Technical supplement to Basin-scale evaluation of 2022–23 Commonwealth environmental water: Fish

Commonwealth Environmental Water Holder's Science Program: Flow Monitoring, Evaluation and Research Program (Flow-MER)

June 2024

Australian Government
Commonwealth Environmental Water Holder

FLOW Monitoring Evaluation Research

Acknowledgement of Country

The project team and the Commonwealth Environmental Water Office (CEWO) respectfully acknowledge the Traditional Owners of the land on which this work is conducted, their Elders past and present, their Nations of the Murray–Darling Basin, and their cultural, social, environmental, spiritual and economic connection to their lands and waters.

Acknowledgements of collaborators and contributors

We take this opportunity to thank the contributors and the many individuals and agencies who provided data to support this evaluation.

We would like to thank the CSIRO team for their efforts in report layout, editing, reviewing and formatting. Special mention to Susan Cuddy whose input, together with formatting specialist, Jill Sharkey, greatly improved the readability of the report.

Citation

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Document history

Date	Version
18 April 2024	Draft delivered to CSIRO for editing and quality check
May-June 2024	Formatting, internal review and response to review period
20 June 2024	Draft final delivered to CEWH

Cover photograph

Image: Releasing a Murray cod
Photo credit: Arthur Rylah Institute

Contents

Figures

Tables

1 Summary

1.1 Graphical summary of analyses

The effects of Commonwealth environmental water on fish are presented graphically in Figure 1.1 for each Selected Area. The degree of confidence in our results was quantified by the probability that Commonwealth environmental water had a positive effect on a given fish response. These probabilities (Bayesian posterior probabilities) range from 0 to 1 and were assigned to categories based on whether the estimated effects were strong (>95 % probability), moderate (90-95 %), weak (80-90 %) or not supported (<80 %).

The flow panels (small panels) in Figure 1.1 (red-blue shading) display the contribution of Commonwealth environmental water to key flow metrics in each Selected Area (x-axis: name of flow metric, for definition of metrics refer to Table 1.1 and Table 3.3; y-axis: timing of metric). The flow colour legend shows the direction and relative effect of Commonwealth environmental water on each flow metric, with darker blue colours indicating larger positive effects, white indicating no effect, and red colours indicating negative effects (e.g. Commonwealth environmental water decreases flow variability in the Lower Murray River).

Commonwealth environmental water decreased the number of low flows days and increased average daily flows (to a lesser extent) to varying degrees at the Selected Areas.

These patterns were most evident in the Goulburn and Lower Murray rivers. The response panels (larger panels) in Figure 1.1 show the degree of confidence that Commonwealth environmental water had a positive effect on each response variable (y-axis) for each species (x-axis; community = community analysis). The confidence colour legend ranges from white (no confidence; no evidence that Commonwealth environmental water had a positive effect) to dark green (high confidence; strong evidence that Commonwealth environmental water had a positive effect). Grey squares indicate no data for that cell (e.g. insufficient data collected to analyse). Note – the Gwydir River System did not have any larval fish surveys, so it does not have larval flow metrics. The Junction of Warrego and Darling rivers Selected Area is not included in this evaluation as it does not have a designated targeted indicator for fish and historically is not included in Basin-scale fish analyses. Fish responses to Commonwealth environmental water differed among species, years, hydrological components, and Selected Area.

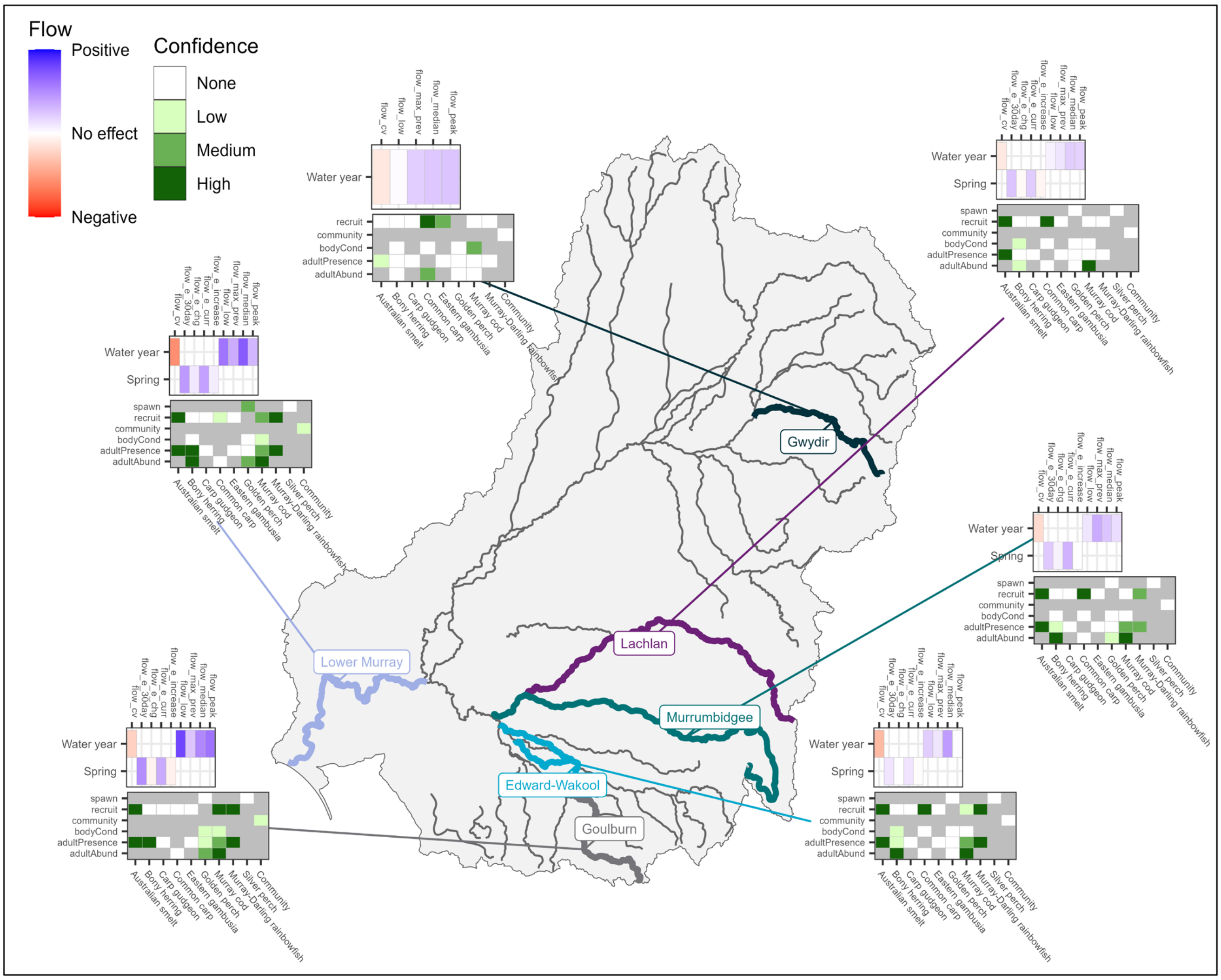


Figure 1.1 Magnitude of Commonwealth environmental water effects on flow metrics (small panels) and the predicted fish response effects based on counterfactual effects (larger panels) for each Selected Area, 2014–23
An A3 size version of this figure is provided in the main Fish report (Hladyz et al. 2024).

1.2 Sensitivity of 2022–23 data

To provide an index of how influential this year's data was on the models, I assess how the modelled estimates changed from the previous report (e.g. parameter sensitivity; Figure 1.2). This metric can be interpreted similar to t-statistics and hence values |t|>2 indicate increasing strong evidence for a statistical change in the slope.

Overall, no values exceeded this threshold. For the 2022–23 models, the largest difference was 1.17 for Murray cod in the adultAbund model (Figure 1.2). Compared to the previous report, the slope for flow_median decreased.

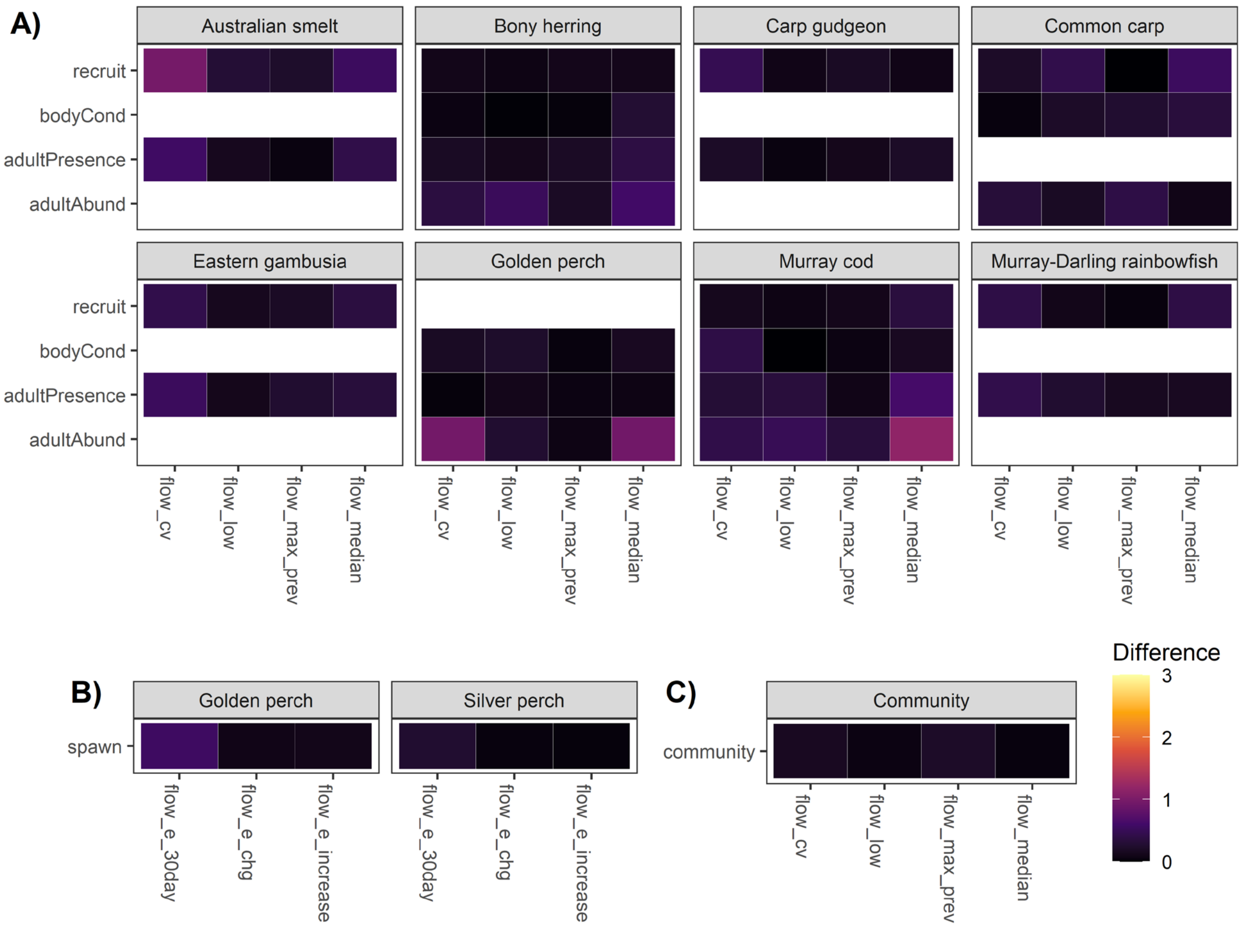


Figure 1.2 Sensitivity of model coefficients with the addition of 2022-23 data
A) shows the differences in sensitivity of recruit, bodyCond, adultPresence, adultAbund for Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, golden perch, Murray cod and Murray-Darling rainbowfish based on 4 annual flow metrics (flow_cv, flow_low, flow_max_prev, flow_median). B) shows sensitivity of spawn to event-based flow metrics (flow_e_30day, flow_e_chg, flow_e_increase. C) shows sensitivity of community mode to annual event-based flow metrics (flow_cv, flow_low, flow_max_prev, flow_median). Colour of tiles show the standardised differences (sensitivity) with black indicating no difference to yellow indicating statistical differences.

1.3 Commonwealth environmental water contributions in 2022–23

Here, I report on the Commonwealth environmental water (CEW) contribution for 2022–23 relative to other years to assess if CEW contributions were lower or higher than previous years. As an assessment metric, I calculated the percentage of times this year's CEW contribution exceeded previous years.

Due to the high flows in 2022–23, the majority of contributions were minimal this year (Figure 1.3), except in the Goulburn in which there was substantial CEW to mitigate low flows (flow_low metric) (similar to other years). The Edward-Wakool indicated the largest contribution to decreasing flow_low; however this should be interpreted with caution as this pattern was driven by no CEW contributions in the previous years and this year's contribution was very small (just one day).

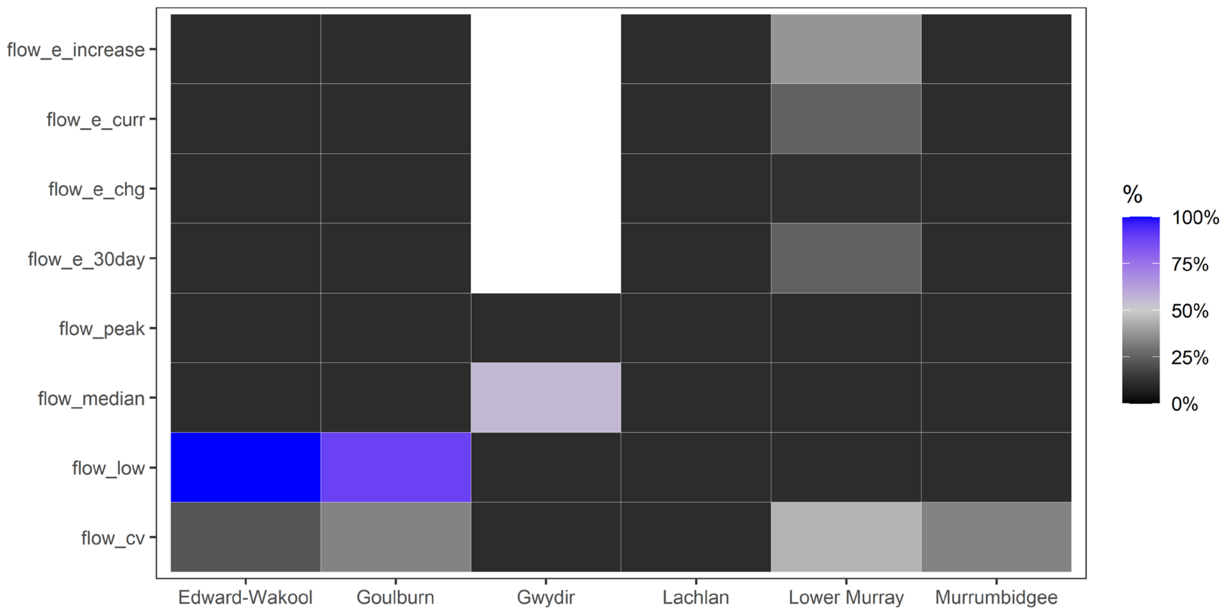


Figure 1.3 CEW contribution to flow components in 6 Selected Areas, 2022–23
Flow components are flow_cv, flow_low, flow_median, flow_peak, flow_e_30day, flow_e_chg, flow_e_curr, flow_e_increase.
Purple/blue squares indicate that the CEW contribution was higher than at least 50% of all years. Note - CEW contributions cause increase or decrease flow_cv as contributions can reduce or increase variation.

1.4 Flow conditions for 2022–23

Figure 1.4 summarises flows in Selected Areas for each season compared to previous years.

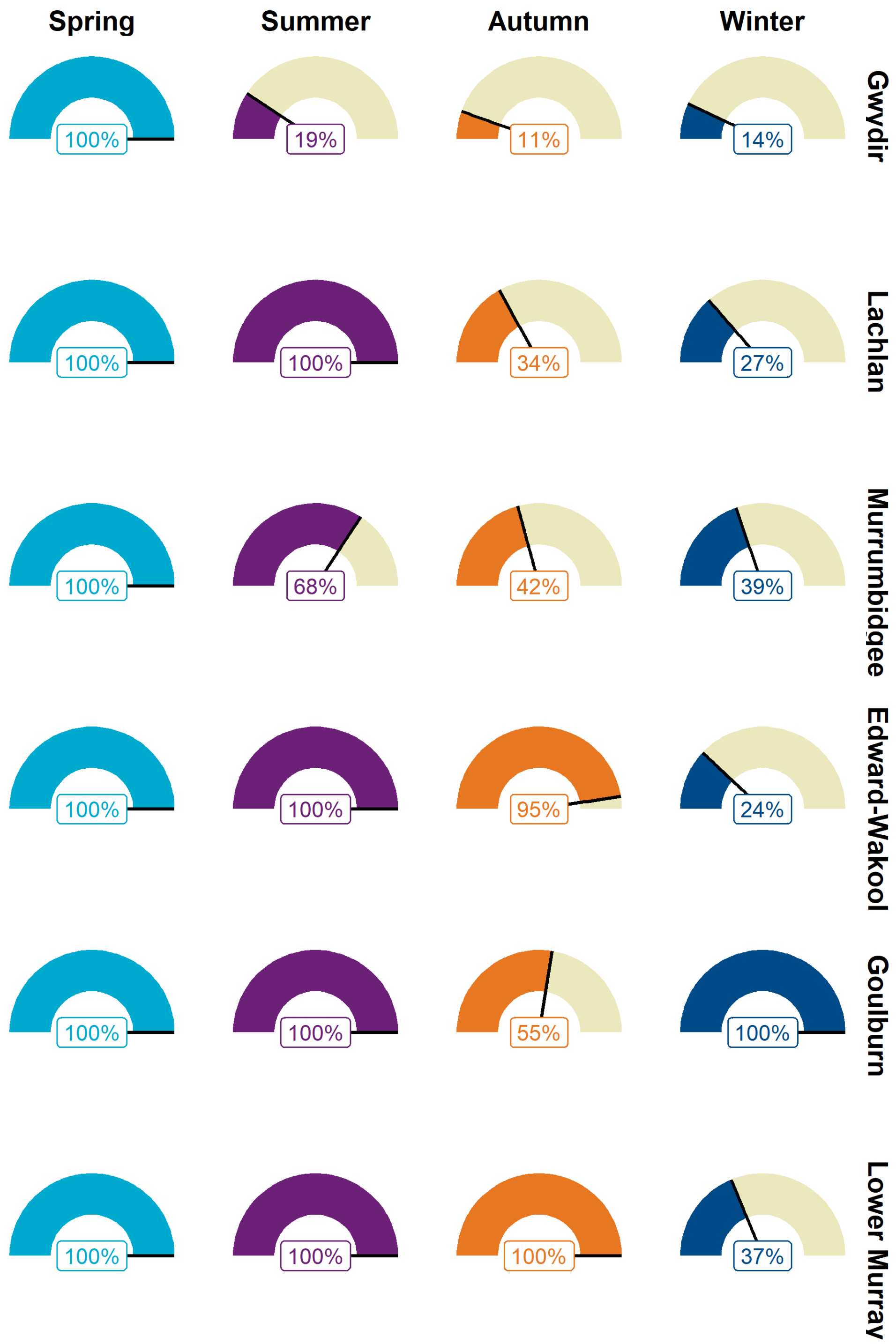


Figure 1.4 Gauge plots of seasonal flows in Selected Areas in 2022–23 compared to previous years
For each Selected Area, the mean flow for each season is calculated and then the percentage of the maximum flow_mean, 2014–23. Therefore, 100% indicates that this year is the maximum (mean) flow recorded for that season across 2014–23.

1.5 Revisions from 2021–22 report

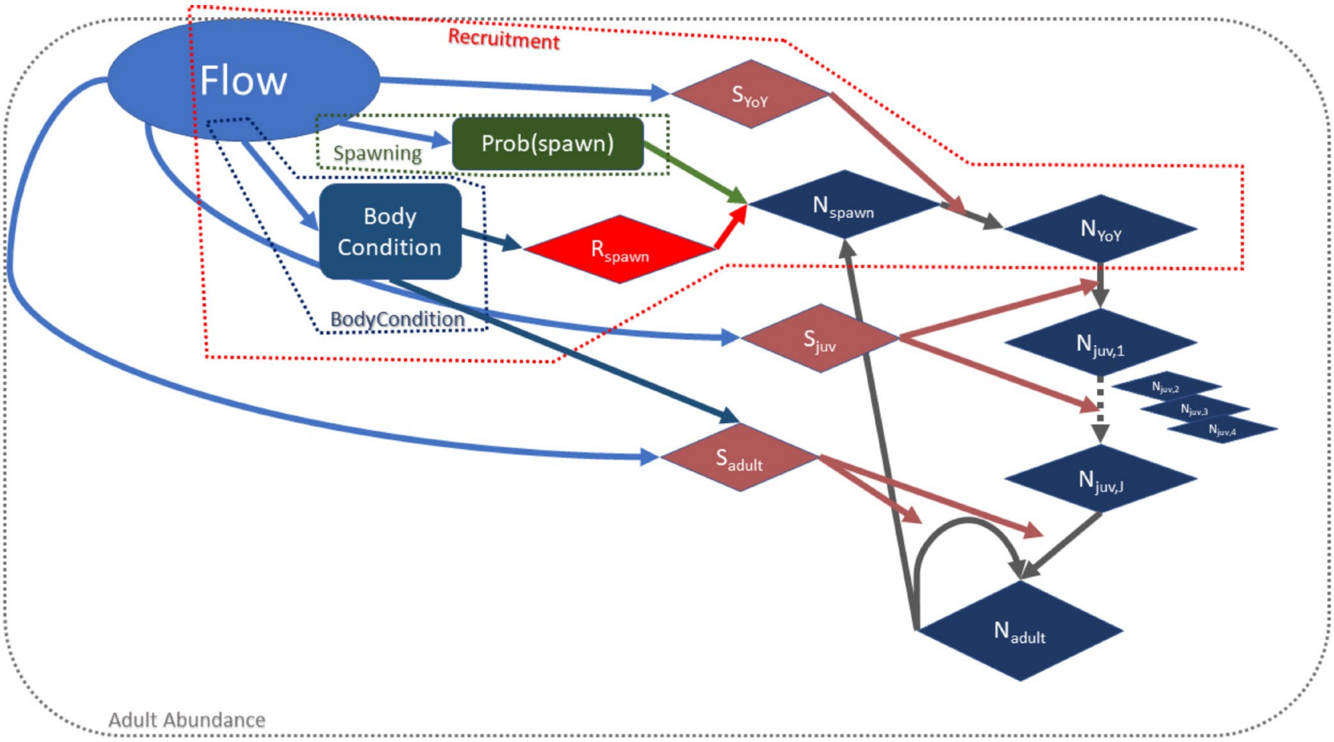
Table 1.1 lists the revisions in this report from that of the previous year.

Table 1.1 Revisions in this report from the 2021–22 Fish Technical Supplement report (Fanson 2023)
Section refers to the section(s) that the revision applies to.

ID	Section	Description	Rationale
1	1.2	Added new section with a new plot assessing model sensitivity with the additional of current year's data	Useful for assessing how this year's data affects the models
2	1.3	Added new section with a plot showing this year's CEW contribution. This provides context for interpreting effects	Useful for context on the magnitude of CEW contributions and if an effect might be expected
3	1.4	Added new section with a gauge plot of flow conditions relative to previous years	Useful to understanding the flows for the given year, e.g. was it a wet or dry spring?
4	3.X.3/4 Key results	Counterfactual plots - updated to density plots with a dot for current year	This change was requested due to dots becoming too cluttered with each additional year
5	3.4.1 Table 3.6	Updated length thresholds for Lower Murray in just 2022–23; see methods for details	Requested change
6	3.X.3/4 Key results	For counterfactual predictions (water year by Selected Area), adjusted definition of 'significance' to be sign(ci_lower) = sign(ci_upper) and >5% difference	Integrates both credible ranges as well as at least a 5% effect size
7	Separate report	Explore flow hydraulic metrics - added separate sections in methods and main document	Exploration requested in regard to hydraulic vs discharge

2 Considerations: Analyses and population processes

The central paradigm to this project is that flow affects population processes. The experimental/analysis design attempts to dissect out each component, though analyses vary in the number of processes included (Figure 2.1).



Unofficial

Figure 2.1 Coarse schematic of the key analyses overlaid onto the population processes

Dashed polygons show the main processes involved in that analysis. S_x – survival rate; N_x – age class population size; R_{spawn} – spawning rate; Prob(spawn) – probability of spawning; YoY – young of year; juv – juvenile. Note: Dashed line between juvenile age classes reflect variable juvenile duration for species.

The **spawning rate analysis** is the most straightforward analysis though complicated by the episodic nature of spawning (and difficulty in sampling). The count data were highly variable (lots of zeros with wide range of catches) and the flow metrics could not quite fully account for that variation, resulting in poor fit with negative binomial (as well as zero-inflated negative binomial models or ZINB). Adopting a binary approach allowed for a defensible model/representation.

The next level up analysis is the **recruitment analysis**. This analysis combines spawning analysis, adult population level, and first year survival (and potentially a bit of body condition). In the recruitment analysis, I try to control for adult population size by including previous year CPUE (catch-per-unit-effort) as a predictor. A complication here is that for say, common carp, juveniles add uncertainty in estimating the true number of females, weakening the relationship.

Adult abundance analysis includes basically all the processes, just with varying time lags depending on age classes included in the survey sample. For instance, total catch included young-of-year for common carp, whereas golden perch did not have young-of-year. An obvious result here is that teasing out flow effects on certain processes becomes more difficult. Negative effects on adult survival may be offset by juvenile-to-adult recruits. Sampling artifacts such as varying detection levels with younger age class also complicate the picture.

As an increasing number of population processes become involved, predicting effects of Commonwealth environmental water becomes more difficult. For instance, how does a 100-fold increase in spawning rate affect adult population once that year-class reaches adult maturity? Density-dependent processes are the norm rather than the exception in ecological systems. I would expect monotonic positive relationships (higher spawning rates = improves population growth rate), just the shape of that relationship is rather complex (e.g. sigmoidal shaped curve).

