Revised estimates of carp biomass dominance in the Murray-Darling Basin

**Abstract:**

Since being introduced to southeast Australia in late 1960s, Common carp have established as a highly successful alien species, particularly across the Murray-Darling Basin (MDB) where they are widely considered to dominate fish biomass in some rivers. Recent estimates suggest that these rivers may contain ≈43,000t of carp. Their high abundance and apparent dominance of freshwater ecosystems has been used to support recent calls to accelerate management interventions including expediting the release of cyprinid herpesvirus-3. Although it has been widely stated in the scientific literature and media that carp comprise up to 90% of fish biomass in MDB rivers, this estimate is based on sparce data that is over 20 years old. It is vital that contemporary estimates of carp biomass as a proportion of total fish biomass are available to inform potential management strategies. Here we use a generalised linear mixed modelling approach to combine almost 3 decades of boat electrofishing data across >1200 sites to calculate annual estimates of the actual proportion of fish biomass comprised by carp across both the greater New South Wales MDB and in key rivers. At the basin scale, our results show that as a proportion of total fish biomass, carp account for ≈45 %, less than half the widely cited estimate. Within key river systems, estimates of carp biomass ranged from ≈20 – 60%. These new estimates will allow more informed debate around the dominance of carp in the MDB and possible management strategies.

**Introduction:**

Biodiversity is a key metric for assessing ecosystem health, but simple diversity and abundance based indices often biases interpretations regarding the dominance of some species, particularly species with many small juveniles and few large adults (Saint-Germain et al., 2007). While within aquatic ecosystems, biomass is generally related to size with smaller species having larger total biomasses and alterations to ecosystem structure can often be better identified through changes in the biomass distribution (either between trophic levels or species) (Trebilco et al., 2013). Biomass is actually correlated with metabolism providing a direct link to energy flows (Brown et al., 2004), allowing for direct interpretation of ecosystem changes. This suggests that for more functional ecological research, biomass is the more appropriate unit as you can quantify predation and energy storage (using biomass as a proxy). With the increasing use of ecosystem models (Perryman et al., 2021; Tulloch et al., 2020), many of which are built on biomass estimates (Christensen and Walters, 2004; Scott et al., 2014), it is increasingly important to quantify biomass within communities.

Within freshwater ecosystems, Common carp *Cyprinus carpio* (henceforth carp) are one of the most highly successful and destructive invasive species in areas where it has been introduced (Lowe et al., 2004). While in some areas carp are a crucial food source (FAO, 2022a, 2022b), the negative impacts of introduced carp are well documented with introductions drive decreases in macrophyte and other submerged plant biomass, reduced water quality and lower species richness of benthic invertebrate (Bajer et al., 2016; Bajer and Sorensen, 2015; Vilizzi et al., 2014). These impacts extend beyond fish with carp introductions also dramatically altering waterbird communities (Maceda-Veiga et al., 2017). These impacts cause many regions to actively manage to reduce carp with targeted eradication or biomass reduction programs (Dalu et al., 2020; Furlan et al., 2019).

Within Australia, carp are prominent across the southeast temperate region with smaller populations in southwest Australia. While abundances and biomass estimates vary widely across habitats, recent estimates suggest during an average hydrological scenario there are 199.2 M individual carp corresponding to 215,456t (Stuart et al., 2021). In a wet hydrological scenario this increases to 357.5 M carp and 368,357t (Stuart et al., 2021). The eastern portion accounted for 96% of the total biomass with much of this located within the Murray-Darling Basin and the perennial rivers having the greatest biomass density (up to 826kg ha-1). Carp are considered so dominate in this system that it is widely stated that up to 90% of the fish biomass in MDB Rivers is carp , but the evidence to back up this statistic is lacking.

Unfortunately, when traced back to its roots, this 90% statistic is based upon sparce data over 20 years old. The statement first appeared in 2004 (Koehn, 2004), where it was attributed to a comprehensive state-wide survey (Harris and Gehrke, 1997). This state-wide survey did not report the percentage of biomass comprised of directly but refers to areas such as the Murray River where carp “can constitute most of the total fish biomass” (Gehrke et al., 1995). This original study by Gehrke et al., (1995) did not measure biomass but did indeed find that carp dominated the wet season samples from the Murray and Murrumbidgee Rivers with over 95% of fish caught being carp (likely to be over 90% of the biomass). Unfortunately, these surveys were based on limited data (1 sample in each river in each wet and dry seasons). Subsequent larger studies with randomised sample designs in 2004 found that in the Murrumbidgee and Murray Rivers, 87 and 49% of the biomass caught was carp respectively, although the mean proportion of alien species (by biomass) across sites was 82 and 56% (Gilligan, 2005a, 2005b), suggesting some variability between sites. Detailed reporting from the Sustainable Rivers Audit (2008-2010) did report percentage biomass of alien and native species at the basin and valley levels from surveys in 2007 - 2010, suggesting alien species biomass (presumably mostly carp) averaged 61% across the basin with individual valleys ranging from 32 – 87% (Davies et al., 2012a, 2012b).

