year for 10 years | Dollars | NA | $0, $20, $50, $100, $200 |
| Native fish per kilometre of river | Number | 75 | 0,+20, +40, +55 |
| Area of wetland free of Carp | 100,000 Hectares | 0 | 0,+5, +15, +25 |
| Number of waterbirds | 1,000 Number | 80 | 0, +20, +40, +60 |
| Chance that options will deliver the outcomes | Percent | NA | 100%, 20%, 50%, 80% |

* The first level is the additional amount of the attributes in 10 years' time under the 'do nothing' counterfactual scenario. The other levels are the changes to the attribute levels under the Virus release strategies.

An initial orthogonal experimental design was used to assign levels to the five attributes across 24 choice sets[8]. It was judged that a respondent would not be able to cope with a questionnaire including 24 choice sets so the experimental design was 'blocked' into four groups of six choice sets. Hence, each respondent was asked six choice sets and so it takes four respondents to cover the full experimental design.

'Prior' estimates of the coefficients of the attribute variables in the CM were estimated using the choice data collected in the initial pilot test of the questionnaire. These priors were used to develop a Bayesian S-efficient experimental design (Scarpa & Rose, 2008) that was used in the subsequent pilot test and the main survey. This approach increases the statistical efficiency of the data collection exercise.

Each choice set used in the questionnaire comprised three alternative Carp virus release options:

- option 1 – no virus release. This option (the status quo or counterfactual option) would result in no additional native fish, wetlands free of Carp or waterbird numbers in 10 years' time, with 100% probability.
- option 2 and option 3 – virus release options. These options would result in additional native fish, wetlands free of Carp and waterbird numbers in 10 years' time, with differing levels of probability.

[8] The NGene software programme was used to develop the experimental designs.

An example choice set is provided in Figure 5

Figure 5: Choice Set Example

Consider each of the following three Options (A, B and C) to release the Carp Virus and control European Carp in Australian freshwater rivers. Suppose Options A, B, and C in the table below are the ONLY ones available. Which one would you choose?

| | **Cost to YOUR household every year for 10 years** **$** | **Native fish per kilometre of river (number)**  | **Area of wetlands free of Carp (hectares)**  | **Waterbirds (number)**  | **Chance that options will deliver the outcomes (percent)** **%** | **Your choice** Tick ONE |
|---|---|---|---|---|---|---|
| **Current Level** | | **75 fish per km** | **0 ha** | **80,000 birds** | | |
| | | | **OUTCOMES (in 10 years)** | | | |
| **Option A (NO virus release)** | **+ $0 per year** | **+ 0 fish per km** | **+ 0 ha** | **+ 0 birds** | **100%** | ☐ |
| **Option B (WITH virus release)** | **+ $50 per year** | **+ 55 fish per km** | **+ 500,000 ha** | **+ 40,000 birds** | **80%** | ☐ |
| **Option C (WITH virus release)** | **+ $100 per year** | **+ 20 fish per km** | **+ 2,500,000 ha** | **+ 60,000 birds** | **50%** | ☐ |

The inclusion of the probability attribute (the chance that options will deliver the outcomes) meant that the models developed from the choice data can be specified in terms of respondents' expected utility. Put simply, the CMs specify that respondents choose between alternatives in terms of the maximum expected value they can enjoy from the alternatives. The expected value of an outcome is defined by the outcome multiplied by its probability of occurring. For instance, if an alternative is producing 55 extra fish per km and the probability of that occurring is 80% then the expected value is 55 x 0.8. Specification of the CM in this way means that respondents' preferences for risk as well as environmental outcomes are incorporated into the valuation process. Not only do different people have different values for example, native fish population restoration, but some are risk averse while others like taking risks.

Follow-up questions included in the questionnaire after respondents had answered the choice sets were designed to detect problems that respondents may have experienced in answering the questionnaire. These included checks to detect protest responses where respondents failed to answer the choice sets accurately because they objected to the process of choosing between alternative outcomes that included a financial payment. Respondents were also asked questions regarding the adequacy and bias of the information provided, whether or not they believed that their answering the survey would have consequences for themselves and for Carp management, and the difficulty of answering the choice questions. The final section of the questionnaire sought socio-economic data that was additional to that asked in the initial sample screening questions that allowed for the stratification of the sample according to gender, age and location.

## Focus Groups

A draft questionnaire was initially tested in four focus groups of 8 to 10 attendees divided equally between gender and across 10-year age brackets (20-29, 30-39, 40-49, 50-59 and 60+) that were held in Parramatta on:

- 16 October 2018 - 4:00pm to 6:00pm;
- 16 October 2018 - 6:30pm to 8:30pm;
- 17 October 2018 - 4:00pm to 6:00pm; and,
- 17 October 2018 - 6:30pm to 8:30pm.

The focus groups involved an initial open discussion to establish the level of familiarity with the Carp issue held by attendees followed by the attendees completing the draft questionnaire. The focus groups then centred discussions around the questionnaire content and style. The key issues arising from the focus groups included the need for:

- more information on:
    - potential negative impacts;
    - the virus;
    - the clean-up of dead Carp;
    - the seriousness of the problem;
    - how Carp were introduced;
    - that the payment would not be voluntary (i.e. a provision rule);
    - the likelihood of outcomes and why these are different between options;
- reassurance that the virus will not impact other species;
- improved clarity of photos;

- placing issue in context of other environmental issues.

The questionnaire was revised to add more information. In addition, the choice sets were changed from containing absolute levels of the attributes to the change levels for each attributed under different options. For example, instead of an alternative showing 120,000 birds as its level, the revised version showed +40,000 birds. This arose because of difficulties focus groups attendees had understanding that the alternatives other than Option 1 were providing improvements in the environmental attributes. This approach also made it clear that Option 1, with levels set at zero, provided no improvement.

Follow-up focus groups of 8-10 people, to test this revised questionnaire, were held in Parramatta on:

- 14 November 2018 - 4:00pm to 6:00pm; and,
- 14 November 2018 - 6:30pm to 8:30pm.

Again, attendees at all focus groups were divided equally between gender and age.

The key issues arising from these focus groups centred around the complexity and amount of information provided.

Likert scale data gathered from focus group attendees' responses to a number of key follow up questions in the two versions of questionnaire are provided in Table 3.

Table 3: Focus Group Feedback on Questionnaire

| | Strongly Agree | Agree | Neither agree or disagree | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| a. I was aware about the impact of European Carp on Australian freshwater waterways before answering this questionnaire (3.5, 3.7) | 1 | 2 | 3 | 4 | 5 |
| b. I understood all the information provided (2.0, 2.3) | 1 | 2 | 3 | 4 | 5 |
| c. I think the information provided was sufficient (2.5, 2.7) | 1 | 2 | 3 | 4 | 5 |
| d. I understood the description of the alternative virus release options (2.4, 3.0) | 1 | 2 | 3 | 4 | 5 |
| e. I understood the concept of making choices between alternative virus release options (2.1, 2.8) | 1 | 2 | 3 | 4 | 5 |
| f. I believe that the survey results will be taken into consideration by the Australian Government (2.7, 2.9) | 1 | 2 | 3 | 4 | 5 |
| g. I believe that the results of the survey will affect decisions made about virus release options (2.7, 2.7) | 1 | 2 | 3 | 4 | 5 |

Note: Strongly agree=1, Agree=2, Neither agree or disagree=3, Disagree=4 and Strongly disagree=5,

● = First set of focus group responses: Initial version of the questionnaire

◍ = Second set of focus group responses: Revised version of the questionnaire

In response to the second set of focus groups, the questionnaire was further revised to simplify the language and the complexity of the text while attempting to maintain the level of information provided, as required by the first set of focus group attendees. An online pilot of 100 responses was then conducted as a final test of the questionnaire.

Data from the first set of focus groups produced CMs that showed respondents were considering wetland improvements to be harmful when making their choices between alternatives: the coefficient on the expected wetland (wetland x probability) variable was negative, indicating that more wetlands meant less well-being. This finding led to some minor changes to the wording used for the wetland attribute in the Choice Sets (and associated text) that were aimed at ensuring that respondents would understand the wetland attribute. The definition of the wetland attribute was changed from 'Area of Wetland Free of Carp' to 'Area of Healthy Wetland'.

## Questionnaire Implementation

The questionnaire was administered between 30 November 2018 and 3 January 2019 by PureProfile using a web-based survey, with two samples drawn from an existing panel of pre-stratified and registered respondents. The two samples were:

- Murray-Darling Basin (MDB) Sample - households with postcodes located within the MDB;
- Rest of Nation Sample - households across Australia excluding those in the MDB.

The drawing of the two samples allowed for the detection of differences in Carp control preferences between the populations of the MDB and the rest of Australia. However, for the purposes of estimating benefits for the national CBA of the Carp Virus release, the MDB and Rest of Nation samples were combined and are hereafter referred to as the National Sample.

# 5. Results

## Responses and Respondent Characteristics

3,195 completed questionnaires were received: 2,985 from the Rest of Nation Sample and 210 from the MDB Sample. These were distributed across the questionnaire blocks as indicated in Table 4.

Table 4: Questionnaire Responses

| Questionnaire | Rest of Nation Sample | MDB Sample |
|---|---|---|
| **Block 1** | 745 | 56 |
| **Block 2** | 738 | 57 |
| **Block 3** | 758 | 43 |
| **Block 4** | 744 | 54 |
| **Total** | 2,985 | 210 |

The sample composition by State/Territory, gender and age is summarised in Table 5.

Table 5: Sampling by State/Territory, Gender and Age

| | **NSW** | | **VIC** | | **QLD** | | **SA** | | **WA** | | **TAS** | | **ACT** | | **NT** | | **Total Rest of Nation Sample** | | **MDB Sample** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | | | | | | | | | | | | | | | | | | | | |
| **Female** | 481 | 51.90% | 372 | 49.30% | 320 | 50.90% | 117 | 49.40% | 181 | 56.90% | 41 | 57.70% | 12 | 54.50% | 14 | 51.90% | 1538 | 51.50% | 89 | 42.38% |
| **Male** | 445 | 48.00% | 381 | 50.50% | 309 | 49.10% | 120 | 50.60% | 137 | 43.10% | 30 | 42.30% | 10 | 45.50% | 13 | 48.10% | 1445 | 48.40% | 121 | 57.62% |
| **Other** | 1 | 0.10% | 1 | 0.10% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 2 | 0.10% | 0 | 0.00% |
| **Total** | 927 | 100.00% | 754 | 100.00% | 629 | 100.00% | 237 | 100.00% | 318 | 100.00% | 71 | 100.00% | 22 | 100.00% | 27 | 100.00% | 2985 | 100.00% | 210 | 100.00% |
| Age | | | | | | | | | | | | | | | | | | | | |
| **Under 18** | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% |
| **18 – 24** | 96 | 10.40% | 69 | 9.20% | 62 | 9.90% | 19 | 8.00% | 31 | 9.70% | 7 | 9.90% | 2 | 9.10% | 2 | 7.40% | 288 | 9.60% | 25 | 11.90% |
| **25 – 29** | 82 | 8.80% | 48 | 6.40% | 41 | 6.50% | 14 | 5.90% | 32 | 10.10% | 4 | 5.60% | 3 | 13.60% | 2 | 7.40% | 226 | 7.60% | 38 | 18.10% |
| **30 – 39** | 207 | 22.30% | 178 | 23.60% | 87 | 13.80% | 41 | 17.30% | 71 | 22.30% | 13 | 18.30% | 7 | 31.80% | 8 | 29.60% | 612 | 20.50% | 43 | 20.48% |
| **40 – 49** | 136 | 14.70% | 123 | 16.30% | 121 | 19.20% | 52 | 21.90% | 56 | 17.60% | 13 | 18.30% | 3 | 13.60% | 3 | 11.10% | 507 | 17.00% | 38 | 18.10% |
| **50 – 59** | 136 | 14.70% | 129 | 17.10% | 118 | 18.80% | 46 | 19.40% | 39 | 12.30% | 15 | 21.10% | 2 | 9.10% | 7 | 25.90% | 492 | 16.50% | 29 | 13.81% |
| **60 – 64** | 85 | 9.20% | 56 | 7.40% | 63 | 10.00% | 20 | 8.40% | 20 | 6.30% | 4 | 5.60% | 3 | 13.60% | 2 | 7.40% | 253 | 8.50% | 37 | 17.62% |
| **65-69** | 74 | 8.00% | 57 | 7.60% | 48 | 7.60% | 21 | 8.90% | 24 | 7.50% | 7 | 9.90% | 0 | 0.00% | 2 | 7.40% | 233 | 7.80% | 25 | 11.90% |
| **70+** | 111 | 12.00% | 94 | 12.50% | 89 | 14.10% | 24 | 10.10% | 45 | 14.20% | 8 | 11.30% | 2 | 9.10% | 1 | 3.70% | 374 | 12.50% | 38 | 18.10% |
| **Total** | 927 | 100.00% | 754 | 100.00% | 629 | 100.00% | 237 | 100.00% | 318 | 100.00% | 71 | 100.00% | 22 | 100.00% | 27 | 100.00% | 2985 | 100.00% | 210 | 100.00% |

Table 6: Samples and National Population Characteristics

| | Questionnaire | Rest of Nation Sample | MDB Sample | National ABS |
|---|---|---|---|---|
| Gender | Female % | 51% | 58% | 51% |
| Age | Min age | 18 | 19 | |
| | Max age | 99 | 77 | |
| | Ave age 18+ | 48 | 45 | 47 |
| Household (HH) | Adults | 2.1 | 2.0 | |
| | Children | 0.6 | 0.6 | |
| | HH size | 2.7 | 2.6 | 2.6 |
| Aboriginal or Torres Strait Islander | % Aboriginal | 2.6% | 5.7% | 2.8% |
| Language | % Speak Another Language | 9.6% | 3.3% | 14.3% |
| School Education | No school | 0% | 0% | 1% |
| | yr 8 | 1% | 0% | 5% |
| | yr 9 | 3% | 2% | 5% |
| | yr 10 | 12% | 15% | 21% |
| | yr 11 | 7% | 9% | 9% |
| | yr 12 | 76% | 74% | 59% |
| Non-School Qualification | No qualification | 18% | 18% | 42% |
| | Certificate | 23% | 31% | 22% |
| | Advanced diploma and diploma | 15% | 16% | 10% |
| | Bachelor degree | 23% | 19% | 18% |
| | Graduate diploma and graduate certificate | 7% | 7% | 2% |
| | Postgraduate degree | 11% | 10% | 6% |
| Household Annual Income | Nil or negative income | 1% | 0% | 2% |
| | $1 - $7,799 | 1% | 2% | 1% |
| | $7,800 – $15,599 | 1% | 1% | 2% |
| | $15,600 – $20,799 | 3% | 2% | 3% |
| | $20,800 – $25,999 | 5% | 8% | 7% |
| | $26,000 – $33,799 | 6% | 3% | 5% |
| | $33,800 – $41,599 | 6% | 3% | 8% |
| | $41,600 – $51,999 | 7% | 10% | 7% |
| | $52,000 – $64,999 | 7% | 11% | 9% |
| | $65,000 – $77,999 | 6% | 9% | 8% |
| | $78,000 – $90,999 | 7% | 6% | 7% |
| | $91,000– $103,999 | 6% | 7% | 6% |
| | $104,000– $129,999 | 9% | 7% | 12% |
| | $130,000– $155,999 | 8% | 5% | 7% |
| | $156,000– $181,999 | 4% | 5% | 5% |
| | $182,000 – $207,999 | 3% | 4% | 4% |
| | $208,000 or more | 4% | 4% | 8% |
| | Not Stated | 15% | 13% | |
| | Average HH Income | $86,410 | $84,914 | |
| | Median HH Income | $84,500 | $71,500 | $74,776 |
| Carp | % who themselves or member of close | 2.6% | 2.4% | |

| | | | | |
|---|---|---|---|---|
| | family is involved with Carp impact assessment or control | | | |
| | % who themselves or a member of your close family, fish in waterways containing European Carp | 17.2% | 37.1% | |
| Not Willing to Pay | % respondents who chose Option A in all choice questions | 18% | 15% | |
| | *Main reasons for choice* | | | |
| | I do not care about the impact of European Carp on Australian freshwater rivers | 11% | 0% | |
| | I do not have any spare money to pay for more European Carp control strategies | 46% | 32% | |
| | I do not think that I should be the one paying for it | 46% | 22% | |
| | I found making a choice too confusing, so I always ticked the first box | 7% | 5% | |
| | I would need to know more about the virus release strategies | 20% | 22% | |
| | Some other reason | 15% | 20% | |

The Rest of Nation Sample was stratified for gender and age and hence these sample characteristics are in accord with the Rest of Nation population. Sample household size and percent of Aboriginal and Torres Strait Islanders were also similar to the National population. However, the percent speaking another language at home was lower than the population, while the level of school education, post school education and median household income were higher than the population.

The target MDB sample size proved difficult to achieve because of the limitations of the on-line survey panel coverage. Hence, the sample was based on a natural fallout of demographics rather than a stratified selection. Consequently, the sample is not representative of the MDB population in terms of gender and age. Compared to the National population, the MDB Sample had a greater proportion of females and had higher levels of Aboriginal and Torres Strait Islanders, people who only speak English at home, year 12 graduates, people with postgraduate degrees but lower median household incomes.

## Biases and Protests

A Likert scale analysis was used to test for any problems that respondents may have had in answering the questionnaire, specifically in relation to the adequacy of, and bias in, the information provided, the level of the payment, and the difficulty of the choice questions.

Table 7 summarises the mean Likert scale response to a sequence of test statements. On average, respondents understood the information provided, thought the information was sufficient, understood the description of the choice alternatives, understood the concept of making choices, believed that the survey results would be taken into account by the Australian Government, and believed that the results of the survey will affect decisions about the virus release. The main difference between the MDB sample and the Rest of National sample was that the MDB sample were more aware of the impact of Carp on Australian freshwater waterways.

These results give confidence in the ability of the questionnaire design to produce valid and accurate responses. In particular, respondent belief in the consequentiality of the survey enhances the validity and reliability of stated preference value estimates (Johnston, et al., 2017). Previous research has indicated that respondents to dichotomous (yes/no) choice WTP questions who indicate that they believe the survey to be consequential provide answers to hypothetical WTP questions that are equal to their actual WTP (Vossler & Evans, 2009; Vossler, Doyon, & Rondeau, 2012).

Table 7: Respondent Feedback on Questionnaire

| | | Strongly Agree | Agree | Neither agree or disagree | Disagree | Strongly Disagree |
|---|---|---|---|---|---|---|
| h. | I was aware about the impact of European Carp on Australian freshwater waterways before answering this questionnaire (2.3, 3.0) | 1 | 2 | 3 | 4 | 5 |
| i. | I understood all the information provided (1.8, 2.0) | 1 | 2 | 3 | 4 | 5 |
| j. | I think the information provided was sufficient (2.0, 2.1) | 1 | 2 | 3 | 4 | 5 |
| k. | I understood the description of the alternative virus release options (2.0, 2.1) | 1 | 2 | 3 | 4 | 5 |
| l. | I understood the concept of making choices between alternative virus release options (1.9, 2.1) | 1 | 2 | 3 | 4 | 5 |
| m. | I believe that the survey results will be taken into consideration by the Australian Government (2.5, 2.6) | 1 | 2 | 3 | 4 | 5 |
| n. | I believe that the results of the survey will affect decisions made about virus release options (2.5, 2.6) | 1 | 2 | 3 | 4 | 5 |

Note: Strongly agree=1, Agree=2, Neither agree or disagree=3, Disagree=4 and Strongly disagree=5,

● = Rest of Nation Sample

◍ = MDB Sample

## Data Analysis

### *Introduction*

Models for each of the samples were estimated using NLOGIT 4.0 (Econometric Software, 2007). However, the focus of this report is on the combined National Sample because it is these results that are most relevant to a national CBA of Carp Virus release policy options[9].

The variables used in the CMs are shown in Table 8 and include the attributes used to describe outcomes across inland freshwater waterways, an ASC to account for systematic unobserved components that influence respondent's choices, and socio-demographic variables. Socio-demographic variables were introduced into all models as interactions with the ASC.

Table 8: Variables Considered in Models

| **Variable code** | **Description** |
|---|---|
| ASC | Alternative Specific Constant (1 = alternative) |
| Cost | Cost of choice alternative ($ pa for 10 years) |
| Fishp | Per 100% probability of an additional native fish per km of waterway in 10 years' time |
| Wetlp | Per 100% probability of an additional 100,000ha of wetlands free of Carp in 10 years' time |
| Birdp | Per 100% probability of an additional 10,000 waterbirds in 10 years' time |
| Age | Age as continuous variable |
| Gender | Respondent gender (1 = male, 0=female, -1=other) |
| Carp | Respondent or close family member works in Carp impact assessment or control (1=yes) |
| Fisher | Respondent or close family fish in waterways containing Carp (1= yes) |
| Adult | Number of adults living in the respondent's household |
| Child | Number of children living in the respondent's household |
| Famsz | Number of adults and children living in the respondent's household |
| Lang | Another language other than English spoken at home (1=yes) |
| PostS1 | Post-secondary school qualification (1=yes for any qualification) |
| PostS2 | Post-secondary school qualification (1=yes for diploma or above (certificate not included)) |
| SchEd | School education (1=year 12 or equivalent) |
| Inc | Annual household income |
| IncDum | Income not stated (1= not stated) |
| Ab | Aboriginal or Torres St Islander (1=yes, 0=no, -1=prefer not to say) |

The expected value for each environmental attribute (fish, wetland, and bird) was calculated by multiplying the level of the environmental attribute by the probability (expressed as a decimal) of it occurring. It is the expected outcome level for each attribute - *Fishp, Wetlp* and *Birdp* - that was included in the models. Hence, the maximum expected outcomes for each attribute were:

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[9] It should be noted that, while there were some observed differences between the MDB Sample and the Rest of Nation Sample with regard to preferences, combining the MDB Sample with the Rest of Nation Sample did not significantly change the Rest of Nation Sample results. A dummy variable for the MDB Sample responses included as a factor influencing choice in the National Sample model was insignificant. This indicates that the modelled explanation of choice was not impacted by the location of respondents in the MDB or elsewhere. Furthermore, estimates of attribute implicit prices did not change significantly between the Rest of Nation model and the National model.