2.1 Water year definition analysis considerations

A water year of 1 September to 31 August is used in these analyses. This differs from the 1 July to 30 June water year used in all other Flow-MER reporting. This difference does not affect the analysis because all flow metrics consider the period from 1 September to the date of sampling (which always occurs before 30 June0). Therefore, flow metrics are calculated on a shorter timeframe than 12 months. This timing was used to align the water year with fish life-history processes.

For the flow metrics calculated from the full water year (1 September–31 August in the analysis), the definition of the water year may affect predictions of fish responses with and without Commonwealth environmental water. These fish responses are population growth rate, reporting rates (frequency of occurrence), body condition, and community nativeness. The degree to which the use of a different water year definition affects predicted Commonwealth environmental water impacts is expected to be minor given most environmental flows delivered for fish occur during spring and summer. However, spawning or recruitment (including predictions of Murray cod and Murray-Darling rainbowfish recruitment at unmonitored gauges) will not be affected because analyses of these variables used metrics defined on a subset of days or months between 1 September and 31 March.

2.2 Future considerations

Future improvements for analyses could look at ongoing discussions around the use of correlative statistical models for predicting Commonwealth environmental water responses versus using process-driven (potentially statistical) models to model Commonwealth environmental water responses (and ‘validate’ model predictions with empirical data/sampling).

3 Fish analyses

3.1 Overview

3.1.1 Background

All analyses in this report were performed using R v4.2 (R Core Team (2022)) using *rstanarm* package (Goodrich et al. 2020), except for the body condition data which were analysed using *lme4* package (Bates et al. 2015) due to prohibitively long computation times. I used a Bayesian linear model approach to better deal with estimation issues with some generalised model due to limited data (e.g. zero spawning in some Selected Areas' monitoring dataset). Specific details about each analysis are outlined in the sections below, but the models had similar basic structures and these shared similarities are outlined directly below.

First, each species was modelled separately for each response variable of interest. The model structure was broken into 3 components:

- response variable (possibly transformed; described in each section below)
- flow covariates (annual or event metrics; see section 3.2)
- spatial/temporal effects that were either fixed or random.

For the spatial/temporal effects, I adopted the following logic. I treated Selected Area as a fixed effect as it appears the experimental design is not random (the basins were selected nonrandomly) and hence extrapolation is likely tenuous. Within each Selected Area sampling dataset, I assumed site (aka samplepoint) as being roughly randomly selected and hence treated site as a random effect. For simplicity, I assume that constant site variation across Selected Areas. As for the temporal component, I assumed that water year was nested in each Selected Area (i.e. assumed independence across Selected Areas conditioned on the flow metrics), except for community analysis in which the data are summarised at the Selected Area-by-water year level and hence I only included a water year random effect. Again, I assume constant variability across Selected Areas. Finally, for the body condition analysis, there is a site-by-year random effect.

After fitting the model, validity of model assumptions was assessed through graphical analysis using posterior predictive checks (*pp_check()*) and Pearson residuals testing main assumptions: normality (where appropriate), heteroscedasticity, nonlinearities (residuals vs. each predictor), and looking for potential outliers (high leverage points). Variable transformations (noted in each analysis section) were used to correct if appropriate or a different statistical distribution if possible. Any model issues are discussed in the analysis document.

To model the counterfactual scenario, I used the final model to predict change in mean response using the provided counterfactual flows. For the annual flow models, I estimated the difference between predicted flows with and without CEW using *posterior_linpred()*, conditioning on the random effects (Goodrich et al. 2020). For analysis in which samplepoint was included, I took the mean flow conditions for that wateryear and used those conditions to predict the effect. For body condition, a conceptual similar approach was used except using parametric bootstrapping of the model.

For event-based models, it is less clear on how to approach the counterfactual scenario. For instance, with spawning, the sampling only records a fraction of the CEW events that did occur, and I may have missed the largest CEW effects. For this report, I took **the maximum CEW scenario for each water year in each Selected Area.** I did this by getting the difference between with and without CEW for each flow metric and then ranked for flow metric the magnitude of the difference. Then I summed the ranks and chose the sampling conditions that had the highest rank. Thus, I weighed each flow metric equally, even if the best model suggests unequal effects (this could be improved in the future). Similar approach was used for body condition, except I used parametric bootstrapping rather than the posterior distributions.

Finally, I present model results with 95% credible intervals (95%CI) [or 95% confidence intervals for body condition].

Table 3.1 Summary of statistical formulas used for each analysis
Rationale for approach is explained in each section below.

Analysis	Species	Equation	Link function	Family
spawn	Golden perch Silver perch	spawned~flow_e_chg + flow_e_increase + flow_e_30day + selected_area + wday + tot_effort + ad_cpue + (1 | selected_area:wateryear) + (1 | samplepoint)	logit	binomial
recruit	Murray cod Common carp Australian smelt Carp gudgeon Bony herring Eastern gambusia Murray-Darling rainbowfish	count~flow_median + flow_cv + flow_low + flow_max_prev + selected_area + tot_effort + ad_cpue + (1 | selected_area:wateryear) + (1 | samplepoint)	log	negative binomial
catchCurveAge	Golden perch	n_fish~age + (1 | birthyear)	log	negative binomial
adultAbund	Golden perch Murray cod Bony herring Common carp	r~flow_median + flow_cv + flow_low + flow_max_prev + selected_area + do_last_year + (1 | wateryear) + (1 | samplepoint)	log	gaussian
bodyCond	Golden perch Murray cod Bony herring Common carp	fulton_index~flow_median + flow_cv + flow_low + flow_max_prev + selected_area + (1 | wateryear) + (1 | wateryear: selected_area) + (1 | samplepoint)	identity	gaussian
adultPresence	Golden perch Murray cod Carp gudgeon Bony herring Common carp Eastern gambusia Australian smelt Murray-Darling rainbowfish	presence~flow_median + flow_cv + flow_low + flow_max_prev + selected_area + (1 | wateryear) + (1 | samplepoint)	logit	binomial
community	Community	prop~flow_median + flow_cv + flow_low + flow_max_prev + selected_area + (1 | wateryear) + (1 | samplepoint)	identity	gaussian

Table 3.2 Terms and variables used in the model structure

Term/variable	Used for
Flow covariates	
flow_median	Standardised daily flow for relevant timing
flow_cv	Coefficient of variability in daily flow for relevant timing
flow_low	Number of days of low flow (below 10th percentile of available data)
flow_max_prev	Standardised maximum antecedent flow

Term/variable	Used for
flow_peak	Peak standardised flow (95th percentile)
Flow event-based covariates	
flow_e_chg	Change in daily flow in 7 days prior to capture
flow_e_increase	Number of days of increasing flow in 7 days prior to capture
flow_e_curr	Median standardised flow in the last 7 days
flow_e_30day	Median standardised flow in the last 30 days
Response variables	
spawned	Spawning occurrence
count	recruit abundance
n_fish	number of fish caught at each age
presence	Presence of that species at that site (for that wateryear)
r	adult abundance catch-per-unit-effort
fulton_index	Fulton's K body condition factor
prop	Proportion of the fish species per selected_area:wateryear:sampelpoint that were native
Other variables	
ad_cpue	current water year's adult abundance catch-per-unit-effort
age	fish age
birthyear	the birth year of an individual fish
do_last_year	indicator variable denoting time since most-recent fish death event or blackwater event at a sample point
tot_effort	sampling effort (log-transformed), either electrofishing time or volume filtered through fyke nets
selected_area	Selected Area site
samplepoint	site within Selected Area
wateryear	the water year in which a survey occurred
wday	Day of year

3.2 Overview of flow metrics and analyses

3.2.1 Description of flow metrics

Flow metrics remained the same as previous years and I used the same 'recruitment' temporal window introduced in the 2021–22 report (September–March).

A brief summary of the variables is given in Table 3.3. Daily flow profiles without and with CEW events are shown in Figure 3.1. Temporal patterns in annual metrics and event metrics are shown in Figure 3.2 and Figure 3.3, respectively. Water year is defined as maximum year between September to August. e.g. Water year 2016 is 2015 September 1st to 2016 August 31st.

To ameliorate effects, leverage effects and improve spacing of flow data, I log-transformed the following flow metrics: flow_median, flow_max_prev, flow_e_curr, flow_e_30day, flow_cv. The following flow metrics were square-root transformed: flow_low.

Table 3.3 Summary of flow metrics used in these analyses

Note: flow_peak correlated strongly with flow_median and was only included in the catch curve analysis in which there was a longer temporal dataset (see catch curve section below).

Short name	Metric	Description
Flow annual covariates		
flow_median	Standardised daily discharge for relevant timing	Increased discharge boosts productivity, leading to improved condition and survival outcomes for fish, and may support fish movements and reproduction by improving connectivity and providing critical movement and spawning cues. Increased discharge may improve water quality in refuge pools during low-flow periods. If timed inappropriately or too frequent, large increases in discharge may reduce egg and larval survival of some species due to sudden changes in hydraulics, depth, or water temperature.
flow_low	Number of days of low discharge (below 10th percentile of available data)	Consistent base flows support survival and condition of fish and support fish movements by increasing connectivity among reaches and rivers. Low flows (below base flows) reduce habitat and food resources, which may increase mortality of all life stages, particularly larvae and fingerlings.
flow_max_prev	Standardised maximum antecedent discharge	Large flows in previous years stimulate productivity, improving food availability and fish condition, which can have positive effects on reproduction in later years. Very large flows may provide lateral connectivity, which increases productivity and connectivity to wetlands and floodplains that provide refuges and feeding opportunities.
flow_cv	Coefficient of variability in daily discharge for relevant timing	Rapid changes in discharge during core spawning period may increase mortality of eggs and larvae but may enhance productivity and improve condition and growth of older cohorts.
flow_daily	Discharge on day of sampling	Discharge at the time of sampling influences detectability of fishes in electrofishing surveys.
flow_peak	Peak standardised discharge (95th percentile)	High flow events are trigger recruitment events but also lead to flooding conditions that may lead to improved productivity but also blackwater events. Note - only used with catch curve analysis as often tightly correlated with flow_median.
Flow event-based covariates		
flow_e_chg	Change in daily discharge in 7 days prior to capture	Short-term increases in discharge and subsequent changes in hydraulics (velocity or depth) may provide spawning cues to some fish species, potentially signalling increased productivity and improved spawning conditions.
flow_e_increase	Number of days of increasing discharge in 7 days prior to capture	Sustained increases in discharge may provide spawning cues and increase the availability of spawning and larval habitat.
flow_e_30day	Median standardised flow discharge in the last 30 days	Higher flow discharge can trigger spawning as higher flow may provide better spawning habitat.

3.2.2 Daily flow profiles across each Selected Area

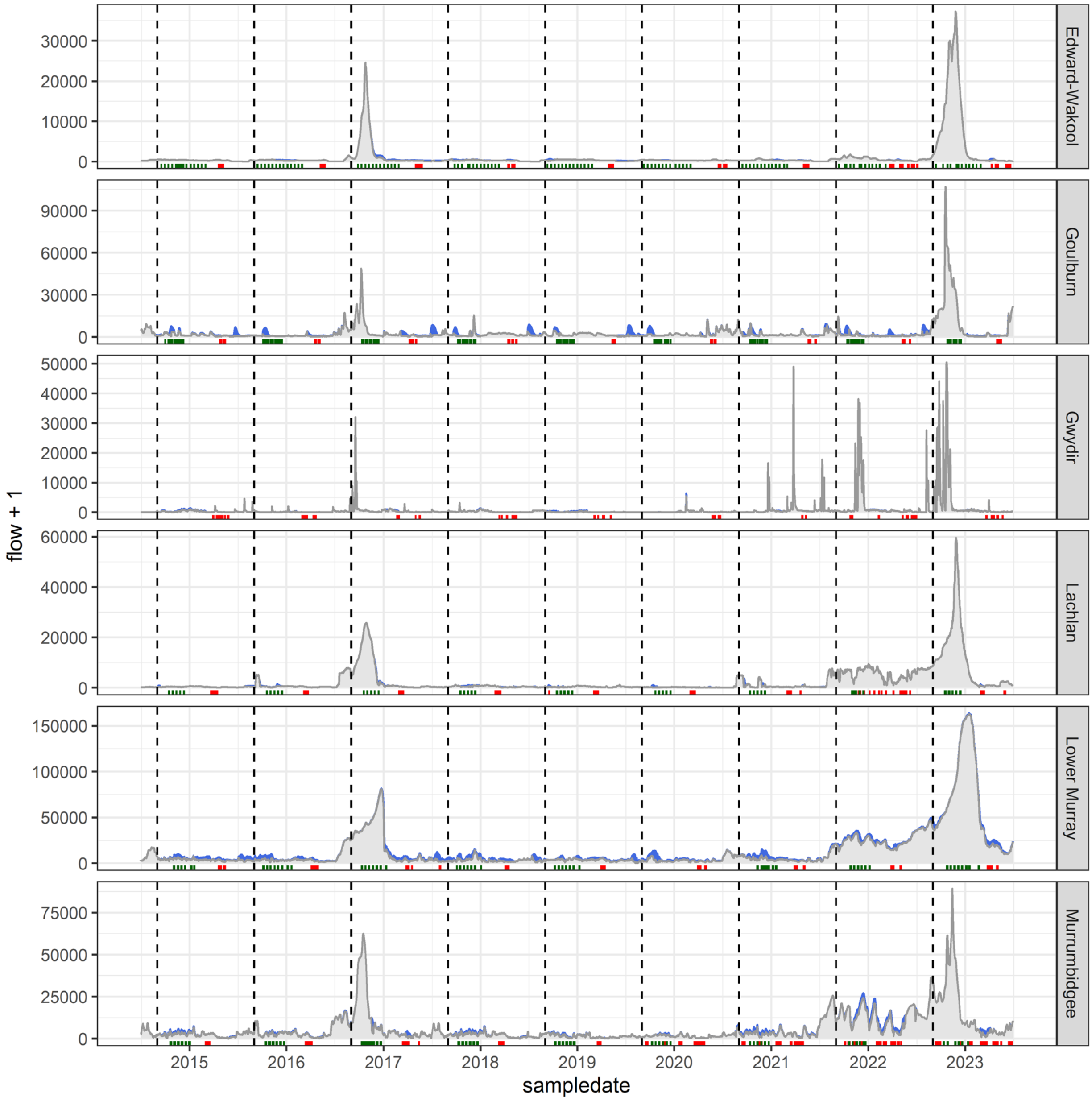


Figure 3.1 Flow profiles for 6 of the 7 Selected Areas : (top set) daily flow+1, (bottom set) daily flow, 2014–23

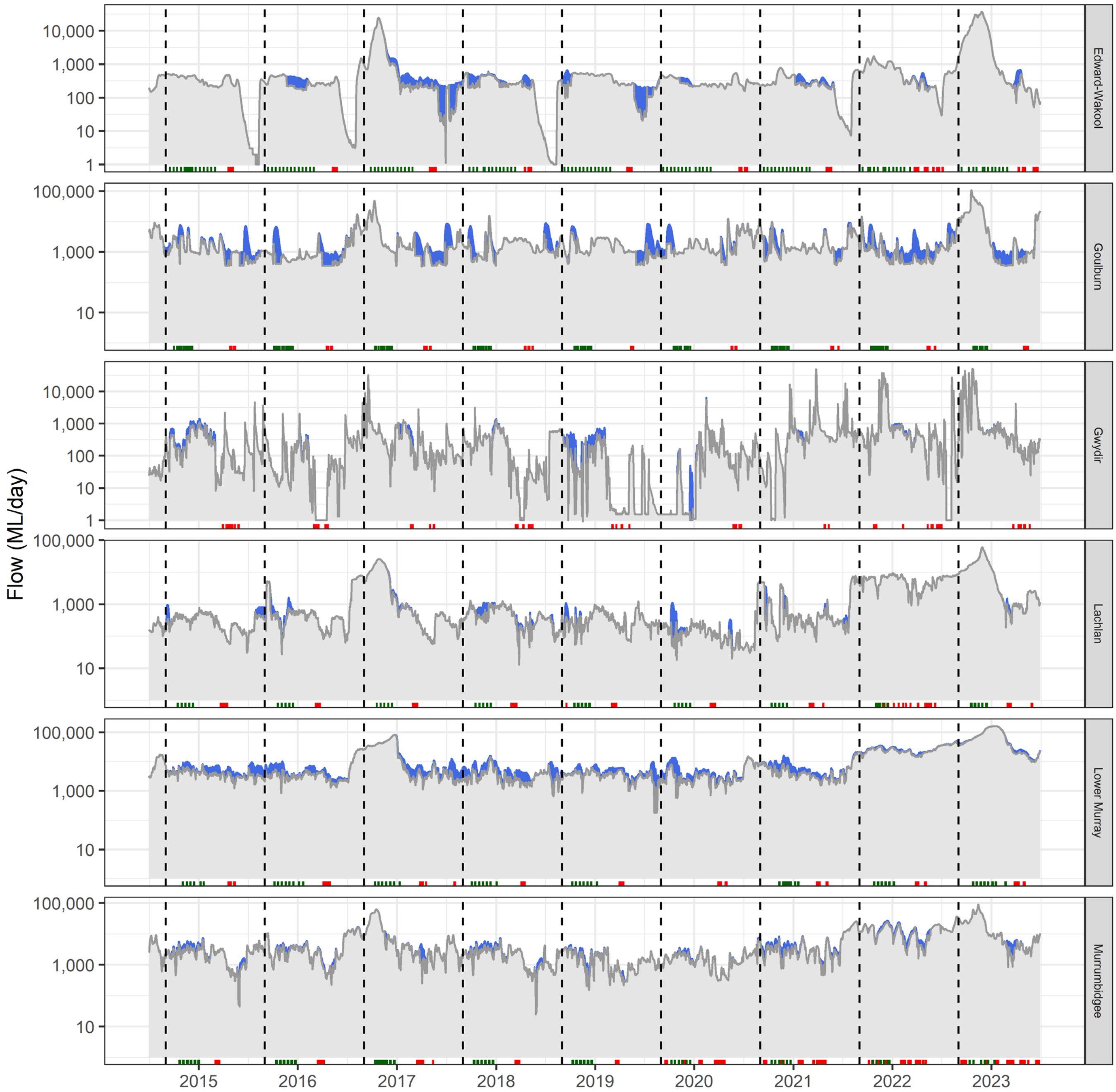


Figure 3.1 (cont'd) Flow profiles for 6 of the 7 Selected Areas : (top set) daily flow+1, (bottom set) daily flow, 2014–23

Grey area shows flow when no CEW is present. Blue area show added CEW volume. Green and red rugs show timing of larval and adult surveys, respectively. Vertical dotted lines are temporal boundaries for each water year. y-axis is log scaled to emphasise a proportional perspective.

3.2.3 Temporal pattern in annual flow metrics

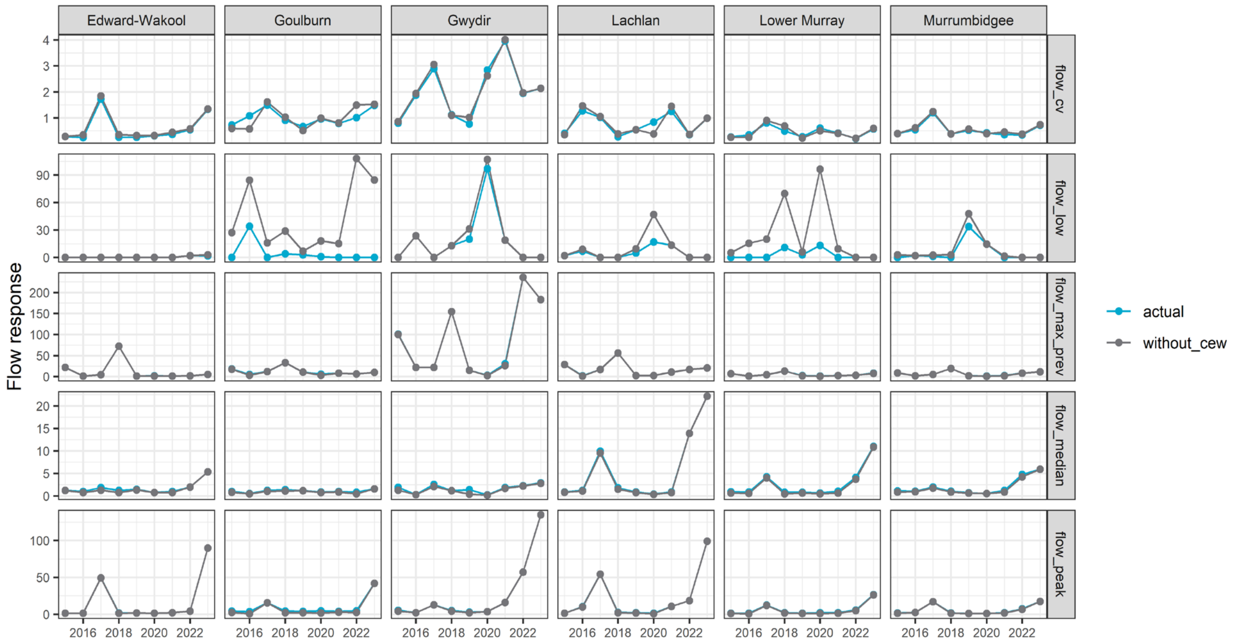


Figure 3.2 Temporal profiles for each annual flow metric, for 6 Selected Areas, 2014–23
Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median, flow_peak. Each point is the mean of all the surveys that water year. Note that flow conditions are based on hydrological conditions up to that event (and hence not the entire water year if the survey date preceded end of water year).

3.2.4 Temporal pattern in event flow metrics

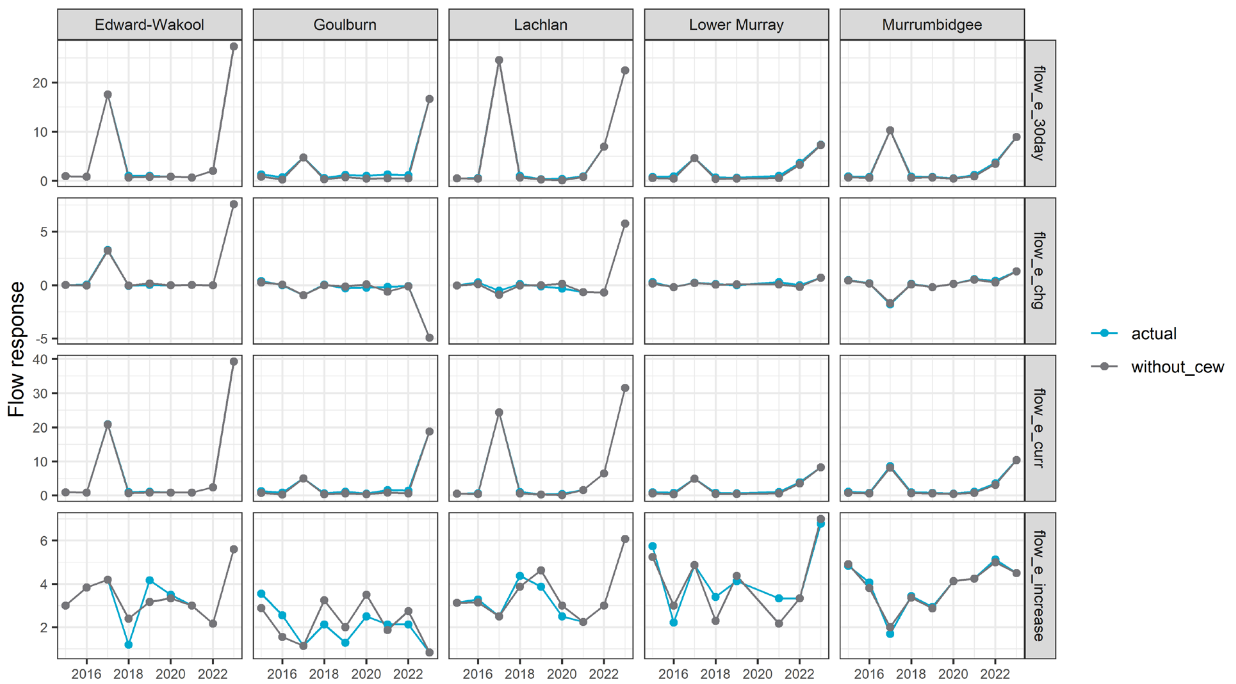


Figure 3.3 Temporal profiles for each flow event metric, by Selected Area, 2014–23
Flow metrics are flow_e_30day, flow_e_chg, flow_e_curr, flow_e_increase. Each point is the mean of all the sampling surveys for that water year. The Gwydir River System was not included as event flow metrics were only calculated for the spawning analysis and spawning was not monitored at this Selected Area.

3.3 Analysis: Spawning presence

3.3.1 Logic and data trimming

Logic

For flow-cued spawners (golden perch and silver perch), flow conditions affect the spawning triggers and survival of recruits. Triggers likely include rapid changes in flow conditions as well as baseline flow levels.

Data trimming

Total sample sizes are shown in Table 3.4. Surveys not conducted during the spring period were not included. Due to the larger number of zeros and the wide range of count data when eggs/larva present, I chose to just analyse the data as presence/absence of spawning. So, I converted count to a binary response variable.

Table 3.4 Summary of sample sizes for silver perch and golden perch spawning dataset for 5 Selected Areas and the percentage of samples that had zero eggs (all years and for just the current year)

Species / Selected Area	# of sites	Years of monitoring	Percent zero eggs (all years)	Percent zero eggs (2023)
Silver perch				
Edward/Kolety–Wakool	9	9	99.5%	100.0%
Goulburn	7	9	96.4%	100.0%
Lachlan	6	9	100.0%	100.0%
Lower Murray	7	8	95.7%	100.0%
Murrumbidgee	6	9	85.4%	100.0%
Golden perch				
Edward/Kolety–Wakool	9	9	100.0%	100.0%
Goulburn	7	9	89.3%	87.5%
Lachlan	6	9	99.1%	100.0%
Lower Murray	7	8	87.2%	100.0%
Murrumbidgee	6	9	81.0%	100.0%

Key exploratory graph(s)

To explore patterns in the data, I looked at temporal patterns in the proportion of sites that recorded spawning each water year (Figure 3.4).