The variation in estimates and decades since these estimates were made suggest they are may no longer be relevant. Combined with the continued use of these statistics as part of regular communications and management decisions, it is imperative to update the estimates of carp as a proportion of biomass in key rivers across the MDB. Since biomass represents the allocation of energy within ecosystems, if decisions regarding altering the current biomass distribution in the Murray Darling Basin are being made, then it is vital that the current distribution of biomass is known.

The state of New South Wales contains the largest portion of the Murray-Darling Basin and these early projects established protocols for standardised sampling of fish communities which continue to the present day under various projects. The largest of these projects include the Sustainable Rivers Audit, Murray Darling Basin Fish Surveys and the Basin Plan Environmental Outcome Monitoring projects. These projects (along with many other smaller projects) have conducted 1,000’s of electrofishing surveys across the NSW MDB since the mid-1990s and present the potential to robustly update estimates of how much biomass in the MDB rivers is comprised of by carp. This study aims to combine almost 30 years of standardised surveys of community composition to quantify the percentage of biomass comprised of by carp in the overall NSW Murray-Darling Basin and in key rivers.

**Methods:**

*Data extraction and preparation*

Data were extracted from the NSW Department of Primary Industries (NSW DPI) Fisheries Freshwater Ecosystem database encompassing data collected during 142 monitoring and research projects between 1994 and December 2022. This database includes catch (numbers of species) and biological data (length, weights, health assessments, etc) collected using a range of methods, including various forms of electrofishing, net samples, angling and eDNA surveys. At the time of writing, 14,110 sampling events (consisting of multiple samples) were recorded in the database across 4,757 sites with >2 million fish sampled from 219 taxa. The boat electrofishing data were collected using standardised techniques (see Robinson et al. (2019) for details). Although there is some variation in the number of samples taken at each site among projects, boat electrofishing surveys usually consisted of 10 ‘shots’ of 90 seconds power on time.

To generate a dataset suitable for analysis across the NSW MDB, all boat electrofishing data from the NSW MDB were extracted and then filtered to only include records from surveys of fish community composition (excluding projects targeting specific species) from elevations <700 m (Carp are not found above this altitude in this region; REFERENCE). Each record contained the catch for a single species in a single electrofishing shot (hereafter referred to as a ‘sample’). This resulted in 38,947 samples (electrofishing shots) from 4076 sampling events across 1,202 sites (Table 1, Figure 1). To convert the abundances of fish into biomasses within each sample we used length weight relationships and the mean length and abundance of each species in each sample. To calculate the proportion of biomass comprised of by carp we divided the carp biomass by the total biomass of fish in the sample. To generate datasets suitable for analyses of key rivers the above filtering steps were undertaken except we selected all samples in each of 9 key rivers regardless of elevation as objective was to get a river scale estimates of carp dominance (Table 1). Sample dates were assigned to sampling seasons based upon seasons starting in July and ending in June, where 2000 refers to sampling seasons ending in June 2000.

**Table 1.** Summary of the datasets used in each analysis. The NSW MDB dataset only included sites of elevation <700m.

|  |  |  |  |
| --- | --- | --- | --- |
| **Dataset** | **Samples** | **Sampling Events** | **Sites** |
| NSW MDB | 38,947 | 4,076 | 1202 |
| Barwon River | 977 | 100 | 38 |
| Castlereagh River | 123 | 16 | 8 |
| Darling-Baaka River | 3,194 | 364 | 124 |
| Gwydir River | 1,597 | 161 | 34 |
| Lachlan River | 3,923 | 321 | 83 |
| Macquarie River | 2,809 | 337 | 59 |
| Murray River | 3,260 | 333 | 71 |
| Murrumbidgee River | 5,260 | 464 | 94 |
| Namoi River | 1,656 | 189 | 35 |

*Data analysis and visualisation*

To visualise potential shifts in the proportion of sampling events (surveys) with carp dominated biomasses we generated annual histograms from the NSW MDB dataset showing the proportion of sampling events with different proportions of carp biomass.