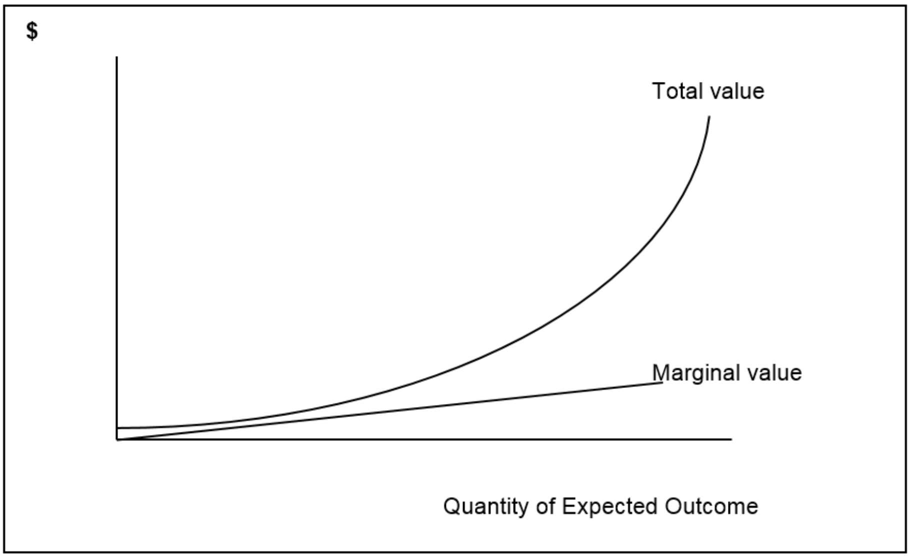
- 44 fish per additional fish per km of a waterway i.e. 0.8 times 55 fish;
- 20 units (100,000ha) of wetland free of Carp i.e. 0.8 times 25 units of wetlands;
- 48 units (1,000 number) of additional waterbirds i.e. 0.8 times 60 units of waterbirds.

### *Conditional Logit Results*

Initial analysis of the samples used CL regression analysis (as outlined in Section 2 above) to model the choices made by respondents. The modelling sequence started with attribute only models and then attribute and socio-demographic variables. Insignificant socio-demographic variables were omitted from the final models.

Initial models were estimated based on expected utility being a linear function of all attributes. However, this resulted in a significant and negative coefficient for the *Wetlp* attribute suggesting that respondent expected utility declined with an increase in the expected area of wetlands free of Carp[10], noting that this decline was the result of a combination of changes in either or both of the area of wetlands and the probability of occurrence. Based on focus group feedback that respondents focused on outcomes with a higher probability of occurring, consideration was given to a nonlinear transformation of the expected outcome attributes. The null hypothesis based on focus group feedback was that respondents would be less likely to choose options with lower levels of expected environmental outcomes and hence would have a lower WTP for these expected environmental outcomes than those occurring with greater certainty. This implies an exponential (i.e. non-linear) transformation of expected outcome attributes. Refer to Figure 6. Various non-linear, exponential transformations were tested.

Figure 6: Exponential Transformation of the Expected Outcome Attributes




The preferred linear and nonlinear CL models for the National Sample are provided in Table 9.

[10] This result was consistent with the findings from the first set of focus groups.

Table 9: Preferred National Sample Conditional Logit Models

| | Linear Attributes | | | Nonlinear Attributes | |
|---|---|---|---|---|---|
| **Variable** | **Coefficients** | **P-value** | **Variable** | **Coefficients** | **P-value** |
| Cost | -0.00542*** | 0.0000 | Cost | -0.00728*** | 0.0000 |
| Fishp | 0.02794*** | 0.0000 | Fishp^3 | 0.89183D-05*** | 0.0000 |
| Wetlp | -0.00940*** | 0.0006 | Wetlp^3 | 0.20048D-04*** | 0.0012 |
| Birdp | 0.01005*** | 0.0000 | Birdp^3 | 0.19887D-05*** | 0.0005 |
| ASC | -0.81164*** | 0.0000 | ASC | -0.19238*** | 0.0089 |
| | | | | | |
| Child | -0.09675*** | 0.0000 | Child | -0.09642*** | 0.0000 |
| Lang | -0.32953*** | 0.0000 | Lang | -0.33096*** | 0.0000 |
| PostS2 | 0.14732*** | 0.0000 | Posts2 | 0.15180*** | 0.0000 |
| Inc | 0.29785D-05*** | 0.0000 | Inc | 0.29566D-05*** | 0.0000 |
| Incdum | -0.27824*** | 0.0000 | Incdum | -0.28417*** | 0.0000 |
| Age | 0.00526*** | 0.0000 | Age | 0.00531*** | 0.0000 |
| Carp | -0.33573*** | 0.0010 | Carp | -0.33795*** | 0.0010 |
| Fisher | 0.40430*** | 0.0000 | Fisher | 0.40711*** | 0.0000 |
| | | | | | |
| AIC | 37858 | | AIC | 38214 | |
| Pseudo R2 | 0.10 | | Pseudo R2 | 0.09 | |
| Log likelihood | -18916 | | Log likelihood | -19094 | |
| Log likelihood base model | -20970 | | Log likelihood base model | -20970 | |
| LLR | 4128 | | LLR | 3752 | |
| Chi2 | 21.03 (12DF) | | Chi2 | 21.03 (12DF) | |

Significance levels: *p = 0.1, **p = 0.05, ***p = 0.01;

Both the linear and nonlinear CL models for the National Sample, reported in Table 9, are statistically significant, as indicated by a significant log-likelihood ratio (LLR) (relative to the base model) for each model greater than the relevant Chi-squared statistic[11].

The attribute coefficients for *Cost*, *Fishp*, *Wetlp* and *Birdp* are all significant at the 1% level in both models.

These coefficients indicate the impact of each attribute on respondents' choices and hence their utility. For example, the expected fish variable (fish x probability) coefficient is positive. This means that respondents were more likely to choose alternatives in the choice sets that had increasing levels of expected fish. The expected wetlands and expected birds variables follow the same pattern. In contrast, respondents were less likely to choose alternatives with higher levels of cost and so the cost variable coefficient has a negative sign. These results conform to *a priori* expectations founded on theory.

However, the expected wetlands variable (wetland x probability) in the linear model does not have the expected sign. The negative coefficient suggests that respondent utility declines with an increase in the area of wetlands free of Carp. This is contrary to expectations as it implies that people do not value an increase in the area of wetlands free of Carp.

The ASC in the linear model is negative and highly significant, indicating that the model as specified has not been able to capture choice factors that are relevant but remain unobserved. The negative sign indicates that there is a systematic preference amongst respondents to choose the status quo option.

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[11] Chi-squared statistic with degrees of freedom equal to the difference in the number of parameters between the model and the base model.

In the nonlinear model where expected outcomes are cubed, all the expected attribute variables including *Wetlp* have coefficients that are significant at the 1% level and have the expected sign. They show an increase in respondent utility with an increase in the expected levels of fish, wetlands and birds and a decline in respondent utility with an increase in *Cost*. In the nonlinear model, the ASC remains significant and negative but the reduced level of significance, indicates that the nonlinear transformations of the attributes have accounted for some of the unexplained systematic determinants of respondent choices.

All significant socio-demographic variables (interacted with the *ASC*) included in the two models have co-efficient signs that are consistent across the models. *Child, Lang* and *Carp* coefficients are significant and negative indicating respondents with a greater number of children, who speak a language other than English at home, or are involved in Carp impact assessment or control (or have close family members that are), are less likely to support virus release strategies). Income was significant and positive indicating that respondents with higher household incomes are more likely to support virus release strategies. Older respondents, those with higher education and those who fish in waterways containing Carp (or have close family members that do), have a higher WTP for virus release strategies. The dummy variable for Income (*Incdum*), which indicates when respondents did not respond to the household income question, was negative and significant indicating that those not responding to the household income question were more likely to choose the status quo, no virus release strategy[12].

An important assumption in CL models is that the error term is IID. This assumption implies that the relative probability of choosing one alternative over another (given that both alternatives have a non-zero probability of choice) is unaffected by the introduction or removal of additional alternatives in the choice set (Louviere, Hensher, Swait, & Adamowicz, 2000). The IID assumption implies that the error terms are independent across alternatives and provides for the use of the CL model which is computationally convenient. However, the IID assumption is unlikely to hold if the preferences of respondents are heterogeneous (Louviere et al., 2000). In this situation, using a CL model can lead to biased estimators of the attribute coefficients and the implicit prices.

A Hausman specification test was used to determine whether the IID assumption holds for the CL models. It was found that the IID assumption is rejected at the 5% confidence level when removing the first or second alternative. Consequently, modelling moved on to the RPL model that allows for the relaxation of the IID assumption and accounts for preference heterogeneity.

### *Random Parameter Logit Results*

The RPL modelling followed the same process as for used for the CL modelling. The modelling sequence commenced with the estimation of an attributes only model and proceeded to the estimation of models that included attribute and socio-demographic variables. Insignificant socio-demographic variables then were omitted from the models. Both linear and nonlinear specifications for expected outcomes of attributes were used.

The *Fishp, Wetlp* and *Birdp* attributes (whether specified as linear or nonlinear) were defined as random variables with a normal distribution. Similar to many other CM studies (e.g. Hanley, Wright, & Adamowicz, 1998; Hensher and Greene, 2003; Rigby, Balcombe, & Burton, 2009), the cost attribute was specified as a fixed parameter.

The model included a common error term for the two choices associated with 'virus release strategies'. This shared error component term accounts for unobserved correlations between the errors of the 'virus release strategy' options (Scarpa, Willis, & Acutt, 2007). The model specifications

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[12] Respondents who did not answer the income question were assigned the mean value of all other respondents' incomes and a dummy variable indicating this assigned a value of 1.

further accounted for the repeated choices made by individual respondents by estimating the models in a panel data format. The models were estimated by simulated maximum likelihood using Halton draws with 1,000 replications (Train, 2003).

The preferred linear and nonlinear RPL models for the National Sample are provided in Table 10.

Table 10: Preferred National Sample RPL Models

| | **Linear** | | | **Nonlinear** | |
|---|---|---|---|---|---|
| **Variable** | **Coefficient Mean** | **P-value** | **Variable** | **Coefficient Mean** | **P-value** |
| **Random Parameters** | | | **Random Parameters** | | |
| Fishp | 0.03847*** | 0.0000 | Fishp^3 | 0.14219D-04*** | 0.0000 |
| Wetlp | -0.00767 | 0.1416 | Wetlp^3 | 0.22977D-04* | 0.0773 |
| Birdp | 0.01202*** | 0.0000 | Birdp^3 | 0.31908D-05*** | 0.0043 |
| **Fixed Parameters** | | | **Fixed Parameters** | | |
| Cost | -0.00947*** | 0.0000 | Cost | -0.01112*** | 0.0000 |
| Lang | -0.64489** | 0.0191 | Lang | -0.80775*** | 0.0044 |
| Inc | 0.71802D-05*** | 0.0000 | Inc | 0.85763D-05*** | 0.0000 |
| IncDum | -0.51210** | 0.0219 | IncDum | -0.61051*** | 0.0080 |
| Age | 0.02181*** | 0.0000 | Age | 0.02425*** | 0.0000 |
| Fisher | 0.92585*** | 0.0000 | Fisher | 0.95889*** | 0.0000 |
| ASC | -1.03578*** | 0.0022 | ASC | -0.48813 | 0.1566 |
| **Standard Deviations of Random Parameters** | | | **Standard Deviations of Random Parameters** | | |
| Fishp | 0.06057*** | 0.0000 | Fishp^3 | 0.21016D-04*** | 0.0000 |
| Wetlp | 0.09984*** | 0.0000 | Wetlp^3 | 0.00024*** | 0.0000 |
| Birdp | 0.04229*** | 0.0000 | Birdp^3 | 0.12195D-04*** | 0.0000 |
| **Standard Deviation of Latent Random Effects** | 3.67096*** | 0.0000 | **Standard Deviation of Latent Random Effects** | 3.95494*** | 0.0000 |
| | | | | | |
| **Model Statistics** | | | **Model Statistics** | | |
| McFadden Pseudo $R^{2\,a}$ | 0.31 | | McFadden Pseudo $R^{2\,a}$ | 0.30 | |
| Log likelihood | -14458 | | Log likelihood | -14737 | |
| AIC | 28,946 | | AIC | 29,502 | |
| N | 19,170 | | N | 19,170[b] | |
| No. of Halton Draws | 1000 | | No. of Halton Draws | 1000 | |

Significance levels: *p = 0.1, **p = 0.05, ***p = 0.01; [a] Compared to a constants only base model; [b] The total number of observations in the model.

In both models, the expected fish and expected bird variable coefficients are highly significant and have the *a priori* positive sign. However, as in the linear CL model, in the linear RPL model the *Wetlp* attribute coefficient is negative although not significant at the 10% level. When the expected wetland attribute variable is transformed to a nonlinear form i.e. cubed, its coefficient is positive (as expected *a priori*) and significant, although only at the 10% level. The ASC is negative and significant, indicating a systematic yet unexplained preference for 'no virus release' strategy in the linear model but not in the non-linear model.

The positive sign on these expected environmental attributes' coefficients in the non-linear RPL model indicates that the well-being of respondents increases with increased levels of these attributes in 10 years' time. The negative sign on the cost parameter indicates that respondents' welfare declines with increasing levels of payment.

The significant standard deviations on the random parameters' coefficients reflect the considerable heterogeneity in preferences towards each of the choice attributes. That is, different individuals have individual-specific parameter estimates that may be different from the sample population mean parameter estimate (Hensher et al., 2005). In some cases, this may involve respondents having values for the attributes that have different signs to those of the mean of respondents. Importantly, there is a significant improvement in the explanatory power of the RPL models compared with the CL models, with significantly lower log likelihood statistic and McFadden Pseudo R-squared statistics of around 0.30. In addition, the transformation renders the ASC insignificant in the non-linear RPL model. This shows that the model does not have any significant omitted factors determining choice. These features confirm the appropriateness of using the RPL non-linear model. Put simply, the recognition of preferences heterogeneity that is allowed through the RPL model and the use of a non-linear functional form provides for a better model of the choice data.

The interactions of the socio-demographic characteristics of respondents with the ASC give an indication of the importance of those characteristics in determining respondents' choices between 'no virus release' and 'virus release' strategies.

Where respondents (or close family members) fish in waterways containing Carp or where respondents are older or have higher family incomes, they were more likely to opt for 'virus release' strategies. Respondents who spoke a second language at home or who did not answer the household income question had a greater propensity to support the status quo, 'no virus release' alternative.

The latent error component is positive and significant in both linear and nonlinear models indicating an unobserved error correlation between the two virus release alternatives that is individual rather than choice specific. It confirms that there is significantly more observed variation in the perception of, and substitutability between, the two virus release options compared to the no virus release option (Kragt & Bennett, 2009).

### *Estimation of Implicit Prices and Welfare*

Respondents are required in a CM survey to make a trade-off between the levels of the non-market attributes and the associated payments. The  (Bateman, Day, Georgiou, & Lake, 2006). If money is one of the attributes, this marginal utility is expressed as the 'marginal WTP' for each individual attribute.

Implicit prices are derived using the formula:

$$WTP = \frac{\beta_{attribute}}{\beta_{\cos ts}}$$

where $\beta_{attribute}$ is the estimated coefficient of the (non-market) attribute, and

$\beta_{cost}$ is the estimated coefficient of the cost attribute[13].

[13] It is important to note that the coefficients estimated for each of the attributes cannot be interpreted separately, apart from the importance of their signs, because they are each confounded with a scale parameter. The division of parameter estimates, as occurs in the estimation of the implicit prices, overcomes this issue because it involves the cancellation of the scale parameter that is included in all coefficient estimates.

The implicit prices (and 95% confidence intervals) for each attribute from the linear and nonlinear CL and RPL models for the National Sample are reported in Table 11. The 95% confidence intervals for the implicit prices were calculated using parametric bootstrapping techniques (Krinsky & Robb, 1986) with 1,000 replications from the unconditional parameter estimates.

Table 11: Implicit Prices per Expected Attribute Level ^3 from Preferred CL Models

| | Linear Models | | | Nonlinear Models | |
|---|---|---|---|---|---|
| | **CL** | **RPL** | | **CL** | **RPL** |
| **Fishp**<br>**95% CI** | $5.15<br>$4.63 $5.76 | $4.06<br>$3.57 $4.57 | **Fishp^3**<br>**95% CI** | $0.001225<br>$0.001114 $0.001346 | $0.001285<br>$0.001140 $0.001405 |
| **Wetlp**<br>**95% CI** | -$1.73<br>-$2.65 -$0.87 | -$0.81*<br>-$1.74 $0.09 | **Wetlp^3**<br>**95% CI** | $0.002754<br>$0.001351 $0.004167 | $0.002066**<br>$0.000219 $0.003970 |
| **Birdp**<br>**95% CI** | $1.85<br>$1.40 $2.34 | $1.27<br>$0.87 $1.69 | **Birdp^3**<br>**95% CI** | $0.000273<br>$0.000144 $0.000397 | $0.000287<br>$0.000123 $0.00442 |
| **ASC included** | -$150 | -$109 | **ASC included** | -$26 | $0 |

* Insignificant at the 10% level.
** Insignificant at the 5% level but significant at the 10% level.
Preferred implicit prices are shaded.

From Table 11 it is evident that for linear models, the implicit prices for *Fishp* and *Birdp* are lower for the RPL model than the CL model, but higher in the RPL model for *Wetlp*. However, based on observation of the 95% confidence intervals, only the *Fishp* implicit price is significantly different across the models. This was confirmed by a more robust test that compared the differences in the implicit prices for the different attributes using the procedures developed by Poe, Giraud, & Loomis (2001).

For the nonlinear models, comparisons of the 95% confidence intervals and the Poe test found that there was no statistically significant difference between the implicit prices derived from the CL and RPL models.

The implicit prices estimated from the RPL models are preferred to those from the CL models as the CL models failed the IID test and the indicators of explanatory power of RPL models are greater than those of the CL models. Furthermore, the nonlinear RPL model is preferred over the linear RPL model as all the attributes in the nonlinear RPL model have the expected sign and the ASC is insignificant.

The implicit prices from the preferred nonlinear RPL model represent respondent households' average marginal WTP p.a. for 10 years for an expected unit change in attribute levels. For each of the attributes the unit change is as follows:

- an expected additional native fish per km of waterway in 10 years' time. This can take many forms: e.g. a 100% probability of an additional fish or a 10% probability of an additional 10 fish per km of waterway in 10 years' time etc.
- an expected additional 100,000 ha of wetland free of Carp in 10 years' time. Again, this change can come about in a range of different ways: e.g. a 100% probability of an additional 100,000 ha free of Carp or a 10% probability of an additional 1,000,000 ha free of Carp in 10 years' time etc.
- an expected additional 1,000 waterbirds in 10 years' time. This can occur under a range of circumstances: e.g. a 100% probability of an additional 1,000 waterbirds or a 10% probability of an additional 100,000 bird in 10 years' time etc.

For the preferred nonlinear RPL model (where the ASC is insignificant), the attribute coefficient is multiplied by the cube of the expected unit change in attribute level to obtain a total implicit price for that level of expected outcome. For example, if the level of additional native fish in waterways in 10 years' time is 10 but the probability of this outcome occurring is 50% then the expected value of the attribute is 5. In the nonlinear RPL model the coefficient for fish ($0.001285), is multiplied by the cube of the expected value outcome i.e. 5*5*5=125. This gives an average annual household WTP of $0.16 for this level of outcome.

Where a specific combination of changes to attribute levels is predicted to occur as a result of a policy change such as the release of the Carp virus, the relevant measure of benefit for inclusion in a CBA of the policy change is the compensating surplus (CS):

$$CS = \frac{-1}{\beta_c} * (V_1 - V_0)$$

where $V_0$ is the utility in the counterfactual situation, $V_1$ is the utility in the change scenario and $\beta_c$ is the coefficient for the cost attribute.

The values for $V_1$ and $V_0$ are estimated with reference to the relevant CM. The values for $V_1$ and $V_0$ are different because the values taken by the attributes differ between the two scenarios. In cases where the ASC coefficient is significant, it will also create a difference between $V_1$ and $V_0$ because the ASC is set to zero for the counterfactual and 1 for the change alternative. All other explanatory variables are common between utility functions.

A negative and significant ASC can have the effect of making the CS negative at low levels of difference between the attributes in the two scenarios. This is because the negative value of the ASC in $V_1$ outweighs the positive effect on utility of the changes in the other attributes. Only when a certain threshold of expected environmental outcome is achieved does WTP become positive, if the positive effects on utility of the environmental improvements are sufficient to outweigh the effect of the negative ASC. A positive and significant ASC has the effect of WTP initially being positive with additional expected environmental outcomes increasing the level of this WTP. Only where the ASC is insignificant can implicit prices alone be used to estimate CS. The effect of including the ASC in welfare calculations i.e. average household WTP is included in the bottom row of Table 12

The preferred nonlinear RPL model does not involve a significant ASC and hence the values of the implicit prices can be aggregated across the changes in attributes to estimate the CS without inclusion of an ASC correction factor[14].

Total (and marginal) WTP of households for each level of expected environmental outcome are summarised in Table 12 and represented in Figure 7 across the ranges of changes in attribute levels that were specified as feasible by the freshwater ecology research team.

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[14] The applied CM literature is equivocal about whether the ASC should be included in value estimation even when it is statistically significant in the models of choice (see Morrison, Bennett, & Blamey, 1999, Hatton MacDonald, Morrison, Rose, & Boyle, 2011). Reasons for omitting the ASC include the proposition that the ASC may be capturing respondents' protests or biases: Some may or may not want to pay for an alternative option but are not concerned about the attribute levels, yea-saying behaviour (if positive) or status quo bias (if negative). However, the unexplained systematic determinants of respondent choices captured by the ASC are unknown and hence ignoring significant and large ASC in the estimation of WTP may significantly bias WTP estimates.