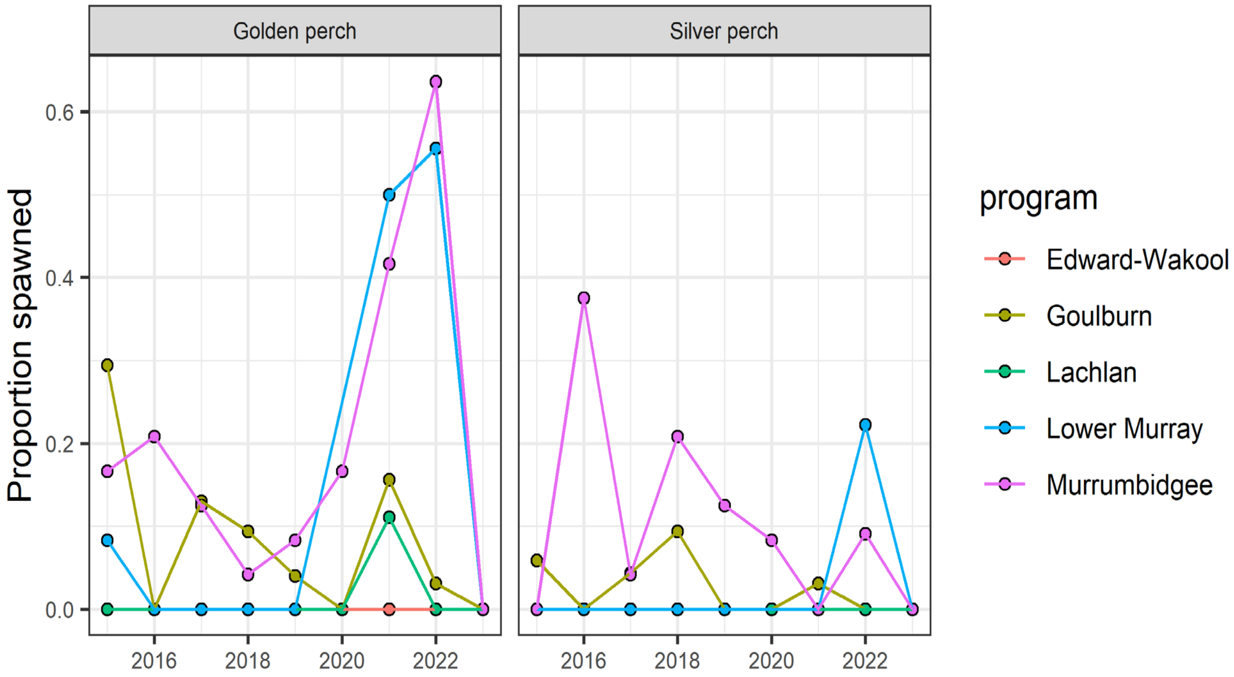


Figure 3.4 Line plot showing change in golden perch and silver perch spawning rates, for 5 Selected Areas over 2014–23

Spawning data were not collected in the Gwydir River System Selected Area.

3.3.2 Data analysis

To test for the effects of flow metrics on spawning, I modeled the probability that a spawning event is detected based on flow conditions. Previous water year's adult CPUE (ad_cpue) was calculated as average CPUE for the Selected Area. I imputed adult CPUE for 2014 as the average of other years.

Using the above approach, I ran a bGLMM (Bayesian General Linear Mixed Model) with a binomial distribution (in a Bayesian framework). As the metrics were the same within a Selected Area, I summed together all sampling events within a Selected Area and used total number of spawning events detected as the response variable. I included the selected annual flow metrics, total volumetric effort (log-scaled), previous water year's adult CPUE (log-transformed), and Selected Area as fixed effects. Selected Area -by-water year was included as a random effect, which helps account for potential overdispersion in the data.

3.3.3 Key results

- Spawning was only detected in the Goulburn (2 golden perch eggs).
- As previously shown, spawning probabilities increased later in the spawning season for both golden perch and silver perch.
- Golden perch had a higher probability of spawning as the number of consecutive days of increasing flow (flow_e_increase).
- Compared to the previous report, the slope for flow_e_30day decreased, resulting in the 95%CrI overlapping with zero (Figure 3.5).

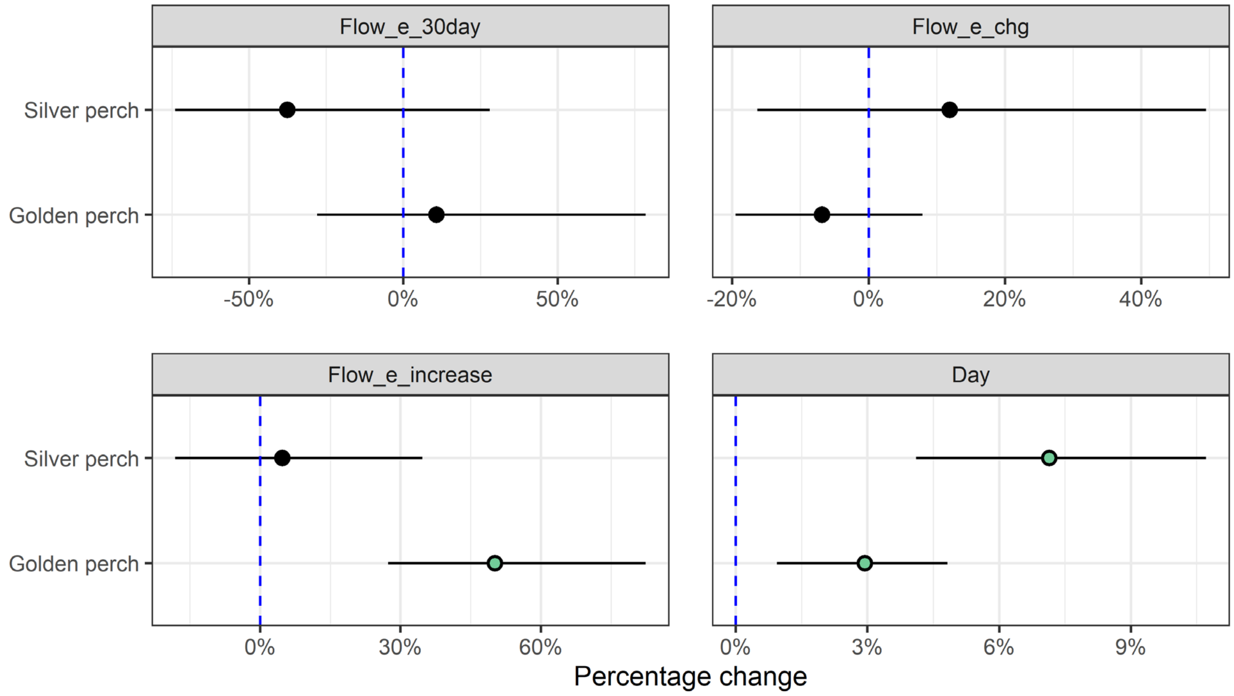


Figure 3.5 Effect of each flow metric on silver perch and golden perch spawning rates
Flow metrics are flow_e_30day, flow_e_chg, flow-e_increase and day.
Error bars are 95%CrI (95% Credible Intervals). Coloured dots indicate significant effects at $p<0.05$ threshold.

Counterfactual predictions

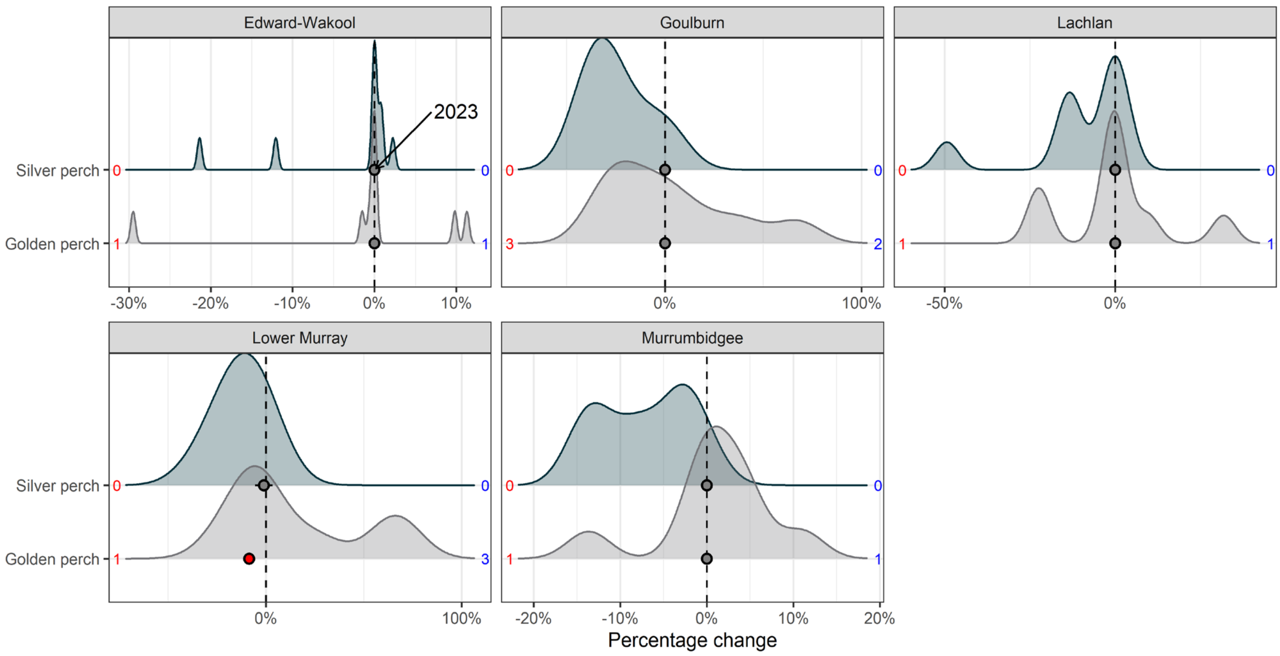


Figure 3.6 Distribution of predicted effect of CEW on silver perch and golden perch spawning rates, by Selected Area
Each density plots shows distribution of effect sizes (scaled to percentage change) across all years covered in this report. Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

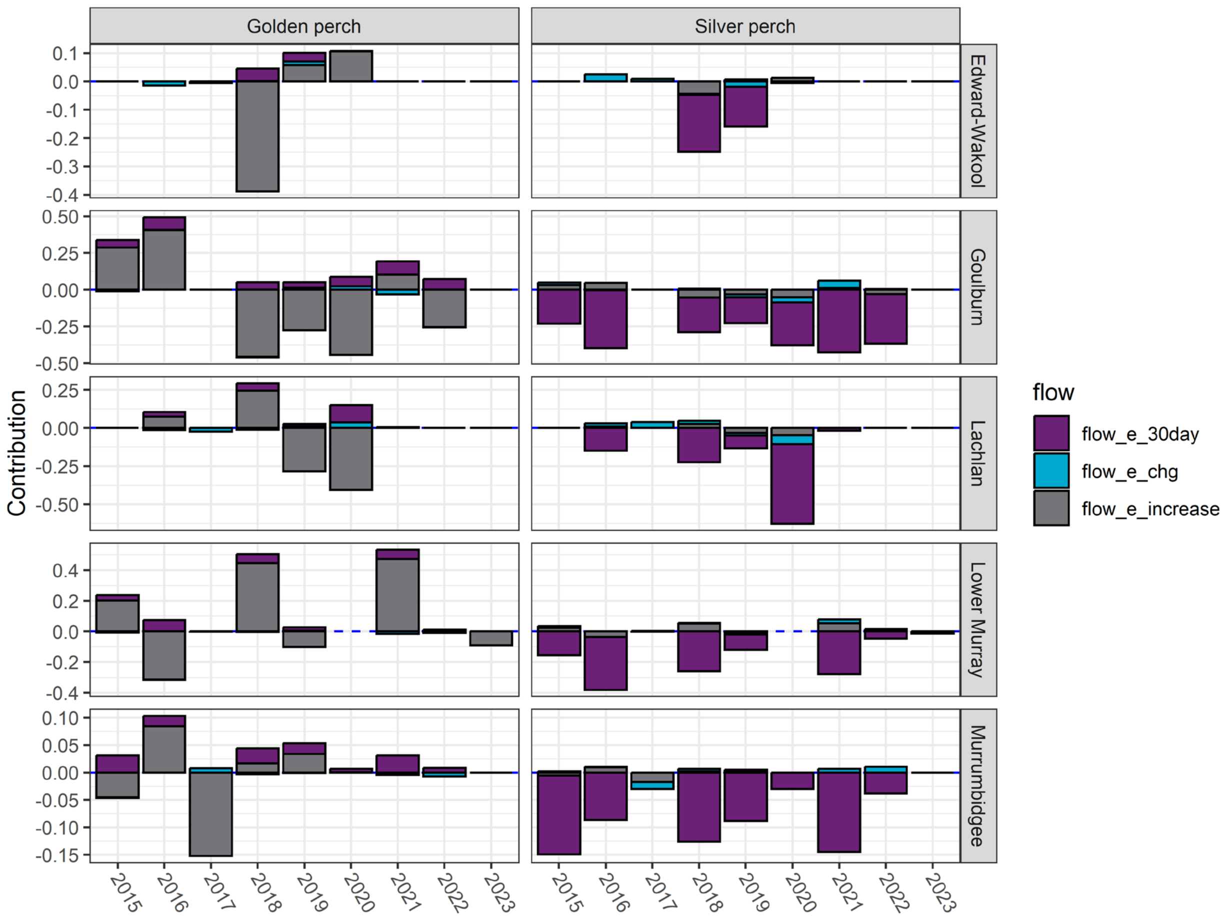


Figure 3.7 Contribution of each flow metric to the predicted CEW effect on spawning rates of silver perch and golden perch, by Selected Area, 2014–23

Flow metrics are flow_e_30day, flow_e_chg, flow_e_increase.

Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on link scale.

3.4 Analysis: Recruit analysis (young-of-year) using abundance data

3.4.1 Logic and data trimming

Logic

Recruits numbers reflect multiple population processes: reproductive output and larval survival. The annual flow metrics were included as predictors affecting these processes.

Data trimming

Species retained for analyses were the MER focal species (Table 3.5). However, only 4 golden perch recruits were caught (and measured) so were dropped for this analysis. For large-bodied species, only electrofishing data were kept and for small-bodied species, only fine fyke data were kept. Length thresholds for large-bodied species were used to determine young-of year recruits (Table 3.6). Length thresholds can be problematic for small-bodied fish species as they can reach maturity quickly and produce multiple generations in less than 1 year (e.g. eastern gambusia). Flow-MER sampling occurs largely at the end of the breeding period for all the focal small-bodied species (especially for Australian smelt, eastern gambusia, carp gudgeon that have a protracted spawning period) and the majority of the sample would be young-of-year. Therefore, detection/abundance of small-bodied species was used as a whole for small-bodied species recruitment which follows the same logic and methodology applied in The Living Murray fish monitoring at Barmah-Millewa Forest Icon site for small-bodied species recruitment (Raymond et al. 2021).

Table 3.5 Summary of sample sizes for recruitment dataset for 7 species across Selected Areas
'Percent zero' is the percentage of sampling events with zero recruits caught (all years and just for current year).

Species	Method	Fish caught	# Selected Areas	Sites	Years	Percent zero (all years)	Percent zero (2023)
Carp gudgeon	finefyke	315,798	6	102	9	5.2%	11.4%
Eastern gambusia	finefyke	66,973	6	102	9	28.4%	30.7%
Murray-Darling rainbowfish	finefyke	11,020	6	102	9	51.3%	84.3%
Australian smelt	finefyke	7,763	6	102	9	59.9%	60.7%
Bony herring	ef	7,394	6	93	9	54.3%	69.5%
Common carp	ef	6,313	6	93	9	37.7%	23.7%
Murray cod	ef	1,356	6	93	9	47.0%	85.9%

Table 3.6 Length thresholds used for assigning new recruits for 7 species, by Selected Area
Values indicate length at one year of age for longer-lived fish species, or the age at sexual maturity for fish species reaching sexual maturity within one year. Dash (–) indicates no record

Species / Year	Edward/Kolety –Wakool	Goulburn	Gwydir	Lachlan	Lower Murray	Murrum bidgee
Australian smelt						
2014–23	40	40	40	40	40	40
Bony herring						
2014–22	–	–	–	–	120	–
2014–23	65	65	67	67		67
2023	–	–	–	–	150	–
Carp gudgeon						
2014–23	35	35	35	35	35	35
Common carp						
2014–23	150	150	155	155	155	155
Eastern gambusia						
2014–23	20	20	20	20	20	20
Golden perch						
2014–22	–	–	–	–	85	–
2014–23	75	75	75	75	–	75
2023	–	–	–	–	135	–
Murray cod						
2014–22	–	–	–	–	155	–
2014–23	220	220	222	222	–	222
2023	–	–	–	–	170	–
Murray-Darling rainbowfish						
2014–23	45	45	45	45	45	45

Key exploratory graph(s)

Violin plot and mean recruit abundance (CPUE) over time for 6 Selected Areas and 7 species is shown in Figure 3.8.

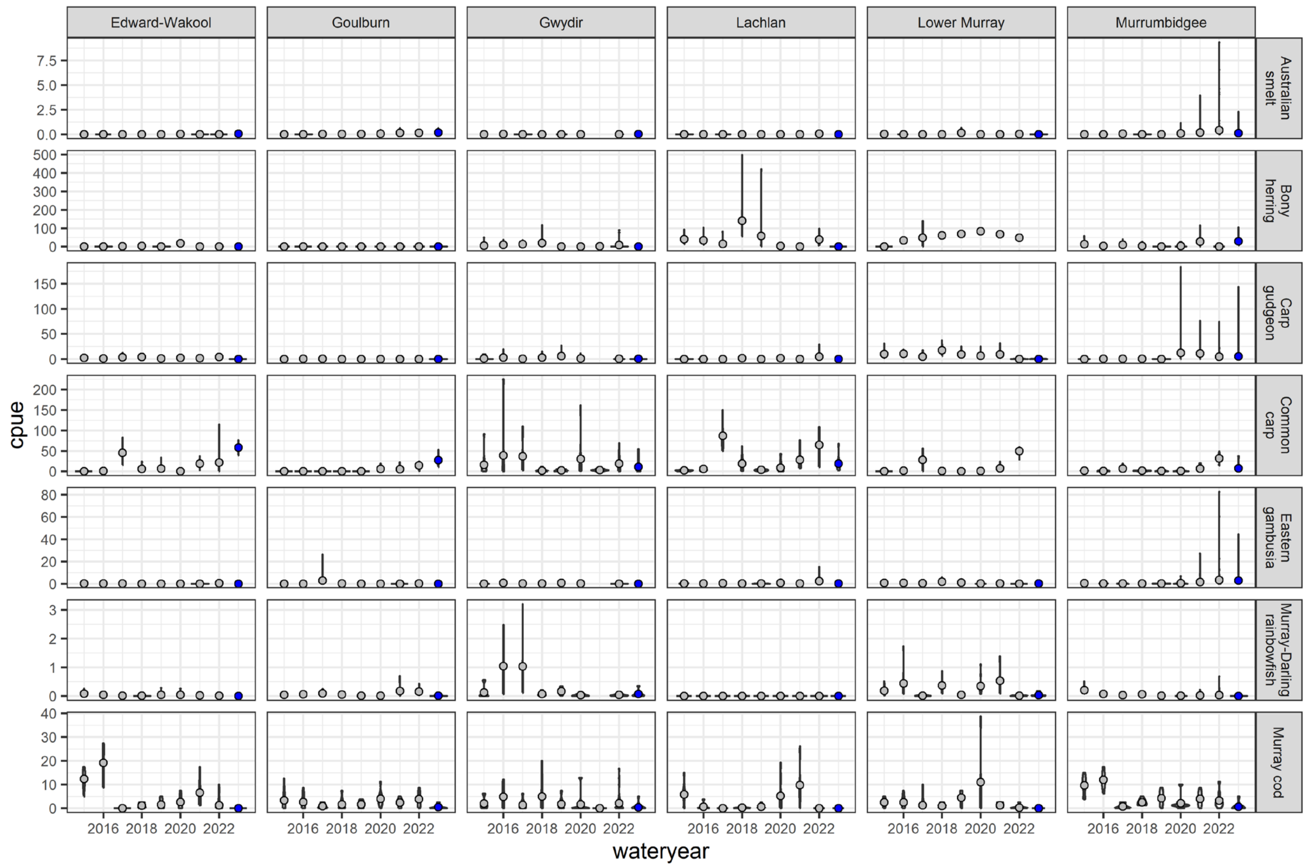


Figure 3.8 Violin plot showing change in recruit abundance (cpue) over time for 7 species, by Selected Area, 2014–23

Species are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, Murray-Darling rainbowfish, Murray cod.

Mean CPUE shown as circles with the blue dot indicating 2023's data.

3.4.2 3.4.2 Data analysis

I ran a GLMM (generalised linear mixed model) with a negative binomial distribution (in a Bayesian framework). Count was the response variable. Fixed effects include annual flow metrics, total effort, Selected Area, and previous adult cpue (log-transformed). Random effects include Selected Area:wateryear and samplepoint.

3.4.3 Key results

- Recruitment of young-of-year was generally low in 2022–23.
- Results are very similar to the previous year.
- Murray cod had increased recruitment rates with fewer low flow days (flow_low) and flow_median (= goldilocks recruitment or possibly detection issue).
- Common carp had increased recruitment rates with increasing flow_median.
- Australia smelt and Murray-Darling rainbowfish had higher recruitment with fewer low flow days.

Flow coefficients

Estimates of flow coefficients for each species are shown in Figure 3.9.

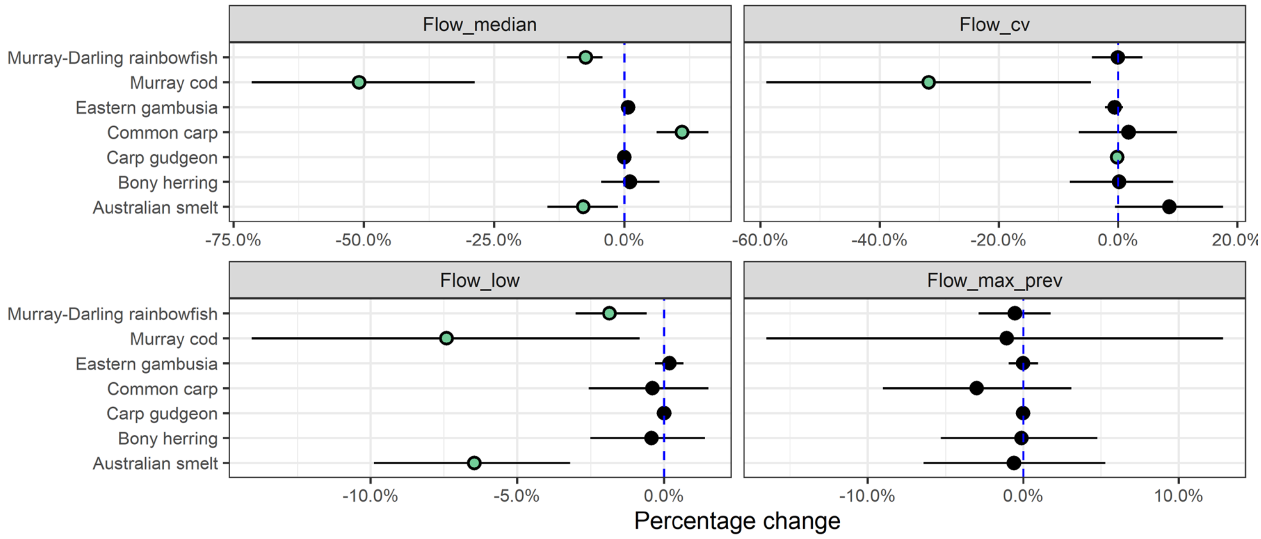


Figure 3.9 Effect of each flow metric on recruitment rates for 7 fish species

Species are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, Murray-Darling rainbowfish, Murray cod.

Flow metrics are flow_median, flow_cv, flow_low, flow_max_prev.

Error bars are 95%CrI. Coloured dots indicate significant effects at p<0.05 threshold.

Counterfactual predictions

The predicted effect and marginal effect of CEW on recruitment is shown (Figure 3.10, Figure 3.11, Figure 3.12, Figure 3.13). Australian smelt are split from the other fish species for better visual clarity (Figure 3.10; Figure 3.12). The positive changes show Commonwealth environmental water increased recruitment.

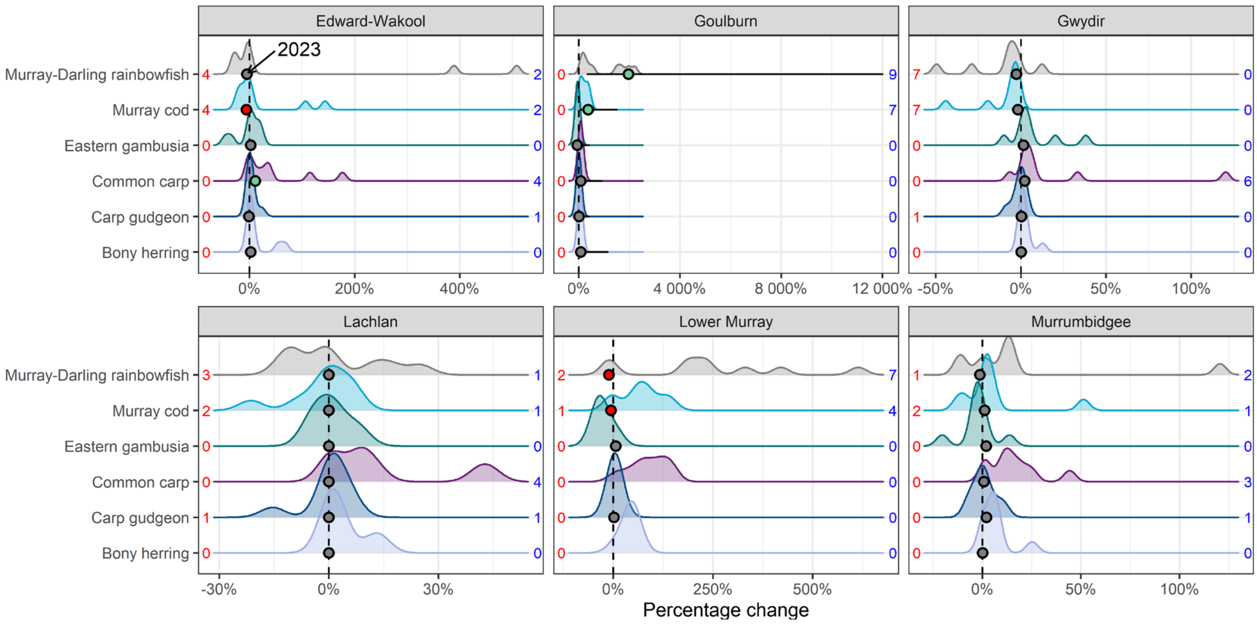


Figure 3.10 Distribution of predicted effect of CEW on recruitment rates for each species (without Australian smelt), by Selected Area

Fish are bony herring, carp gudgeon, common carp, eastern gambusia, Murray cod, Murray-Darling rainbowfish. Australian smelt dropped due to large error bars distorting scale.

