

# Quantifying the impacts of carp and waterbirds on aquatic vegetation within a regulated lowland river

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## Key Points

- Aquatic vegetation provides many habitat benefits for aquatic and terrestrial fauna, but in some cases there are severe negative effects of fauna on those plants.
- In-situ experimental exclosures for the introduced European carp and native waterbirds were used to measure their impacts on aquatic vegetation and vegetation recovery.
- There was dramatic recovery of aquatic vegetation in most exclosures within a few years.
- Carp had a greater negative impact on aquatic vegetation recovery than waterbirds, but waterbirds had significant impacts on recruitment of littoral species on the river margin.
- Understanding the impact of carp and waterbirds allows for improved management expectations, informs decisions, and provides information for communicating with local communities.

## Abstract

European carp (*Cyprinus carpio*) and waterbirds are known to have impacts on aquatic vegetation, but these impacts are rarely quantified in natural systems and neither is the rate of vegetation recovery if those animals are excluded. We installed eight paired (control/treatment) carp and waterbird exclosures (2.4 x 2.4 m) in the Campaspe River, northern Victoria, to measure the changes in aquatic plant cover and richness when those fauna taxa were excluded. Vegetation cover and richness were spatially mapped within each exclosure on seven occasions from 2018 to 2021. Overall, carp and waterbirds had significant negative impacts on aquatic and littoral vegetation cover and richness, with recovery greatest when both taxa were excluded. Carp appeared to have greater impacts on aquatic vegetation, while waterbird impacts were greatest for littoral vegetation. Vegetation responses were highly variable depending on water depth and existing vegetation. Waterway management that facilitates recruitment and growth of aquatic vegetation as well as mitigating fauna impacts may help negate these impacts and enhance vegetation outcomes.

## Keywords

Management, Environmental flows, Macrophytes, Invasive species, Grazing, Exclosures, Experiment

## Introduction

There are many important interactions between flora and fauna in waterways; some are beneficial, and others are detrimental. European carp (*Cyprinus carpio*), hereafter 'carp', are a significant pest of many Australian waterways (Koehn 2004) and currently make up the highest fish biomass in eastern Australia (Stuart et al. 2021). Carp influence aquatic and emergent vegetation directly because of their benthic feeding method where seeds or seedlings are consumed and sediments are disturbed (Crivelli 1983), and indirectly through the alteration of water attributes such as turbidity (e.g. Weber and Brown 2009). It is likely that the presence of carp in many Victorian waterways is adversely affecting aquatic and emergent vegetation abundance and diversity. Understanding the impacts of carp on aquatic vegetation is therefore important for setting management objectives and actions for vegetation outcomes where these impacts may prevent or limit benefits of management actions such as environmental flows.

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In addition, native waterbirds are common within many south-east Australian waterways and some are specialised herbivores. These species feed on aquatic plants in a variety of ways, such as grazing on littoral grasses, sedges and herbs (e.g. some species of duck and large rails), removing leaves from submerged aquatic plants (Eurasian Coot, Black Swan, Hardhead), eating seeds or fruiting bodies from emergent vegetation (various ducks) or uprooting submerged aquatic plants to consume bulbous rhizomes (Brolga, Magpie Goose). While these species may have negative effects on aquatic vegetation populations, waterbirds are also vectors for the spread of aquatic and emergent plant propagules and may provide population benefits for some of these flora species (e.g. Raulings et al. 2011).

It is difficult to quantify the impacts of carp and waterbirds on vegetation or estimate the magnitude and rate of aquatic and emergent vegetation recovery if they were excluded. A series of recent investigations in Gunbower Forest's ephemeral floodplain wetlands in northern Victoria, through The Living Murray initiative, evaluated the effect of carp exclosures on aquatic vegetation (Bennetts 2021). That work showed strong evidence for large increases in aquatic vegetation cover and richness in the absence of carp, but the responses were spatially patchy and were heavily influenced by water quality in some wetlands. The study indicated that the potential benefits of flow management and environmental flows on aquatic indigenous vegetation may be severely compromised where carp are present. This is critical information for waterway managers who are aiming to improve aquatic vegetation diversity or extent through water management, because the presence of carp could mean that their objectives are unachievable or take longer to achieve.