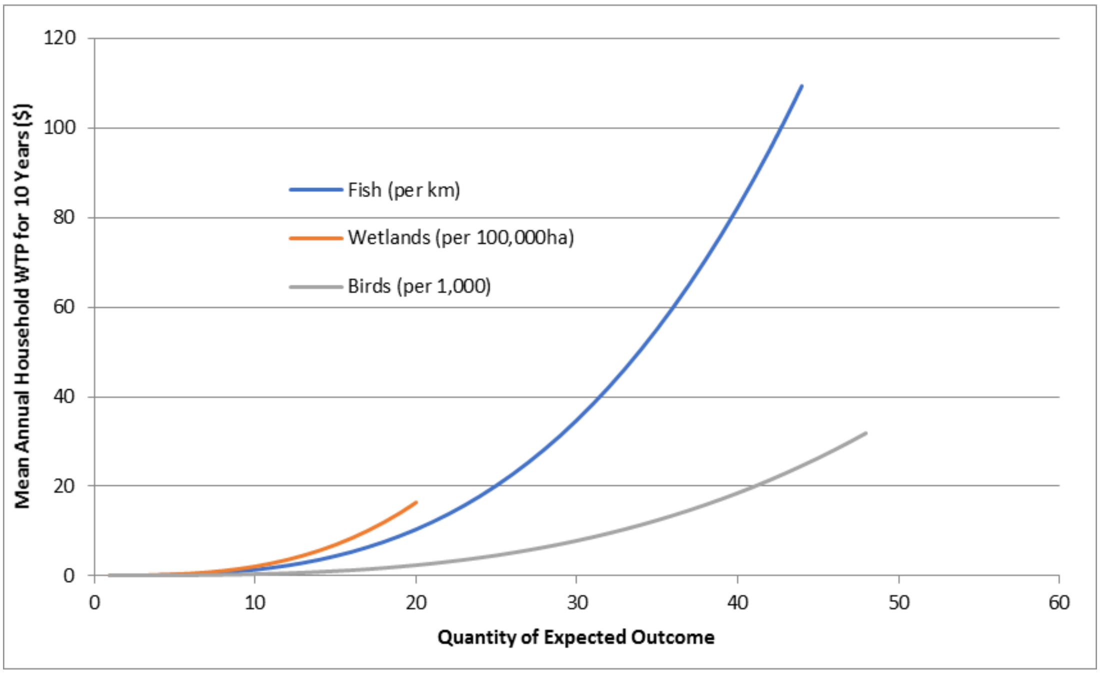
Table 12: Mean Annual Household WTP for 10 Years for Different Levels of Expected Environmental Outcomes in 10 years' Time

| Quantity (Expected Outcome)* | Fish | | Wetlands (100,000ha) | | Birds (1,000) | |
|---|---|---|---|---|---|---|
| | Total WTP | Marginal WTP | Total WTP | Marginal WTP | Total WTP | Marginal WTP |
| 1 | $0.00 | | $0.00 | | $0.00 | |
| 2 | $0.01 | $0.01 | $0.02 | $0.01 | $0.00 | $0.00 |
| 3 | $0.03 | $0.02 | $0.06 | $0.04 | $0.01 | $0.01 |
| 4 | $0.08 | $0.05 | $0.13 | $0.08 | $0.02 | $0.01 |
| 5 | $0.16 | $0.08 | $0.26 | $0.13 | $0.04 | $0.02 |
| 6 | $0.28 | $0.12 | $0.45 | $0.19 | $0.06 | $0.03 |
| 7 | $0.44 | $0.16 | $0.71 | $0.26 | $0.10 | $0.04 |
| 8 | $0.66 | $0.22 | $1.06 | $0.35 | $0.15 | $0.05 |
| 9 | $0.94 | $0.28 | $1.51 | $0.45 | $0.21 | $0.06 |
| 10 | $1.29 | $0.35 | $2.07 | $0.56 | $0.29 | $0.08 |
| 11 | $1.71 | $0.43 | $2.75 | $0.68 | $0.38 | $0.09 |
| 12 | $2.22 | $0.51 | $3.57 | $0.82 | $0.50 | $0.11 |
| 13 | $2.82 | $0.60 | $4.54 | $0.97 | $0.63 | $0.13 |
| 14 | $3.53 | $0.70 | $5.67 | $1.13 | $0.79 | $0.16 |
| 15 | $4.34 | $0.81 | $6.97 | $1.30 | $0.97 | $0.18 |
| 16 | $5.26 | $0.93 | $8.46 | $1.49 | $1.18 | $0.21 |
| 17 | $6.31 | $1.05 | $10.15 | $1.69 | $1.41 | $0.23 |
| 18 | $7.49 | $1.18 | $12.05 | $1.90 | $1.67 | $0.26 |
| 19 | $8.81 | $1.32 | $14.17 | $2.12 | $1.97 | $0.29 |
| 20 | $10.28 | $1.47 | $16.53 | $2.36 | $2.30 | $0.33 |
| 21 | $11.90 | $1.62 | | | $2.66 | $0.36 |
| 22 | $13.68 | $1.78 | | | $3.06 | $0.40 |
| 23 | $15.64 | $1.95 | | | $3.49 | $0.44 |
| 24 | $17.76 | $2.13 | | | $3.97 | $0.48 |
| 25 | $20.08 | $2.31 | | | $4.48 | $0.52 |
| 26 | $22.59 | $2.51 | | | $5.04 | $0.56 |
| 27 | $25.29 | $2.71 | | | $5.65 | $0.60 |
| 28 | $28.21 | $2.92 | | | $6.30 | $0.65 |
| 29 | $31.34 | $3.13 | | | $7.00 | $0.70 |
| 30 | $34.70 | $3.36 | | | $7.75 | $0.75 |
| 31 | $38.28 | $3.59 | | | $8.55 | $0.80 |
| 32 | $42.11 | $3.83 | | | $9.40 | $0.85 |
| 33 | $46.18 | $4.07 | | | $10.31 | $0.91 |
| 34 | $50.51 | $4.33 | | | $11.28 | $0.97 |
| 35 | $55.10 | $4.59 | | | $12.30 | $1.02 |
| 36 | $59.96 | $4.86 | | | $13.39 | $1.08 |
| 37 | $65.09 | $5.14 | | | $14.53 | $1.15 |
| 38 | $70.51 | $5.42 | | | $15.75 | $1.21 |
| 39 | $76.23 | $5.71 | | | $17.02 | $1.28 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 40 | $82.24 | $6.02 | | | $18.36 | $1.34 |
| 41 | $88.57 | $6.32 | | | $19.78 | $1.41 |
| 42 | $95.21 | $6.64 | | | $21.26 | $1.48 |
| 43 | $102.17 | $6.96 | | | $22.81 | $1.55 |
| 44 | $109.47 | $7.30 | | | $24.44 | $1.63 |
| 45 | | | | | $26.15 | $1.70 |
| 46 | | | | | $27.93 | $1.78 |
| 47 | | | | | $29.79 | $1.86 |
| 48 | | | | | $31.73 | $1.94 |

*Quantity refers to:
per additional expected fish per km of waterway in 10 years' time
per additional expected 100,000 ha of wetlands free of Carp in 10 years' time
per additional expected 1,000 waterbirds in 10 years' time

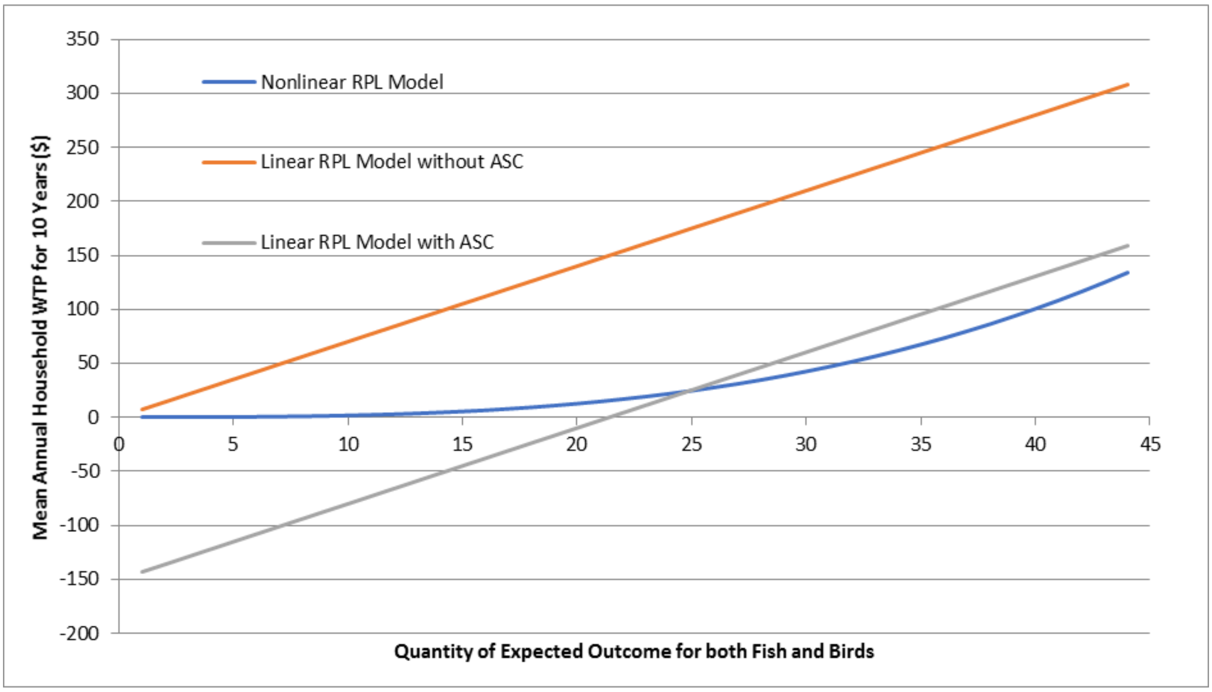
Figure 7: Mean Household WTP for 10 Years for Different Levels of Expected Environmental Outcomes in 10 years' Time




Some indication of how WTP varies between the linear and nonlinear RPL models is provided in Figure 8. This shows how mean annual household WTP varies between models as the expected level of both fish and birds increases to 44 units (of both).[15] The linear RPL model derived estimates of WTP is shown with and without the impact of the ASC.

[15] The expected wetlands attribute is excluded, as its coefficient is negative for the linear model and positive for the nonlinear model.

Figure 8: Mean Household WTP for 10 Years for Different Levels of Expected Environmental Outcomes in 10 Years' Time for Both Fish and Birds




A linear model that ignores the ASC shows a higher level of WTP at every level of expected environmental outcome. Including the ASC, shifts WTP $150 dollars lower at every level of expected environmental outcome. The nonlinear model (where the ASC was not significant and so is excluded from WTP estimates) has a positive WTP at all levels of expected environmental outcome but it is low at low levels and escalates as expected outcomes become greater. This pattern of values indicates that respondents did not perceive much value in releasing the Carp Virus unless some threshold level of expected environmental improvements could be achieved. In the non-linear model, values remain close to zero for up to 15 units. Likewise, in the linear model that includes the ASC, values do not become positive until around 22 units are expected.

It is most important to recognise that the values estimated by the CM exercise are limited to the range of levels that the attributes took in the choice sets. Extrapolation beyond those levels is not justified by the models. This is particularly the case for the non-linear models. These models show increasing WTP as attribute levels rise but the rate of increase (the marginal WTP) is also increasing. This observed pattern of preferences should not be assumed to extend to higher levels of the attributes because it implies increasing additional utility as higher levels of the attributes are achieved. Such a pattern of preferences is contrary to the assumption of preference satiation[16] which states that eventually, people will be willing to pay less and less for more of a good or service.

### *Data Analysis for the Murray Darling Basin*

Linear and nonlinear CL and RPL models estimated for the MDB Sample are provided in Table 13 and Table 14. Of particular interest is that the *Wetlp* attribute coefficient is insignificant in all models while the *Birdp* attribute coefficient is insignificant in the preferred RPL models[17]. Hence,

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[16] Known in economics as the law of diminishing marginal utility.
[17] The relatively small size of the MDB sample means that the models estimated have lower levels of efficiency. This means that the confidence intervals around the coefficient estimates are necessarily wider. Hence, it is more likely that estimates will be insignificantly different from zero.

respondents in the MDB Sample were primarily motivated in their responses by the level of expected native fish in the waterways, with a higher level of expected native fish being associated with a higher utility and greater likelihood of choosing a virus release option. The WTP for expected levels of native fish in the MDB Sample were not statistically different from those for the National Sample.

Table 13: Preferred MDB Sample Conditional Logit Models

| | Linear | | | Nonlinear | |
|---|---|---|---|---|---|
| **Variable** | **Coefficients** | **P-value** | **Variable** | | |
| Cost | -0.00733*** | 0.0000 | Cost | -0.00939*** | 0.0000 |
| Fishp | 0.03300*** | 0.0000 | Fishp3 | 0.10973D-04*** | 0.0000 |
| Wetlp | -0.00054 | 0.9596 | Wetlp3 | 0.19241D-04 | 0.4225 |
| Birdp | 0.01294** | 0.0133 | Birdp3 | 0.43890D-05** | 0.0483 |
| ASC | -1.07350*** | 0.0000 | ASC | -0.30759* | 0.0778 |
| | | | | | |
| Child | -0.16248** | 0.0107 | Child | -0.16145** | 0.0155 |
| Lang | -1.21620*** | 0.0010 | Lang | -1.21989*** | 0.0100 |
| Inc | 0.14001D-04*** | 0.0000 | Inc | 0.14139D-04*** | 0.0000 |
| Carp | 1.99853*** | 0.0011 | Carp | 2.06249*** | 0.0009 |
| | | | | | |
| AIC | 2279 | | AIC | 2309 | |
| Pseudo R2 | 0.17 | | Pseudo R2 | 0.16 | |
| Log likelihood | -1130 | | Log likelihood | -1146 | |
| Log likelihood base model | -1368 | | Log likelihood base model | -1368 | |
| LLR | 477 | | LLR | 445 | |
| Chi2 | 15.51 (8DF) | | Chi2 | 15.51 (8DF) | |

Significance levels: *p = 0.1, **p = 0.05, ***p = 0.01;

Table 14: Preferred MDB Sample RPL Models

| | Linear | | | Nonlinear | |
|---|---|---|---|---|---|
| **Variable** | | | **Variable** | | |
| **Random Parameters** | | | **Random Parameters** | | |
| Fishp | 0 .06364*** | 0.0000 | Fishp3 | 0.25300D-04*** | 0.0000 |
| Wetlp | 0.02898 | 0.2495 | Wetlp3 | 0.68575D-04 | 0.3839 |
| Birdp | 0.01167 | 0.3636 | Birdp3 | -0.37329D-06 | 0.9608 |
| **Non-random Parameters** | | | **Non-random Parameters** | | |
| Cost | - 0.01239*** | 0.0000 | Cost | -0.01421*** | 0.0000 |
| Child | | | Child | -0.63436* | 0.0918 |
| Inc | | | Inc | 0.35914D-04*** | 0.0000 |
| ASC | 1.27096** | 0.0187 | ASC | -0.22466 | 0.7607 |
| **Standard Deviations of Random Parameters** | | | **Standard Deviations of Random Parameters** | | |
| Fishp | 0.07428*** | 0.0000 | Fishp3 | 0.32273D-4*** | 0.0000 |
| Wetlp | 0.16126*** | 0.0002 | Wetlp3 | 0.00045*** | 0.0007 |
| Birdp | 0.07865*** | 0.0000 | Birdp3 | 0.52701D-04*** | 0.0000 |
| **Standard Deviation of Latent Random Effects** | 4.40054*** | 0.0000 | **Standard Deviation of Latent Random Effects** | 4.54374*** | 0.0000 |
| | | | | | |
| **Model Statistics** | | | **Model Statistics** | | |
| McFadden Pseudo $R^{2\,a}$ | | 0.38 | McFadden Pseudo $R^{2\,a}$ | | 0.38 |

| | | | | | |
|---|---|---|---|---|---|
| Log likelihood | | -853 | Log likelihood | | -864 |
| N | | 1,260 | n | | 1260 |
| No. of Halton Draws | | 1000 | No. of Halton Draws | | 1000 |

Significance levels: *p = 0.1, **p = 0.05, ***p = 0.01; [a] Compared to a constants only base model; [b] The total number of observations in the model.

Table 15: Implicit Prices from Preferred CL and RPL Models for the MDB Sample

| | **Linear Models** | | | | | **Nonlinear Models** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **CL** | | **RPL** | | | **CL** | | **RPL** | |
| **Fishp** | $4.50 | | $5.14 | | **Fishp^3** | $0.001169 | | $0.001780 | |
| **95% CI** | $3.21 | $6.52 | $3.55 | $7.24 | **95% CI** | $0.000838 | $0.001609 | $0.001244 | $0.002432 |
| **Wetlp** | -$0.07* | | $2.34* | | **Wetlp^3** | $0.002049* | | $0.000068575* | |
| **95% CI** | -$3.09 | $2.29 | -$0.98 | $5.32 | **95% CI** | -$0.002316 | $0.006501 | -$0.00434 | $0.013763 |
| **Birdp** | $1.77 | | $0.94* | | **Birdp^3** | $0.000467 | | $0.000026* | |
| **95% CI** | $0.58 | $3.35 | -$0.63 | $3.03 | **95% CI** | $0.000061 | $0.000909 | -$0.0009 | $0.000829 |
| **ASC included** | -$146 | | -$103 | | **ASC included** | -$33 | | $0 | |

* Not Significant

# 6. Application of National Results

The results from the National Sample can be incorporated in a CBA of any virus release strategy for control of Carp.

Mean annual household WTP values, reported in Table 16, for different levels of expected environmental outcome can be converted to a present value per household using the recommended discount rate. Generally, a discount rate of around 7% is preferred[18]. This present value WTP per household for the expected level of environmental outcome can then be extrapolated across the national population of households to estimate the community's WTP for the expected level of change in attribute levels[19]. This necessitates assumptions about whether non-respondents hold the same values as those of respondents included in the sample. A conservative approach is to aggregate WTP values to the proportion of the population given by the questionnaire response rate (see, e.g. Bennett, 2008). However, a difficulty with online panel surveys is that traditional response rate information is not available. However, traditional mail-out, mail-back surveys typically achieved 10% to 30% response rates. Consequently, for this study, it is suggested that results be aggregated to 30% of the National population of 9,000,728 households (i.e. 2,700,218 households).

Table 16 summarises the aggregated present value of Australian households WTP for different levels of expected environmental outcomes in 10 years' time.

Table 16: Total WTP of Australian Households (Present Value @7%) for Different Levels of Expected Environmental Outcomes in 10 years' Time

| Quantity (Expected Outcome)* | Fish | Wetlands (100,000ha) | Birds (1,000) |
|---|---|---|---|
| 1 | $24,372 | $39,187 | $5,442 |
| 2 | $194,973 | $313,499 | $43,535 |
| 3 | $658,035 | $1,058,059 | $146,932 |
| 4 | $1,559,786 | $2,507,991 | $348,283 |
| 5 | $3,046,456 | $4,898,420 | $680,240 |
| 6 | $5,264,277 | $8,464,470 | $1,175,455 |
| 7 | $8,359,476 | $13,441,266 | $1,866,579 |
| 8 | $12,478,285 | $20,063,930 | $2,786,264 |
| 9 | $17,766,933 | $28,567,588 | $3,967,161 |
| 10 | $24,371,651 | $39,187,363 | $5,441,922 |
| 11 | $32,438,667 | $52,158,381 | $7,243,198 |
| 12 | $42,114,213 | $67,715,764 | $9,403,641 |
| 13 | $53,544,517 | $86,094,637 | $11,955,902 |
| 14 | $66,875,810 | $107,530,125 | $14,932,634 |

[18] Refer to NSW Treasury (2017) *NSW Government Guide to Cost Benefit Analysis,* Policy and Guideline Paper 17-03.

[19] The socio-demographic characteristics of the sample differed from those of the catchment population with respect to one of the explanatory socio-demographic variables - income. The average annual household income for the sample was higher than for the catchment population. The income variable is positive in the preferred ML model suggesting that higher income respondents are more likely to choose 'new stormwater management actions' than lower income respondents. However, as seen by the comparison of models and implicit prices between Sample 1 and Sample 2, which have different socio-demographic characteristics, including mean income, this has not translated into statistically significant differences in WTP for attributes.

| | | | |
|---|---|---|---|
| 15 | $82,254,322 | $132,257,351 | $18,366,486 |
| 16 | $99,826,282 | $160,511,440 | $22,290,112 |
| 17 | $119,737,921 | $192,527,516 | $26,736,162 |
| 18 | $142,135,468 | $228,540,703 | $31,737,288 |
| 19 | $167,165,153 | $268,786,125 | $37,326,142 |
| 20 | $194,973,207 | $313,498,906 | $43,535,375 |
| 21 | $225,705,859 | | $50,397,638 |
| 22 | $259,509,338 | | $57,945,584 |
| 23 | $296,529,876 | | $66,211,863 |
| 24 | $336,913,701 | | $75,229,128 |
| 25 | $380,807,045 | | $85,030,029 |
| 26 | $428,356,135 | | $95,647,219 |
| 27 | $479,707,204 | | $107,113,348 |
| 28 | $535,006,480 | | $119,461,069 |
| 29 | $594,400,193 | | $132,723,033 |
| 30 | $658,034,573 | | $146,931,891 |
| 31 | $726,055,851 | | $162,120,294 |
| 32 | $798,610,255 | | $178,320,896 |
| 33 | $875,844,017 | | $195,566,346 |
| 34 | $957,903,365 | | $213,889,297 |
| 35 | $1,044,934,530 | | $233,322,400 |
| 36 | $1,137,083,742 | | $253,898,307 |
| 37 | $1,234,497,231 | | $275,649,669 |
| 38 | $1,337,321,226 | | $298,609,137 |
| 39 | $1,445,701,957 | | $322,809,363 |
| 40 | $1,559,785,655 | | $348,283,000 |
| 41 | $1,679,718,548 | | $375,062,697 |
| 42 | $1,805,646,868 | | $403,181,108 |
| 43 | $1,937,716,844 | | $432,670,882 |
| 44 | $2,076,074,706 | | $463,564,673 |
| 45 | | | $495,895,131 |
| 46 | | | $529,694,907 |
| 47 | | | $564,996,654 |
| 48 | | | $601,833,024 |

To apply these values then requires estimation of the average level of expected environmental outcome[20] for native fish, wetlands and birds, "with" a virus release strategy, compared to "without" a virus release strategy.

If based on the judgement of scientists, it was considered that a virus release strategy would result in:

- a 50% probability of an additional 30 native fish per km of waterway i.e. an expected level of 15; and

[20] Across all inland waterways currently infested with Carp.

- a 20% probability of an additional 1,000,000 ha i.e. an expected level of 2 (units are 100,000ha); and
- an 80% probability of an additional 40,000 waterbirds i.e. an expected level of 32 (units are 1,000 waterbirds);

then reading from Table 16 the environmental benefits would be $261 million i.e. $82 million plus $313,000 plus $178 million.

These benefits together with other market benefits can then be compared to the market and nonmarket costs of the strategy.

# 7. Conclusions

This study shows that households across Australia have a positive WTP for the outcomes of Carp Virus release strategies, namely an increase in the:

- expected number of native fish per km of waterway across all the waterways currently affected by Carp;
- expected hectares of wetlands free of Carp; and
- expected population size of waterbirds.