Each density plots shows distribution of effect sizes (scaled to percentage change). Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

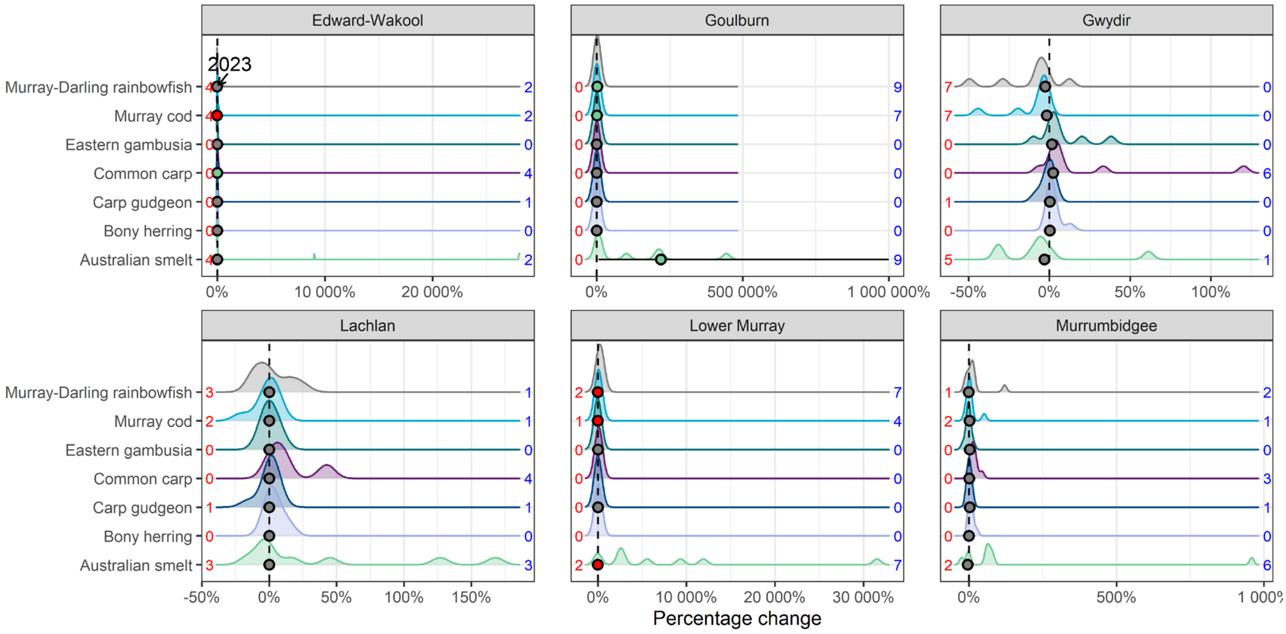


Figure 3.11 Distribution of predicted effect of CEW on recruitment rates for each species, by Selected Area
Fish are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, Murray cod, Murray-Darling rainbowfish.
Each density plots shows distribution of effect sizes (scaled to percentage change). Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

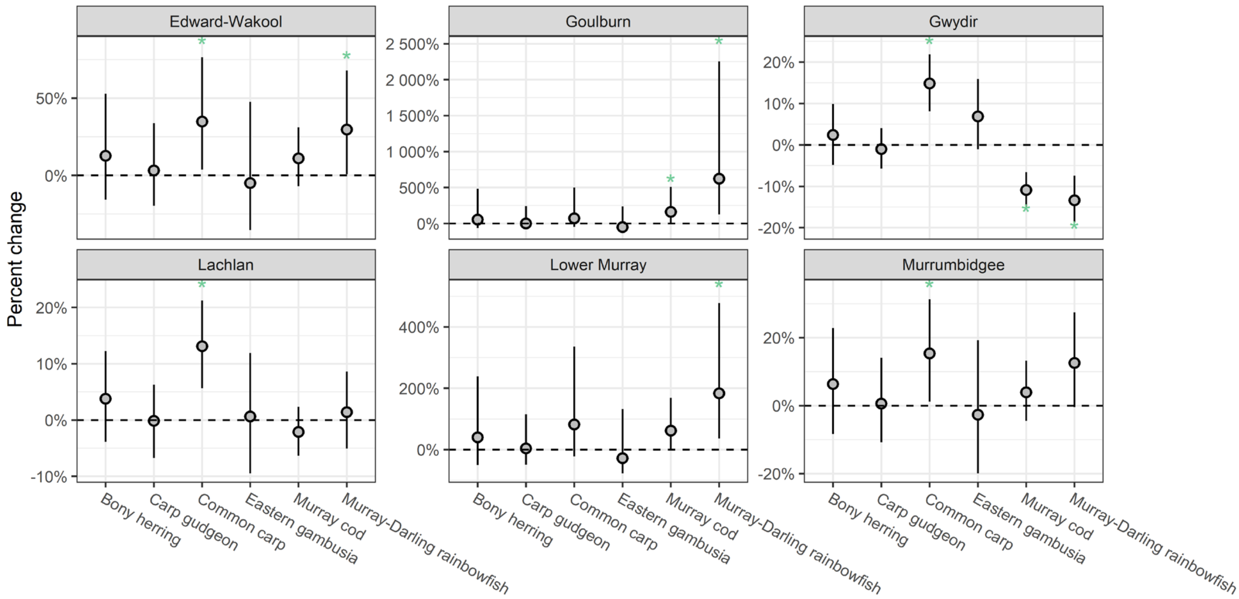


Figure 3.12 Predicted effect of CEW on recruitment rates for each species (without Australian smelt), by Selected Area
Fish species are bony herring, carp gudgeon, common carp, eastern gambusia, Murray cod and Murray-Darling rainbowfish. Effect sizes have been scaled to percentage change with CEW. Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively).

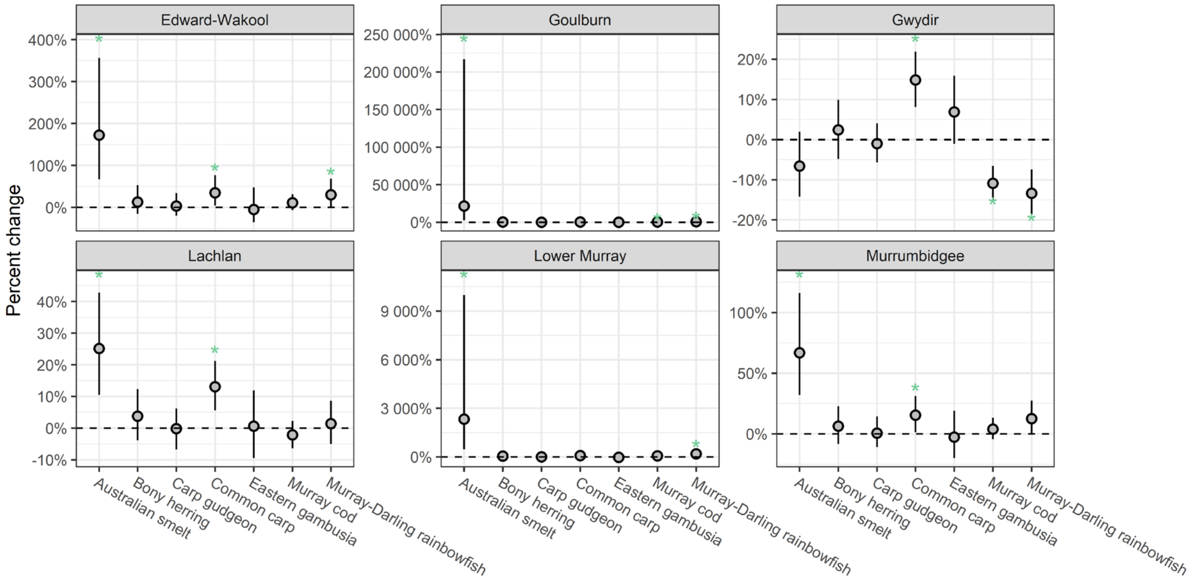


Figure 3.13 Predicted effect of CEW on recruitment rates for each species (with Australian smelt), by Selected Area
Fish species are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, Murray cod and Murray-Darling rainbowfish. Effect sizes have been scaled to percentage change with CEW. Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively).

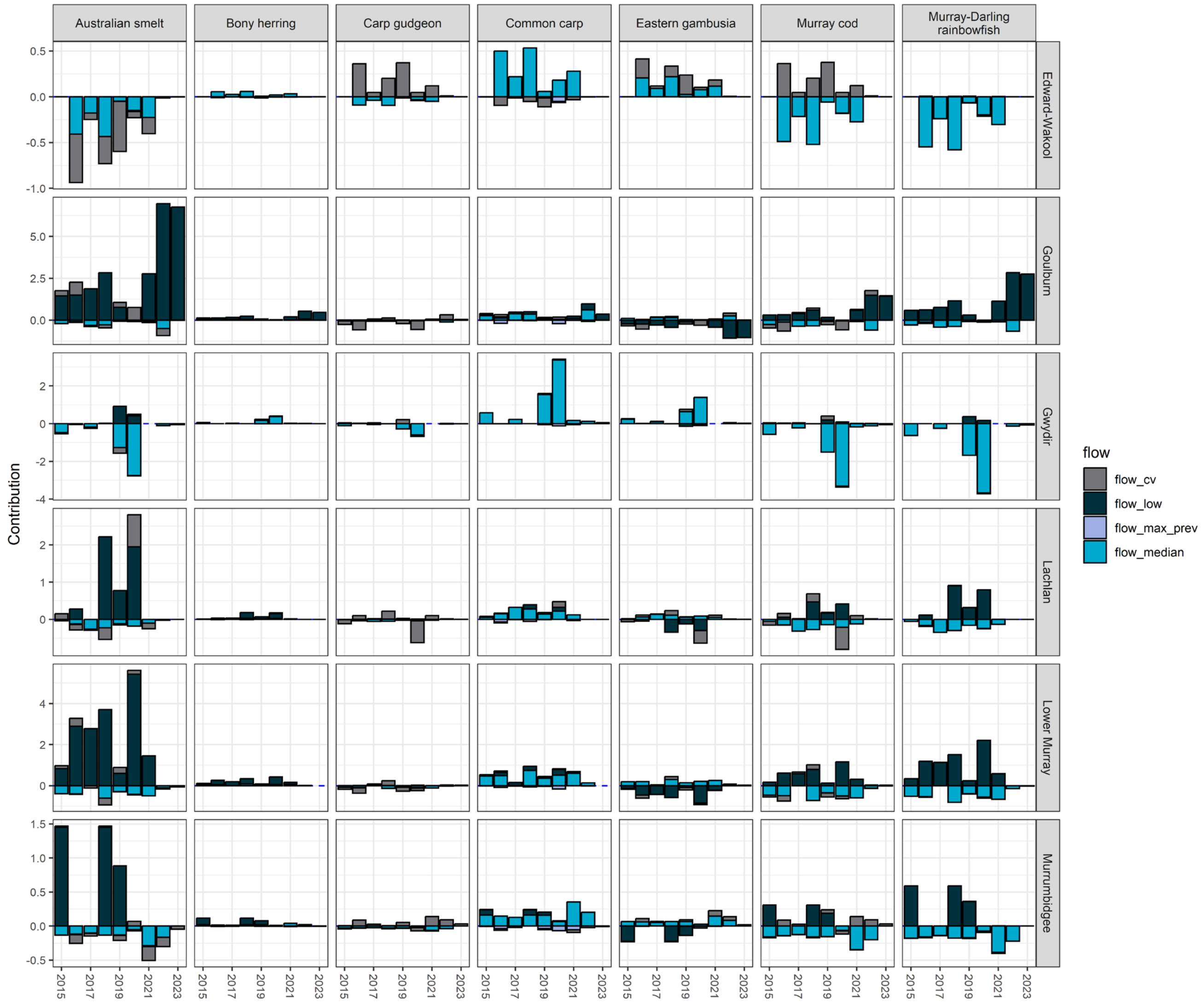


Figure 3.14 Contribution of each flow metric on the predicted CEW effect on recruitment rates of 7 fish species, by Selected Area, 2014–23

Fish species are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, Murray cod, Murray-Darling rainbowfish. Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median. Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on link scale.

3.5 Analysis: Catch curve analysis

3.5.1 Logic and data trimming

Logic

Flow-MER has the potential to improve our understanding of CEW effects on recruitment through the collection of otolith-based age data. These data enable the calculation of recruitment strength using catch-curve regression analyses. Estimated recruitment strength can be linked to observed flow metrics (see Tonkin et al. 2021), which can inform scenarios-based modelling of population outcomes with and without Commonwealth environmental water, further clarifying the influence of water management on recruitment outcomes. For Flow-MER, relating annual flow metrics with recruitment strength is not yet achievable for 3 reasons. First, observed and counterfactual discharge sequences are not available prior to 2014. Second, catch curve regressions work best above a threshold age when mortality and detection rates become constant, a situation that occurred only for golden perch in the current Flow-MER fish monitoring dataset.

Third, sample sizes were low for fish spawned before 2014, that is, otolith samples predominantly represented younger fish spawned after 2014.

Data trimming

The catch curve analysis required extensive data filtering in order to provide a usable dataset (Table 3.7). For Murray cod, over 80% were less than 3-year-old and confounding detection and variable survival rates (e.g. survival rates are likely very variable the first few years). Therefore, no analysis was conducted for Murray cod or bony herring, over 90% were less than 3 year old. As catch curves are questionable for young ages (e.g. variable mortality rates, detection issues) I did not run a catch curve regression and rather rely on the recruit abundance analysis which has less assumptions. For golden perch, there were sufficient data for the Lower Murray River. Murrumbidgee had reasonable sample sizes but multiple catch across years from the same birth year were very rare and when present, they often had increasing counts with the older ages (rather than decreasing counts due to mortality) suggested potential detection complications (e.g. more effort or better detection). Therefore, I provide an analysis of just the Lower Murray River in which I identity higher and lower recruitment years.

Table 3.7 Summary of sample sizes for catch curve dataset (Murray cod, golden perch, bony herring) in Selected Areas

Table shows number of fish aged each year (2015–18 grouped to reduce table size) and the total number of fish (# fish). Percent <3yr indicates percentage of fish less than 3 years old. Born in 2015–23 indicates the number of fish within the CEW flow data range. Dash (–) in a cell indicates no record.

Species/Selected Area	2015–18	2019	2020	2021	2022	2023	# fish	Percent <3yr	Born in 2015–23
Murray cod									
Edward-Wakool	–	–	–	–	–	–	49	98%	6
Lachlan	–	–	–	–	–	–	54	31%	7
Lower Murray	38	18	130	17	2	11	216	100%	216
Murrumbidgee	–	–	–	–	–	–	47	47%	5
Golden perch									
Edward-Wakool	–	–	–	–	–	–	26	0%	0
Goulburn	–	–	–	–	–	–	26	12%	0
Gwydir	–	–	–	–	–	–	66	17%	22
Lachlan	–	–	–	–	–	–	61	36%	3
Lower Murray	481	113	121	91	106	93	1,005	10%	158
Murrumbidgee	–	–	–	–	–	–	86	2%	7
Bony herring									
Edward-Wakool	–	–	–	–	–	–	46	80%	11
Gwydir	–	–	93	41	121	96	667	75%	580
Lachlan	372	100	98	100	33	95	798	99%	755
Lower Murray		122	100	120	111	120	930	92%	901
Murrumbidgee	375	100	100	100	37	87	799	100%	769

Key exploratory graph(s)

Change in golden perch recruit abundance over time in the Lower Murray is shown in Figure 3.15.

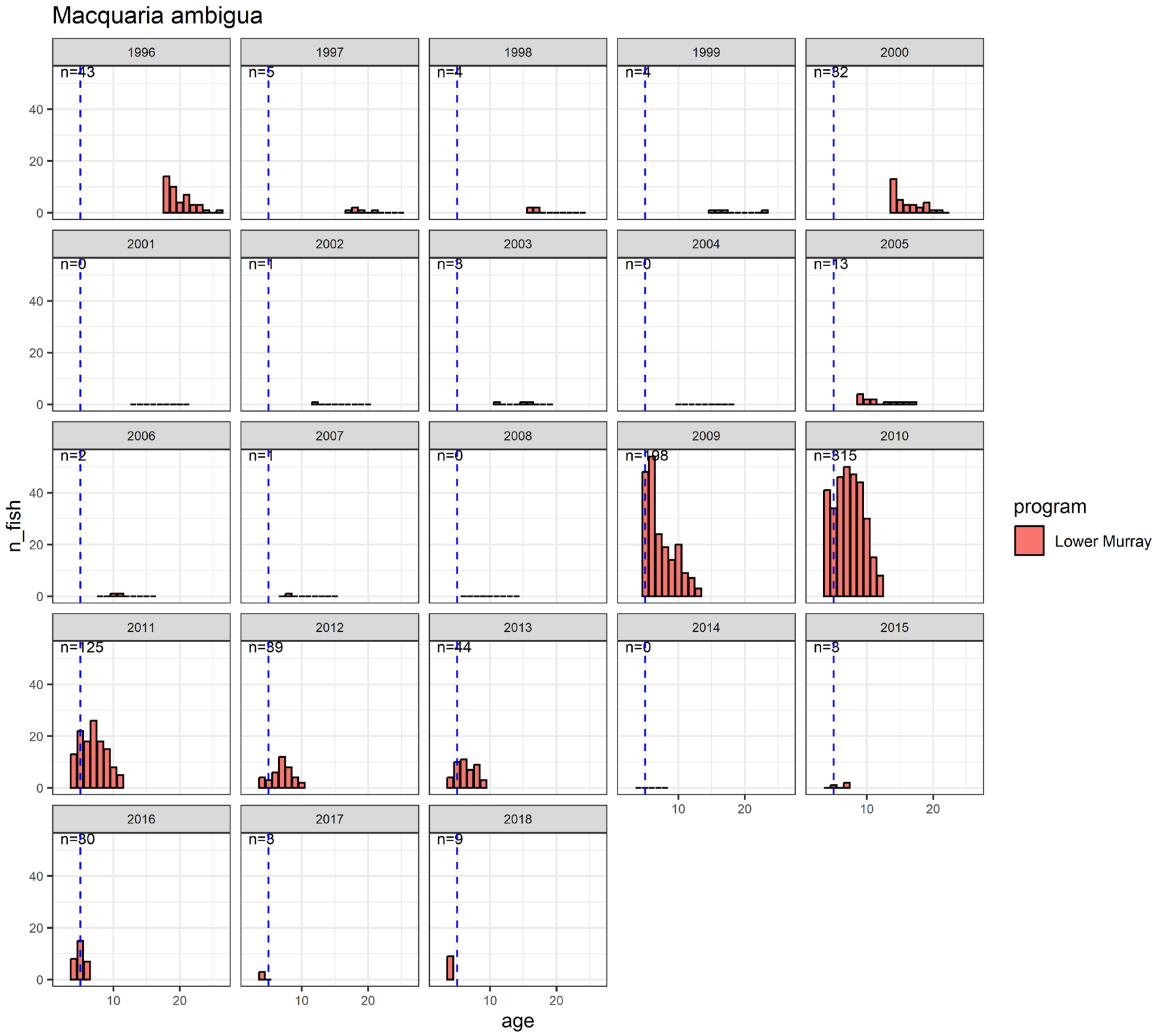


Figure 3.15 Histogram showing age classes by birth year (1996 to 2018) for golden perch in the Lower Murray Selected Area

Dotted line shows 5-year cutoff.

3.5.2 Data analysis

I first calculated birthyear as follows: wateryear of sampledate - age - 1. for example, a fish caught on 2000MAY03 and aged at 0 (YOY) would be birthyear = 2000 - 0 - 1 = 1999. For the analysis, I ran a catch curve regression on the golden perch data. The dataset was expanded to include all possible ages for sampling, up to the max age caught for golden perch. The response variable was number of fish caught at each age and was assumed to follow a negative binomial distribution. The fixed effects were age and Selected Area . Birthyear was included as a random effect. I extracted the estimate for each birth year to provide an indication of recruitment strength. Standard errors were obtained by sampling the posterior distribution.

As an exploratory process, I combine the recruitment strength (year) with historical flow data extracted from NSW constraint project for Lock 9. Annual flow metrics for birthyear were linked to recruitment strength years and then graphically explored.

3.5.3 Key results

Recruitment strengths for each birthyear were estimated for golden perch and results presented in Figure 3.16.

- Model results delineated varying recruitment strengths only in golden perch, mainly in the Lower Murray where we had substantial data and hence higher statistical power.

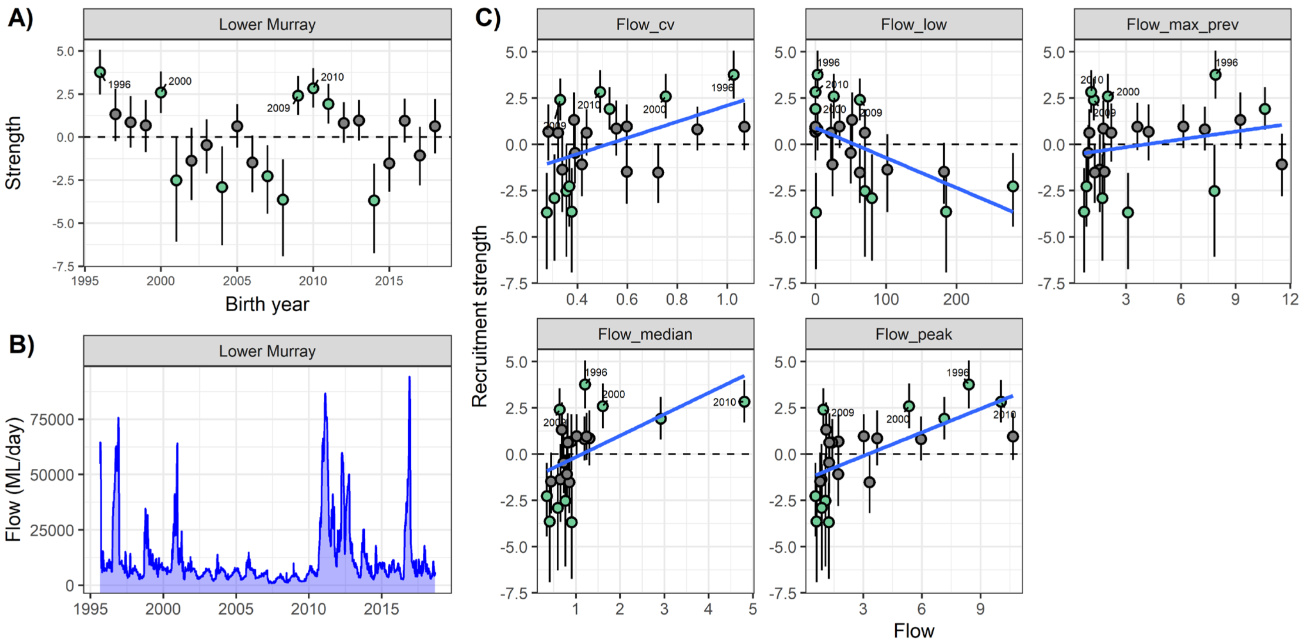


Figure 3.16 A) Recruitment strength estimates for golden perch by birthyear; B) daily flow for Lower Murray; and C) relating recruitment strengths to flow metrics for fish collected during 2014-15 to 2022-2023
Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median, flow_peak.
Birth year ranges from 1996 to 2018. Recruitment strength is the random effect estimate for each water year from the model. In C), year is shown for the strong recruitment years and the blue lines show a naive regression line for exploratory purposes. Error bars are 95%CrI.

3.6 Analysis: Adult abundance

3.6.1 Logic and data trimming

Logic

Flow metrics may affect adult survival across the years.

Data trimming

Only large-bodied fish were kept as small-bodied were likely young-of-year recruits and hence analysed in the recruit analysis (Table 3.8). If there were multiple surveys per water year per sample point, I selected the latest date. This ensured a single sampling point at the latest part of the year (incorporates more of the water year flow conditions). I dropped any surveys from September to December to make comparisons more comparable.

Table 3.8 Summary of sample sizes for adult dataset and the percentage of samples that had zero catch for bony herring, common carp, Murray cod and golden perch across Selected Areas

Species	Fish	# Selected Areas	Sites	Years	Percent Zero (all years)	Percent Zero (2023)
Bony herring	113,318	6	62	9	22.6%	8.5%
Common carp	44,619	6	62	9	0.0%	0.0%
Murray cod	4,032	6	62	9	13.5%	15.3%
Golden perch	3,144	6	62	9	16.2%	22.0%

Key exploratory graph(s)

Change in fish CPUE over time across all Selected Areas and fish death events are shown in Figure 3.17.