Because of the large impact of carp in many aquatic systems, the interest in this knowledge by water managers, and recent investment in understanding the potential impacts of carp control measures (Diggle et al. 2012; Taylor et al. 2012; Hayes et al. 2013; Patil et al. 2015; Stuart et al. 2021), it was valuable to conduct a case study into the impacts of carp exclusion in a river system that builds on the work conducted in Gunbower Forest. While it is possible in some wetlands to remove carp from the entire system, this is much more difficult within a river where there are co-occurring native fish species. In this study we used a set of carp exclosures, similar to those used in the Gunbower study, on the Campaspe River to test the applicability of exclosures in a flowing system, as well as obtaining evidence of the potential impacts of carp (and carp control) and waterbirds on aquatic and riparian vegetation. The study is a part of the Victorian Environmental Flows, Monitoring and Assessment Program (VEFMAP).

The aim of the study was to seek evidence about the possible direct impacts of carp on aquatic and riparian vegetation, which would allow us to understand the prospective benefits and limitations of environmental flows more fully in systems occupied by carp. The potentially confounding effects of waterbirds were later included as important context where both taxa are having impacts. The indirect effects of carp on water quality attributes were not addressed in this study, as these factors could not be controlled by the treatments.

Our study was designed to test the following hypotheses:

- Control plots are likely to have limited growth and establishment of aquatic and emergent vegetation compared to treatment plots that exclude carp and/or waterbirds.
- Carp have greater impact on aquatic plants, while waterbirds have greater impacts on littoral species.

## **Methods**

### ***Study location and design***

Eight exclosure sites with paired treatment exclosures (fenced) and controls (unfenced) (n=16 plots, Figure 1) were installed in December 2018 along a 200 m section of the Campaspe River at Barnadown, in north-central Victoria. Sites were located along a depth gradient from shallow (exposed to air at low flow) to deep (25-40 cm) (Table 1). Substrates were either silt/sand or gravel. The study location was chosen because it had (a) no livestock access, (b) existing data and or observations of carp and waterbird presence and impacts, and (c) a

diversity of vegetation within the river channel. Following evidence of waterbird herbivory impacting the unfenced controls in the first year of the study, the control plots were fenced with modified enclosures containing slots allowing carp access but restricting waterbirds (Figure 1); these were installed in December 2019. Two control plots could not be fenced because of woody obstructions, so new controls were added for those and were called ‘ControlB’ enclosures. Despite the open top of the enclosures, the small dimensions made flight access difficult for waterbirds and there were no obvious waterbird impacts recorded in fenced enclosures. So, control plots were open to carp for the full study duration but were only open to waterbirds for the first 12 months. Enclosures were positioned with one of the corners pointing upstream in the direction of flow to reduce the amount of debris catching on the walls. All enclosures were 2.4 m x 2.4 m in area and 1.2 m high, and were made using a steel frame with galvanised weld mesh (50 x 50 mm netting) on all walls. Enclosures were fixed to the river bed with 4 steel posts 2.1–2.4 m long, embedded in the corners. A coarse woody debris deflector was installed upstream to intercept large logs that may collide with enclosures.



**Figure 1. Carp and waterbird (treatment) enclosures and carp only (control) enclosure fences on the Campaspe River [left], a schematic of a control plot with two carp access slots [right top], and an example of mapped vegetation from enclosures, each polygon is a vegetation patch with different colours for each plant species [right bottom].**

**Table 1. Enclosure plots within the study area. Control enclosures were unfenced for the first 12 months before new fences were installed to allow carp access and exclude birds. Control B enclosures had no fence for the entire study. Depth indicates approximate mean depth for the plot at low and baseflows.**

Site number	Treatment (carp/bird exc.)	Control (bird exc.)	Control B (no exc.)	Depth (cm)	Substrate
1	Y	Y		0-5	Silt/sand
2	Y	Y		0-5	Gravel
3	Y	Y	Y	2-7	Gravel
4	Y	Y		2-7	Gravel/silt
5	Y	Y	Y	5-10	Silt/sand
6	Y	Y		10-20	Silt/sand
7	Y	Y		20-30	Silt/sand
8	Y	Y		25-40	Silt/sand