The preferred model was a RPL model with a nonlinear (cube) transformation of the expected value levels for the Fish, Wetlands and Waterbirds attributes. The non-linear form means that WTP estimates are not constant across expected levels of the attributes: WTP increases as the expected level of an attribute increases.

Importantly, this pattern of values indicates that respondents did not perceive much value in releasing the Carp Virus until expected environmental improvements were greater than 10 to 15 units of expected environmental outcome.

Expected outcomes units are:

- per additional native fish per km of river;
- per 100,000ha of wetlands free of Carp; and
- per 1,000 waterbirds.

Values generated from the study can be used to undertake *ex ante* economic evaluations (CBA) of proposed virus release strategies.

# Part 4: Synthesis

## Overview

The following section first synthesises the current and potential future costs and benefits of Carp in Australia based on the information previously presented in Parts 1 to 3 to provide a baseline against which to investigate the benefits of potential Carp control strategies. Then, the likely benefits and costs associated with the control of Carp through the implementation of the NCCP are described.

## The Current and Potential Future Costs of Carp in Australia

### Current Carp Biomass in Australian Waterways

In the 45 years since Carp first escaped into the MDB they have invaded almost all major aquatic habitat types in south-eastern Australia and now inhabit a total estimated aquatic area of 16 569 $km^2$. There is considerable variation in estimates of Carp biomass density (kg/ha) among and within the representative aquatic habitats, ranging from 0 to 1,200 kg/ha. Carp density tends to be higher for lowland rivers and adjacent wetlands than for upland rivers and deep impoundments. For example, the lower Murray River (SA) had some of the highest recorded biomass estimates, reflective of the series of regulated, slow-flowing weir pools and permanent adjacent wetlands, which provide optimal habitat for Carp (Stuart, et al., 2019).

As part of the body of research conducted under the NCCP, Stuart, et al. (2019) developed a national estimate of Carp biomass for Australia. The study estimated that the total biomass of Carp in south-eastern Australia in 2018 was 205,774 tonnes with standing waterbodies containing the highest biomass at 162,838 tonnes with the remainder found in rivers at 42,936 tonnes. For WA and Australian irrigation channels, where Carp biomass was more coarsely estimated, the study found there was an additional 15,855 and 3,570 tonnes respectively. However, Carp biomass in all regions fluctuates significantly depending on the prevailing climate (wet versus dry years). In a wet year, the total Carp biomass in Australia may be as high as 368,357 tonnes.

#### *Potential Future Carp Biomass without Additional Intervention*

A secondary NCCP biomass study modelled potential future Australian Carp biomasses for two hydrological scenarios (drought or flood) for the year 2023. The study found that the drought scenario produced about the same or slightly reduced biomasses from the static 2018 estimate. The estimates of Carp biomasses in 2023 using an intial population size equivalent to the 2018 mean estimate were between 167,960 to 172,895 tonnes for the drought scenario and 428,808 to 444,144 for the flood scenario. A maximum additional biomass for WA and Australian irrigation channels was estimated at 30,464 tonnes (Todd, et al., 2019).

# Estimation of Total, Current Impact Costs of Carp

## Estimation of Total Market Impact Costs of Carp

Analysis of the data from the market impact costs of Carp survey found that the existing Carp biomass have negligible direct impacts on market costs for primary water users (irrigators, irrigation/ water authorities, and water treatment plants). However, indirect impacts through turbidity and sediment loads in source water for water treatment plants were found to have an effect on water treatment costs. Based on the data collected, the estimated cost associated with the treatment of source water for turbidity/ sediment was between $12 and $89.7 million per treatment plant per year. The average water treatment costs for turbidity/ sediment were estimated at $211,494 per plant per year.

To form an estimate of the market impact costs of Carp based on water treatment costs for turbidity, it would be necessary to quantify the causal relationship between Carp biomass and turbidity levels. Based on the findings of the desktop literature review there is evidence of a positive relationship between Carp biomass and turbidity (Vilizzi et al., 2015; Weber & Brown, 2009). The exact functional relationship between Carp biomass and turbidity, however, is not clear with estimates varying widely from 50kg/ha -100 kg/ha for noticeable difference in turbidity up to 500kg/ha for large shifts in turbid water states (DELWP, 2017; Vilizzi et al., 2015; Brown & Gilligan, 2014; Weber & Brown, 2009). Vilizzi et al. (2015) reported that specifying how any critical level of Carp biomass impacts on turbidity is problematic due to the differing nature of the experiments carried out. NCCP researchers also pointed out that there was not a single unifying ecologically significant Carp biomass that would apply equally for all habitats in Australian waterways with respect to variables including turbidity and biomass, or diversity, of other species (Jennifer Marshall, pers. comm., 2019).

Overall, the market impact cost data were indicated that Carp do not impose significant costs on the market sector and that any significant damage they have caused, and still cause, are likely to be more strongly related to non-market costs via a range of causal pathways. Further, as no quantitative causal relationship between Carp biomass and turbidity levels was available, the market costs associated with the impact of Carp in Australian waterways was assumed to be low, if not negligible.

## Estimation of Total Non-Market Impact Costs of Carp

Non-market costs were calculated based on a per-household WTP for changes in particular environmental outcomes (native fish, native waterbirds, and area of healthy wetlands) over 10 years' time following Carp suppression. These changes were identified by an ecological expert elicitation panel, with units of change identified as per additional expected native fish per km of river, per expected additional 10,000 ha of wetland free of Carp, and per additional expected 1,000 waterbirds. The range of possible total WTP calculated for Australian households was $24,372 - $2.08 billion for fish, $39,187 - $313.5 million for wetlands, and $5,422 - $601.8 million for waterbirds, with the specific values within these ranges being dependent on the extent of environmental recovery forecast after a reduction in Carp biomass.

An estimate of the current, total non-market impact costs of Carp in Australian waterways would require an estimate of current impact of Carp on each of the key environmental attributes. For example, it would require an estimate of the total number of native Australian fish (no. of fish per km of river) that are currently displaced/non-existent due to current Carp biomass. Alternatively, this could be viewed as an estimate of the maximum, total number of native fish (per km of river) that would be restored if 100% of the current Carp biomass were removed from Australian waterways. The NCCP's ecological risk assessment study (Beckett, Caley, Hill, Nelson, & Henderson, 2019) reported that the ecosystem impacts of Carp may not be observed until Carp abundance/ biomass exceeds a threshold density. Declines in aquatic vegetation cover and detrimental effects of aquatic macrophytes have been observed at Carp densities ranging from 68 to 450 kg/ha, and a decline in the use of wetlands by native waterfowl was observed when Carp densities exceeded approximately 100 kg/ha. Such ecosystem impacts are most commonly reported in shallow, off-stream habitats where Carp congregate.

Based on the existing science and available literature, ecological experts and other NCCP researchers were not able to provide credible, science-based estimates of the relationship between the current Carp biomass and the numbers of native fish, native waterbirds, and area of healthy wetlands that could be expected without the presence of Carp in Australian waterways. As a result, a quantitative estimate of the total non-market impact costs of Carp was not able to be calculated.

## Overall Total Impact Costs of Carp

The NCCP CBA project collected a range of highly relevant market and non-market impact cost data that may be used to estimate a total impact costs of Carp in Australian waterways. However, current knowledge of the relationship between Carp biomass and turbidity, and the relationship between Carp biomass and key environmental attributes was not adequate to allow for a credible estimate of the total impact costs of Carp to be calculated with the current project.

If future research elucidates and quantifies such key relationships associated with the impact of Carp biomasses on Australian waterways, then an overall estimate of the total impact costs of Carp, using existing market and non-market cost data provided in the current study, may be possible.

# Potential Benefits and Costs of Carp Control through the NCCP

## Benefits of Carp Control through the NCCP

The fundamental assumption that underpinned the development of the NCCP was that improved control of Carp in Australian waterways would result in benefits to the Australian community as a whole through reduced negative economic, environmental and social Carp impacts.

In the context of the current NCCP Carp CBA project (2016-132), improved Carp control is taken to mean reducing current and future negative Carp impacts through a direct reduction and potential ongoing suppression of the Carp population (biomass) achieved through the strategic release of CyHV-3.

Reduction and potential ongoing suppression of the Carp biomass in Australian waterways is expected to lead to:

1. Improved biodiversity outcomes (e.g. increased populations of native fish, other vertebrates such as waterbirds, invertebrates, and aquatic plants etc.), and
2. Improved water quality through reduced turbidity and erosion, improved biodiversity, and reduced incidence of algal blooms.

Each of the potential benefits of Carp control are likely to be associated with reduced impact costs to the Australian community. For example, improved water quality is likely to contribute to reduced water treatment costs, improved ecosystem health, and enhanced aesthetic and recreational amenity of Australian waterways. The potential magnitude of such benefits of Carp control are explored in the Murray-Murrumbidgee CBA case study described later in this report (see CASE STUDY: The Murray-Murrumbidgee System – Cost-Benefit Analysis).

## Potential Costs of Implementing Carp Control through the NCCP

Implementation of the NCCP (i.e. the strategic release of CyHV-3 in Australian waterways for improved Carp control) is a significant undertaking and will involve a great deal of planning, coordination, cooperation, and people-power to achieve the potential benefits of reducing the Carp biomass in Australian waterways.

There will be costs associated with the preparations required for release of the virus, physical release of the virus into the Australian Carp population, potential carcass management or clean-up and disposal of dead Carp where the virus successfully reduces the Carp population, and ongoing monitoring, evaluation and reporting during and after implementation of the NCCP. There may also be costs associated with ongoing tactical use of the virus as a Carp biocontrol method in the future to maintain suppression of the Carp biomass. The following sections describe the broad categories of costs that may be incurred throughout implementation of the NCCP. Specific regional NCCP costs, and the likely magnitude of the such costs, then are explored in the Murray-Murrumbidgee case study described later in this report (see Part 4: CASE STUDY 1).

### *Pre-release: planning and virus preparation*

Preparation for the release of CyHV-3 is likely to involve substantial coordination and cooperation between State and local government bodies, researchers, natural resource managers, environmental groups, and various other sectors of the Australian community. The opportunity cost of time spent for those involved in the planning and preparation for implementation of the NCCP must be accounted for in any detailed costing.

Further, to enable wide-spread, strategic release of the virus there may be costs associated with:

- Planning and communications activities such as the development of regional implementation plans and regional communications and engagement activities prior to release of the virus.
- Strategic management including jurisdictional level planning, management of policy and direction of the plan within a jurisdiction.
- Virus propagation, maintenance and storage. Such costs are likely to include propagation of the virus in laboratories, and the subsequent maintenance of the propagated virus during the NCCP implementation period.
- Training of specialist personnel for virus release.
- Training and ongoing preparedness of personnel and equipment for effective Carp carcass management (including potential clean-up and disposal of carcasses) post-virus release,
- Ongoing monitoring and assessment of prevailing hydrological conditions, long-range and seasonal weather forecasts and resource availability for NCCP implementation and
- Establishment and maintenance of efficient and effective communication channels between NCCP implementation regions and stakeholders (including personnel and agencies involved in release, carcass management, monitoring and evaluation (M&E) as well as communication with the broader Australian public).

### ***NCCP Implementation***

#### *Initial Virus Release*

The NCCP proposes to release the CyHV-3 virus across all areas of Carp biomass with the initial focus of release to be on regulated and more perennial waterbodies and rivers of the MDB. The strategy calls for the virus to be released in spring, when Carp aggregate, and within the permissive temperature range of the virus. Broadscale, strategic release of the virus will require the deployment of resources across large river systems during permissive temperature periods. Follow up releases are possible in non-regulated areas in subsequent years (Jamie Allnutt, pers. comm., 2019). Costs associated with the initial (Year 1) release of the virus may include:

- Shipping/ transport of the virus to strategic release locations throughout the MDB.
- Destruction of Carp. The costs of destruction of Carp are likely to include those for activities around the securing of a supply of Carp for exposure to the virus, and then the processes associated with exposure of those Carp to the virus and the release of exposed Carp in the designated/ target areas. Components of destruction costs may include:
    - Surveillance of Carp aggregations pre- and post- virus release,
    - Collection of samples along the exposure pathway for quality control,
    - Salaries or other such compensation for specialised personnel to execute physical release of the virus into Australian Carp populations,
    - Salaries or other such compensation for non-specialised personnel (e.g. recreational fishers) engaged to support the virus release,
    - Hire and/or purchase of tools and equipment required for execution of virus release (e.g. boats and fish catching equipment, syringes or other virus paraphernalia, electrofishing equipment, vehicles and trucks, refrigeration, etc.),

  - Direct and indirect costs related to management and manipulation of water flows (e.g. implementing artificial barriers or pumping) to optimise virus transmission through Carp aggregations, and
  - Equipment and bait or berley potentially used to create artificial Carp aggregations for virus release.
  - Costs for stores and other consumables for activities such as destruction and subsequent surveillance and carcass collection and disposal.
- M&E of key issues and constraints that may stymie effective implementation of the NCCP including peak holiday/tourism periods, climate conditions (e.g. temperature and rainfall), and prevailing ecosystem conditions (particularly water availability/ flow).

### *Post-Virus Release Carcass Management*

To mitigate the potential negative impacts of mass Carp mortalities that may occur if CyHV-3 is released into Australian waterways, the NCCP has included research and planning for the implementation of Carp carcass management strategies post-virus release.

Cost-effective, low impact carcass management options, such as water flow management to disperse Carp carcasses, will be utilised wherever possible. Physical carcass removal is expected to be conducted only at priority clean-up locations determined by both the quantity of carcasses present and the proximity of the dead fish mass to sensitive features within and adjacent to the affected waterway (e.g. regional town water supply weirs and intake pumps, residential areas, key recreation/tourist sites, habitats of threatened aquatic species). A combination of manual and mechanical removal techniques is likely to be employed and will be determined according to specific waterway type and expected Carp carcass quantities.

Response times for effective carcass management also are critical. Dead Carp are not expected until 5 or more days after initial release of the virus (unless a 'trojan Carp' method is used, in which case monitoring for the first signs of moribund fish would be necessary). Fish carcasses are known to sink approximately three days after death, and therefore become unable to be removed. Hence, the ability to quickly respond to fish kills should the virus be released will be critical to the perceived success of the combined CyHV-3 release and Carp carcass management strategies.

Costs associated with the Carp carcass management efforts post-virus release are likely to include:

- Planning and surveillance for the collection and disposal of Carp carcasses. This is likely to include costs for surveillance and planning at a tactical level and may include costs associated with field activities to collect information from target areas of operations such as field inspections and interviews, the use of geospatial information systems (GIS), and collection, collation, confirmation and interpretation of information.
- Collection and disposal of Carp carcasses. Methods of carcass management/carcass disposal are likely to vary on a case by case basis. However, such costs may include:
  - Engagement of contractors for dead Carp removal (including patrol of waterways, collection of Carp carcasses, and disposal of dead Carp),
  - Employment of regional Carp carcass management coordinators and teams for regional central command locations and forward command operational locations (including layby areas for equipment and staff facilities),
  - Hire and/or purchase of tools and equipment required for carcass management and clean-up operations (e.g. boats, booms, nets, mechanical vacuum trucks, rubbish skimmer barges, skip bins, shovels, etc.),

  - Transport (potentially refrigerated) of Carp carcasses to processing and/or disposal locations,
  - Processing or disposal of carcasses (e.g. digging of in-ground pits) including any costs associated with government regulatory requirements (e.g. permits), and
  - Planning, coordination and cooperation related to the use of waste or processing facilities, access to waterways, permitted transport routes, and location and design of approved disposal pits.
- Strategic management costs that may include jurisdictional planning, management of policy and direction of the plan within a jurisdiction, records management, legal activities, jurisdictional analysis and reporting, accounts payable/ receivable and finance management. Costs associated with computing hardware and software also may be relevant.
- Tactical management costs associated with line of sight management of activities including field activities and community-based activities, budget management, operations management, resource management (including personnel and contractors), and logistics such as travel and accommodation. Tactical management costs also may include:
  - Work health and safety costs, and
  - Facilities costs including those for fit out and maintenance.
- Availability of standby, back up resources (e.g. emergency funds, trained personnel, facilities, etc.) in case of unforeseen incidents associated with Carp mortalities and/or carcass management operations.
- Monitoring, evaluation, reporting and improvement (MERI) activities. It is likely that such activities will be required, in the pre-release, planning phase, during implementation of the NCCP (virus release and carcass management phase) and post-release to ensure optimal impact and communication with key stakeholders.
- Ongoing community engagement, media and communications activities to report key elements of the NCCP implementation to stakeholders and ensure ongoing cooperation and acceptance.

### Potential Cost Mitigating Factors

In assessing the feasibility of using CyHV-3 as a biocontrol agent for Carp, the NCCP recognised that there would be a need to examine waste utilisation options for the dead Carp biomass. Project 2016-180: *Options for Utilisation of Carp Biomass* was funded to address this information gap.

A number of laboratory and small- and large-scale pilot trials were conducted to investigate the potential options for Carp biomass utilisation. Options trialled included:

1. Enzyme (alcalase) hydrolysis to produce organic fertiliser or aquafeed,
2. Rendering to produce Carp meal and oil,
3. Use as a food source for black soldier fly (*Hermetia illucens*) larvae production,
4. High pressure pasteurisation trials on raw minced Carp product for pet food,
5. Composting,
6. Fermentative hydrolysis to produce fertiliser, and

7. 'Worm tea' treatment to produce vermicast[21].

Additional trials were undertaken by Goulburn Valley Water to investigate the use of Carp wastewater as a potential input to biogas production following anaerobic digestion.

Following completion of the trials and consultation with various industry partners, a CBA was conducted on 14 possible supply chain scenarios based on four key processing pathways. The four pathways were selected based on the fact that they were found to enable viable commercial scenarios, assuming Carp biomass was available, free at the water's edge.

Though not all carcass utilisation methods explored proved commercially viable at the time of testing, the project showed that there are a number of technically viable community and commercially based options for the utilisation of the Carp biomass that may result from the implementation of the NCCP. There was serious commercial interest in further developing some of these options, particularly fish rendering, composting and enzyme hydrolysis.

The net profits that may be realised through the utilisation of some of dead Carp biomass may offset some of the virus release and carcass management costs associated with implementation of the NCCP. However, the best option for most areas is likely to be the implementation of near-site (within 10km) above-ground composting to avoid transport and disposal costs while allowing composted material to be used later (Jennifer Marshall, pers. comm., 2019).

### *Post-Implementation*

After the proposed initial release of the virus and associated carcass management operations, some ongoing monitoring will likely be required to track and evaluate the ongoing effect of the virus within the river ecosystems and longer-term impacts of the implementation of the NCCP on Carp biomass and overall ecosystem health.

Further, should the virus be used tactically for biocontrol of Carp in the future (e.g. periodic re-release of the virus to supplement Carp control in future years), additional release, carcass management and MERI costs similar to those previously described may also be applicable.

## Other Potential Impact Costs Associated with Virus Release

Should CyHV-3 be released into Australian waterways for Carp control, the expected mass mortalities of Carp may lead to some short- to medium-term negative impacts. CyHV-3 impact pathways and socio-economic impacts for affected communities were explored in two key NCCP research projects (*Biocontrol of European Carp: Ecological risk assessment for the release of Cyprinid herpesvirus 3 (CyHV-3) for Carp biocontrol in Australia, Volumes 1-3* (Beckett et al., 2019) and *Socio-economic impact assessment and stakeholder engagement* (Schirmer et al., 2019)). The following summarises the types of negative impacts that may be associated with Carp deaths post-virus release:

### *Socio-economic impacts*

Groups identified as having potential to experience direct impact from implementation of the NCCP include commercial Carp fishers and other commercial fishers, native fish aquaculture businesses, traditional custodians of regions experiencing Carp invasion, the tourism sector, recreational fishers, and koi hobbyists, breeders and associated organisations. Some direct and indirect impacts also are

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[21] Vermicast (also known as worm castings, worm humus, worm manure, or worm faeces) is the end-product of the breakdown of organic matter by earthworms and is used as an organic fertiliser and soil conditioner because it contains water-soluble nutrients.

likely to be experienced by residents of communities in which Carp invasion has occurred (Schirmer et al., 2019). The types of impact costs associated with release of CyHV-3 may include:

1. Loss of amenity for:
    a. Residents in affected areas,
    b. Recreational fishers, and/or
    c. Tourists.

    Loss of amenity following the release of the Carp virus will be driven by temporary reduced water quality and, potentially, noise and odour associated with carcass management.
2. Reduced wellbeing. Release of the Carp virus is likely to affect the wellbeing of:
    a. Traditional owners through impacts on health of Country,
    b. Commercial Carp fishers and other fishers,
    c. Koi hobbyists, breeders and associated supply businesses, and
    d. Residents and other businesses that rely on Carp-affected waterways for income.
3. Reduced regional incomes. Specifically:
    a. Commercial Carp fishers are likely to experience increased costs (e.g. testing for infection in harvested Carp, reduced catch volumes, etc.) and, potentially, reduced demand and/or loss of market access due to the release of CyHV-3.
    b. Koi hobbyists and businesses may experience increased costs associated with implementation of biosecurity measures, the replacement of infected stock, and/or reduced demand and loss of market access.
    c. Temporary loss of, or reduction in, employment where earning opportunities are impacted by the virus release. For example, tourism activities, cultural guide activities, growing/harvesting of native foods, etc.
4. Increased water treatment costs because of blockages caused by fish carcasses, treatment to remove excess organic matter and chemical residues (particularly ammonia) and/or increased incidence of algal blooms or disease (e.g. botulism) associated with high levels of organic matter.
5. Increased risk of productivity loss for primary producers (livestock and cropping) from incidence of disease (e.g. botulism) and/or poor water quality.
6. Damage to public and/or private land and waterways accessed for implementation of the NCCP and subsequent carcass management activities.
7. Potentially, increased costs for waterway and land rehabilitation for private landholders and/or local governments in Carp affected areas.

### *Ecological impacts*

A number of biological, ecological and physical scenarios were identified as exposure pathways that may follow from the release of CyHV-3. Impact costs associated with such exposure pathways may include:

1. Decreased populations of native aquatic species through:
    a. Blackwater events and/or low DO levels (plausible),
    b. Widespread cyanobacterial blooms (plausible),
    c. Exposure to the microorganisms associated with decomposing fish carcasses (plausible),

d. Removal of a dominant and stable food source (plausible),

e. Increased predation because of prey switching (plausible – see d.),

f. Outbreaks of botulism (plausible for type C or C/D, no concrete evidence that type E is present in Australia),

g. Exposure to the direct pathogenic effects of CyHV-3 (unknown, species specificity testing is ongoing), and/or

h. Exposure to direct pathogenic effects of mutated strains of CyHV-3 with altered species specificity (as above at g.).