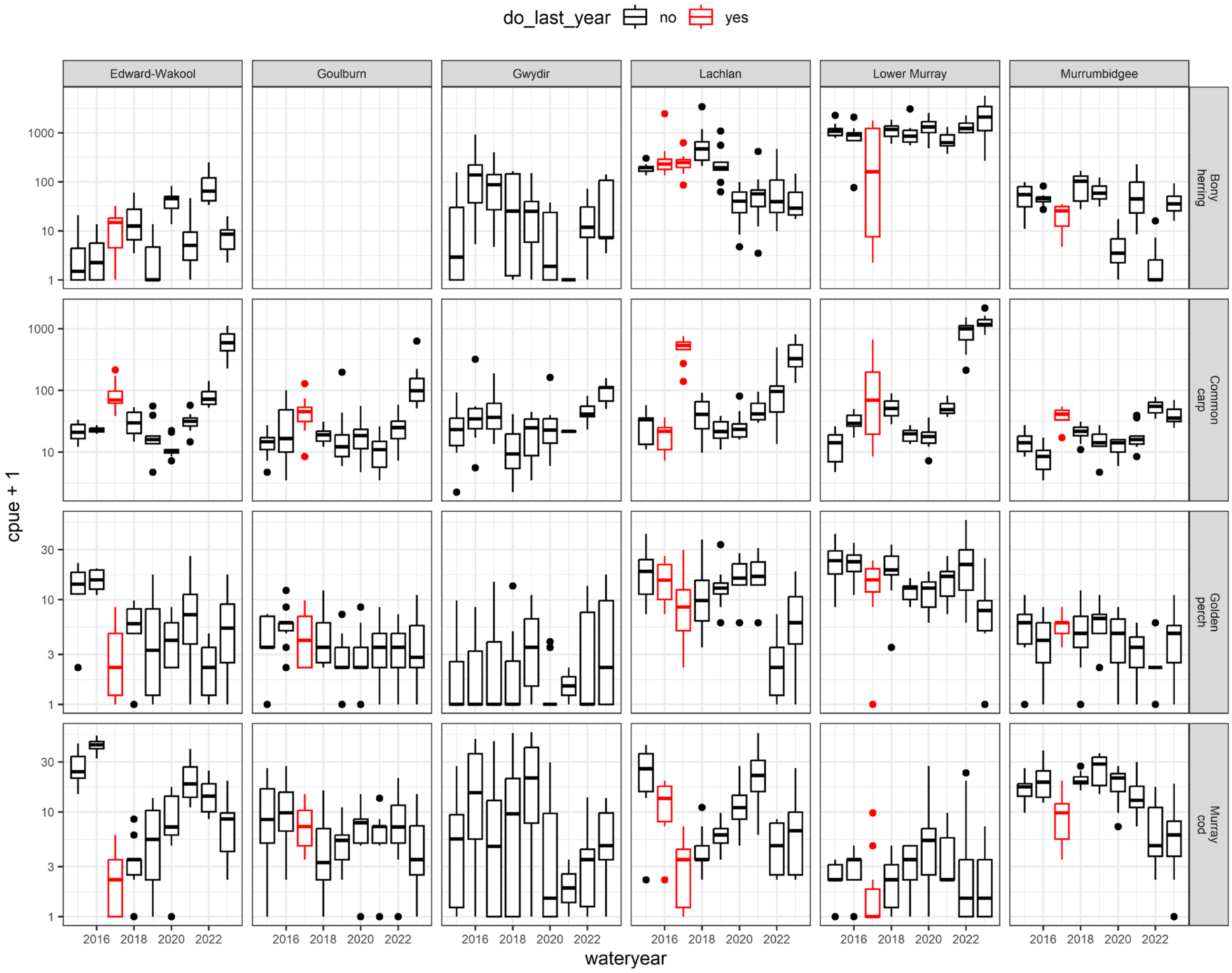


Figure 3.17 Boxplot showing CPUEs over time for 4 fish species , by Selected Area 2014–23
Fish species are bony herring, common carp, golden perch and Murray cod. Fish deaths (DO events) are highlighted as red.

3.6.2 Data analysis

For the analysis, the main hypotheses are focused on the effect of flow on growth rate between years. Consequently, I modeled log growth rate as the following:

$$R = log\left(\frac{CPUE_t + 1}{CPUE_{t-1} + 1}\right)$$

I ran a linear mixed model (LMM) in a Bayesian framework with growth rate as the response variable. As fixed factors, I included annual flow metrics, Selected Area and if last year was a fish kill event. Selected Area:wateryear and samplepoint were included as random effects.

3.6.3 Key results

- Murray cod had similar catch rates to the previous year. Catch rates increased with decreasing flow_median, smaller flow_cv, and fewer flow_low. Higher flow_max_prev increased catch rates.
- Bony herring catch rates were variable (in relation to previous year) across Selected Areas. Decreasing flow_median, fewer flow_low and higher flow_max_prev increased catch rates.
- Golden perch were similar or slightly higher than previous year. Catch rates increased with decreasing flow_median.
- Common carp catch rates were high this year. Common carp increased with higher flow_median and higher flow_low.

Flow coefficients

Estimates of flow coefficients for each species are shown in Figure 3.18.

Non-flow coefficients

Common carp

Common carp did not show any fish death event effect, but this may have been hidden by the large number of recruits appearing in the CPUE (up to 75% being young-of-year). Therefore, this analysis is driven more by the recruit dynamics than adult population trends.

Bony bream

The fish death event result is mainly driven by the Lower Murray and Murrumbidgee Selected Area data with no obvious effect in the Edward/Kolety–Wakool river system and the Lachlan River System.

Murray cod and golden perch

Fish death events were obvious in the data for Murray cod across most systems and for golden perch in the Edward/Kolety–Wakool and Lachlan Selected Areas. These fish death events will have strong residual effects potentially complicating flow relationships. For instance, in the Edward/Kolety–Wakool, Murray cod continue to recover since 2016/17, almost approaching pre-fish death levels. A similar pattern is found in the Lachlan. Such recovery may have less to do with flow conditions and more with density-dependent population processes. The population models in the Flow-MER Basin-scale research theme may provide more insights about this hypothesis (Todd et al. 2022).

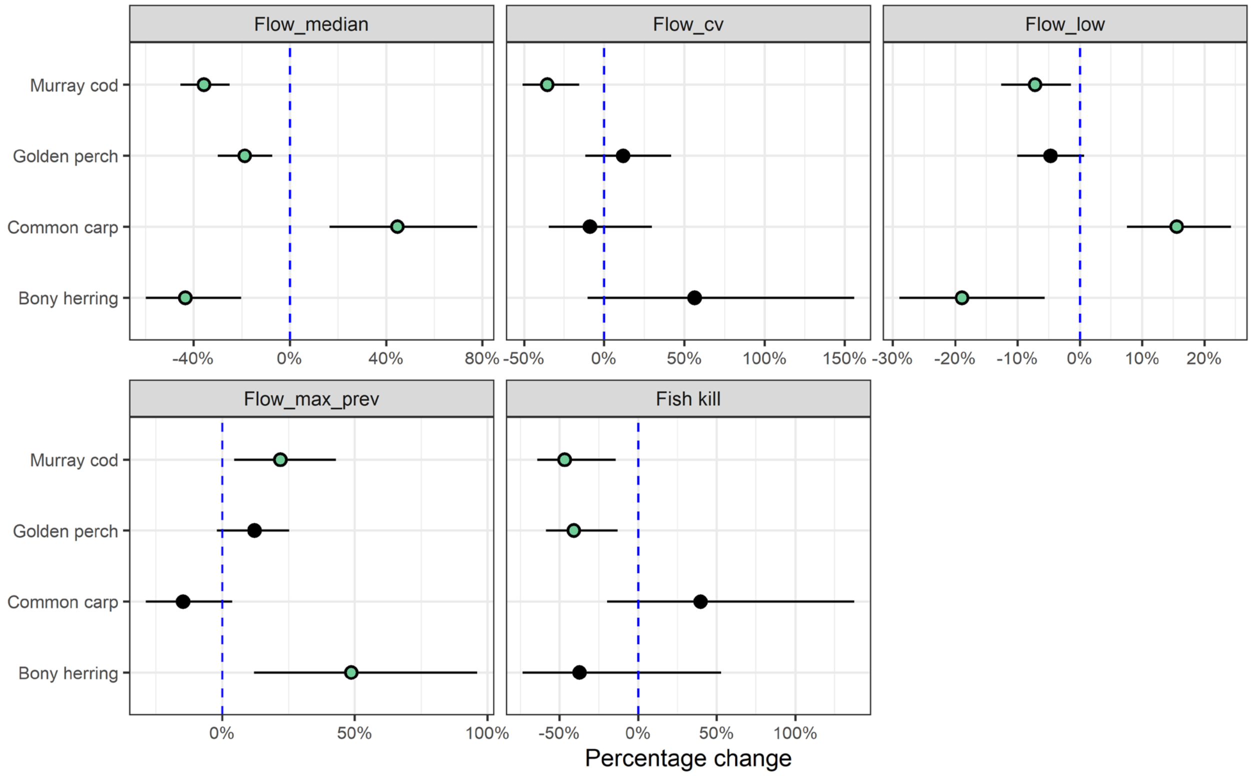


Figure 3.18 Effect of each flow metric on adult abundance for bony herring, common carp, golden perch and Murray cod

Flow metrics are flow_median, flow_cv, flow_low, flow_max_prev, plus fish deaths.
Error bars are 95%CrI. Coloured dots indicate significant effects at p<0.05 threshold.

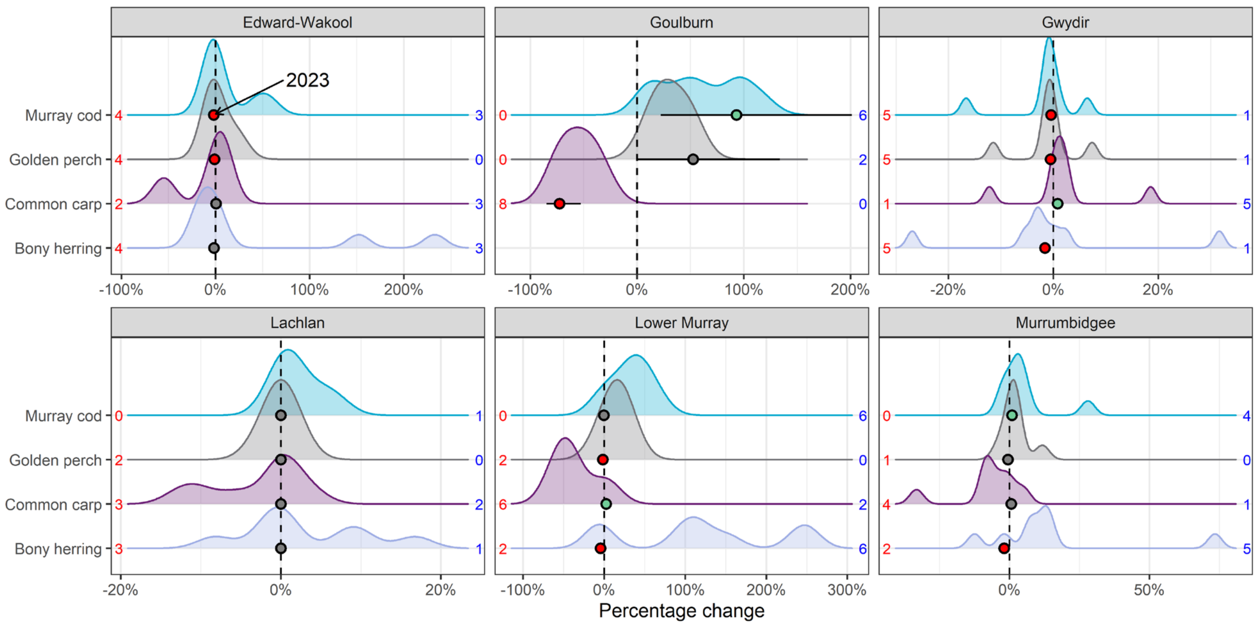


Figure 3.19 Distribution of predicted effect of CEW on adult abundance for bony herring, common carp, golden perch and Murray cod, by Selected Area

Each density plots shows distribution of effect sizes (scaled to percentage change) across all years covered in this report. Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

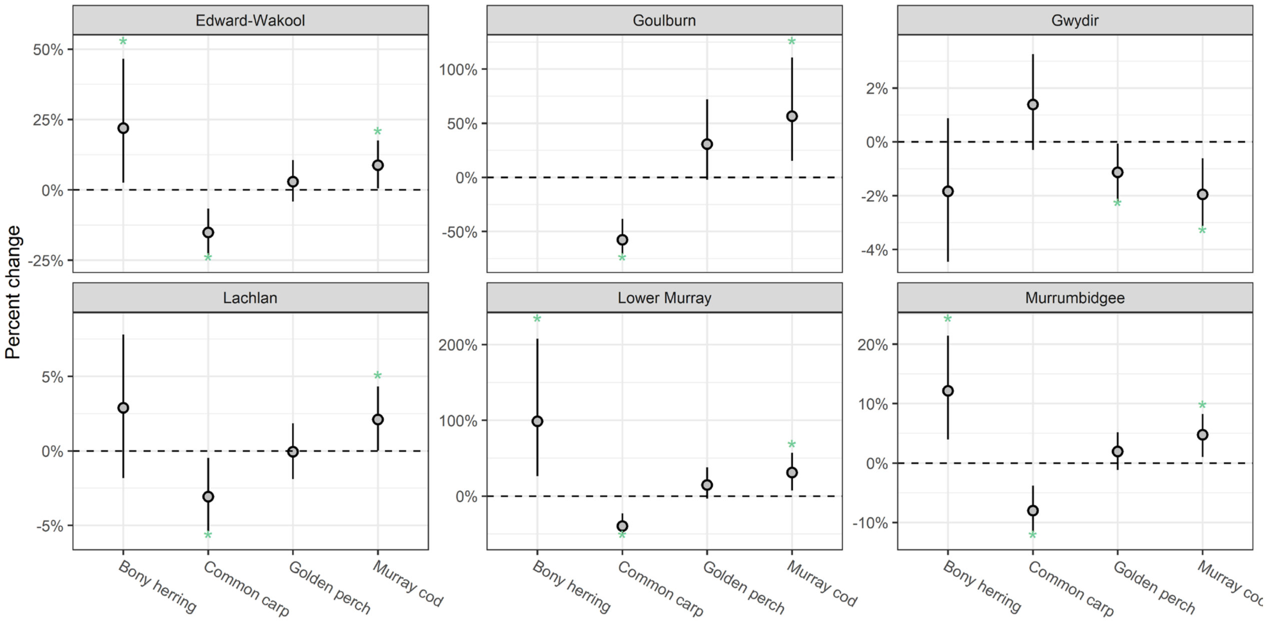


Figure 3.20 Predicted effect of CEW on adult abundance for bony herring, common carp, golden perch and Murray cod, by Selected Area

Effect sizes have been scaled to percentage of mean Fulton Index for each species. Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively)

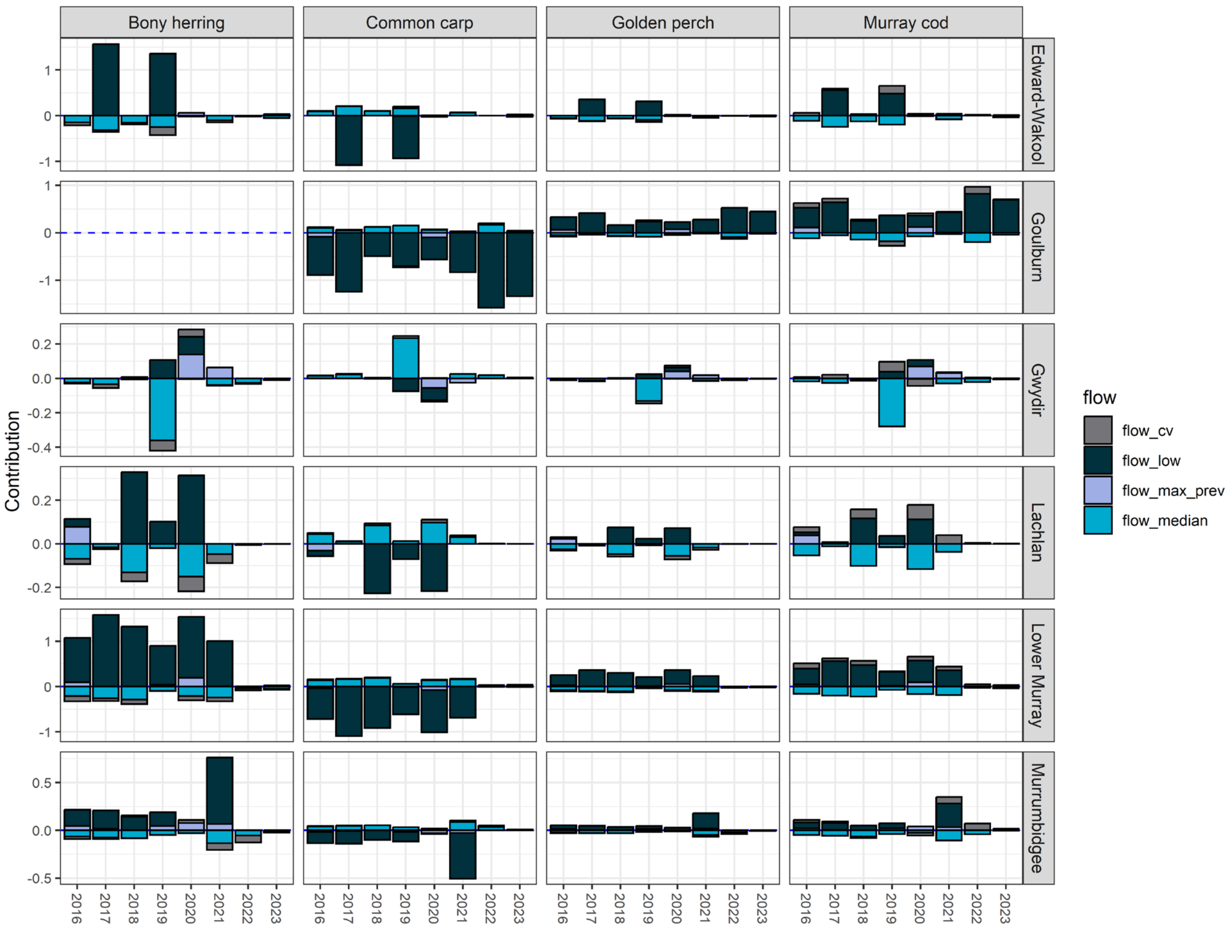


Figure 3.21 Contribution of each flow metric on the predicted CEW effect on adult abundance of 4 fish species, by Selected Area, 2015–23

Fish species are bony herring, common carp, golden perch, Murray cod. Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median. Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on link scale.

3.7 Analysis: Adult body condition

3.7.1 Logic and data trimming

Logic

Flow conditions affect river productivity and hence have knock-on effects for fish condition. I assumed that sampled body condition represents roughly the last 6–12 months of river conditions (beginning of wateryear to sample date).

To test for the effects of flow metrics on body condition, I modeled the Fulton Index (proxy for body condition; Froese (2006)) in relation to the kept annual flow metrics.

$$\text{Fulton Index} = 100 * \frac{weight}{length^3}$$

I used a linear mixed model (LMM) with an untransformed Fulton Index. I included the annual flow metrics and Selected Area as the fixed factor. Selected Area:wateryear, samplepoint, and samplepoint:year were included as random effects. Due to computation slowness using a Bayesian approach with such large sample size, I used lmer() from the *lme4* package (Bates et al. 2015).

Data trimming

Only fish that could be linked to a survey in catch dataset were included. Only fish with sufficient numbers across most Selected Areas were analysed (Table 3.9). Next, I explored the relationship between length and weight to assess any outliers in the data. As there were obvious outliers, I used the 4 times the standardised residuals method to identity those outliers. Therefore, I ran a linear regression for each species (log(weight) ~ log(length)) and identified outliers (Figure 3.22). The method worked well, though could be improved for bony herring. Bony herring had decreasing variance on log-scale, which likely reflects measurement error becoming proportionally larger at small sizes. For now (time-limitations), I kept the outlier criteria the same, but model improvements could be had with future refinements to bony herring such as using weighted regression approaches.

Table 3.9 Summary of sample sizes for body condition dataset and for which species were analysed (yes/no), 2014–23

Species	Analysed?	Fish (total)	Fish (current)	# Selected Areas	Sites	# of years
Bony herring	Yes	24,321	1,628	6	77	9
Common carp	Yes	9,187	2,101	5	73	9
Golden perch	Yes	3,667	300	6	68	9
Murray cod	Yes	3,994	269	6	76	9
Spangled perch	No	811	95	1	19	8
Goldfish	No	708	114	6	58	9
Carp gudgeon	No	211	134	2	17	3
Murray-Darling rainbowfish	No	187	180	3	10	6
Silver perch	No	174	20	5	39	9
Freshwater catfish	No	84	6	2	18	9
Eastern gambusia	No	80	80	1	8	1
Australian smelt	No	39	39	1	8	1

Species	Analysed?	Fish (total)	Fish (current)	# Selected Areas	Sites	# of years
Redfin perch	No	29	24	4	9	3
Trout cod	No	26	4	1	5	6
Unspecked hardyhead	No	14	14	1	4	1
Oriental weatherloach	No	10	2	2	5	2

Key exploratory graph(s)

I explored the relationship between length and weight to assess any outliers in the data and these are shown in Figure 3.22. The change in Fulton Index over time across all Selected Areas and species is shown in Figure 3.23.

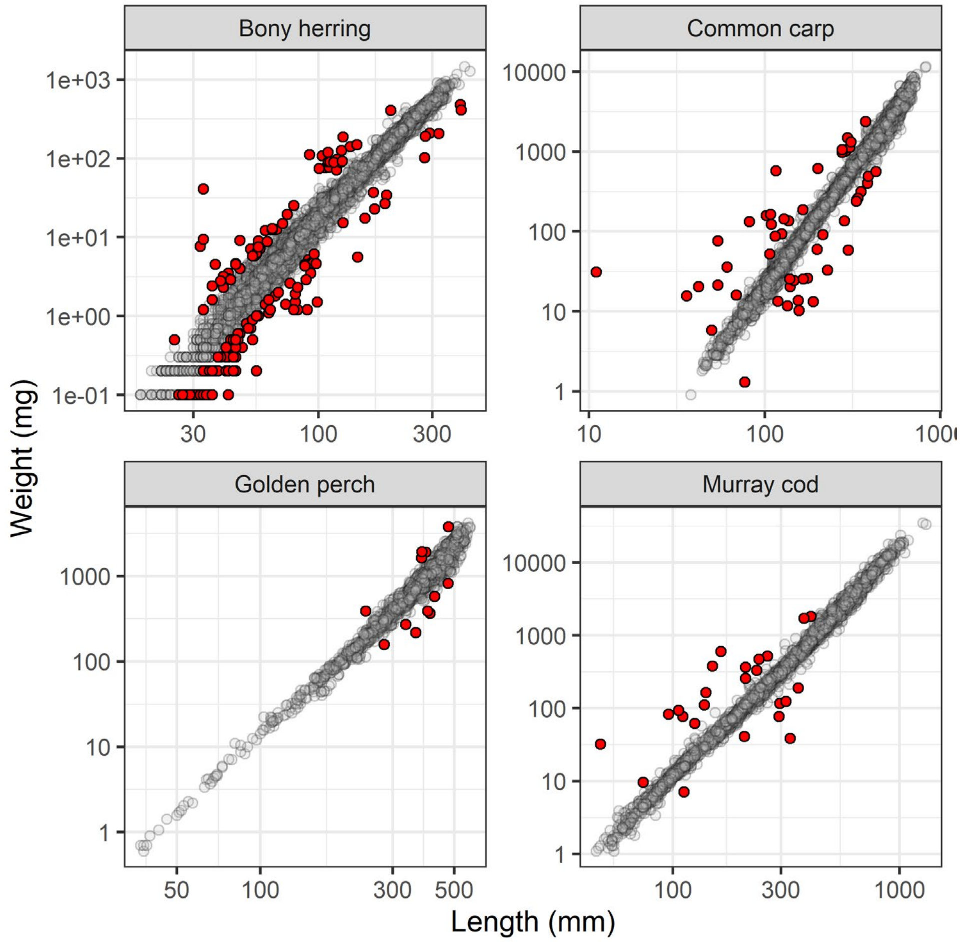


Figure 3.22 Exploratory graph looking for potential outliers in length:weight for bony herring, common carp, golden perch and Murray cod

Red dots show outliers using 4 times the standardised residuals method. Grey circles show non-outlier data.

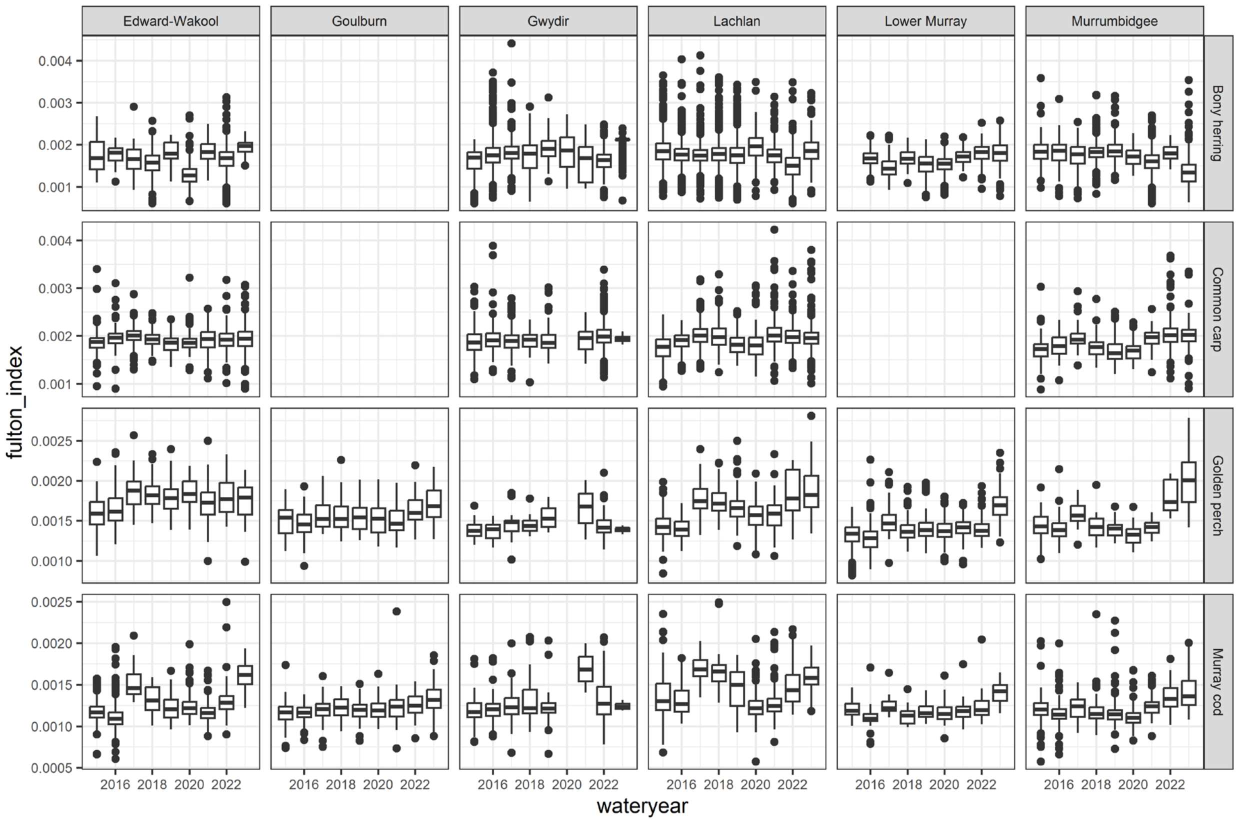


Figure 3.23 Boxplot showing change in Fulton Index time for bony herring, common carp, golden perch and Murray cod, by Selected Area, 2014–23

3.7.2 Data analysis

As noted above, I removed outliers from the analysis using four times the standardised residual method. With the remaining data, I undertook the following approach. To test for the effects of flow metrics on body condition, I modeled the Fulton Index (proxy for body condition) in relation to the annual flow metrics. I used a linear mixed model (LMM) with an untransformed Fulton Index. I included the annual flow metrics and Selected Area as the fixed factor. Selected Area:wateryear, samplepoint, and samplepoint:year were included as random effects. Due to computation slowness using a Bayesian approach, I used lmer() from the lme4 package (Bates et al., 2015).