## **Vegetation surveys**

Surveys were undertaken on seven occasions from 2018 to 2021 (December 2018, March 2019, June 2019, December 2019, April 2020, December 2020, and April 2021). During a survey, each plot was photographed from fixed photo points at the side and above, and the area of all patches of each plant species present within the plot were mapped on paper. The maps were subsequently digitised into polygons (Figure 1) and the percentage extent of each species in each plot was calculated using ImageJ (Schindelin et al. 2012). The extent indicated the cover of each patch but did not incorporate density of plant material within patches, so was not equivalent to foliage projective cover. The individual species extents were then summed to give a total extent across all species within each plot, so where co-occurring species have overlapping extents the total can exceed 100%.

## **Carp in the study area**

Standardised annual electrofishing surveys (boat and bank-mounted) were conducted in the study area as part of the Victorian Environmental Flows, Monitoring and Assessment Program (VEFMAP; see Tonkin et al. 2019). Surveys from the closest site to the study area (~3 km upstream) indicated that carp, largely adult fish ( $\geq 450$  mm fork length) were common in the area throughout the study period (DELWP unpublished data). Carp were also observed within the study site during vegetation surveys. The density of fish (CPUE ranging from 15-43 fish per 1000 electrofishing seconds) are similar to many other regulated river systems in Victoria and are not considered particularly high (e.g. Stuart et al. 2021).

## **Waterbirds in the study area**

Waterbird abundance and diversity was not included in the initial study design and no formal bird density surveys were conducted. However, consideration of bird impacts on aquatic plants was added after it was observed that grazing by several bird species was possibly affecting cover and diversity of aquatic plant communities within control plots. Waterbird species observed utilizing aquatic or littoral vegetation were Australian Wood Duck (*Chenonetta jubata*), Pacific Black Duck (*Anas superciliosa*) and Australasian Swamphen (*Porphyrio melanotus*). These bird species are primarily herbivores; the wood duck grazes on streamside grasses and herbs, the black duck eats leaves, flowers and seeds of aquatic and riparian ground-cover plants, and the swamphen specializes on the basal stems of reeds and sedges (Marchant and Higgins 1990).

## **Results**

A year after the treatments were applied, descriptive data summaries showed all exclosures with no carp or waterbird access had greater vegetation extent and richness than unfenced controls. This trend increased substantially through time, with greater vegetation recovery after two years for all but one treatment, which remained relatively stable throughout the study. Treatment plots that excluded both carp and waterbirds generally recovered more strongly than control exclosures with carp access and waterbird exclusion.

## **Percentage increase in vegetation extent**

Vegetation extent increased in all treatment plots over the study period. On average, treatment exclosures increased by 98% and control exclosures increased by 27% over the study period. However, there was large variation in summed vegetation extent changes between exclosure plots based on starting condition (initial vegetation extent and diversity), water depth, and potentially substrate (min: 7%, max: 291%). Shallow exclosures showed a much stronger recovery than deeper ones with extent responses generally declining along the depth rank from site 1 to 8 (Figures 2 and 3). While recruitment or resprouting was rapid in shallow exclosures, the deepest exclosures (site 8) only recorded vegetation after 16 months following exclusion. After waterbird exclusion from controls, vegetation increases were more variable and generally smaller than exclusion of both carp and waterbirds, apart from control site 2 which declined in extent while unfenced in the first year but had a dramatic increase in extent following mass recruitment of plants on the exposed soils following fencing (Figure 3). Both the treatment and control plots of site 2 contained exposed soils and

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inundated soils along a shallow gradient and the exposed soils showed mass plant recruitment in both cases (following exclusion of waterbirds from the control). In general, shallow exclosures showed a trend for a greater percentage increase in vegetation than deeper exclosures, irrespective of substrate type. The largest changes were observed in shallow plots where the soil surface was periodically exposed (sites 1 and 2).