2. Cyanobacterial blooms, exposure to decomposition microorganisms, and potential outbreaks of botulism may also affect livestock and humans.
3. A reduction of the Carp biomass in Australian waterways may also result in the resurgence of other invasive animal and plant species.

### *Summary*

Though a number of potential negative socio-economic and ecological impacts were identified the majority were considered to be low risk. Further, mitigation activities undertaken throughout implementation of the NCCP including planning, community engagement, and carcass management are likely to significantly reduce the risk and potential magnitude of such negative impacts. Also, most negative impacts are expected to be short-term, experienced over a period of weeks, and are likely to be offset by medium- to long-term positive impacts from improved ecosystem health from the reduction and suppression of the Carp biomass.

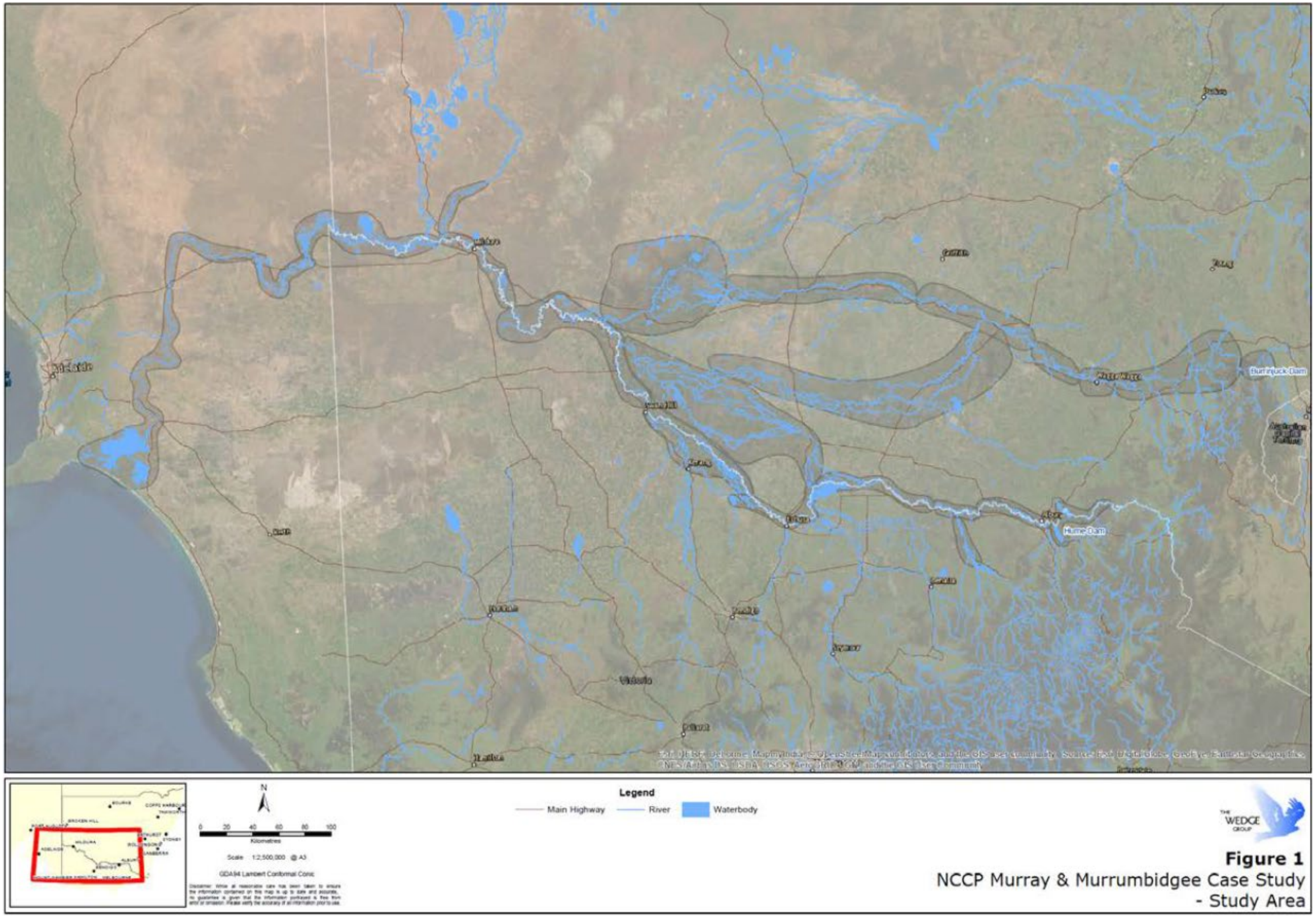
# CASE STUDY: The Murray-Murrumbidgee System – Cost-Benefit Analysis

## Region Definition

The Murray-Murrumbidgee river system represents the southern zone for the proposed initial deployment of CyHV-3. The case study region, shown in Figure 9, covers both the Murray and Murrumbidgee river systems, including the Hum and Burrinjuck reservoirs, through to the Murray Mouth. The system also includes the Edward-Wakool system, the Darling River (Wentworth weir pool extent) and the Lower Lakes in SA.

The Murray-Murrumbidgee system was selected as the case study region for the CBA because (1) the system contains the highest Carp biomass and densities of all the case study areas reviewed by the NCCP, (2) some parts of the region have high environmental values (including the Ramsar wetlands), and (3) detailed NCCP implementation cost data were available for the Murray-Murrumbidgee system.

Figure 9: Map of the Murray-Murrumbidgee Case Study Region




Source: The Wedge Group Pty Ltd (2019)

## Carp Density and Distribution

Carp are widely distributed and abundant and occur in most types of waterway in most parts of the Murray-Murrumbidgee system. Carp biomass mapping was conducted by NCCP researchers and provided as a series of ArcGIS[22] web maps. Biomass estimates indicated that the Carp population density across the Murray-Murrumbidgee varies widely with distributions from less than 50-100kg/ha to more than 500kg/ha. Higher impact Carp densities are present in the connected and typically regulated systems of the MDB. This is due to the fact that regulated systems create suitable conditions for Carp population growth (The Wedge Group Pty Ltd, 2019). The screenshot presented in Figure 10 provides an example of the web map output for the Murray-Murrumbidgee case study region.

A further NCCP project focused on developing detailed costings for the potential implementation of the NCCP for various case study regions (*National Carp Control Plan: Murray and Murrumbidgee River Systems Case Study – Outcomes Report* (The Wedge Group Pty Ltd, 2019)). The project interrogated the 2019 NCCP Carp biomass data and divided the Murray-Murrumbidgee into approximately 23 operational reaches based on river regulation units (reaches between regulators and weirs) and an initial assessment of the risks and opportunities associated with release of CyHV-3 (reproduced in Figure 11). Average biomasses for each reach in the case study region, encompassing both waterbodies and rivers, were estimated and are reproduced in Table 17. The operational reaches and biomass estimates then were used to inform the most likely virus release and carcass management strategies for the Murray-Murrumbidgee system.

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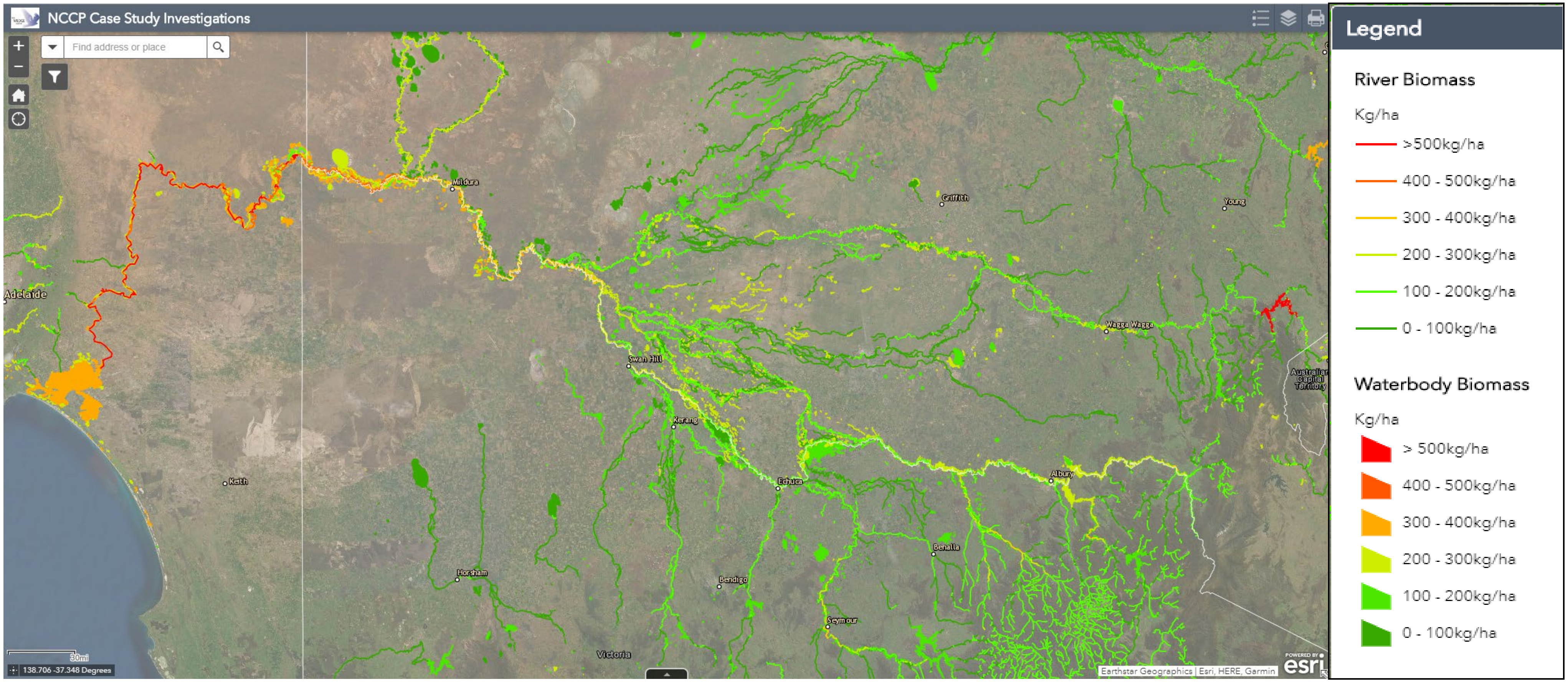
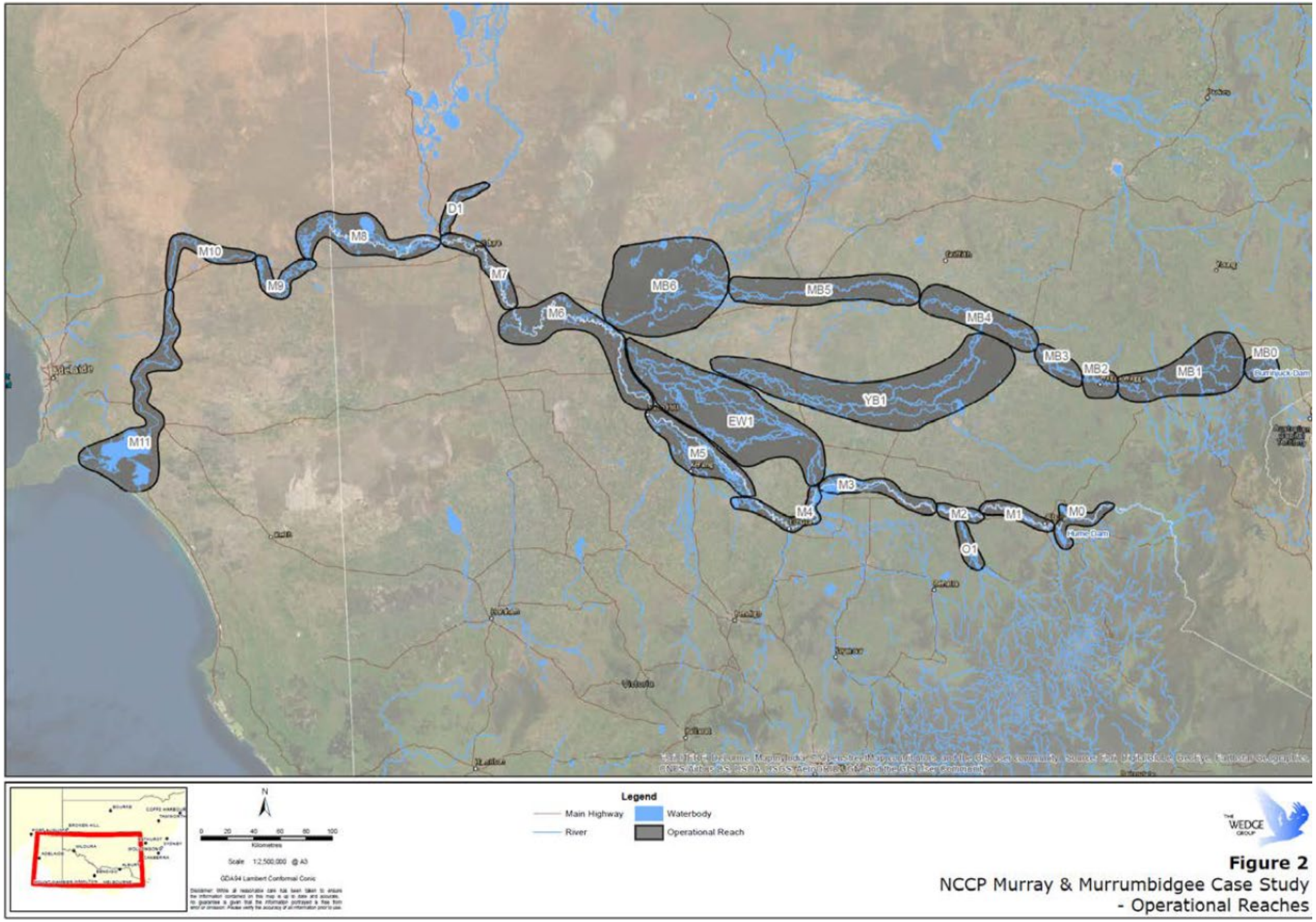
[22] ArcGIS is a mapping and spatial analytics software from the Esri Geospatial Cloud, a global market leader in GIS.

Figure 10: Carp Biomass Map of the Murray-Murrumbidgee Case Study Region




Source: ArcGIS Web map screenshot: https://wedge.maps.arcgis.com/apps/webappviewer/index.html?id=aac9fd9c3ebc46718c8b189cf83a464b

Figure 11: Proposed NCCP Implementation Operational Reaches for the Murray-Murrumbidgee Case Study Region




Source: The Wedge Group Pty Ltd (2019)

Table 17: Reach by Reach Average Biomass Estimates for the Murray-Murrumbidgee Case Study Region

| **Reach by Reach Average Biomass Estimates**<br>***Derived from "A national carp biomass estimate for Australia. Unpublished Client Report for the Fisheries Research and Development Corporation". (Citation below)*** | | | | |
|---|---|---|---|---|
| **Reach** | **Waterbody Kgs** | **River Kgs** | **Total Kgs** | **Total Tonnes** |
| M0 | 4,855,571 | 23,515 | 4,879,086 | 4,879 |
| M1 | 217,018 | 219,514 | 436,533 | 437 |
| M2 | 1,242,003 | 162,036 | 1,404,040 | 1,404 |
| M3 | 3,107,825 | 394,808 | 3,502,634 | 3,503 |
| M4 | 3,638,884 | 346,762 | 3,985,646 | 3,986 |
| M5 | 1,961,633 | 516,416 | 2,478,049 | 2,478 |
| M6 | 1,065,543 | 1,504,616 | 2,570,158 | 2,570 |
| M7 | 909,426 | 988,198 | 1,897,624 | 1,898 |
| M8 | 6,558,356 | 2,458,752 | 9,017,107 | 9,017 |
| M9 | 2,502,421 | 986,828 | 3,489,250 | 3,489 |
| M10 | 967,513 | 1,333,318 | 2,300,831 | 2,301 |
| M11 | 29,801,524 | 1,961,906 | 31,763,430 | 31,763 |
| O1 | 35,768 | 119,977 | 155,744 | 156 |
| D1 | 33,495 | 203,983 | 237,478 | 237 |
| EW1 | 1,781,181 | 1,049,566 | 2,830,747 | 2,831 |
| MB0 | 3,987,892 | 3,206 | 3,991,098 | 3,991 |
| MB1 | 34,693 | 377,003 | 411,697 | 412 |
| MB2 | 48,115 | 82,703 | 130,818 | 131 |
| MB3 | 38,993 | 151,754 | 190,747 | 191 |
| MB4 | 847,765 | 207,771 | 1,055,536 | 1,056 |
| MB5 | 390,228 | 337,163 | 727,391 | 727 |
| MB6 | 4,102,117 | 471,181 | 4,573,299 | 4,573 |
| YB1 | 2,694,509 | 556,856 | 3,251,365 | 3,251 |
| | | **Total** | **85,280,308** | **85,280** |

Source: The Wedge Group Pty Ltd (2019)

## Description of Likely Virus Release and Carcass Management Strategy

Descriptions of the assumptions underpinning the proposed CyHV-3 virus release and Carp carcass management strategies for the Murray-Murrumbidgee system are presented in the NCCP report *National Carp Control Plan: Murray and Murrumbidgee River Systems Case Study – Outcomes Report* compiled by The Wedge Group Pty Ltd (2019). Overall, the implementation plan for the NCCP encompasses four key phases:

1. Planning,
2. Operations,
3. Adaptive management, and
4. Completion.

NCCP Technical Paper #6 (*Implementation*) describes, in detail, the implementation structures and systems to be applied as well as strategies and tactics covering implementation of key activities including:

- Resource mobilisation,
- Program management and administration,
- Pre-release surveillance,
- Carp virus release,
- Carcass management,
- Post-release surveillance, and
- Demobilisation.

The following sections provide a brief overview of the release and carcass management strategies for the purpose of the case study CBA.

### *Virus Release in the Murray-Murrumbidgee System*

Virus deployment was developed to achieve a widespread reduction and long-term suppression of Carp populations to a density of less than 150kg/ha. Four primary biological preconditions are likely to determine the impact of the virus on current Carp populations:

1. The permissive water temperature for virus activation and infection (18° to 28°),
2. Recrudescence of latent infections,
3. Carp aggregation behaviour to achieve virus transmission between fish, and
4. The proportion of Carp infected within a given sub-population.

Carp spawning behaviour provides the best opportunity to initiate outbreaks of CyHV-3-induced disease. Adult Carp move to access suitable spawning habitat in early spring, forming large aggregations immediately prior to spawning. Aggregations place numerous Carp in direct physical contact. The virus will be deployed by introducing infected Carp into aggregations within target subpopulations.

The most effective virus deployment strategy will target as many aggregations as possible within the subpopulations comprising a given metapopulation. Deployment will need to occur during a relatively narrow time period when Carp aggregating behaviour and permissive water temperatures coincide. Approximately 5% of the total Carp present within each subpopulation will need to be infected to (a) trigger an outbreak that provides initial knockdown, and (b) ensure that a proportion of infected Carp develop latent infections to trigger outbreaks in future years (FRDC, 2019).

For virus release in the Murray-Murrumbidgee system it was assumed that:

- The virus release will be concurrent across multiple reaches and river systems, from upstream to downstream, and will target Carp aggregations at permissive water temperatures.
- The release will target reaches with estimated Carp biomass above 150kg/ha and areas of known, or induced, Carp aggregations.
- The virus release will occur through direct injection of fish from target aggregations. Target infection rates are 3% to 5% of the biomass in each subpopulation injected annually over the two-year active release period.

### *Carcass Management in the Murray-Murrumbidgee System*

Post-virus release, it will not be possible to conduct carcass removal operations of all waterways, nor will it be considered necessary to clean up all waterways. Cost-effective, low impact carcass management options, such as water flow management to disperse Carp carcasses, will be utilised wherever possible. However, priority carcass removal/clean-up sites will be selected based on a risk matrix that relates the expected quantity of carcasses to sensitive features within, and adjacent to, affected waterways. Four thresholds of biomass (less than 100kg/ha, 100 to 250kg/ha, 250 to 500kg/ha and more than 500kg/ha) and four thresholds of proximity to sensitive features (within/adjacent, less than 1km, between 1km and 5km and more than 5km) have been selected to help determine risk and therefore priority for clean-up. Physical removal of Carp (both live Carp and Carp carcasses) also will be implemented in areas of high biomass with cold water pollution, for example, downstream of the Burrinjuck reservoirs, where the temperatures for activation and infection for the virus may be suboptimal.

Physical carcass removal/clean-up operations will likely be conducted only in the first year after the initial virus release. Clean-up activities will include five distinct steps:

1. Collection of carcasses from the water or shoreline,
2. Placement of carcasses into receptacles such as fish boxes, bags, skip bins, etc.,
3. Placement of full receptacles from the shoreline/boats into trucks, utes, trailers etc. for transport,
4. Transport full receptacles to processing facilities or pre-determined disposal locations, and
5. Empty carcasses from receptacles into the facility/disposal location.

A mixture of manual and mechanical techniques will likely be employed across the Murray-Murrumbidgee depending on waterway type and the expected quantity of carcasses. After the virus is released, contractors will be employed to patrol affected waterways within designated priority clean-up areas and conduct the clean-up activities. In the event of unexpected or very large fish kills, community groups may be engaged to assist the NCCP carcass removal operations.

Priority carcass management locations include areas above urban water treatment plants, water offtakes, areas around townships and high recreational use areas. Carcass removal operations at priority sites are expected to continue for several weeks following virus release and will cease when the quantity of carcasses collected per day falls below 100kg.

For the Murray-Murrumbidgee case study region, the following carcass management assumptions were applied  (The Wedge Group Pty Ltd, 2019):

- Release of the Carp virus will achieve a 60% knockdown of the Carp biomass in any one sub-population in Year 1.
- Carcass management resources will be deployed concurrently across multiple river reaches with a level of surge capacity available to mitigate impacts and risk sites.
- Carcass disposal will be to near-site surface composting facilities on leased, freehold land.

### *Other Assumptions*

The conceptual NCCP implementation plan is based on the following three key assumptions:

1. The NCCP be implemented over a three-year active period commencing when all statutory planning, environmental and budgetary approvals have been obtained.
    a. Year 1: implementation planning, communications and stakeholder engagement activities.
    b. Year 2 and 3: active resource mobilisation, management and administration.
2. Release of the virus will occur during a period of average river flows.
3. Carp virus release and carcass management will occur largely concurrently across the Murray and Murrumbidgee river system.