3.7.3 Key results

- Murray cod condition increased with higher flow_median, flow_cv, and flow_max_prev
- Bony herring had higher body condition in lower flow_median and flow_cv

Flow coefficients

Estimates of flow coefficients for each species are shown in Figure 3.24.

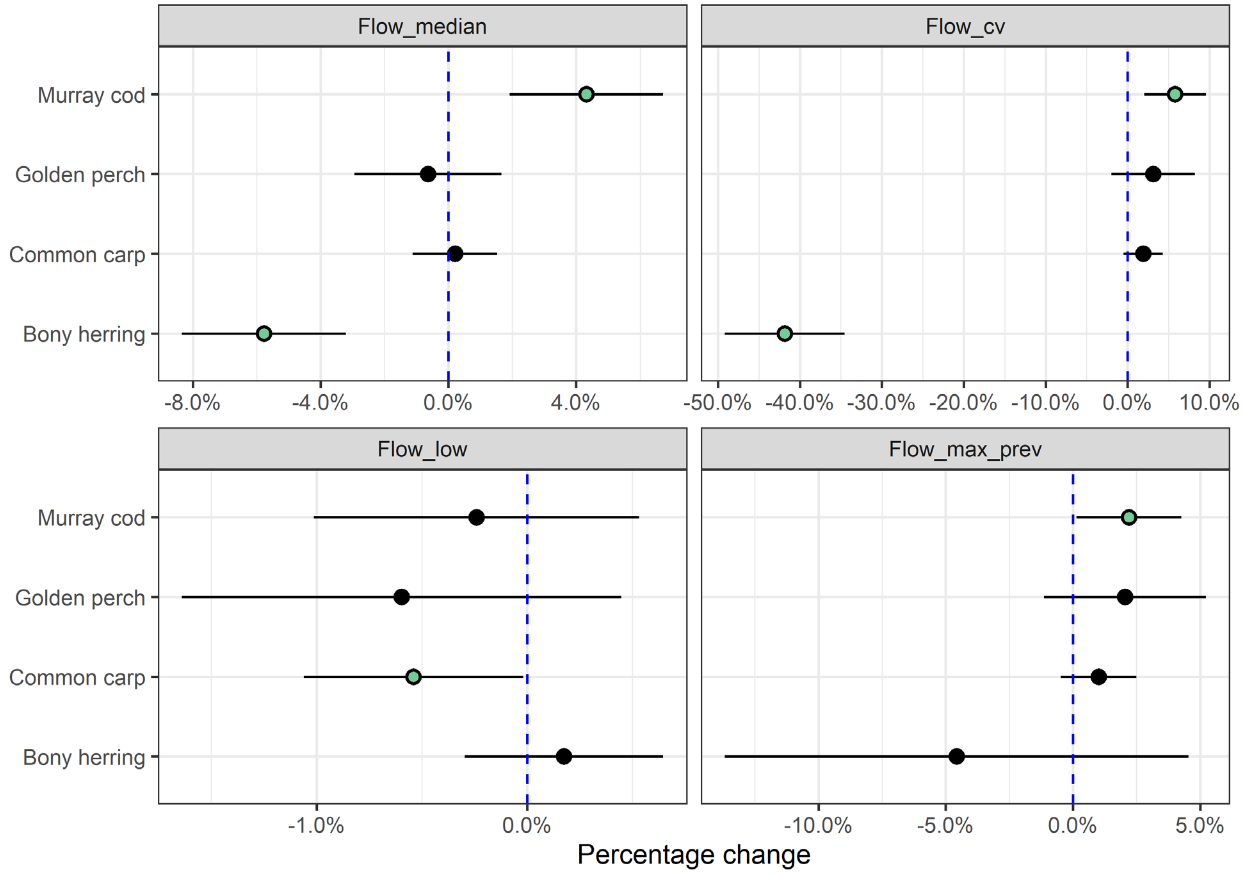


Figure 3.24 Effect of each flow metric on body condition for 4 fish species
Fish species are bony herring, common carp, golden perch and Murray cod. Flow metrics are flow_median, flow_cv, flow_low, flow_max_prev. Error bars are 95%CrI. Coloured dots indicate significant effects at $p<0.05$ threshold.

Counterfactual predictions

The predicted effect and marginal effect of Commonwealth environmental water on species body condition are shown. The positive changes show Commonwealth environmental water increased body condition (Figure 3.25; Figure 3.26).

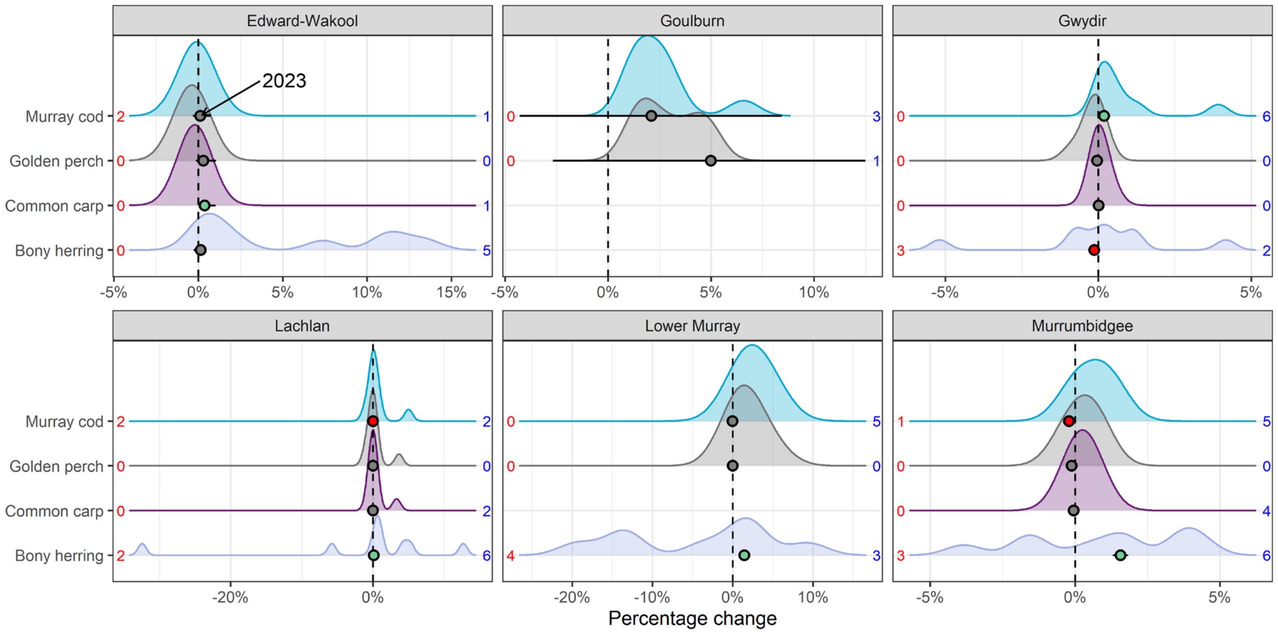


Figure 3.25 Distribution of predicted effect of CEW on body condition for bony herring, common carp, golden perch and Murray cod, by Selected Area

Each density plots shows distribution of effect sizes (scaled to percentage change) across all years covered in this report. Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

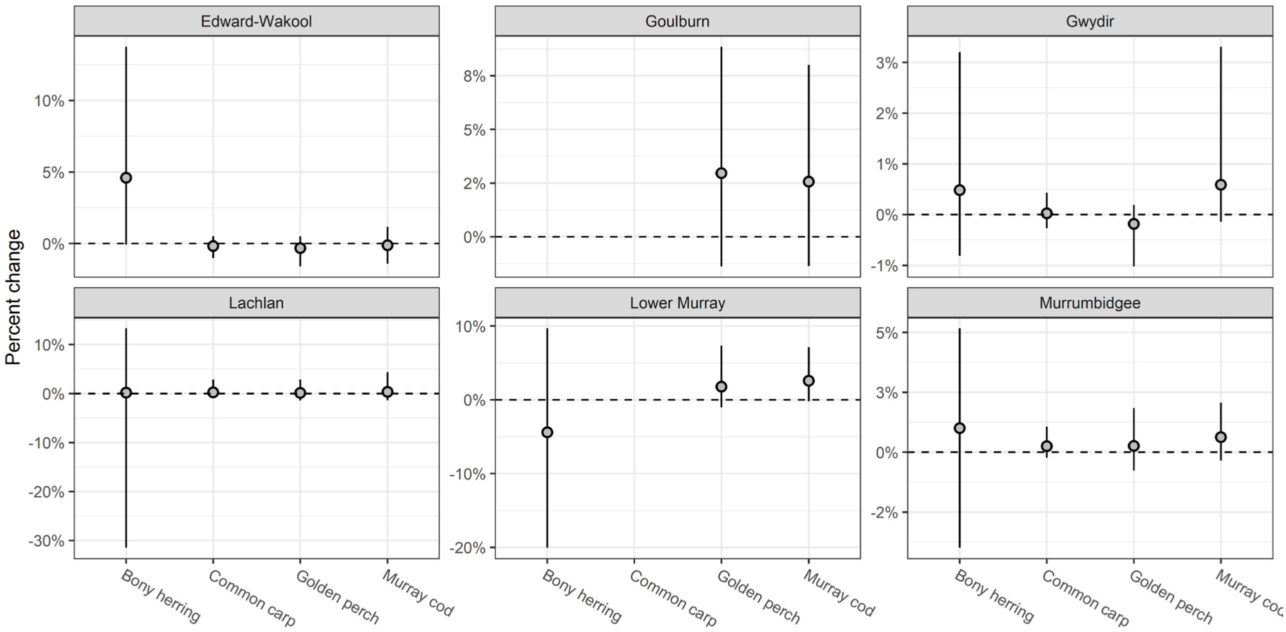


Figure 3.26 Predicted effect of CEW on body condition for bony herring, common carp, golden perch and Murray cod, by Selected Area

Effect sizes have been scaled to percentage of mean Fulton Index for each species. Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively)

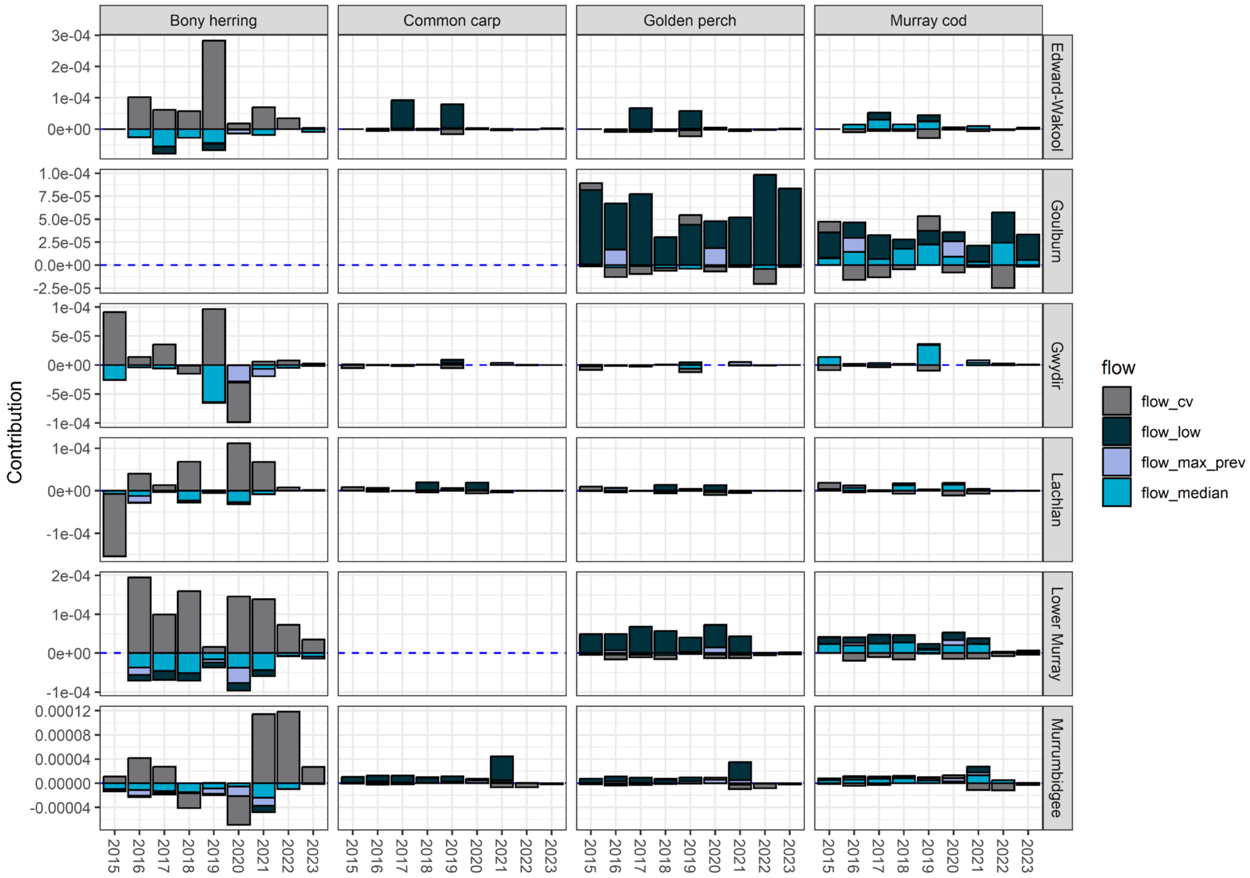


Figure 3.27 Contribution of each flow metric on the predicted CEW effect for body condition of 4 fish species, by Selected Area

Fish species are bony herring, common carp, golden perch and Murray cod. Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median. Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on raw scale.

3.8 Analysis: Adult presence/distribution

3.8.1 Logic and data trimming

Logic

Flows support hydrological connectivity, thereby increasing available habitat and food resources and providing more suitable conditions for fish movement and colonisation.

Data trimming

If there was multiple surveys per water year per site I selected the latest date. This ensured a single sampling point and was comparable with other years. As common carp was present at every site every year, it was dropped from the analysis.

Key exploratory graph(s)

Proportion of sites that species were present over years and across Selected Areas is shown in Figure 3.28.

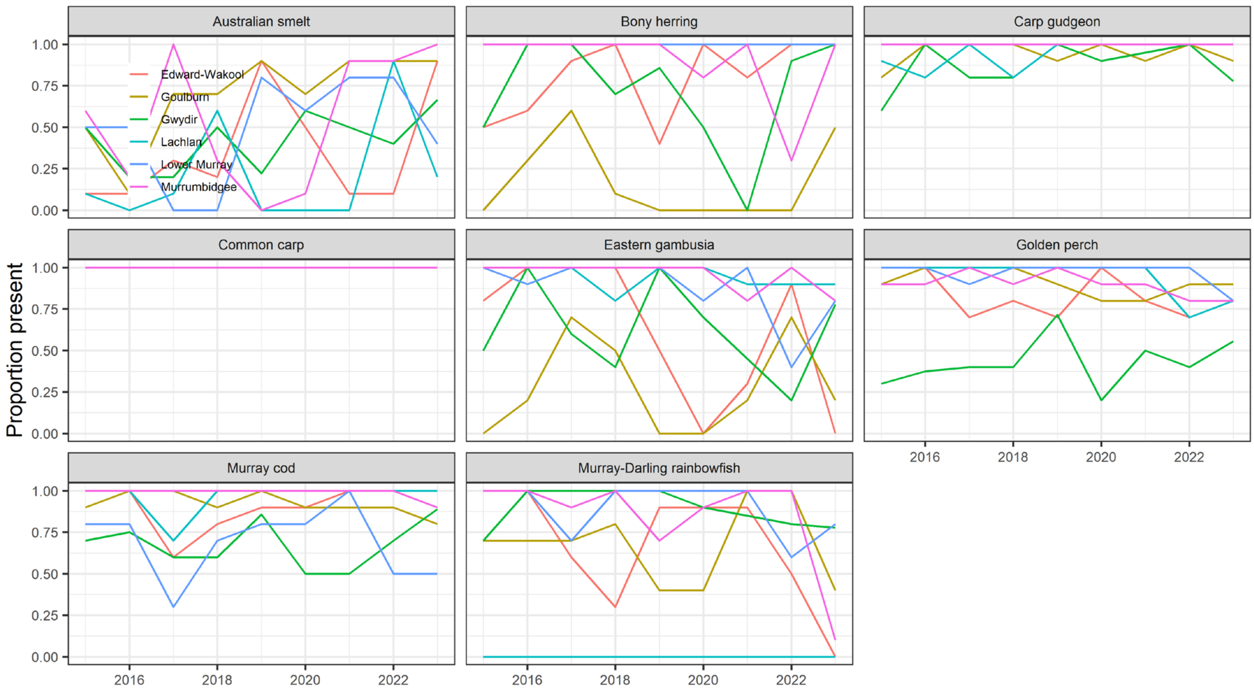


Figure 3.28 Temporal plot showing proportion of sites in each Selected Area with that species present, 2014–23
Fish species are Australian smelt, bony herring, carp gudgeon, common carp, eastern gambusia, golden perch, Murray cod, Murray-Darling rainbowfish.

3.8.2 Data analysis

Using the above approach, I ran a GLMM (generalised linear mixed model) with a Bernoulli distribution (in a Bayesian framework). The response variable was the presence of that species at that site (for that wateryear). I included the annual flow metrics and Selected Area as the fixed factor. Selected Area:wateryear and samplepoint were included as random effects. However, Selected Area:wateryear caused convergence issues so it was reduced to wateryear only for the analysis.

3.8.3 Key results

- Decreasing flow_median increased presence of all fish except carp gudgeon and Australian smelt
- Decreasing flow_low increased presence of Murray-Darling rainbowfish, Murray cod, Bony herring, and Australian smelt

Flow coefficients

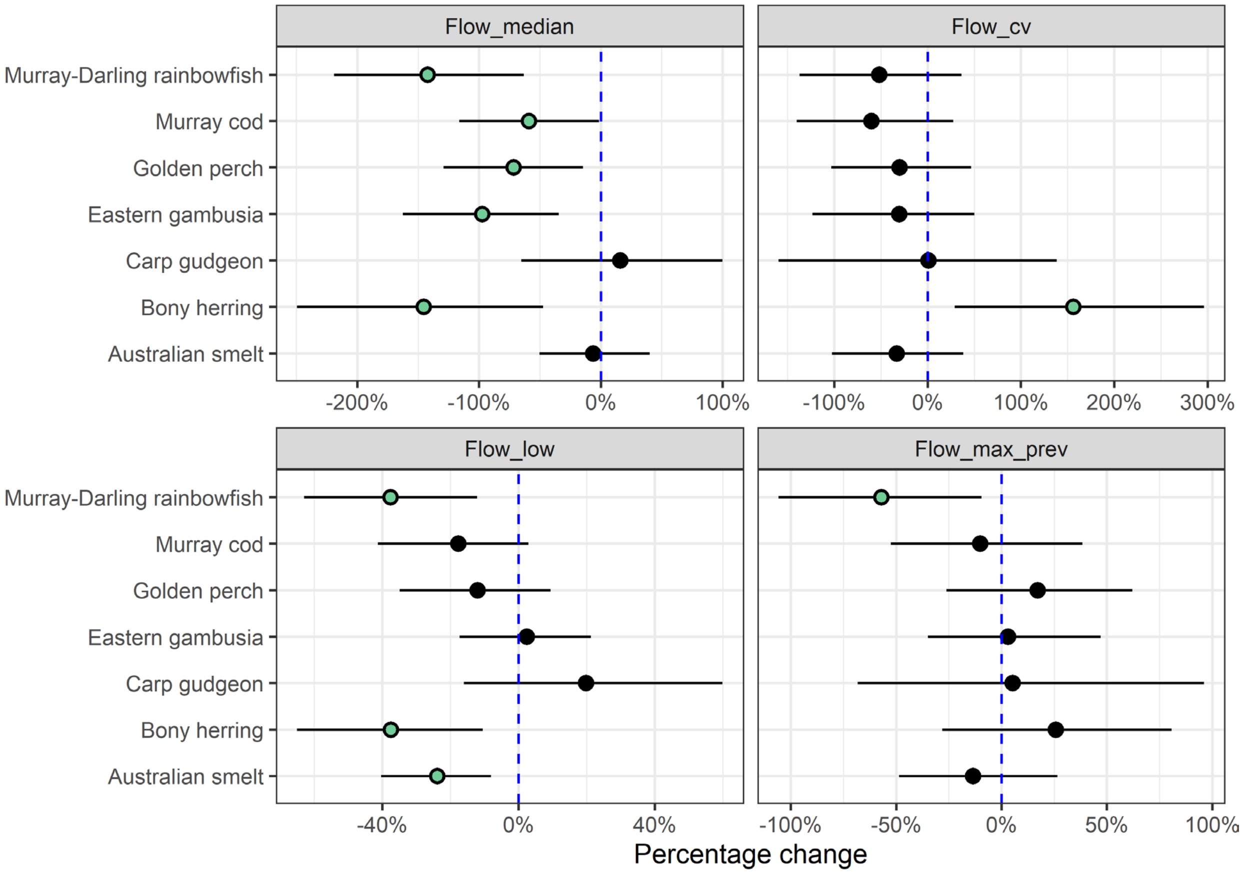


Figure 3.29 Effect of each flow metric on adult presence of 7 fish species

Species are Australian smelt, bony herring, carp gudgeon, eastern gambusia, golden perch, Murray cod and Murray-Darling rainbowfish. Flow metrics are flow_median, flow_cv, flow_low, flow_max_prev. Error bars are 95%CrI. Coloured dots indicate significant effects at p<0.05 threshold.

Counterfactual predictions

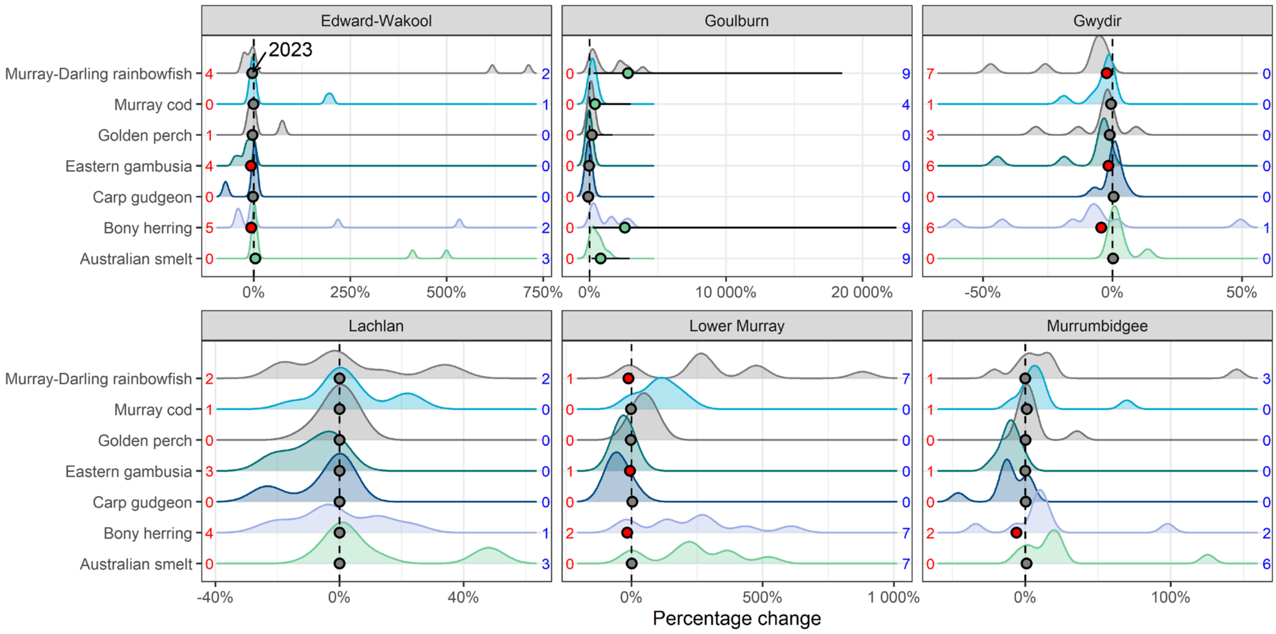


Figure 3.30 Distribution of predicted effect of CEW on adult presence for each species, by Selected Area
Species are Australian smelt, bony herring, carp gudgeon, eastern gambusia, golden perch, Murray cod and Murray-Darling rainbowfish. Each density plots shows distribution of effect sizes (scaled to percentage change) across all years covered in this report. Vertical dash line shows no effect (0%); left of line indicates negative effect and right a positive effect. Red and blue numbers indicate number of years in which there was a significant negative and positive, respectively. Point indicates current year estimate with colour indicating if contribution was significant (green=positive; red=negative) or not (grey).