In general, littoral species had greater extent in shallow exclosures where soil was exposed (sites 1-3), whereas deeper exclosures were dominated by aquatic species (sites 4-8). Eel grass (*Vallisneria australis*) was the most abundant species overall but was also heavily impacted by waterbird grazing. This species was most abundant in deeper sites, in particular sites 5 and 7. In site 7, the extent of Eel grass was relatively consistent, although the density of patches varied visually among surveys, which was not captured by our data. Pondweed (*Potamogeton sulcatus*) was one species observed to be particularly responsive to exclosures, with 0.5% cover in only one plot at the commencement of the study to being found in four plots in the final survey with a cover range of 8% to 54%.

### Species richness

Twenty-five flora species or taxa were recorded within the control and exclosure plots. These were dominated in richness by littoral species that colonise the fringing areas of the bank toe, but also included six aquatic (emergent, submerged, and floating) species and charaphytes. No species considered fully terrestrial was recorded in any plot during the study. All treatment exclosures (except site 7) had an increase in species richness over the full study period (Figure 3). After waterbird exclusion from controls, richness only increased in sites 1 and 2, i.e. the only plots with exposed soil. In general, treatment exclosures that were shallow showed a greater increase in species richness than moderate to deep exclosures, with the deep exclosures showing no or slower increases in species richness. A maximum of five individual plant recruits were recorded in any plot that had no soil exposure, compared to hundreds of seedlings in exposed plots. Although plant recruitment in exposed soil was dominated by littoral species, aquatic species were recorded germinating in exposed soil and shallow water within the plots.



**Figure 2. Photos of exclosure 1 (shallow), showing fringing and aquatic species colonising the seasonally and shallowly inundated depths, and Exclosure 5 (deep) showing aquatic vegetation expansion (including algae). First photo June 2019, second in December 2020.**

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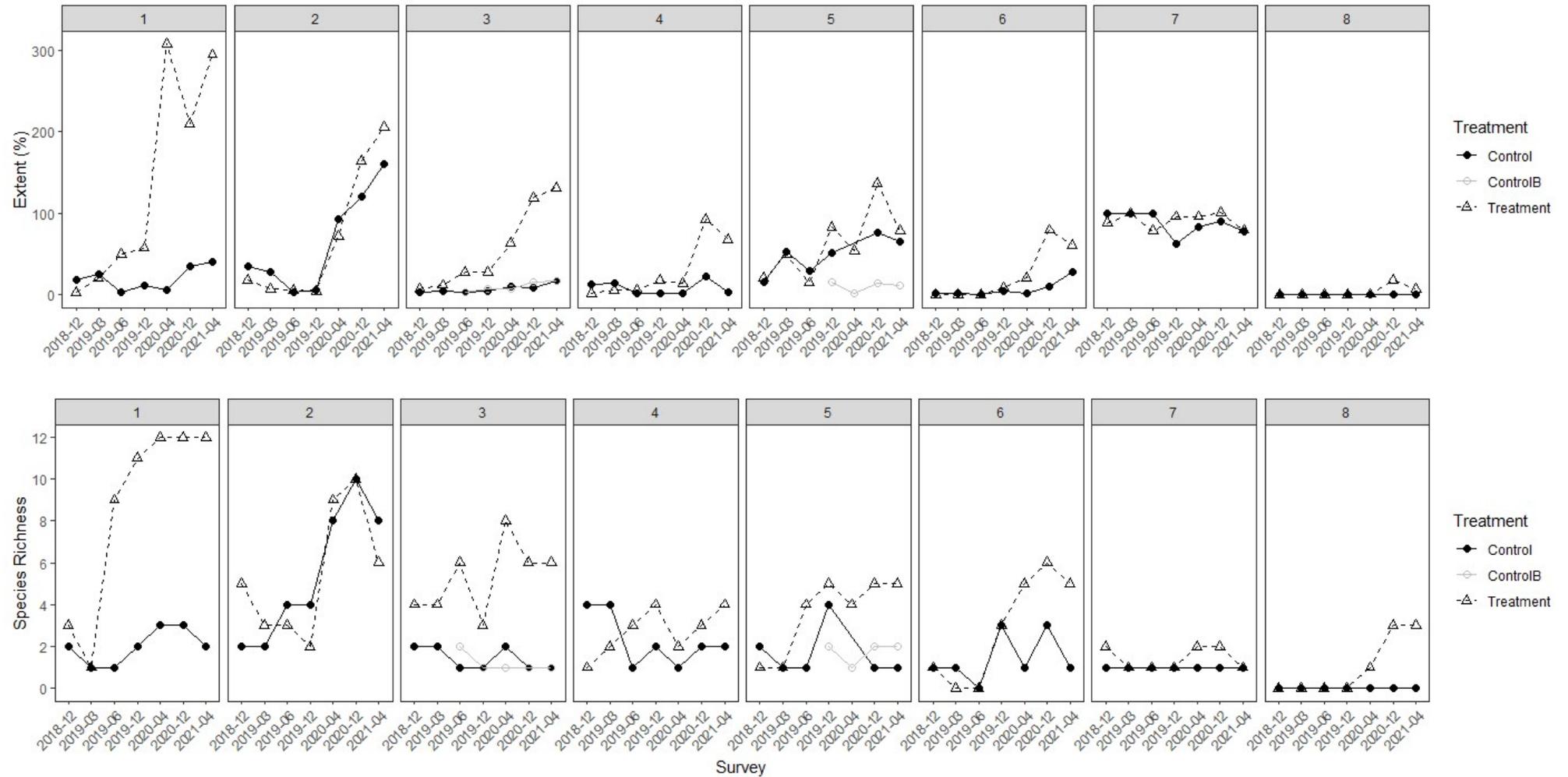