## Impacts of Carp Control in the Murray-Murrumbidgee System

### Overview

As described in Parts 1 to 3 of this report, the reduction of Carp biomass through implementation of the NCCP (release of CyHV-3 in Australian waterways) is likely to contribute to a number of medium- to long-term positive impacts, and some potential short-term negative impacts. These impacts will likely apply to both specific Carp affected ecosystems and the broader Australian community. In general, for the Murray-Murrumbidgee system, impacts of Carp control through the NCCP are likely to include:

### Short-Term Negative Impacts

Potential short-term negative impacts associated with the implementation of the NCCP were described previously in this report (see Part 4: Other Potential Impact Costs Associated with Virus Release). Though a number of potential negative socio-economic and ecological impacts were identified, the majority were considered to be low risk. Further, mitigation activities undertaken throughout implementation of the NCCP including planning, community engagement, and carcass management are likely to significantly reduce the risk and potential magnitude of such negative impacts.

Socio-economic impacts may include reduced amenity and community wellbeing and some negative economic impacts such as increased costs, reduced productivity and/or incomes. Possible ecological impacts include decreased populations of native aquatic species and increased risk of health impacts on livestock and native species, particularly birds. Refer to the relevant NCCP reports for further detail (*Biocontrol of European Carp: Ecological risk assessment for the release of Cyprinid herpesvirus 3 (CyHV-3) for Carp biocontrol in Australia, Volumes 1-3* (Beckett et al., 2019) and *Socio-economic impact assessment and stakeholder engagement* (Schirmer et al., 2019)).

### Medium- to Long-Term Positive Impacts

The medium- to long-term positive impacts associated with the reduction and ongoing suppression of Carp biomass in the Murray-Murrumbidgee system can be broadly categorised as:

1. Improved biodiversity outcomes (e.g. increased populations of native fish, other vertebrates such as waterbirds, invertebrates, and aquatic plants etc.), and
2. Improved water quality through reduced turbidity and erosion, improved biodiversity, and reduced incidence of algal blooms.

Direct impacts of Carp control are likely to result in a number of positive secondary impacts including:

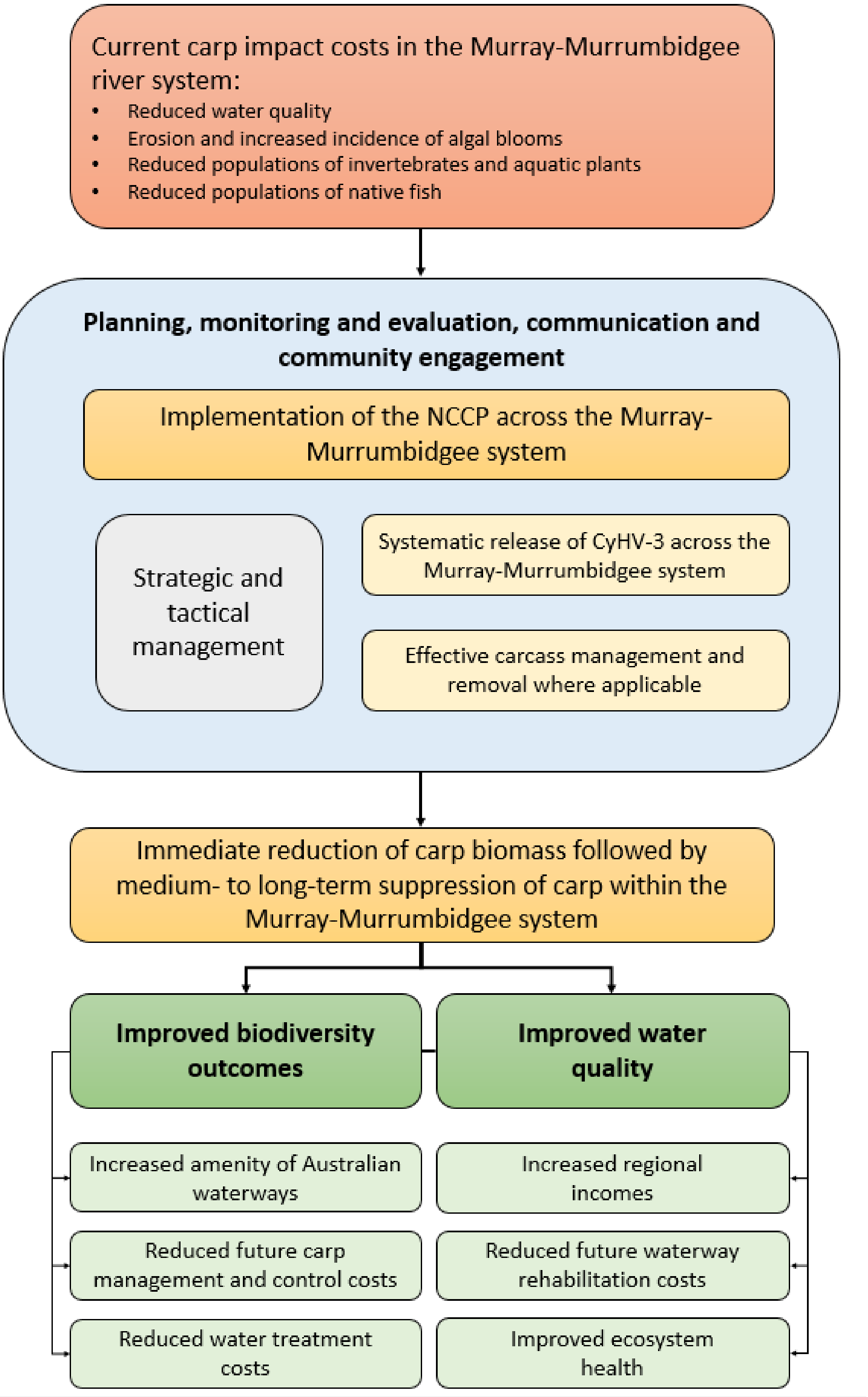
- Increased amenity of Australian waterways for residents, recreational fishers and tourists.
- Increased regional incomes driven by:
  - Enhanced cultural activities for traditional owners,
  - Growth in employment opportunities related to tourism and increased revenues for tourism businesses,
  - Expanded business opportunities for native aquaculture businesses, and
  - Increased profitability for fishing related businesses.
- Reduced water treatment costs.

- Overall improved ecosystem health and resilience, particularly for Australian wetlands.
- Reduced future Carp management and control costs.
- Reduced future costs associated with rehabilitation of Carp affected waterways.
- Potentially, increased productivity for some primary producers (livestock and cropping) through improved water quality.

## Pathways to Impacts

Figure 12 shows the pathway to impacts for Carp control through release of CyHV-3 in the Murray-Murrumbidgee system.

Figure 12: Pathways to Impact for Carp Control in the Murray-Murrumbidgee System



# A Cost-Benefit Analysis Framework for Implementation of the NCCP in the Murray-Murrumbidgee System

## Overview

Social CBA is a process of identifying, measuring and comparing the social benefits and costs of an investment, project or program such as the proposed NCCP. Two hypothetical states of the world are compared – the world **with** the proposed program, and the world **without** the proposed program (the counterfactual). The role of the CBA is to measure/ estimate the difference between the with and without scenarios and provide decision-makers with relevant information about the potential level and distribution of the proposed program's expected benefits and costs (Campbell & Brown, 2003).

Over the course of the current project, a number of key constraints were identified that prohibited credible quantification (valuation) of some of the costs and the benefits associated with the proposed future implementation of the NCCP. A primary constraint is the complexity and diversity of highly variable and interrelated factors that are sensitive to location, year, and environmental, ecological, and social conditions. Other constraints included a lack of existing data, available literature, and scientific evidence on which to base credible and robust assumptions for the estimation of some costs and benefits. Also, limited resources (time and project budget) that prevented the NCCP project teams from collecting new data or conducting additional research required to fill current cost and benefit information gaps. As a result of these constraints, NCCP management and the CBA project team agreed that the CBA report would focus on identifying the range of potential costs and benefits of implementing the NCCP in the Murray-Murrumbidgee system and would describe a CBA framework that could be used to undertake a full, quantitative CBA for the implementation of the NCCP at a regional level in the future.

The following sections describe a framework for undertaking a CBA for the proposed implementation of the NCCP in the Murray-Murrumbidgee system.

## Costs

Direct and indirect costs associated with the potential implementation of the NCCP in the Murray-Murrumbidgee system must be considered when comparing the costs and benefits of the proposed investment. The types of direct and indirect costs associated with implementation of the NCCP were identified and described previously in Part 4 (Potential Costs of Implementing Carp Control through the NCCP and Other Potential Impact Costs Associated with Virus Release). The following sections outline the specific NCCP cost considerations for the Murray-Murrumbidgee system.

### *NCCP Implementation Costs for the Murray-Murrumbidgee System*

Operational resources required to implement the NCCP across the Murray-Murrumbidgee river system over a three-year period were estimated on a reach by reach basis. Cost estimates then were developed using Expert Estimation Genesis software (The Wedge Group Pty Ltd, 2019). Operational requirements and associated costings were based on the NCCP implementation plan for the Murray-Murrumbidgee system described in NCCP Technical Paper #6 (*Implementation*).

The total estimated cost of implementing the NCCP across the Murray-Murrumbidgee region is approximately $191.3 million (2018/19 dollar terms) over three years. Primary costs incurred in Year 1 will be costs associated with implementation planning, communications and stakeholder engagement activities. Resource mobilisation, virus release, carcass management and post-release M&E would occur in Years 2 and 3. The operational resources and cost estimates for Year 3 were adjusted to reflect the reduction in total biomass from release of the virus in Year 2 (The Wedge Group Pty Ltd, 2019). For a detailed breakdown of the NCCP implementation costs for the Murray-

Murrumbidgee case study region refer to the relevant NCCP report (*National Carp Control Plan: Murray Murrumbidgee River Systems Case Study – Outcomes Report* (The Wedge Group Pty Ltd, 2019)).

For the purposes of the case study CBA framework, it was assumed that the virus would not be used tactically for further biocontrol of Carp 10 years after initial release of the virus in the Murray-Murrumbidgee system. However, should tactical use of the virus be considered in the future (e.g. CyHV-3 as a biocide for ongoing suppression of Carp biomass) additional costs, similar to those for implementation of the NCCP (e.g. planning and strategic management, virus deployment, carcass management, M&E etc.), would need to be considered.

#### *Contingency Costs*

Current NCCP management recognised that there is a risk that, during the active operational phase of the proposed NCCP, the virus may spread outside initial planning and control zones causing additional Carp mortalities that would require additional carcass management resources to be deployed quickly to mitigate potential negative impacts. NCCP management estimates that funds required for carcass management contingencies would be approximately $12.5 million for a period of one year for the Murray-Murrumbidgee case study region. This estimate was based on a 30% contingency on the approximate carcass management costs for Year 1 (Karl Mathers, pers. comm., 2019).

### ***Other Costs Associated with NCCP Implementation in the Murray-Murrumbidgee system***

#### *Post-Implementation Monitoring and Evaluation*

Australia wide, long-term M&E will be required to assess ongoing impacts of CyHV-3 on the Australian carp population and to monitor changes in ecosystem health post-virus release. The NCCP estimates that the additional cost of such M&E activities will be (Jamie Allnutt, pers. comm., 2019):

- $1.0 million per year for 10 years for NSW and the Australian Capital Territory (ACT), and
- $0.5 million per year for 10 years for VIC, SA, and QLD.

For the Murray-Murrumbidgee system that covers areas of NSW, VIC and SA, the estimated M&E cost would be approximately $2 million per year for 10 years.

#### *Short-Term Negative Impact Costs*

Potential short-term negative impact costs associated with the proposed implementation of the NCCP across the Murray-Murrumbidgee region may include:

- Loss of amenity for residents, recreational fishers, and/or tourists.
- Reduced wellbeing for traditional owners, commercial Carp fishers and other fishers, Koi hobbyists, breeders and supply businesses, and residents and other businesses that rely on Carp affected waterways for income.
- Reduced regional incomes due to increased costs, reduced demand or market access, and/or reduced employment.
- Increased water treatment costs, particularly in the event of high levels of ammonia.
- Increased risk of productivity loss for primary producers.
- Damage to public and/or private land and waterways accessed for implementation of the NCCP and subsequent carcass management activities.

- Potentially, increased costs for waterway and land rehabilitation for private landholders and/or local governments in Carp affected areas.
- Decreased populations of native aquatic species.
- Cyanobacterial blooms, exposure to decomposition microorganisms, and potential outbreaks of botulism may also affect livestock and humans.
- Resurgence of other invasive animal and plant species.

## Non-market costs

Loss of amenity, reduced wellbeing, and decreased populations of native aquatic species are considered non-market impacts and valuation would require the application of appropriate non-market valuation techniques or benefit transfer. In the case of decreased numbers of native fish, the WTP study described in Part 3 of this report could potentially be used to indirectly estimate the expected value of a decrease in native fish numbers. However, as the original study focused on Australian households' WTP for an improvement in environmental outcomes through a reduction in carp biomass, an extended set of appropriate assumptions and qualifications would have to be made.

## Market costs

Reduced regional incomes, increased water treatment costs, increased risk of productivity loss, damage to public/ private land, increased waterway rehabilitation costs and potential negative health impacts on livestock and humans could be estimated using market-based data. The following outlines some of the types of data and assumptions that would be required for estimation of such market costs.

### Reduced regional incomes

To estimate the impact of short-term reductions in regional incomes associated with the virus release would require, at a minimum:

- Data on the type and number of businesses/ individuals negatively affected by release of CyHV-3 in the Murray-Murrumbidgee region,
- Estimates of likely negative changes to net profits/ income/ employment that would occur as a direct result of release of the virus across the Murray-Murrumbidgee system, and
- Information on the extent of the time period over which such changes are likely to occur.

### Increased water treatment costs

An NCCP research project, led by Water Research Australia, developed a water treatment cost calculator that would enable the additional costs of water treatment for a particular virus release and carcass management scenario to be estimated. Best- and worst-case scenarios could be used to calculate a range of expected additional water treatment costs for the Murray-Murrumbidgee system based on the planned release and carcass management strategies provided by the NCCP. However, use of the calculator requires knowledge of appropriate water treatment methods and chemical input costs.

### Increased risk of productivity loss for primary producers

To estimate the potential impact of implementation of the NCCP on primary producers in the Murray-Murrumbidgee region would require, at a minimum:

- Data on the number and type of primary producers drawing water for irrigation, or using water for livestock, sourced from CyHV-3 affected waterways,
- Data on the existing water quality in the Murray-Murrumbidgee system and data on current productivity levels (e.g. crop yields, farm gross margins, commodity prices, and economic return per ha or per tonne),

- An estimate of current productivity losses attributable to poor water quality (including decreases in water quality caused by adverse events such as algal blooms) and an estimate of the relationship between changes in water quality and changes in productivity for various agricultural commodities (e.g. broad acre cropping, beef cattle, dairy cattle, etc.),
- An estimate of the likely change in water quality for relevant water sources across the Murray-Murrumbidgee region after release of the Carp virus, and
- Information on extent of the time period over which changes would be likely to occur and any longer-lasting impacts.

**Damage to public/ private land and waterways and increased costs of rehabilitation**

Estimating the costs associated with damage to land and waterways and increased future costs of rehabilitation would require, at a minimum:

- Data on the likely location, type and magnitude of damage to land and waterways (e.g. riverbanks where vehicle and machinery access may be required for carcass management post-virus release),
- Data on the costs (including time and resources) associated with repairing any damage or compensating landholders for the damage, and
- An estimate of the additional costs incurred to rehabilitate waterways/ regions impacted by CyHV-3 (e.g. revegetation, restocking of native fish, etc.) that would not have been incurred without implementation of the NCCP (i.e. rehabilitation costs specifically attributable to the release of the Carp virus).

**Negative health impacts for livestock and humans**

Negative health impacts for livestock could be measured through productivity changes (e.g. increased stock losses due to disease caused by release of the Carp virus and subsequent mass fish deaths). Human health impacts could be valued through estimation of medical costs associated with changes in health resulting from incidence of disease caused by release of CyHV-3 or exposure to waterborne bacteria/ microorganisms/ pathogens attributable to the death and decomposition of Carp in waterways throughout the Murray-Murrumbidgee region.

The estimation of health impact costs also would require assumptions about the relationship between implementation of the NCCP and changes in water quality, incidence of disease, and increases in waterborne bacteria etc.

### *Cost Mitigation through Utilisation of Carp Biomass in the LRC*

Costings for implementation of the NCCP in the Murray-Murrumbidgee system assume that any physical removal of Carp carcasses at priority sites will involve disposal of carcasses at near-site (within 10 km) surface composting facilities on leased, freehold land (Jennifer Marshall, pers. comm, 2019). Any positive impacts stemming from the use of composted Carp material in the future would offset a component of the NCCP's carcass management costs in the Murray-Murrumbidgee region.

## Benefits

Potential short-, medium-, and long-term positive impacts (benefits) associated with the potential implementation of the NCCP in the Murray-Murrumbidgee system must be considered when comparing the costs and benefits of the proposed investment. The primary types of benefits associated with implementation of the NCCP were identified and described previously in Part 4 (Benefits of Carp Control through the NCCP). The following sections outline the specific NCCP benefit considerations for the Murray-Murrumbidgee system.

### *Benefits of NCCP Implementation for the Murray-Murrumbidgee System*

#### *Short-Term Benefits*

Based on the current NCCP Implementation strategy for the Murray-Murrumbidgee system there are unlikely to be any significant short-term net benefits associated with release of the Carp virus. That is, the costs of implementation of the NCCP (including short-term negative impacts of CyHV-3 such as reduced amenity and regional incomes) are likely to exceed any short-term positive impacts, such as temporary increases to employment created by Carp control activities, over the proposed three year period of the NCCP.

#### *Medium- and Long-Term Benefits*

The primary medium- to long-term categories of benefits associated with the reduction and ongoing suppression of Carp biomass in the Murray-Murrumbidgee system will be associated largely with improved biodiversity outcomes and improved water quality across the system (see Figure 12 for a graphical representation of likely pathways to impacts).

Direct benefits of Carp control are likely to result in a number of positive secondary benefits including:

- Increased amenity of rivers and waterbodies in the Murray-Murrumbidgee system for residents, recreational fishers and tourists.
- Increased regional incomes across the Murray-Murrumbidgee region driven by:
  - Enhanced cultural activities for traditional owners,
  - Growth in employment opportunities related to tourism and increased revenues for tourism businesses,
  - Expanded business opportunities for native aquaculture businesses, and
  - Increased profitability for fishing related businesses.
- Reduced water treatment costs.
- Overall improved ecosystem health and resilience, particularly for wetlands such as the Ramsar wetlands, Kerang lakes, and Hattah lakes.
- Reduced future Carp management and control costs across the Murray-Murrumbidgee system.
- Reduced future costs associated with rehabilitation of Carp affected waterways.
- Potentially, increased productivity for some primary producers (livestock and cropping) through improved water quality.

### *A Framework for the Potential Valuation of Benefits*

Similar to the estimation of costs associated with implementation of the NCCP, benefits of the implementation of the proposed NCCP may be valued by applying various economic techniques. In general, estimation of benefits that may occur because of the release of CyHV-3 requires:

- A baseline estimate of the current, total impact costs of Carp for the Murray-Murrumbidgee system (see Part 4: Estimation of Total, Current Impact Costs of Carp).
- Evidence of the relationship between the release of the Carp virus and the subsequent reduction and suppression of the carp biomass.
- Evidence of the specific relationship between reduced carp biomass and each of the key drivers of positive impacts (such as improved water quality, increased numbers of native fish, etc.). That is, what change (type and magnitude) would occur because of the reduction in carp biomass.

  For example, if the Carp biomass in a particular reach of the Murray-Murrumbidgee was reduced by 60% by the end of implementation of the NCCP, and the resulting level of Carp biomass was maintained for the next 10 years, how many additional native fish (number of native fish per km of river) would be present in that given reach after 10 years if all other factors were held at their base values.
- Data on the value or prices associated with the change (e.g. WTP values for particular increases in native fish numbers, see Part 3 Part 3: A Choice Modelling Study to Estimate the Non-Market Impact Costs of Carp and the Non-Market Benefits of Carp Control).
- Information on how the current impact costs of Carp may change without the implementation of the proposed NCCP (the counterfactual).

Research conducted through the NCCP was able to provide data to fulfill some of the CBA information needs listed above. For example, significant NCCP research was undertaken to investigate the relationship between the proposed release of CyHV-3 and the Carp biomass for different regions around Australia. Also, the market and non-market economic analyses conducted in the current CBA project produced data that could contribute to estimates for a number of the potential impact costs and benefits of Carp and Carp control via the proposed NCCP.

However, through the current CBA project, NCCP management and the CBA project team found that current knowledge of the relationship between changes in Carp biomass and changes in the key drivers of potential benefits such as turbidity and key environmental attributes (for example, increases in numbers of native fish, numbers of waterbirds, and areas of healthy wetlands) was not adequate to allow for a credible estimate of the baseline (current) impact costs of Carp to be made for the Murray-Murrumbidgee case study region within the scope of the current project. Further, although expert opinion was sought (see NCCP report *NCCP: The Likely Medium- to Long-Term Ecological Outcomes of Major Carp Population Reductions* (Nichols et al., 2019)) the NCCP found that there was not enough credible, science-based evidence to provide quantitative estimates of the magnitude of changes that may result from implementation of the NCCP over the medium- to long-term (for example, how many additional native fish per km of river will be present in the Murray-Murrumbidgee system as a result of release of CyHV-3 in 10 years' time).

As a result of the lack of data, and constraints on project resources, the follow sections qualitatively describe the potential benefits of Carp control using CyHV-3 in the Murray-Murrumbidgee system and outlines how such benefits may be valued in the future if additional data become available or additional research is undertaken to fill key information gaps.

### *Non-Market Benefits*

A number of the benefits identified previously could not be valued using traditional market mechanisms and would require the application of appropriate and specific non-market economic techniques. Such benefits include:

- Increased amenity for residents, recreational fishers and/or tourists, and
- Increased ecosystem health and resilience.

Some attributes of improved ecosystem health were addressed by the CM study described in Part 3 of this report. The CM study estimated household WTP for improvements (increases) in three key environmental attributes:

1. Numbers of native fish (measured as number of fish per km of river),
2. Numbers of native waterbirds (measured as an overall number of birds), and
3. Area of healthy wetland (measured as the area of wetland free of Carp).