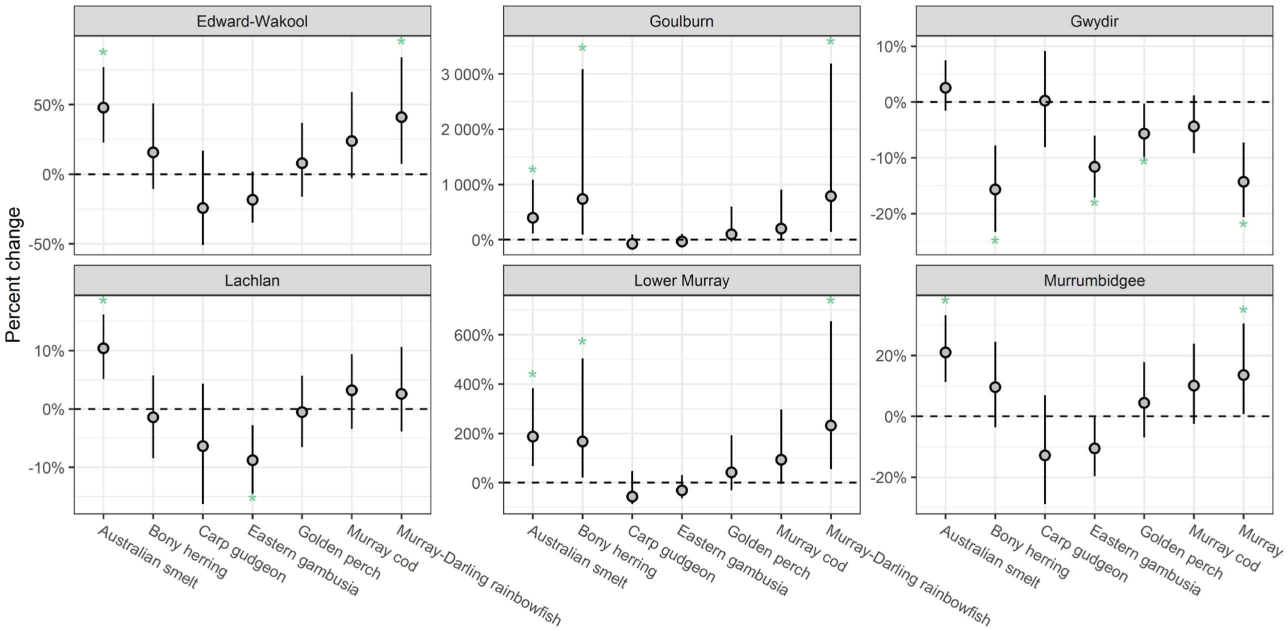


Figure 3.31 Predicted effect of CEW on adult presence for each species, by Selected Area
Species are Australian smelt, bony herring, carp gudgeon, eastern gambusia, golden perch, Murray cod and Murray-Darling rainbowfish. Effect sizes have been scaled to percentage of mean Fulton Index for each species. Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively)

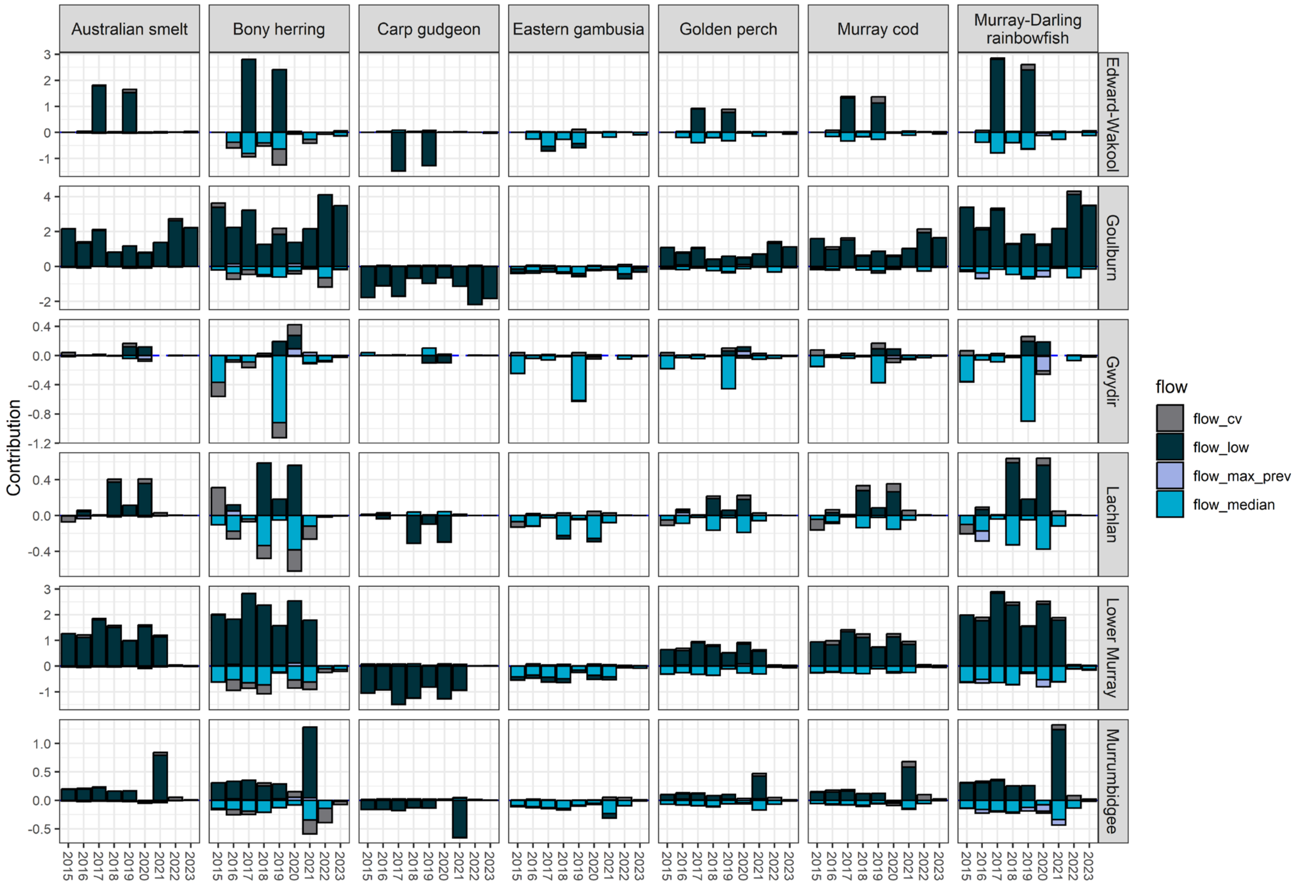


Figure 3.32 Contribution of each flow metric on the predicted CEW effect on adult presence of 7 fish species, by Selected Area, 2014–23

Species are Australian smelt, bony herring, carp gudgeon, eastern gambusia, golden perch, Murray cod and Murray-Darling rainbowfish. Flow metrics are flow_cv, flow_low, flow_max_prev, flow_median. Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on link scale.

3.9 Analysis: Community metric

3.9.1 Logic and data trimming

Logic

Flows support hydrological connectivity, thereby increasing available habitat and food resources and providing more suitable conditions for native fish movement and colonisation.

Data trimming

I dropped any sites that had no catch data. I calculated the proportion of the fish species per Selected Area:wateryear:sampelpoint that were native (Table 3.10).

Table 3.10 Summary of sample sizes for community analysis showing number of introduced and native species at the 6 Selected Areas, 2014–23

Selected Area	Introduced	Native	Sites	Years
Edward/Kolety–Wakool	4	9	10	9
Goulburn	5	10	11	9
Gwydir	3	9	10	9
Lachlan	4	8	11	9
Lower Murray	4	11	10	9
Murrumbidgee	4	9	10	9

Key exploratory graph(s)

The change in community index over time across all Selected Areas and species is shown in Figure 3.33 and species scientific names with common names is shown in Table 3.11.

Table 3.11 Fish species collected in Flow-MER adult fish population surveys using Category 1 methods across all Selected Areas, 2014–23

Common name	Species name	Introduced/Native
Australian smelt	*Retropinna semoni*	Native
Bony herring	*Nematalosa erebi*	Native
Carp gudgeon	*Hypseleotris spp*	Native
Common carp	*Cyprinus carpio*	Introduced
Dwarf flathead gudgeon	*Philypnodon macrostomus*	Native
Eastern gambusia	*Gambusia holbrooki*	Introduced
Flathead gudgeon	*Philypnodon grandiceps*	Native
Freshwater catfish	*Tandanus tandanus*	Native
Golden perch	*Macquaria ambigua*	Native
Goldfish	*Carassius auratus*	Introduced
Murray cod	*Maccullochella peelii*	Native
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	Native
Oriental weatherloach	*Misgurnus anguillicaudatus*	Introduced
Redfin perch	*Perca fluviatilis*	Introduced
River blackfish	*Gadopsis marmoratus*	Native
Silver perch	*Bidyanus bidyanus*	Native
Spangled perch	*Leiopotherapon unicolor*	Native
Trout cod	*Maccullochella macquariensis*	Native
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Native
Obscure galaxias	*Galaxias oliros*	Native
Community	*community*	Native

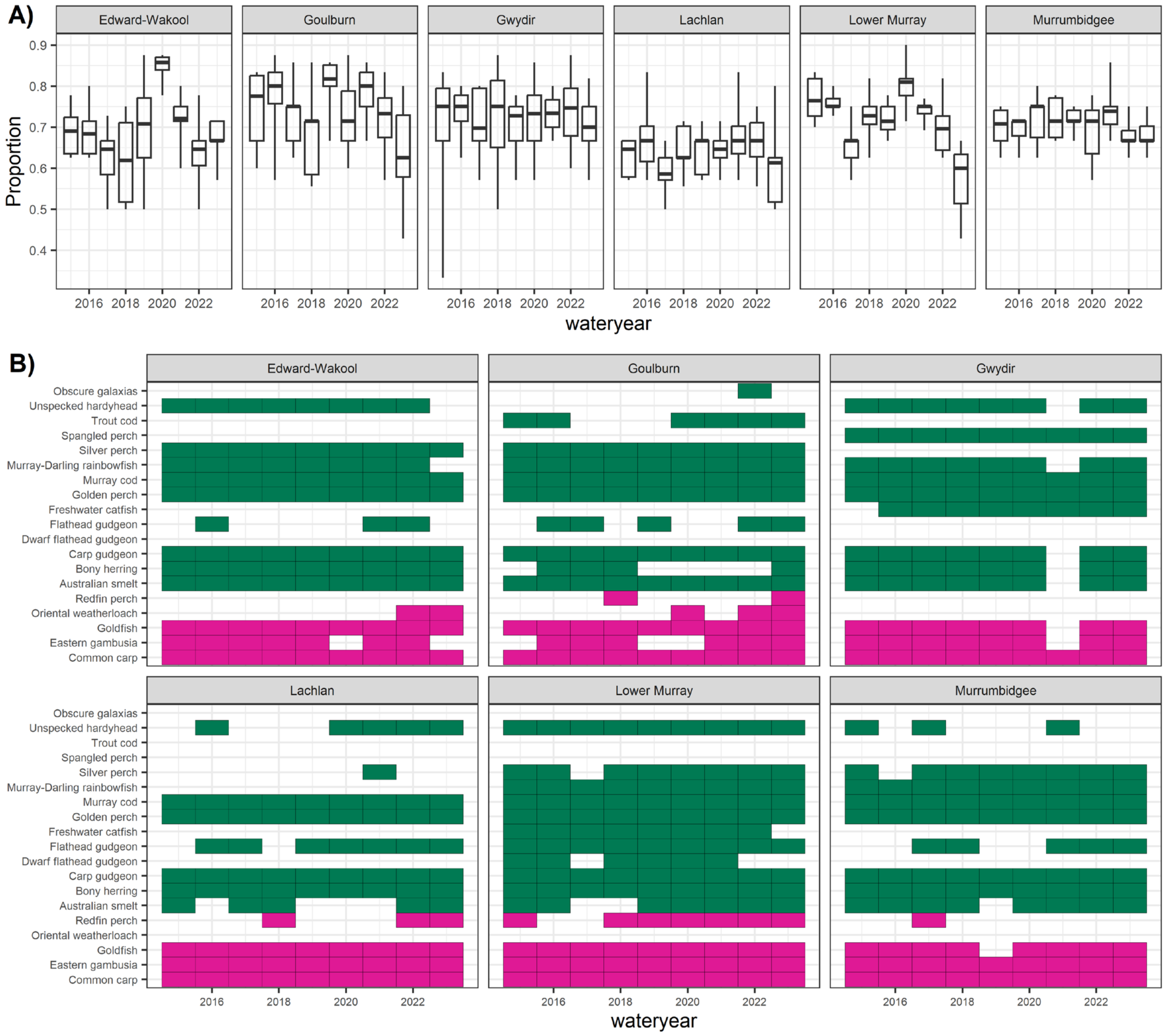


Figure 3.33 (A) Boxplot showing change in community index over 2014–23 for species, by Selected Area and (B) presence of each species over 2014–23

A is an aggregated metric over all species and is the proportion of catch that is native. Species are common carp, eastern gambusia, goldfish, oriental weatherloach, redfin perch, Australian smelt, bony herring, carp gudgeon, dwarf flathead gudgeon, flathead gudgeon, freshwater catfish, golden perch, Murray cod, Murray-Darling rainbowfish, silver perch, spangled perch, trout cod, unspecked hardyhead, obscure galaxias. Pink indicates introduced species. Green indicates Native species.

3.9.2 Data analysis

Using the above approach, I ran a bGLMM (Bayesian generalised linear mixed model) with a Gaussian distribution. I included the annual flow metrics and Selected Area as fixed effects. Wateryear was included as a random effect to account for the correlational structure.

3.9.3 Key results

- Similar results to previous report with no effects emerging

Flow coefficients

Estimates of flow coefficients for the community metric is shown in Figure 3.34.

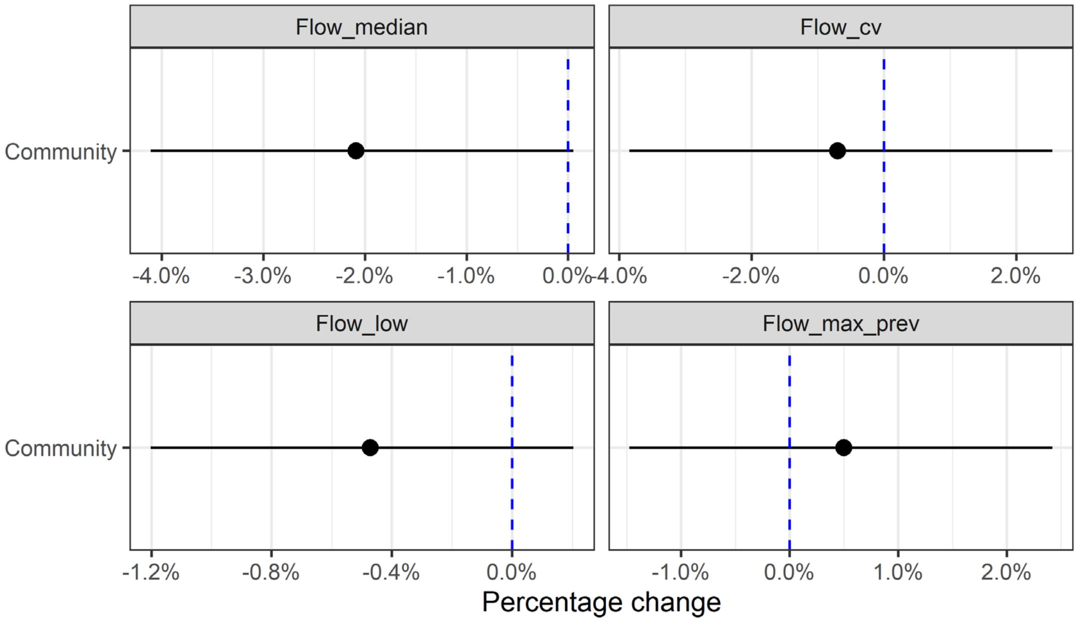


Figure 3.34 Predicted effect of each flow metric on community metric for each species
Flow metrics are flow_median, flow_cv, flow_low, flow_max_prev. Error bars are 95%CrI.

Counterfactual predictions

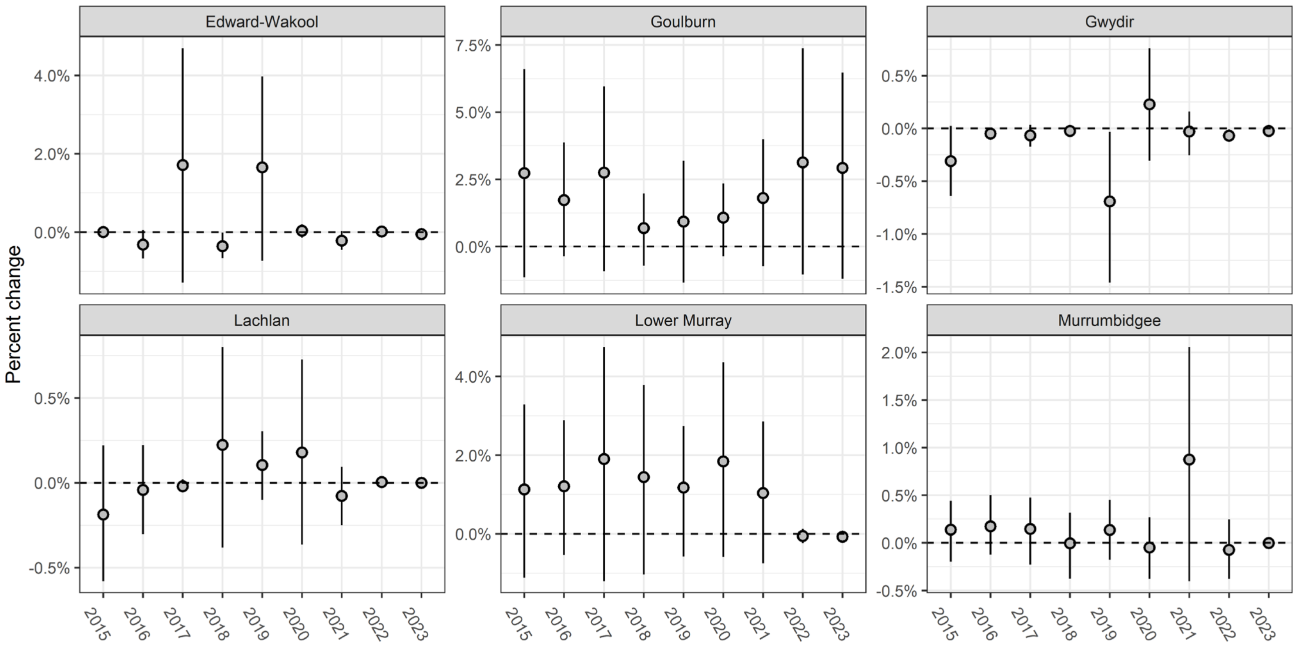


Figure 3.35 Predicted effect of CEW on community metric, by Selected Area, 2014–23
Error bars are 95%CrI.

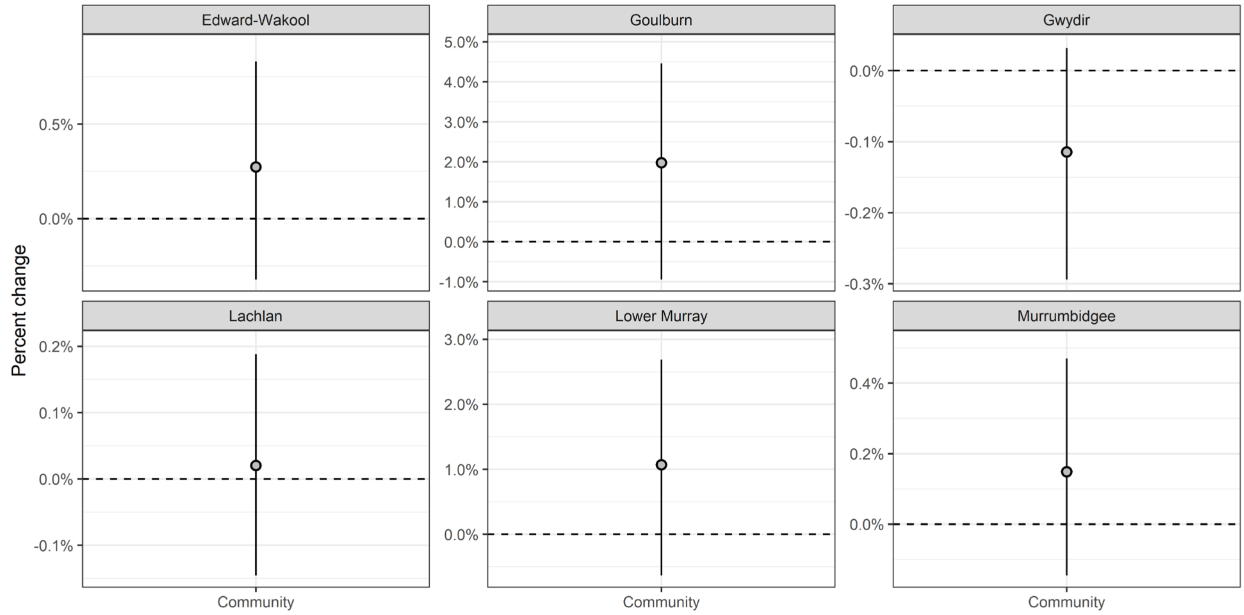


Figure 3.36 Predicted effect of CEW on community metric, by Selected Area
Error bars are 95%CrI. * - indicates 95%CrI do not overlap with 0 (* above and below error bars indicate positive and negative effects, respectively)

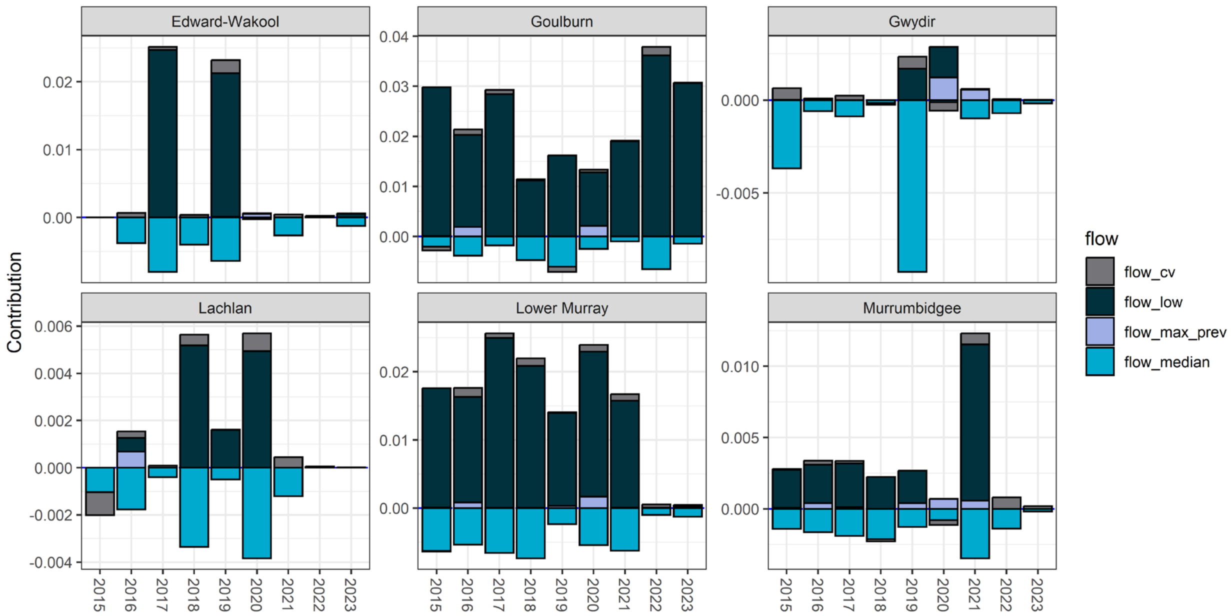


Figure 3.37 Contribution of each flow metric on the predicted CEW effect for community metric, by Selected Area, 2014–23
Flow metrics are flow_median, flow_max_prev, flow_low and flow_cv. Negative effects are shown as bars below 0 and positive effects above. Effect sizes are on raw scale.

3.10 Analysis: Predicting Commonwealth environmental water contribution on Murray cod recruitment at unmonitored areas across the Murray–Darling Basin

3.10.1 Logic and data trimming

Logic

Recruits numbers reflect multiple population processes: reproductive output and larval survival. The annual flow metrics were included as predictors affecting these processes.

Data trimming

See Analysis: Recruit analysis (young-of-year) using abundance data Section 3.4. Additionally, we dropped any flow sites in which there was less than two years of flow data as well as flows that were negative or if Without-

3.10.2 Data analysis

As part of the results, I predicted Commonwealth environmental water effects across the Basin using predicted flow relationships. Using the full flow dataset, I applied the flow metric algorithms to every gauge. For any flow gauges missing without_cew data, I assumed no Commonwealth environmental water. Next, I used the Murray cod recruitment model and predicted the difference between actual and without_cew scenarios (positive differences indicate improved recruitment). To visualise these effects, I mapped the maximum difference across all years for each gauge and mapped these differences on the Basin's river system. Predicted effects of Commonwealth environmental water on Murray cod recruitment and Murray-Darling rainbowfish recruitment at all gauges, with lower and upper bounds, is available with request from the author.