To quantify the proportion of fish biomass comprised of by carp while accounting for unequal sampling effort over both time and space we used Bayesian generalised linear mixed models. As the response variable (proportion of carp by biomass) included both zeros and ones, we used a zero-one augmented beta error distribution following the guidelines of Douma and Weedon (2019). For the overall NSW MDB model, we included 3 random intercept effects: ‘Water Resource Planning Area’, ‘Sample Date’ and ‘Site’ and 1 fixed effect of ‘Sampling Season’. The ‘Water Resource Planning Area’ effect accounts for the nesting of sites within larger geographical regions while the ‘Sample Date’ and ‘Site’ effects account for dependency in the sampling design with multiple samples on the same day and repeated sampling at sites over time. For the each river we ran a separate model of the same structure except for the exclusion of the ‘Water Resource Planning Area’ random effect. All models were fit within R v4.2.1 (R Core Team, 2021), using the ‘brms’ package (Bürkner, 2018, 2017), with weakly informative priors of normal(0,1). Model convergence assessed visually and using the R-hat statistics. The overall NSW MDB model included 4,000 iterations (half as a warm-up) while the individual river model used 20,000 iteration (half as a warm-up).

To generate predictions of the proportion biomass of carp in each model Sampling\*Season combination we generated prediction plots for each species based upon the expectation of the posterior predictive distribution, not including the random effects using the R package ‘tidybayes’ (Kay 2021). This results in a distribution of estimates showing the likely true values.

Map

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**Figure 1.** Distribution of samples used in the analyses of carp biomass as a proportion of total fish biomass. Bubble size shows the number of electrofishing shots (samples) while colour shows the major rivers (white being other samples). The larger Murray-Darling Basin is shown in light grey.

**Results:**

Overall, in the NSW Murray-Darling Basin, it was evident from the survey level histograms that over time there have consistently been both surveys that only found carp (100% carp biomass) and surveys that found no carp biomass (0% carp biomass, Figure 2). While overall most of the histograms were left skewed with most surveys finding a moderate or high level of carp biomass there appears to be a temporal trend where the proportion of surveys which found no (0%) carp biomass is decreasing (also 100% carp biomass to a lesser extent).

When accounting for all the dependencies in the data structure with the mixed effect model, it was revealed that the proportion of biomass that carp contribute to the fish community has been relatively stable since 1995 with an overall median of 44.3 % (95% CI: 40.5 - 47.4%). The annual median estimates ranged from 41.1% (95%CI: 38.7 – 43.4%) in 2010 to 46.4 % (95% CI: 44.0 – 48.4%) in 2002, although the 95% credible intervals on these estimates overlapped in most years (Figure 3). The only noticeable decline in biomass occurring from 2004 to 2010 when it appears that the % carp biomass was trending down.

Calendar

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**Figure 2.** Histograms showing the percentage of surveys with different levels of carp biomass each sampling season (Year ending June 30th). n shows the number of surveys undertaken each sampling season.

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**Figure 3.** Annual estimates of the percentage of biomass contributed by carp in the overall NSW Murray-Darling Basin. The dots show the median estimates, thick grey bars show the 80% credible intervals (CI), and the thin grey bars show the 95% CIs.

At the river scale, the results were more variable. The Macquarie River consistently showed the highest proportion of carp biomass (followed by the Lachlan and Namoi Rivers). The Gwydir and Darling-Baaka Rivers showed the lowest proportion of biomass contributed by carp with estimates generally ranging from 20 – 40% (Figure S1). These low percentage biomass estimates are reflective of the data at the river level with the Darling-Baaka having very few surveys where only carp were observed and the Gwydir having a high proportion of surveys with no carp detected (Figure S2). There were some years in some of the models which gave very large error bars (e.g. Lachlan River 2002, Gwydir River 1998; Figure S2), these were generally caused by low sampling effort in those years. The Castlereagh River had large error bars for all years driven by low sampling effort overall in this river.

**Discussion**

Our results demonstrate that across the NSW MDB the proportion of carp by biomass is substantially lower than previously stated and remarkably stable over time. We show that a more accurate assessment of the proportion of carp by biomass is 44.3% (40.5 – 47.4%), approximately half the commonly stated 90%. Recognising the change in this statistic has the potential to inform and reshape some of the debate surrounding management of carp in the Murray Darling Basin.