The WTP estimates produced by the CM study, with appropriate assumptions and qualifications, may be used to estimate the value of improved ecosystem health (using the three specific attributes studied) in any future CBA if information on the relationship between reduced Carp biomass and each attribute becomes available.

### *Market Benefits*

Other benefits identified for the Murray-Murrumbidgee case study may potentially be estimated using market mechanisms.

#### Increased regional incomes

The data and assumptions required to estimate the benefit of increased regional incomes associated with the reduction of Carp biomass in the Murray-Murrumbidgee would be of a similar nature to the information requirements used to estimate the short-term negative impact costs associated with reduced regional incomes during and immediately after implementation of the NCCP. Estimation of medium- to long-term benefits from increased regional incomes would require, at a minimum:

- Data on current and futures types and numbers of businesses/ individuals affected by release of CyHV-3 in the Murray-Murrumbidgee region (both positively and negatively affected),
- Estimates of likely changes (positive and negative) in net profits/ income/ employment that would occur as a direct result of release of the virus across the Murray-Murrumbidgee system, and
- Information on the on extent of the time period over which any such changes are likely to occur.

#### Reduced water treatment costs

As for the short-term negative impact costs associated with increased water treatment costs because of implementation of the NCCP, reduced water treatment costs from improved water quality in the medium- to long-term could be estimated using Water Research Australia's water treatment cost calculator. To estimate the benefits of reduced water treatment costs also would require assumptions/ information about:

- Baseline data on water quality levels for source water in different reaches across the Murray-Murrumbidgee river system,
- Data on current and likely future costs of water treatment,

- Data on the relationship between reduced carp biomass and improved water quality (e.g. reduced turbidity levels, reduced organic matter and other chemical/nutrient levels attributable to the reduction of Carp biomass), and
- Information on the on extent of the time period over which any changes are likely to occur.

### Reduced future Carp management and control costs

Estimation of the benefits of reduced future Carp management and control costs would require, at a minimum:

- Information on the type and magnitude of Carp management and control activities likely to occur post-implementation of the NCCP,
- Data on the current and potential future costs of Carp management and control activities post-implementation, and
- Information on the on extent of the time period when future Carp management and control activities are likely to occur.

### Reduced future land/ waterway rehabilitation costs

To estimate the value of medium- to long-term reductions in the future costs of land and waterway rehabilitation because of reduced Carp biomass would require, at a minimum:

- Information on the likely type, magnitude and location of current and potential future land and water rehabilitation activities likely to occur after implementation of the NCCP,
- An estimate of the current and potential future costs of land and water rehabilitation activities, and
- Information on the on extent of the time period over which any rehabilitation activities would occur.

### Increased productivity for some primary producers

Estimating the benefits associated with potential increased productivity for some primary producers from improved water quality in the Murray-Murrumbidgee region would require, at a minimum:

- Data on the current and potential future numbers and types of primary producers drawing water for irrigation, or using water for livestock, sourced from CyHV-3 affected waterways,
- Data on the existing water quality in the Murray-Murrumbidgee system and data on current productivity levels (e.g. crop yields, farm gross margins, commodity prices, and economic return per ha or per tonne),
- An estimate of the likely positive change in water quality for relevant water sources across the Murray-Murrumbidgee region attributable to the release of the Carp virus,
- Data on the relationship between water quality changes and changes in productivity for various agricultural commodities (e.g. broadacre cropping, beef cattle, dairy cattle, etc.), and
- Information on the on extent of the time period over which any positive changes would be likely to occur.

### *Other CBA Considerations*

*Risk Factors*

To ensure a complete economic model to estimate the expected impact of implementation of the NCCP within the Murray-Murrumbidgee, risk factors along the pathways to impacts will need to be identified and estimated.

Pre-Release

Risk factors that may affect the implementation and successful impact of the NCCP, pre-release of the virus, may include:

- Successful of virus propagation, transport and secure storage of viable CyHV-3 for release.
- Availability of resources for NCCP implementation (e.g. specialist and non-specialist personnel, processing and disposal facilities, equipment, etc.).
- Policy or regulatory change (future implementation of the NCCP could be affected by policy or regulation change at any level of government).
- Negative community attitudes and pushback against implementation of the NCCP.

During Implementation (Release and Carcass Management)

There are several risk factors that may affect costs and potential benefits given implementation of the NCCP within the Murray-Murrumbidgee system. Implementation risk factors may include:

- Low virus efficacy resulting in poor Carp mortality rates. This could be due to prevailing climate conditions (e.g. temperature) contrary to near-release forecasts or an unexpected epidemiological response contrary to modelled predictions.
- Availability of contractors for carcass clean-up.
- Physical access to waterways at priority clean-up sites.
- Ability to react to large fish kills fast enough to mitigate potential negative impacts (e.g. blackwater events).
- Capacity to manually or mechanically remove enough Carp biomass to mitigate potential negative impacts at priority clean-up sites.
- Availability of processing and disposal sites and resources for transporting and, potentially, storing dead Carp.

Post-implementation

Assuming successful implementation of the NCCP. There may be exogenous factors that affect the actual realisation of benefits in the short- and long-term after implementation of the NCCP in the Murray-Murrumbidgee region. Such risk factors may include:

- Climate and other environmental factors.
- Competition with native fish and other flora/fauna species because of increases to populations of other invasive species (e.g. tilapia).
- Incidence of disease in native fish or bird populations.

Such factors may reduce or negate some of the positive impacts potentially associated with Carp control in the Murray-Murrumbidgee system. For example, climate, competition or disease could prevent the recovery of native fish and waterbird populations even in the absence of Carp in regional waterways.

### Summary

The potential future benefits of implementation of the NCCP in the Murray-Murrumbidgee case study region are inherently uncertain. Therefore, a complete and detailed economic model to estimate the benefits and costs of Carp control through the use of CyHV-3 in the Murray-Murrumbidgee system would need to estimate the magnitude of various risks along the pathways to impacts and apply those risk values to relevant costs and benefits. This process would result in the estimation of **expected** values for the CBA.

## The Counterfactual

As described previously, given a proposed investment, project or program such as the proposed NCCP, the role of a CBA is to measure/ estimate the difference between the 'with' and 'without' investment scenarios and provide decision-makers with relevant information about the potential level and distribution of the proposed investment's expected benefits and costs.

Defining the 'without intervention' scenario (the counterfactual) to assist with describing and quantifying impacts is often one of the more difficult steps to make in any CBA. The 'without' scenario usually lies somewhere between the status quo or business as usual case, and the more extreme position that the intervention would have happened anyway (but at a later time), or that the benefits would have been delivered anyway through another mechanism. An important issue is that the definition of the 'without' scenario is made as consistently as possible between analyses.

Various forms of Carp control have been researched and/or implemented in Australian waterways since the 1970s. For example, physical removal (e.g. Carp fishing competitions) and investments in genetic research, such as the daughterless Carp initiative, have been funded in an effort to reduce Carp numbers. However, such techniques, particularly in the absence of a nationally coordinated approach to Carp control, have not been effective at significantly reducing the Carp biomass to date.

Due to the current lack of alternative and viable control methods available, the primary counterfactual assumed for the Murray-Murrumbidgee CBA case study is that, without the proposed NCCP, biocontrol of Carp within the catchment would not take place. That is, without implementation of the NCCP, CyHV-3 would not be released in the Murray-Murrumbidgee system and Carp control would continue as it has in the past using conventional, ad-hoc physical removal methods (status quo).

Based on this primary counterfactual assumption, specific definition and estimation of the counterfactual for a CBA associated with implementation of the NCCP in the Murray-Murrumbidgee system would require, at a minimum, data associated with:

- The most likely scenario for water quality and biodiversity conditions across the Murray-Murrumbidgee system (including rivers and waterbodies).
- What would most likely happen to the income of businesses/ individuals in affected regions without release of the virus.
- Likely livestock and human health outcomes in the region over time in the absence of CyHV-3.
- Current and likely future costs of Carp management and control in absence of Carp virus release.
- Current and likely future costs of land and waterway repair and rehabilitation activities in the absence of the Carp virus.
- Current and likely future productivity levels for primary producers in affected regions of the Murray-Murrumbidgee system without the release of the virus.

- The opportunity cost of time spent for those involved in the planning, implementation and ongoing M&E of the NCCP over the three-year implementation period.
- Any risk factors that may apply to costs and benefits in the absence of the proposed NCCP.

## Aggregation and Estimation of Investment Criteria for the NCCP in the Murray-Murrumbidgee System

Following the identification and estimation of the full suite of costs and benefits associated with the proposed implementation of the NCCP in the Murray-Murrumbidgee case study region and the counterfactual scenario, taking risk factors along the pathways to impacts into account, the expected costs and benefits **with** the proposed NCCP investment could be compared to the expected costs and benefits **without** the proposed NCCP investment. This comparison would facilitate the estimation of investment criteria for appraisal of the proposed investment in the Murray-Murrumbidgee system. Investment criteria would include the expected NPV, BCR, IRR and the Modified IRR. In general, an NPV greater than zero and a BCR greater than one would indicate positive returns to the proposed investment. Further definitions of the economic terms can be found in the Glossary section of this report.

It should be noted that an economic model of this nature is only as good as the data and assumptions that underpin it. A key limitation of any regional CBA study for the proposed implementation of the NCCP is the need for, and attainability of, data on multi-year weather-driven hydrological conditions which drive carp impacts, and ecological and economic outcomes with or without release of CyHV-3. However, by providing a template for the estimation of investment criteria, further appraisal of the proposed investment using available data closer to potential release can be facilitated should the decision be taken to advance the NCCP.

# Discussion & Conclusion

The current project aimed to identify and estimate the total, current impact cost of Carp in Australia (particularly for the MDB) and to identify, estimate and compare the expected costs and benefits of Carp biocontrol through implementation of the proposed NCCP for the Murray-Murrumbidgee case study region.

Smith (2005) noted: '*Two factors make it difficult to assess the effects of Carp in natural systems. First, Carp have been established in most parts of the MDB for several decades and documented information on the condition of river and wetland environments before their introduction is scarce. Thus, true 'before and after' comparisons are not possible. Second, the establishment of Carp in Australia was preceded, and assisted, by co-occurring anthropogenic influence.'*

Further, Koehn, Brumley & Gehrke (2000) found that many of the ecological and economic impacts of Carp are covariate with other factors, and it is difficult to identify the proportion of costs directly attributable to Carp.

Over the course of the CBA process, a number of key constraints were identified that prohibited credible estimation of the total, current impact costs of Carp and quantification (valuation) of some of the costs and the benefits associated with the proposed implementation of the NCCP. Thus, the CBA report has focused on identifying the categories of potential impact costs of Carp in Australia, and the categories of potential costs and benefits of implementing the NCCP in the Murray-Murrumbidgee system.

The report also provides market and non-market impact cost data and describes a CBA framework that could be used to undertake a full, quantitative CBA for the implementation of the NCCP at a regional level in the future. Such regional level CBAs could be used to demonstrate the value of the proposed NCCP investment to decision-makers and other stakeholders. Regional level CBAs, such as the Murray-Murrumbidgee case study region, also could be aggregated to estimate the total potential costs and benefits of the NCCP at a national scale (noting that this form of aggregation would not take into account economies of scale that may be achieved through implementation of the NCCP at a national level).

CISS (2012) concluded that: *'Despite limitations in the methods used in trying to determine the impacts of Carp, it is impossible to conclude that our inland ecosystems would not be better off without them. Carp are certainly consuming resources that could otherwise be available to native species'.*

Though the full range of costs and benefits could not be quantified within the scope of the current study, the report provides useful information on the likely costs and benefits associated with the NCCP that may help to inform decision-makers and stakeholders about the current impact of Carp in Australia and the potential impacts of Carp biocontrol through the release of CyHV-3 in Australian waterways.

# Recommendations

One of the most critical information gaps identified through the CBA process was the lack of available data/scientific-evidence associated with the potential relationship between reductions in Carp biomass and the drivers of key medium- and long-term impacts such as changes in water quality (e.g. reduced turbidity) and biodiversity outcomes (e.g. increased numbers of native fish and waterbirds, and increased areas of healthy wetlands).

Any future CBA would benefit from additional research, or further elicitation of expert opinion, to quantify these relationships. Ideally, this would include information that might elucidate the relationships between Carp, other introduced species, anthropogenic impacts to Australian ecology and various environmental outcomes. This would facilitate collation of credible estimates of the likely benefits of Carp biocontrol via implementation of NCCP.

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# Glossary

| | |
|---|---|
| Cost-Benefit Analysis | A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue. |
| Benefit Transfer | A practice used to estimate economic values for ecosystem services by transferring information available from studies already completed in one location or context to another. |
| Benefit-Cost Ratio | The ratio of the present value of investment benefits to the present value of investment costs. |
| Choice Modelling | a 'stated preference' technique that can be used to estimate non-market environmental benefits and costs. It involves a sample of people, who are expected to experience the benefits/costs, being asked a series of questions about their preferences for alternative future resource management strategies |
| Contingent Valuation | a method of estimating the value that a person places on a good. The approach asks people to directly report their willingness to pay (WTP) to obtain a specified good, or willingness to accept (WTA) to give up a good, rather than inferring them from observed behaviours in regular market places. |
| Discount Rate | the interest rate used in discounted cash flow analysis to determine the present value of future cash flows. |
| Discounting | The process of relating the costs and benefits of an investment to a base year using a stated discount rate. |
| Internal Rate of Return | The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs. |
| Market Impact | Impact costs and benefits that can be measured using traditional market mechanisms (e.g. market price). |
| Modified Internal Rate of Return | The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate). |
| Net Present Value | The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs. |
| Non-Market Impact | Changes to goods and services not traded in traditional markets (e.g. amenity, welfare, etc.) |
| Present Value | the current value of a future sum of money or stream of cash flows given a specified rate of return. |
| Present Value of Benefits | The discounted value of benefits. |
| Present Value of Costs | The discounted value of investment costs. |
| Revealed Preference | a method of analysing choices made by individuals, mostly used for comparing the influence of policies on consumer behaviour. Revealed preference models assume that the preferences of consumers can be revealed by their purchasing habits. |
| Stated Preference | a family of techniques that use individual respondents' statements about their |

preferences in a set of options to estimate utility functions.

# Appendices

## Appendix 1: Original Project Objectives

The initial contract between Agtrans Research and FRDC for Project 2016-132 (Impact Costs of Carp and Expected Benefits & Costs Associated with Carp Control in the Murray Darling Basin) was fully executed in the second half of calendar 2017. In the original contract the project objectives and schedule were as follows:

1. Quantify the current and future costs of Carp being present in Australia by sector of the community affected.

2. Calculate the likely benefits of addressing Carp impacts in Australia through the National Carp Control Plan (NCCP) (in market and non-market value terms).

3. Specify the distribution of costs and benefits of different community groups.

4. Form strong links with the parallel NCCP risk management project (project code: 2017-054) with regard to exchange of information on risk management issues and cost and benefit information.

5. Work closely with other project teams to quantify costs of implementing the NCCP once methods are defined; this will allow the total benefits of control to be compared with total costs of implementing the NCCP.

6. Submit a draft report to the NCCP National Coordinator by June 2018 that addresses the likely benefits and costs of proceeding with the NCCP.

7. Prepare a second report of likely benefits and costs of implementing the NCCP that contributes to a Cabinet Submission in September 2018.

# Appendix 2: Pilot Survey Summary & Findings

## Overview

Information on the potential market impact costs of Carp was synthesised following a desktop literature review (see Part 1: Desktop Literature Review). Based on the types of potential impacts identified an informal market cost pilot survey for primary water users was developed. The pilot survey was carried out using both email and phone interviews. Responses to the pilot survey then were used to inform a more detailed survey to identify and estimate the current market impact costs of Carp in Australia without the potential release of the CyHV-3 virus.

## Method

Approximately 20 primary water users (including irrigators, irrigation/ water authorities, and water treatment plants) were contacted across QLD, NSW, VIC, and SA. Contact was first made via phone so that the NCCP CBA project team could explain the purpose and details of the pilot survey. Following successful phone contact, respondents were sent an email containing the pilot survey questionnaire. The questions posed differed depending on the type of primary water user being surveyed. The following sections outline the specific questions asked of the survey respondents.

### *Survey Respondents*

The following organisations were contacted for the pilot survey questionnaire:

- Cotton Australia (re irrigation)
- The Irrigation Research & Extension Committee
- Horizon Farming Pty Ltd (a lead contact for SA dairy irrigators)
- Dairy Australia (re irrigation)
- The Australian Rice Growers' Association (re irrigation)
- Coliban Water Victoria (water treatment plant)
- Rice Research Australia Pty Ltd (re irrigation)
- Scott Williams (primary producer/irrigator)
- Murrumbidgee Irrigation

### *Pilot Survey Questionnaire 1: Water Treatment Plants*

The following pilot questions were posed to respondents that identified as representatives of water treatment plants.

1. Please state your source/s of water for water treatment.
2. Does increased turbidity/sediment in your source of raw water increase water treatment costs? If so, what are the sources of the increased costs? (for example, increase alum costs, electricity, labour costs, filtration per flocculation cycle).
3. Do treatment costs for treating source/raw water turbidity vary with the level of turbidity in the source water? If so, what are the costs per millilitre (in terms of increased/decreased NTU) e.g. increased of NTU from 100 NTU to 500 NTU increase treatment costs by X amount or X%?

4. Is there any increase in capital expenditure on water treatment facilities as a result of higher turbidity?
5. Are there any additional costs to treating source water for blue-green algae due to increases in the intensity of the blooms? If so, what are the increased costs (in dollar terms or %)?
6. Is there a threshold level of algal blooms/blackwater events that would require the water treatment facility to shut down?
7. Would mass fish deaths be an issue for water treatment? (e.g. in terms of smell, blackwater, nutrients). What are the associated costs for water treatment plants because of mass fish deaths?

### *Pilot Survey Questionnaire 2: Irrigation/ Water Authorities and Irrigators/Primary Producers in Carp Affected Regions*

The following pilot questions were posed to respondents that identified as representatives of irrigation/ water authorities or irrigators/ primary producers in Carp affected regions.

1. Please state your source of water for irrigation.
2. Do Carp directly affect your irrigation operations or increase your costs of water delivery (i.e. – maintenance, pump blocking)?
3. If Carp do affect your operations, what are the estimated costs per year? These may be approximate costs and expressed in any units appropriate (e.g. mL, km of channel, days etc.).
4. Do Carp affect your costs of maintaining irrigation channels? If yes, what are the additional costs?
5. Is there a particular level of turbidity/sediment at which irrigation pumps become blocked?
6. If they become blocked, what are the costs for operations (for example, in terms of pump downtime, increase maintenance costs)?
7. Does the presence of algal blooms in irrigation source water affect your farm operations? If so, can you make an estimate of the impact on farm profitability due to the presence of algal blooms (i.e. increased costs, reduced yields, reduced quality, livestock health)?

## Key Findings

The informal pilot survey found that irrigation/ water authorities and irrigators/primary producers did not perceive Carp to be a notable problem. All such respondents indicated that Carp either did not have a direct effect on irrigation operations or that their impact was negligible. However, one respondent stated:

> *"…the only real and substantial cost I see is related to the damage they do instream which effects river health and water quality and then we have lost entitlement over time and the community has lost water through the MDBA trying to reduce these impacts.*
>
> *We do from time to time have issues with Carp blocking syphons when they are prolific but that would be the only direct impact I could see."*

Water treatment plants were more likely to be affected by Carp however, respondents indicated that, given the underlying conditions in various water sources, it was unlikely that Carp contribute to turbidity is such a way as to significantly impact water treatment costs.

### *Next Steps*

The informal responses obtained through the pilot survey process were used to develop a more detailed questionnaire for the formal market impact costs of Carp survey conducted in January 2019.

# Appendix 3: Market Cost Survey Summary & Findings

## Overview

Feedback from the initial, informal pilot survey (Appendix 2: Pilot Survey Summary & Findings) was used to develop a final, comprehensive market cost survey that was distributed by email in January of 2019. Responses from the final market cost survey were recorded in a Microsoft Excel® spreadsheet. Results then were organised, aggregated and assessed by primary water user type and by region. The resulting data on the current impact costs of Carp, without the potential release of CyHV-3, were then used to inform the CBA for the Murray-Murrumbidgee case study (Part 4: Synthesis).

## Method

Three separate survey questionnaires were developed, each tailored to a particular primary water user group (irrigators, irrigation/ water authorities, and water treatment plants). Potential survey respondents were identified through consultation with NCCP personnel (including state representatives) and the pilot survey.

The market impact costs of Carp surveys were sent to a total of 83 potential respondents (14 irrigators, 16 irrigation/ water authorities, and 53 water treatment plants). Respondents were distributed spatially across QLD (8 potential respondents), NSW (45), VIC (20), SA (3) and other regions (7). The surveys were conducted by email over the period 15 January to 8 February 2019.

The following sections outline the specific questions asked of the survey respondents.

### *Survey Respondents*

Table 3.1 lists the organisations were contacted to complete the market impact costs of Carp survey questionnaire. In the table, 'I' indicates an irrigator/primary producer, 'IA' indicates an irrigation/ water authority, and 'WTP' indicates a water treatment plant respondent.