Figure 3. Vegetation extent and richness within each survey plot throughout the study in each of the eight sites. Sites are ranked from 1 to 8 based on depth (shallowest to deepest).

## **Conclusions**

We recorded substantial effects of fauna on vegetation (specifically vegetation recovery) in the study area. Vegetation recovery was greatest where both carp and waterbirds were excluded. Excluding waterbirds had only a small impact on aquatic vegetation recovery, suggesting that carp had a greater negative impact on vegetation extent and richness compared to waterbirds. Pondweed as an example had dramatic increases in cover in treatment exclosures and are known to be sensitive to carp (Fletcher et al. 1985). Waterbird impacts were greatest in the shallow sites with exposed soils, which were too shallow for carp and ideal grazing locations for waterbirds. These areas are accessible to other vertebrate grazers but there was no evidence of their presence within the stream margins and it is considered very unlikely that they would graze bank margin seedlings. However, declines in Eel grass density were recorded in most sites where waterbirds were present; suggesting that waterbirds may have a greater impact on leaf cover/density than overall vegetation extent.

The starting state of the vegetation affected the rate of vegetation recovery and expansion, but the spatial patterns of species richness and extent were inconsistent. Depth of water influenced species composition; shallower exclosures had greater species richness than deeper exclosures as the exposed soil allowed for colonization of diverse littoral species. Summed vegetation extent was generally lower with increased depth as there were fewer species co-occurring when only aquatic species could persist, which commonly have low diversity in Australian streams (Quinn et al. 2011). Deeper water does not necessarily prevent the growth of aquatic vegetation, but it is likely to reduce rates of colonisation and recovery as observed in our study, which will be exacerbated by carp benthic feeding (Crivelli 1983).

Many additional factors not evaluated in this study, such as flow rate, are also likely to impact vegetation recovery rates, as slower water is more conducive to rapid recovery than faster water (Riis et al. 2008). There is also a possibility that the exclosure itself influenced the results by changing flow dynamics but this has not appeared to be significant and the installation of control exclosures should mitigate any effects. This case study also suggests that responses were not dramatically different between different substrate types, but further information is needed to clarify this effect.

Although this study involved a small number of samples and the findings may not be representative of other locations, it nevertheless provides valuable insights into this important problem, both from a methodological and outcomes perspective. The implications for waterway management are that the Campaspe River, and probably other waterways, would be expected to have an increased local extent and diversity of vegetation within the river channel if carp were reduced or eliminated. Flow management to increase soil exposure within the river channel during natural low-flow periods is also likely to have significant impacts on aquatic and littoral vegetation recruitment. However, more information regarding the vegetation responses to different carp densities, sizes, and the interaction with waterbirds is needed to confidently attribute causes and magnitudes of responses.

When seeking to improve river health, the impact of carp on native vegetation needs to be considered for setting of realistic objectives and timelines for recovery, and to manage community expectations.

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