*Comparison with previous estimates*

In general, our estimates for the proportion of biomass comprised of by carp are lower than previously reported. The comprehensive SRA surveys undertaken between 2007 and 2010 found that on average 61% of biomass was comprised of alien species, with most of this likely to be carp. The SRA program varied in methodology from the current analysis with a strict spatially stratified sampling program, with multiple sampling methods, designed to best represent different habitats within the valley and basin scales and allow for large scale conclusions to be drawn with relatively simple analyses. In contrast, the current analysis focused only on boat electrofishing surveys and included many more samples and sites where representative community sampling was undertaken. Generalised linear mixed models were used to control for unequal sampling effort and repeated sampling at some sites. This allowed for a larger dataset (both spatially and temporally) to be analysed and unbiased estimates to be produced. By focusing on only boat electrofishing sites, the current study is likely more representative of larger main channel habitats than smaller tributaries which may require other methods such as backpack electrofishing to sample. We believe the focus on boat electrofishing data would accurately represent the key river habitats and by excluding smaller shallower sites, may actually overestimate carp proportions across the basin as the smaller, shallower habitats tend to have lower proportions of carp (by biomass) compared to main channel habitats (REF).

Some previous estimates of carp biomass have considered wetland habitats, which the current study did not include due to electrofishing rarely being a suitable method for sampling those habitats. Wetlands are known to be key habitats for carp, particularly for breeding and recruitment. The estimates from the current study are not representative of the wetland systems and further investigation is warranted regarding the species composition of wetland habitats.

This study was only focused on the NSW portion of the MDB which accounts for ≈57% of the basin. Previous large-scale surveys such as the Sustainable Rivers Audit surveyed the whole MDB and reported catchment level results for percentage of biomass comprised by alien species. It is worth noting that in this previous survey large variation was found between catchments (32 – 87%) and our results are focussed only on the NSW portion of the MDB. While some of our estimates for key NSW rivers align with reported alien biomass proportions from the SRA reports (Castlereagh River, Darling-Baaka, Macquarie River), our estimates for the corresponding timepoints for some rivers were up to 20% lower (Gwydir River, Lachlan River, Murrumbidgee River). This may be due to the current study only including main river channel in our estimates, if the off-channel and creek habitats sampled previously had high carp dominance then this would raise the overall catchment estimate. As our estimates largely align with proportions seen in the raw histograms, we are confident in our conclusions.

*Management Implications*

Carp in Australia is a pest species and management decisions are driven by the National Carp Control Plan. Currently a large focus is on whether a carp virus should be released as a method of biological control. There are several persuasive arguments both for and against the release of the virus although a number of statements have been made using the previous estimate of 90% of the biomass in MDB rivers is comprised of carp. Our study seeks to address these statements and provides an up-to-date assessment of the likely proportion of biomass comprised by carp across the key rivers in the NSW MDB. It is unlikely that the biomass of carp has ever been sustained at near 90% at the river scale for any period of time. Following large spawning events, carp biomass may increase but high juvenile mortality generally results in the biomass returning to pre-spawning levels. Revising the estimated proportion of biomass in the communities comprised of by carp has significant implications, it is no longer about releasing the virus into rivers where they are almost entirely dominated by carp biomass, it is now about a community which on average has less than half the biomass made up of carp.

The recent estimates of carp biomass by Stuart et al. (2021) suggest that during an average hydrological scenario there are 42,936t (95% CI: 23,055-77,769) of carp biomass in eastern Australian Rivers (of which most are in Murray Darling Basin). If we extrapolate from our estimates of the carp as a percentage of the biomass (44.3%, 95% CI: 40.5 - 47.4%), we can estimate the total biomass of fish in the rivers as 96,921t (95% CI: 48,537 – 192,022t). If we further assume that the percentages of biomass comprised of by carp are similar in wetland systems, the total fish biomass across the eastern region where carp are located as documented by Stuart et al. (2021) could be as large as 464,958t (95% CI: 247,958 – 880,202t). These are obviously ballpark estimates, but they serve to provide context to the possible magnitude of fish populations across the Murray Darling Basin and will hopefully prompt further work into quantifying the biomass of all species across the region, along a similar style to that undertake for carp.

*Conclusions*

These revised estimates of what proportion of biomass is comprised of by carp are less than half of what was previously stated in both scientific literature and the media. Updating these statistics as part of ongoing management decisions is vital if well-informed decisions are to made.

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**Supplementary Material** A picture containing diagram

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Figure S1 Annual estimates of the percentage of biomass contributed by carp in the key NSW rivers. The dots show the median estimates, thick grey bars show the 80% credible intervals (CI), and the thin grey bars show the 95% CIs.

Timeline

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Figure S2 Histograms showing the percentage of surveys with different levels of carp biomass in each of the key rivers (all years pooled). n shows the number of surveys undertaken each sampling season.

* Tables of estimates?