Table 3.1: Market Impact Costs of Carp - Survey Respondents

| WTP/I/IA | State/Region | Organisation | Date Sent |
|---|---|---|---|
| I | Australia | National Irrigators Council | 18/01/2019 |
| I | MDB | Murray Darling Association | 18/01/2019 |
| I | NSW | Gwydir Valley Irrigators Association | 18/01/2019 |
| I | NSW | Upper Namoi Cotton Growers Association | 18/01/2019 |
| I | NSW | Lower Namoi Cotton Growers Association | 18/01/2019 |
| I | NSW | Lachlan Valley Water | 18/01/2019 |
| I | NSW | Murrumbidgee Food and Fibre Association | 18/01/2019 |
| I | NSW | Southern Riverina Irrigators | 18/01/2019 |
| I | NSW | NSW Irrigators Council | 18/01/2019 |
| I | NSW | Namoi Water | 18/01/2019 |
| I | QLD | Darling Downs Cotton Growers Association | 18/01/2019 |
| I | VIC | Victorian Farmers Federation | 18/01/2019 |
| I | Australia | Irrigation Australia | 21/01/2019 |
| I | Australia | Cotton Australia | 21/01/2019 |
| IA | VIC | Southern Rural Water | 15/01/2019 |
| IA | VIC | Goulburn Murray Water | 15/01/2019 |

| | | | |
|---|---|---|---|
| IA | NSW | Jeelong Irrigation | 16/01/2019 |
| IA | NSW | West Corurgan Irrigation | 16/01/2019 |
| IA | NSW | Murrumbidgee Irrigation | 16/01/2019 |
| IA | NSW | Coleambally Irrigation Co-operative | 16/01/2019 |
| IA | NSW | Buddah Lake Irrigators Association | 16/01/2019 |
| IA | NSW | Western Murray | 16/01/2019 |
| IA | NSW | Murray Irrigation | 16/01/2019 |
| IA | NSW | Narromine Irrigation | 16/01/2019 |
| IA | NSW | Moira Private Irrigation | 16/01/2019 |
| IA | NSW | Trangie Nevertire Irrigation | 16/01/2019 |
| IA | SA | Renmark Irrigation | 16/01/2019 |
| IA | SA | Central Irrigation Trust | 16/01/2019 |
| IA/WTP | VIC | GWM Water | 23/01/2019 |
| IA/WTP | VIC | Lower Murray Water | 23/01/2019 |
| WTP | Australia | Water Research Australia | 15/01/2019 |
| WTP | VIC | Barwon Water | 23/01/2019 |
| WTP | VIC | Central Highland Water | 23/01/2019 |
| WTP | VIC | City West Water | 23/01/2019 |
| WTP | VIC | Coliban Water | 23/01/2019 |
| WTP | VIC | East Gippsland Water | 23/01/2019 |
| WTP | VIC | Gippsland Water | 23/01/2019 |
| WTP | VIC | Goulburn Valley Water | 23/01/2019 |
| WTP | VIC | Melbourne Water | 23/01/2019 |
| WTP | VIC | North East Water | 23/01/2019 |
| WTP | VIC | South East Water | 23/01/2019 |
| WTP | VIC | South Gippsland Water | 23/01/2019 |
| WTP | VIC | Wannon Water | 23/01/2019 |
| WTP | VIC | Western Water | 23/01/2019 |
| WTP | VIC | Westernport Water | 23/01/2019 |
| WTP | VIC | Yarra Valley Water | 23/01/2019 |
| WTP | ACT | Icon Water | 24/01/2019 |
| WTP | N SW | Hilltops Council | 24/01/2019 |
| WTP | NSW | Riverina Water County Council | 24/01/2019 |
| WTP | NSW | Tamworth Regional Council | 24/01/2019 |
| WTP | NSW | Dubbo Regional Council | 24/01/2019 |
| WTP | NSW | Orange City Council | 24/01/2019 |
| WTP | NSW | Griffith City Council | 24/01/2019 |
| WTP | NSW | Parks Shire Council | 24/01/2019 |
| WTP | NSW | Moree Plains | 24/01/2019 |
| WTP | NSW | Gunnedah Shire | 24/01/2019 |
| WTP | NSW | Edward River | 24/01/2019 |
| WTP | NSW | Berrigan Shire | 24/01/2019 |
| WTP | NSW | Cowra Shire | 24/01/2019 |
| WTP | NSW | Liverpool Plains Shire | 24/01/2019 |
| WTP | NSW | Narromine Shire | 24/01/2019 |

| | | | |
|---|---|---|---|
| WTP | NSW | Goulburn Mulwaree | 25/01/2019 |
| WTP | NSW | Cabonne Council | 25/01/2019 |
| WTP | NSW | Murray River Council | 25/01/2019 |
| WTP | NSW | Lachlan Shire Council | 25/01/2019 |
| WTP | NSW | Leeton Shire | 25/01/2019 |
| WTP | NSW | Greater Hume Council | 25/01/2019 |
| WTP | NSW | Cootamundra-Gundagai | 25/01/2019 |
| WTP | NSW | Forbes Shire | 25/01/2019 |
| WTP | NSW | Warrumbungle Shire | 25/01/2019 |
| WTP | NSW | Glen Innes Severn Council | 25/01/2019 |
| WTP | NSW | Upper Lachlan Shire | 25/01/2019 |
| WTP | NSW | Central Tablelands Water | 25/01/2019 |
| WTP | QLD | Biosecurity Queensland | 25/01/2019 |
| WTP | SA | SA Water | 25/01/2019 |
| WTP | QLD | Southern Regional Downs | 8/02/2019 |
| WTP | QLD | Paroo Shire Council | 8/02/2019 |
| WTP | QLD | Western Downs Regional Council | 8/02/2019 |
| WTP | QLD | Murweh Shire Council | 8/02/2019 |
| WTP | QLD | Goondiwindi Regional Council | 8/02/2019 |
| WTP | QLD | Balonne Shire Council | 8/02/2019 |
| WTP | NSW | City of Albury | 8/02/2019 |
| WTP | NSW | Federation Council | 8/02/2019 |

### *Survey Questionnaire 1: Water Treatment Plants*

The following pilot questions were posed to respondents that identified as representatives of water treatment plants.

#### *Preface*

Agtrans Research has been contracted by the Fisheries Research Development Corporation (FRDC) to undertake a cost-benefit analysis on the potential release of a Carp herpes virus to reduce Carp populations in Australian waterways. The analysis being undertaken is part of the National Carp Control Plan (NCCP). A part of our brief is to estimate the current costs of Carp (both market and non-market) to the various communities affected by Carp as well as the potential benefits and costs (both market and non-market) associated with virus release. Such estimates would inform the NCCP and support their advice to the Australian Government on the merits of the release of the virus. One component of the brief is to explore the current cost implications of Carp and the potential reduction of Carp numbers for water treatment plant costs.

NOTE: Data obtained through this survey will be used in an aggregate cost-benefit analysis. Information will be treated as sensitive and individual responses will not be shared publicly. Responses can be approximations if information is not available.

#### *Questionnaire*

1. Please state the name of the water authority/council and the number of water treatment plants used for this survey response. If answering for a number of water treatment plants, councils or water authorities, please list them below.

| Water Authority/Council: | Name of Water Treatment Plants | Type of source water (River, dam etc.) | Geographic location of water intake (e.g. nearest town) |
|---|---|---|---|
| [name] | | | |
| | | | |
| | | | |
| | | | |

2. What is the average annual quantity of water treated (i.e. megalitres (ML) treated per year) for each of the water treatment plants listed above?

| Water Treatment Plant | Average quantity of water treated per year (ML) |
|---|---|
| | |
| | |
| | |
| | |

3. What is the average annual cost of water treatment per ML for each of the water treatment plants listed above?

| Water Treatment Plant | Average annual cost of water treatment per ML |
|---|---|
| | |
| | |
| | |
| | |

4. What is the average annual level of turbidity (NTU) recorded from source water for each water treatment plant listed above (pre-treatment)?

| Water Treatment Plant | Average turbidity level of source water (NTU) |
|---|---|
| | |
| | |
| | |
| | |

5. What proportion of total water treatment costs are related to treatment of turbidity/sediment (e.g. 20%)?

| Water Treatment Plant | Proportion of water treatment costs related to turbidity/sediment |
|---|---|
| | |
| | |
| | |
| | |

6. If there is an increase in turbidity from the average level of turbidity stated in Question 4 (from all sources), what is the percentage increase in treatment costs from source/raw water sources listed in Question 1?

| **Increase in source water NTU** | **Percentage increase from average source water turbidity in water treatment costs** |
|---|---|
| 10 NTU | |
| 20 NTU | |
| 40 NTU | |
| 50 NTU or above | |

7. Are there additional costs for treating water infected with an algal bloom? If yes, what are the additional costs (percentage increase in water treatment costs) depending on the severity of the algal bloom?

| **Severity of algal bloom** | **Percentage increase in water treatment costs** |
|---|---|
| Very Low | |
| Low | |
| Medium | |
| High | |
| Very High | |

8. If a blackwater (low water oxygen) event occurs, what is the additional cost of treatment (percentage increase in water treatment costs) depending on the severity of the blackwater event?

| **Severity of blackwater event** | **Percentage increase in water treatment costs** |
|---|---|
| Very Low | |
| Low | |
| Medium | |
| High | |
| Very High | |

9. What would be the increase in cost of water treatment due to a large fish kill event in source water causing for example, an increase in ammonia or decrease in dissolved oxygen?

   Example: If a large fish kill occurred in the source water and ammonia levels increased above a certain threshold, what would be the cost to the water treatment plants(s) to purchase water from other sources in order to maintain supply (cost per ML treated)?

| **Event** | **Additional Costs per event (per ML treated or purchased)** |
|---|---|
| Increase in ammonia and decrease in dissolved oxygen | |
| Other (please state) | |
| Other (please state) | |

### *Survey Questionnaire 2: Irrigation/ Water Authorities*

The following pilot questions were posed to respondents that identified as representatives of irrigation/ water authorities.

#### *Preface*

Agtrans Research has been contracted by the Fisheries Research Development Corporation (FRDC) to undertake a cost-benefit analysis on the potential release of a Carp herpes virus to reduce Carp populations in Australian waterways. The analysis being undertaken is part of the National Carp Control Plan (NCCP). A part of our brief is to estimate the current costs of Carp (both market and non-market) to the various communities affected by Carp as well as the potential benefits and costs (both market and non-market) associated with virus release. Such estimates would inform the NCCP and support their advice to the Australian Government on the merits of the release of the virus. One component of the brief is to explore the current cost implications of Carp on irrigation authorities and the change in irrigation authorities costs due to the potential reduction of Carp numbers.

NOTE: Data obtained through this survey will be aggregated and used in an aggregate cost-benefit analysis. Information will be treated as sensitive and individual responses will not be shared publicly. Responses can be approximations if information is not readily available.

#### *Questionnaire*

1. Please state your source of water and location of water for irrigation supply

| | |
|---|---|
| Water source for irrigation to supply customers (river, water storage, etc.) | |
| | |
| Location of water source/s intake (nearest town) | |
| | |

2. Due to pump blockages from fish and turbidity, please state the average number of blockages and average costs per blockage below. Please note that answers may be approximations.

| | |
|---|---|
| Average annual number of pump blockages | |
| Average cost of a pump blockage incident | |

3. What is the annual percentage of blockages due to fish, turbidity and sediment, and other?

| **Cause of blockage** | **Percentage** |
|---|---|
| Fish | |
| Turbidity/Sediment | |
| Other (please specify) | |

4. At varying levels of sediment and turbidity, what is the approximate annual frequency of blockages for each level of sediment/turbidity in source water?

| | **Sediment and turbidity levels** | | | | |
|---|---|---|---|---|---|
| | **Very High** | **High** | **Medium** | **Low** | **Very Low** |
| Number of blockages per annum at each level of | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| sediment and turbidity | | | | | |

5. If your organisation maintains irrigation channels, what is the annual cost of channel maintenance and the percentage of overall costs attributed to fish and to turbidity/sediment?

| | |
|---|---|
| Average total annual cost of channel maintenance ($) | |
| Percentage of maintenance costs attributed to fish (%) | |
| Percentage of maintenance cost attributed to turbidity/sediment (%) | |

### *Survey Questionnaire 3: Irrigators/Primary Producers in Carp Affected Regions*

#### *Preface*

Agtrans Research has been contracted by the Fisheries Research Development Corporation (FRDC) to undertake a cost-benefit analysis on the potential release of a Carp herpes virus to reduce Carp populations in Australian waterways. The analysis being undertaken is part of the National Carp Control Plan (NCCP). A part of our brief is to estimate the current costs of Carp (both market and non-market) to the various communities affected by Carp as well as the potential benefits and costs (both market and non-market) associated with virus release. Such estimates would inform the NCCP and support their advice to the Australian Government on the merits of the release of the virus. One component of the brief is to explore the current cost implications of Carp on irrigators and the change in irrigator costs due to the potential reduction of Carp numbers.

NOTE: Data obtained through this survey will be generalised and used in an aggregate cost-benefit analysis. Information will be treated as sensitive and individual responses will not be shared publicly. Responses can be approximations if information is not readily available.

#### *Questionnaire*

1. Please state the source/location of water for your irrigation operations

| | |
|---|---|
| Water source for irrigation (name of river, farm dam etc.) | |
| | |
| Location of water source/s intake (nearest town) | |
| | |

2. Do fish directly affect your irrigation operations? (please tick)

| | |
|---|---|
| Yes | |
| No | |

3. If yes, please explain how in the box below.

| |
|---|
| |

| |
|---|
| |

4. What is an estimate of the annual total cost (in dollar terms) of maintaining your irrigation channels? These costs may include any pump blockage costs.

| **Annual cost of maintaining irrigation channels** | **Cost ($/p.a.)** |
|---|---|
| Annual cost of maintaining irrigation channels | |

5. What is the percentage split between fish and turbidity of any maintenance costs?

| | |
|---|---|
| Percentage of maintenance costs due to fish (%) | |
| Percentage of maintenance costs due to turbidity (%) | |
| Percentage of maintenance costs due to other factors (%) | |

6. Please state the annual frequency and cost of pump blockages. Please note these can just be approximations. If dollar costs per blockage are unknown, please state the time and resources used.

| | |
|---|---|
| Average annual number of pump blockages | |
| Average cost of pump blockage incident ($) | |

7. What is the annual proportion of blockages due to fish, turbidity and sediment, and other factors?

| | |
|---|---|
| Percentage of blockages due to fish (%) | |
| Percentage of blockages due to turbidity/sediment (%) | |
| Percentage of blockages due to other factors (%) | |

8. What is the frequency of pump blockages at various levels of sediment and turbidity from source water?

| | **Sediment and Turbidity levels** | | | | |
|---|---|---|---|---|---|
| | **Very High** | **High** | **Medium** | **Low** | **Very Low** |
| Number of blockages per annum at varying levels of turbidity | | | | | |

## Results by Primary Water User Type

### *Irrigators*

Only one response was received from an irrigator/primary producer despite the survey being promoted on Irrigation Australia's social media channels and the questionnaire being circulated by a number of irrigation authorities. The single respondent indicated that Carp were not an issue and caused no direct costs to their irrigation operations. This finding was in line with the preliminary findings from the pilot survey that indicated that Carp either did not have a direct effect on irrigation operations or that their impact was negligible.

### *Irrigation/ Water Authorities*

Responses were received from three irrigation/ water authorities: Western Murray, Jemalong, and West Corurgan and the following data were obtained.

1. Sources and locations of water for irrigation supply.\

| **Irrigation Authority** | **Water Source** | **Water Location** |
|---|---|---|
| Western Murray | Murray River | Buronga/ Coomealla/ Curlwaa |
| Jemalong | Lachlan River | Forbes |
| West Corugan | Murray River | Cowra |

2. Average number and cost of irrigation pump blockages due to fish and turbidity.

| **Irrigation Authority** | **Average No. of Blockages p.a.** | **Average Cost per Blockage** |
|---|---|---|
| Western Murray | 1 | 3 hours labour |
| Jemalong | 0 | 0 |
| West Corugan | 0 | n/a |

n/a: not applicable

3. Proportion of annual blockages caused by (1) fish, (2) turbidity and sediment, and (3) other.

| **Irrigation Authority** | **Proportion of Annual Blockages Caused By** | | |
|---|---|---|---|
| | **Fish** | **Turbidity and Sediment** | **Other** |
| Western Murray | 0% | 0% | 5% |
| Jemalong | 0.5% | 1% | 3% |
| West Corugan | 0% | NS | NS |

NS: not stated

4. Frequency of blockages at various levels of turbidity and sediment in the source water.

| **Irrigation Authority** | **Level of Source Water Turbidity/ Sediment & Frequency of Blockages** | | | | |
|---|---|---|---|---|---|
| | **Very High** | **High** | **Medium** | **Low** | **Very Low** |
| Western Murray | 0 | 0 | 0 | 0 | 0 |
| Jemalong | 10% | 5% | 2% | 0 | 0 |
| West Corugan | NS | NS | NS | NS | NS |

NS: not stated

5. Average, annual cost of irrigation channel maintenance and the percentage of overall maintenance costs attributable to fish and/or turbidity and sediment.

| **Irrigation Authority** | **Average Cost of Channel Maintenance ($ p.a.)** | **Proportion of Maintenance Costs Attributable to Fish** | **Proportion of Maintenance Costs Attributable to Turbidity and Sediment** |
|---|---|---|---|
| Western Murray | n/a | n/a | n/a |
| Jemalong | 140,000 | 0.5% | 70% |
| West Corugan | 200,000 | 0% | NS |

n/a: not applicable
NS: not stated

### *Water Treatment Plants*

The market impact costs of Carp survey was sent to 53 local councils and water treatment plants. Three councils responded stating that their water source was ground water and that, therefore, they were not directly impacted by Carp. A further three water treatment authorities in VIC stated that they sourced their water from Melbourne Water and therefore did not complete the survey because they do not directly operate water treatment plants.

Usable survey responses were received from seven councils/ water treatment plants across NSW and VIC. Despite the low response rate, the responses received covered 101 water treatment plants taking water from a variety of sources including rivers, bores, creeks, irrigation channels, reservoirs, lakes and basins.

The format of responses varied considerably. Response data were entered into an Excel® spreadsheet for analysis. The following aggregate data were obtained from the water treatment plant survey responses.

1. Source water types

Data on the source of water was provided for 90 of the 101 water treatment plants. The following table summarises the water sources for the 90 plants.

| **Water Source** | **No. of Water Treatment Plants** |
|---|---|
| River | 36 |
| Bore | 3 |
| Creek | 12 |
| Irrigation | 8 |
| Dam | 13 |
| Lake | 9 |
| Reservoir | 7 |
| Basin | 2 |
| Total (n) | 90 |

2. Average, annual quantity of water treated

The average quantity of water treated by the water treatment plants surveyed (n = 101) was 1,047 ML p.a.. The minimum reported was 3 ML p.a., the maximum was 25,832 ML p.a. and the median was 265 ML p.a.

3. Average cost of water treatment ($/ML)

The average, annual cost of water treatment for the treatment plants surveyed (n = 94) was $808/ML. The minimum cost was $40/ML, the maximum was $7,720/ML and the median was $273/ML. Seven of the 101 water treatment plants did not provide a response to this question.

4. Average turbidity of source water pre-treatment

The average turbidity of source water pre-treatment was estimated at 12.16 NTU[23] (n = 101). The minimum pre-treatment turbidity for the water treatment plants surveyed was reported at 0.32 NTU, the maximum reported was 89.14 NTU, and the median was 5.92 NTU.

5. Proportion of water treatment costs attributed to turbidity

The average proportion of water treatment costs attributed to turbidity was 25%. 56 of the 101 water treatment plants provided data. The minimum attribution was 10%, the maximum reported was 45% and the median was 28%.

6. Proportional increases in water treatment costs due to increased levels of turbidity

The following table presents the aggregate results for data provided by 49 (of 101) water treatment plants estimating the increase in water treatment costs due to various increases in source water turbidity levels.

| **Estimated increase in water treatment costs (% increase)** | **Turbidity and increase** | | | |
|---|---|---|---|---|
| | **10 NTU** | **20 NTU** | **40 NTU** | **50 NTU or above (doesn't include carting costs)** |
| Average | 6.51% | 12.10% | 20.45% | 21.23% |
| Median | 3.00% | 6.00% | 15.00% | 15.00% |
| Minimum | 0.00% | 5.00% | 5.00% | 10.00% |
| Maximum | 100.00% | 150.00% | 200.00% | 250.00% |

7. Additional costs associated with water affected by algal blooms

Survey respondents indicated that the cost would depend on the type of treatments employed and the potential additional cost of tankering/water carting. Further, should an algal bloom result in above threshold ammonia/toxin levels costs could increase up to 4000%.

41 of the 101 water treatment plants provided estimates of the potential increase in water treatment costs that would be incurred in the event of algal blooms of various severity. The following table shows the aggregate results.

| **Estimated Increase in Water Treatment Costs** | **Severity of Algal Bloom** | | | | |
|---|---|---|---|---|---|
| | **Very Low** | **Low** | **Medium** | **High** | **Very High** |

[23] According to the Australian Drinking Water Guidelines, an acceptable level for consumption is under 0.2 Nephelometric Turbidity Unit (NTU) with aesthetically pleasing water being < 5 NTU.

| (%) | | | | | |
|---|---|---|---|---|---|
| Average | 1.59% | 6.16% | 7.93% | 10.00% | 13.54% |
| Median | 0.00% | 5.00% | 10.00% | 10.00% | 12.50% |
| Minimum | 0.00% | 0.00% | 0.00% | 0.00% | 5.00% |
| Maximum | 5.00% | 10.00% | 10.00% | 20.00% | 20.00% |

8. Additional costs associated with blackwater events

Data were provided 40 of 101 water treatment plants with respect to increased water treatment costs associated with potential black water (low dissolved oxygen) events. The following table presents the aggregate results.

| **Estimated Increase in Water Treatment Costs (%)** | **Severity of Blackwater Event** | | | | |
|---|---|---|---|---|---|
| | **Very Low** | **Low** | **Medium** | **High** | **Very High** |
| Average | 1.50% | 1.50% | 7.75% | 10.25% | 11.77% |
| Median | 0.50% | 0.50% | 10.00% | 10.00% | 12.50% |
| Minimum | 0.00% | 0.00% | 1.00% | 1.00% | 1.00% |
| Maximum | 5.00% | 5.00% | 10.00% | 20.00% | 25.00% |

9. Additional water treatment costs associated with a large-scale fish kill event

Survey respondents indicated that the main concern associated with large-scale fish kills was above threshold ammonia levels in source water. If a fish kill event were to lead to ammonia levels above treatable thresholds, then the source water would be deemed unsafe (treatment/ disinfection ineffective) and carting water would be the only alternative. Carting costs were estimated to be between $13,000 and $32,000 per ML. Cartage would only be possible up to 500 kilolitres per day and extended use of water carting may require water restrictions to be imposed on affected towns/populations.

## Key Findings/ Summary

The existing Carp biomass were reported to have negligible direct impacts on costs for primary water users. Turbidity and sediment loads in source water for water treatment plants were found to have an affect on water treatment costs. Based on the data collected, the average quantity of water treated across 101 water treatment plants in NSW and VIC was 1,047 ML p.a. at an average cost of $808 per ML (total annual cost of $845,976) however treatment costs varied significantly between water treatment plants. On average, the water treatment facilities surveyed indicated that 25% of their water treatment costs could be attributed to treating turbidity/ sediment. Therefore, it is estimated that the treatment of source water for turbidity/ sediment costs, on average, $211,494 per treatment plant per year. However, the existing literature, supported by survey responses, indicated that it was unlikely that Carp activities contributed significantly to source water turbidity levels.

Overall, the survey data were interpreted as indicating that Carp do not impose significant costs on the market sector and that any significant damage they have caused, and still cause, are likely to be more strongly related to non-market costs via a range of causal pathways.

# 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

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www.carp.gov.au