Predicting effect across the basin for Murray cod

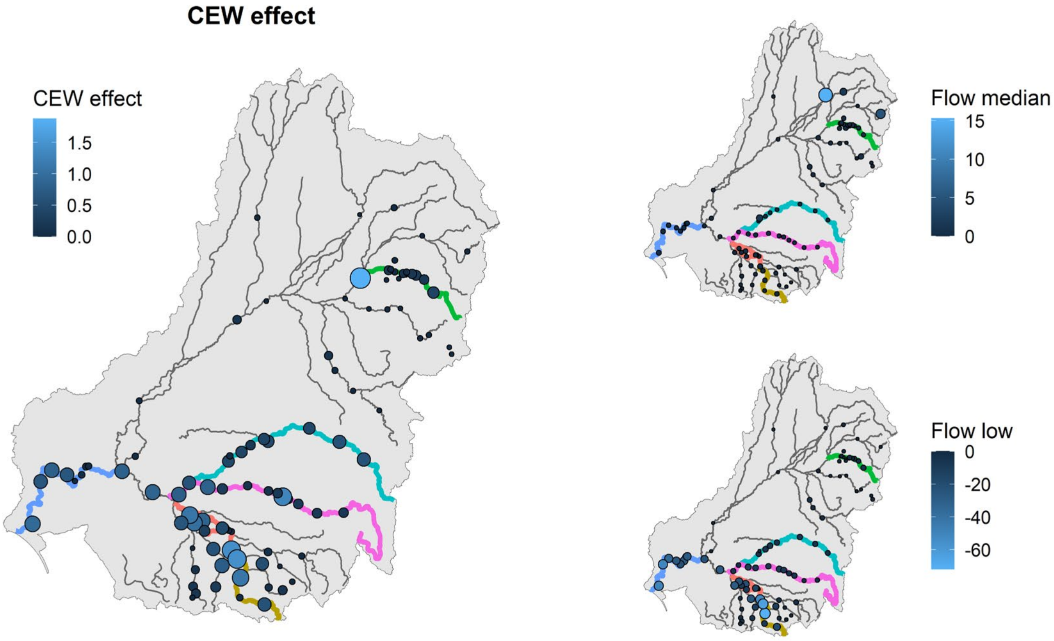


Figure 3.38 Maps of predicted CEW effects on recruitment rates for Murray cod across the Basin
CEW effect map shows the relative effect size for each flow gauge with larger circles and lighter blues indicating larger effects. Smaller maps on right show differences between actual flows and modelled without CEW for flow_median and flow_low (two key flow metrics for Murray cod). For flow median, larger circles/lighter blues indicate increased flow_median due to CEW. For flow_low, larger circles/lighter blues indicate number of low flow days (flow_day) decreased with the CEW flows (i.e. declining flow_low indicates less low flow days and in theory better flow environment).

Predicting effect across the basin for Murray-Darling rainbowfish

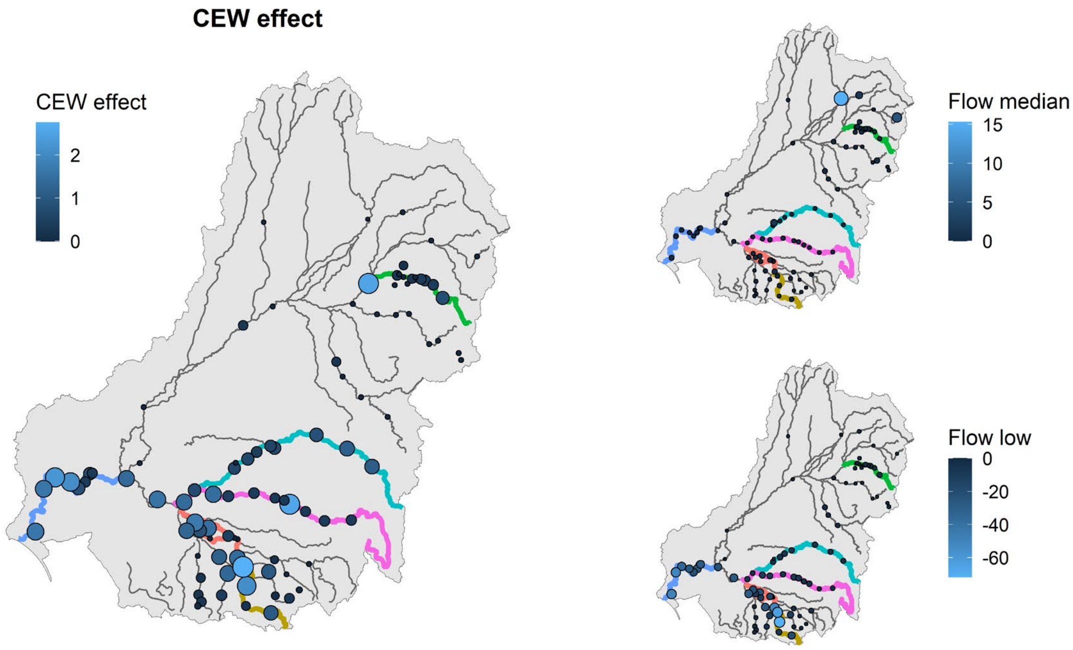


Figure 3.39 Map showing predicted CEW effects on recruitment rates for Murray-Darling rainbowfish across the Basin
CEW effect map shows the relative effect size for each flow gauge with larger circles and lighter blues indicating larger effects. Smaller maps on right show differences between actual flows and modelled without CEW for flow_median and flow_low (2 key flow metrics for Murray cod). For flow median, larger circles/lighter blues indicate increased

flow_median due to CEW. For flow_low, larger circles/lighter blues indicate number of low flow days (flow_day) decreased with the CEW flows (i.e. declining flow_low indicates less low flow days and in theory better flow environment).

4 References

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Fanson B (2023, unpublished) Technical supplement to Basin-scale evaluation of 2021–22 Commonwealth environmental water: Fish. Internal technical note, Applied Aquatic Ecology, Arthur Rylah Institute, Department of Energy, Environment and Climate Action, Victoria.

Froese R (2006) Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. *Journal of Applied Ichthyology*, *22*(4), 241–253.

Goodrich B, Gabry J, Ali I, Brilleman S (2020) *Rstanarm: Bayesian applied regression modeling via Stan.* Retrieved from https://mc-stan.org/rstanarm

Hladyz S, Baumgartner L, Bice C, Broadhurst, B, Butler G, Fanson B, Giatas G, Koster W, Lyon J, McCasker N, Stocks, J, Stuart I, Thiem J, Tonkin Z, Ye Q, Yen J and Zampatti B (2024) Basin-scale evaluation of 2022–23 Commonwealth environmental water: Fish. Flow-MER Program. Commonwealth Environmental Water Holder, Department of Climate Change, Energy, the Environment and Water, Australia.

R Core Team (2022) *R: A language and environment for statistical computing*. Retrieved from https://www.R-project.org/

Raymond SM, Duncan M, Tonkin Z, Robinson W (2021) Barmah-Millewa fish condition monitoring (2007-2021). Arthur Rylah Institute for Environmental Research unpublished client report for the Murray-Darling Basin Authority. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Todd CR, Wootton HF, Koehn JD, Stuart IG, Thiem JD, Baumgartner LJ, … Zampatti BP (2022) Fish population models to inform Commonwealth Environmental Watering. Arthur Rylah Institute for Environmental Research Client Report, Victoria.

Tonkin Z, Yen J, Lyon J, Kitchingman A, Koehn JD, Koster WM, et al. (2021) Linking flow attributes to recruitment to inform water management for an Australian freshwater fish with an equilibrium life-history strategy. *Science of the Total Environment*, *752*, 141863.

Appendix A Statistical tables for all analyses

A.1 Analysis: Spawning presence

Table A.1 Estimate of the effect of Commonwealth environmental water on recruitment rates of golden perch and silver perch, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown.

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Golden perch							
Edward-Wakool	-0.019	-0.046	0.008	-0.042	0.001	-0.031	-0.004
Goulburn	-0.013	-0.243	0.197	-0.183	0.160	-0.110	0.114
Lachlan	-0.017	-0.108	0.075	-0.086	0.056	-0.061	0.033
Lower Murray	0.104	-0.020	0.235	0.013	0.210	0.033	0.162
Murrumbidgee	0.008	-0.054	0.064	-0.035	0.057	-0.023	0.037
Silver perch							
Edward-Wakool	-0.037	-0.083	0.012	-0.070	0.002	-0.058	-0.011
Goulburn	-0.294	-0.651	0.126	-0.562	0.035	-0.452	-0.066
Lachlan	-0.124	-0.271	0.053	-0.242	0.006	-0.191	-0.029
Lower Murray	-0.141	-0.347	0.086	-0.298	0.038	-0.237	-0.021
Murrumbidgee	-0.076	-0.179	0.028	-0.145	0.014	-0.122	-0.019

A.2 Analysis: Recruits analysis (young-of-year) using abundance data

Table A.2 Estimate of the effect of Commonwealth environmental water on recruitment rates, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	0.30	0.04	0.57	0.08	0.50	0.15	0.43
Goulburn	0.54	-0.68	1.79	-0.40	1.55	-0.10	1.18
Gwydir	0.14	0.08	0.20	0.09	0.19	0.11	0.17
Lachlan	0.12	0.05	0.19	0.07	0.18	0.09	0.16
Lower Murray	0.60	-0.25	1.47	-0.08	1.27	0.19	1.08
Murrumbidgee	0.14	0.01	0.27	0.04	0.25	0.07	0.21
Eastern gambusia							
Edward-Wakool	-0.05	-0.44	0.39	-0.38	0.26	-0.28	0.14
Goulburn	-0.71	-2.51	1.22	-2.11	0.75	-1.74	0.14
Gwydir	0.07	-0.01	0.15	0.00	0.13	0.02	0.10

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Lachlan	0.01	-0.10	0.11	-0.08	0.09	-0.05	0.06
Lower Murray	-0.33	-1.48	0.84	-1.20	0.60	-0.99	0.19
Murrumbidgee	-0.03	-0.22	0.18	-0.18	0.14	-0.14	0.07
Carp gudgeon							
Edward-Wakool	0.03	-0.22	0.29	-0.17	0.22	-0.10	0.16
Goulburn	0.02	-1.09	1.22	-0.95	0.84	-0.55	0.62
Gwydir	-0.01	-0.06	0.04	-0.05	0.03	-0.04	0.02
Lachlan	-0.00	-0.07	0.06	-0.05	0.05	-0.04	0.03
Lower Murray	0.04	-0.68	0.77	-0.54	0.57	-0.35	0.39
Murrumbidgee	0.01	-0.11	0.13	-0.09	0.10	-0.06	0.07
Murray cod							
Edward-Wakool	0.10	-0.07	0.27	-0.03	0.24	0.02	0.19
Goulburn	0.97	0.12	1.80	0.34	1.65	0.57	1.42
Gwydir	-0.12	-0.16	-0.07	-0.15	-0.08	-0.14	-0.09
Lachlan	-0.02	-0.07	0.02	-0.06	0.01	-0.04	0.00
Lower Murray	0.48	-0.01	0.99	0.10	0.89	0.22	0.74
Murrumbidgee	0.04	-0.05	0.12	-0.03	0.10	-0.00	0.08
Murray-Darling rainbowfish							
Edward-Wakool	0.26	0.01	0.52	0.06	0.45	0.13	0.39
Goulburn	1.98	0.81	3.16	1.05	2.87	1.41	2.58
Gwydir	-0.14	-0.21	-0.08	-0.19	-0.09	-0.18	-0.11
Lachlan	0.01	-0.05	0.08	-0.04	0.06	-0.02	0.05
Lower Murray	1.04	0.31	1.75	0.49	1.61	0.65	1.37
Murrumbidgee	0.12	-0.01	0.24	0.02	0.21	0.06	0.18
Bony herring							
Edward-Wakool	0.12	-0.17	0.42	-0.12	0.34	-0.03	0.27
Goulburn	0.43	-1.01	1.76	-0.66	1.47	-0.30	1.10
Gwydir	0.02	-0.05	0.09	-0.03	0.08	-0.02	0.06
Lachlan	0.04	-0.04	0.12	-0.02	0.10	-0.00	0.07
Lower Murray	0.34	-0.70	1.22	-0.34	1.14	-0.18	0.78
Murrumbidgee	0.06	-0.09	0.21	-0.06	0.16	-0.01	0.14
Australian smelt							
Edward-Wakool	1.00	0.51	1.52	0.59	1.38	0.72	1.23
Goulburn	5.37	3.07	7.68	3.54	7.15	4.01	6.41
Gwydir	-0.07	-0.15	0.02	-0.14	-0.00	-0.11	-0.03
Lachlan	0.22	0.10	0.36	0.12	0.32	0.16	0.29
Lower Murray	3.19	1.74	4.61	2.08	4.32	2.32	3.79
Murrumbidgee	0.51	0.28	0.77	0.31	0.70	0.37	0.62

A.3 Analysis: Adult abundance

Table A.3: Estimate of the effect of Commonwealth environmental water on adult abundance, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	-0.16	-0.26	-0.07	-0.24	-0.08	-0.21	-0.11
Goulburn	-0.86	-1.24	-0.48	-1.14	-0.55	-1.08	-0.69
Gwydir	0.01	-0.00	0.03	0.00	0.03	0.01	0.02
Lachlan	-0.03	-0.06	-0.00	-0.05	-0.01	-0.04	-0.02
Lower Murray	-0.50	-0.73	-0.26	-0.69	-0.32	-0.62	-0.38
Murrumbidgee	-0.08	-0.12	-0.04	-0.12	-0.05	-0.10	-0.06
Murray cod							
Edward-Wakool	0.08	0.00	0.16	0.03	0.15	0.04	0.12
Goulburn	0.45	0.14	0.74	0.19	0.67	0.30	0.62
Gwydir	-0.02	-0.03	-0.01	-0.03	-0.01	-0.03	-0.01
Lachlan	0.02	0.00	0.04	0.01	0.04	0.01	0.03
Lower Murray	0.27	0.07	0.45	0.13	0.43	0.18	0.37
Murrumbidgee	0.05	0.01	0.08	0.02	0.07	0.03	0.06
Golden perch							
Edward-Wakool	0.03	-0.04	0.10	-0.03	0.08	-0.00	0.07
Goulburn	0.27	-0.02	0.54	0.06	0.49	0.12	0.41
Gwydir	-0.01	-0.02	-0.00	-0.02	-0.00	-0.02	-0.01
Lachlan	-0.00	-0.02	0.02	-0.02	0.01	-0.01	0.01
Lower Murray	0.14	-0.04	0.32	0.01	0.28	0.05	0.22
Murrumbidgee	0.02	-0.01	0.05	-0.00	0.04	0.00	0.03
Bony herring							
Edward-Wakool	0.20	0.02	0.38	0.05	0.33	0.11	0.29
Gwydir	-0.02	-0.05	0.01	-0.04	0.00	-0.03	-0.00
Lachlan	0.03	-0.02	0.08	-0.01	0.07	0.01	0.05
Lower Murray	0.69	0.23	1.12	0.36	1.05	0.45	0.91
Murrumbidgee	0.11	0.04	0.19	0.06	0.18	0.08	0.16

A.4 Analysis: Adult body condition

Table A.4 Estimate of the effect of Commonwealth environmental water on body condition, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown.

Species /Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	-0.000003	-0.000020	0.000010	-0.000015	0.000005	-0.000009	0.000002
Gwydir	0.000000	-0.000005	0.000009	-0.000003	0.000003	-0.000002	0.000001
Lachlan	0.000004	-0.000017	0.000057	-0.000011	0.000014	-0.000004	0.000007
Murrumbidgee	0.000008	-0.000008	0.000034	-0.000005	0.000027	-0.000002	0.000019
Murray cod							
Edward-Wakool	-0.000001	-0.000017	0.000014	-0.000012	0.000008	-0.000006	0.000003
Goulburn	0.000031	-0.000017	0.000097	-0.000005	0.000079	0.000007	0.000056
Gwydir	0.000008	-0.000002	0.000044	0.000000	0.000021	0.000001	0.000009
Lachlan	0.000005	-0.000019	0.000060	-0.000011	0.000015	-0.000003	0.000009
Lower Murray	0.000031	-0.000002	0.000085	-0.000001	0.000070	0.000002	0.000050
Murrumbidgee	0.000007	-0.000004	0.000025	-0.000003	0.000020	-0.000001	0.000015
Bony herring							
Edward-Wakool	0.000073	-0.000001	0.000218	-0.000000	0.000202	0.000003	0.000170
Gwydir	0.000009	-0.000015	0.000058	-0.000013	0.000026	-0.000004	0.000020
Lachlan	0.000004	-0.000561	0.000236	-0.000110	0.000210	0.000002	0.000096
Lower Murray	-0.000072	-0.000329	0.000158	-0.000296	0.000136	-0.000236	0.000038
Murrumbidgee	0.000017	-0.000069	0.000089	-0.000049	0.000076	-0.000029	0.000065
Golden perch							
Edward-Wakool	-0.000005	-0.000027	0.000008	-0.000021	0.000004	-0.000013	0.000001
Goulburn	0.000046	-0.000021	0.000138	-0.000006	0.000111	0.000009	0.000082
Gwydir	-0.000003	-0.000015	0.000003	-0.000008	0.000001	-0.000004	0.000000
Lachlan	0.000002	-0.000023	0.000045	-0.000015	0.000012	-0.000007	0.000005
Lower Murray	0.000025	-0.000015	0.000102	-0.000006	0.000078	-0.000002	0.000049
Murrumbidgee	0.000004	-0.000012	0.000028	-0.000009	0.000021	-0.000005	0.000013

A.5 Analysis: Adult presence/distribution

Table A.5 Estimate of the effect of Commonwealth environmental water on body condition, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Eastern gambusia							
Edward-Wakool	-0.20	-0.43	0.02	-0.37	-0.02	-0.33	-0.10
Goulburn	-0.36	-1.38	0.71	-1.14	0.47	-0.96	0.09
Gwydir	-0.12	-0.19	-0.06	-0.17	-0.08	-0.16	-0.09
Lachlan	-0.09	-0.16	-0.03	-0.14	-0.04	-0.12	-0.06
Lower Murray	-0.37	-1.02	0.27	-0.85	0.14	-0.72	-0.07
Murrumbidgee	-0.11	-0.22	0.00	-0.20	-0.03	-0.17	-0.06
Carp gudgeon							
Edward-Wakool	-0.28	-0.71	0.16	-0.61	0.05	-0.49	-0.05
Goulburn	-1.33	-3.30	0.67	-2.89	0.19	-2.18	-0.18
Gwydir	0.00	-0.08	0.09	-0.07	0.07	-0.04	0.04
Lachlan	-0.07	-0.18	0.04	-0.15	0.02	-0.11	-0.01
Lower Murray	-0.82	-2.09	0.39	-1.82	0.07	-1.35	-0.13
Murrumbidgee	-0.14	-0.34	0.07	-0.30	0.02	-0.24	-0.03
Murray cod							
Edward-Wakool	0.21	-0.03	0.46	0.02	0.41	0.09	0.34
Goulburn	1.10	-0.07	2.31	0.16	2.01	0.54	1.73
Gwydir	-0.04	-0.10	0.01	-0.09	-0.00	-0.07	-0.01
Lachlan	0.03	-0.04	0.09	-0.02	0.08	0.00	0.06
Lower Murray	0.66	-0.05	1.38	0.07	1.20	0.26	1.00
Murrumbidgee	0.10	-0.03	0.21	0.01	0.20	0.03	0.15
Golden perch							
Edward-Wakool	0.08	-0.18	0.31	-0.11	0.27	-0.06	0.19
Goulburn	0.69	-0.45	1.94	-0.25	1.60	0.05	1.25
Gwydir	-0.06	-0.11	-0.00	-0.10	-0.01	-0.09	-0.03
Lachlan	-0.01	-0.07	0.06	-0.05	0.04	-0.04	0.02
Lower Murray	0.35	-0.38	1.07	-0.21	0.90	-0.01	0.71
Murrumbidgee	0.04	-0.07	0.16	-0.06	0.13	-0.01	0.10
Murray-Darling rainbowfish							
Edward-Wakool	0.34	0.07	0.61	0.14	0.56	0.21	0.47
Goulburn	2.18	0.87	3.49	1.13	3.13	1.50	2.81
Gwydir	-0.15	-0.23	-0.08	-0.22	-0.10	-0.19	-0.12
Lachlan	0.03	-0.04	0.10	-0.03	0.08	-0.01	0.06
Lower Murray	1.20	0.44	2.02	0.60	1.82	0.82	1.60

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Murrumbidgee	0.13	0.01	0.27	0.02	0.23	0.06	0.19
Bony herring							
Edward-Wakool	0.15	-0.11	0.41	-0.05	0.36	0.00	0.27
Goulburn	2.12	0.63	3.46	1.07	3.22	1.45	2.86
Gwydir	-0.17	-0.27	-0.08	-0.24	-0.10	-0.22	-0.12
Lachlan	-0.01	-0.09	0.06	-0.07	0.04	-0.05	0.02
Lower Murray	0.98	0.19	1.80	0.34	1.58	0.59	1.42
Murrumbidgee	0.09	-0.04	0.22	-0.01	0.19	0.04	0.17
Australian smelt							
Edward-Wakool	0.39	0.20	0.57	0.25	0.53	0.28	0.47
Goulburn	1.61	0.75	2.47	0.85	2.21	1.14	2.02
Gwydir	0.03	-0.02	0.07	-0.01	0.06	-0.00	0.05
Lachlan	0.10	0.05	0.15	0.06	0.14	0.07	0.12
Lower Murray	1.05	0.51	1.58	0.64	1.46	0.78	1.31

A.6 Analysis: Community metric

Table A.6 Estimate of the effect of Commonwealth environmental water on community metric, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Community							
Edward-Wakool	0.00	-0.00	0.01	-0.00	0.01	-0.00	0.01
Goulburn	0.02	-0.01	0.04	-0.00	0.04	0.01	0.03
Gwydir	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00
Lachlan	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00
Lower Murray	0.01	-0.01	0.03	-0.00	0.02	0.00	0.02
Murrumbidgee	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00

A.7 Analysis: Predicting Commonwealth environmental water contribution on Murray cod and Murray-Darling rainbowfish recruitment at unmonitored areas across the Murray–Darling Basin

The table showing Basin-wise CEW effects with 60%, 80%, and 90% credible intervals for recruitment rates analysis is available on request to the author.

Appendix B Table of Commonwealth environmental water effects

B.1 Summary table across all analyses

Table B.1 Confidence categories for statistical analyses

Confidence is the posterior probability that the value of a fish response is increased by the delivery of Commonwealth environmental water.

Value	Category	Description
0.00–0.05	strong negative	Greater than 95% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.05–0.10	moderate negative	90–95% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.10–0.20	weak negative	80–90% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.20–0.80	no association	Less than 80% probability that response was lower or higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.80–0.90	weak positive	80–90% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.90–0.95	moderate positive	90–95% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.95–1.00	strong positive	Greater than 95% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water

Table B.2 Estimate of the effect of Commonwealth environmental water on population processes for each focal species

The CEW effect is the difference in each response between the observed data (with CEW) and a counterfactual scenario (without CEW), averaged over all survey years. Positive values reflect increases in a response due to CEW. Lower and upper bounds are 10th and 90th percentiles over all survey years. Confidence is the posterior probability that the response is greater with than without CEW, with confidence categories assigning these values to broad classes as described in Table B.1. Selected Areas (abbreviated in the table) are Edward/Kolety–Wakool river systems, Goulburn River, Gwydir River System, Lachlan River System, Lower Murray River and Murrumbidgee River System, respectively. The Junction of Warrego and Darling rivers Selected Area is not included as it does not have a designated targeted indicator for fish and historically is not included in Basin-scale fish analyses.

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Australian smelt					
Edward-Wakool	Recruit abundance	1.00	0.51	1.52	strong positive
	Adult distribution	0.39	0.20	0.57	strong positive
Goulburn	Recruit abundance	5.37	3.07	7.68	strong positive
	Adult distribution	1.61	0.75	2.47	strong positive

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Gwydir	Recruit abundance	-6.8e-02	-1.5e-01	0.02	moderate negative
	Adult distribution	0.03	-1.6e-02	0.07	weak positive
Lachlan	Recruit abundance	0.22	0.10	0.36	strong positive
	Adult distribution	0.10	0.05	0.15	strong positive
Lower Murray	Recruit abundance	3.19	1.74	4.61	strong positive
	Adult distribution	1.05	0.51	1.58	strong positive
Murrumbidgee	Recruit abundance	0.51	0.28	0.77	strong positive
	Adult distribution	0.19	0.11	0.29	strong positive
Bony herring					
Edward-Wakool	Recruit abundance	0.12	-1.7e-01	0.42	no association
	Adult abundance	0.20	0.02	0.38	strong positive
	Fulton's K condition	7.3e-05	-1.4e-06	2.2e-04	weak positive
	Adult distribution	0.15	-1.1e-01	0.41	weak positive
Goulburn	Recruit abundance	0.43	-1.0e+00	1.76	no association
	Adult distribution	2.12	0.63	3.46	strong positive
Gwydir	Recruit abundance	0.02	-5.0e-02	0.09	no association
	Adult abundance	-1.9e-02	-4.6e-02	8.7e-03	weak negative
	Fulton's K condition	8.7e-06	-1.5e-05	5.8e-05	no association
	Adult distribution	-1.7e-01	-2.7e-01	-8.2e-02	strong negative
Lachlan	Recruit abundance	0.04	-4.0e-02	0.12	no association
	Adult abundance	0.03	-1.8e-02	0.08	weak positive
	Fulton's K condition	3.8e-06	-5.6e-04	2.4e-04	weak positive
	Adult distribution	-1.4e-02	-8.9e-02	0.06	no association
Lower Murray	Recruit abundance	0.34	-7.0e-01	1.22	no association
	Adult abundance	0.69	0.23	1.12	strong positive
	Fulton's K condition	-7.2e-05	-3.3e-04	1.6e-04	no association
	Adult distribution	0.98	0.19	1.80	strong positive
Murrumbidgee	Recruit abundance	0.06	-8.7e-02	0.21	no association
	Adult abundance	0.11	0.04	0.19	strong positive
	Fulton's K condition	1.7e-05	-6.9e-05	8.9e-05	no association
	Adult distribution	0.09	-3.7e-02	0.22	weak positive
Carp gudgeon					
Edward-Wakool	Recruit abundance	0.03	-2.2e-01	0.29	no association
	Adult distribution	-2.8e-01	-7.1e-01	0.16	weak negative
Goulburn	Recruit abundance	0.02	-1.1e+00	1.22	no association
	Adult distribution	-1.3e+00	-3.3e+00	0.67	weak negative
Gwydir	Recruit abundance	-1.0e-02	-5.9e-02	0.04	no association

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
	Adult distribution	2.5e-03	-8.5e-02	0.09	no association
Lachlan	Recruit abundance	-1.8e-03	-7.0e-02	0.06	no association
	Adult distribution	-6.6e-02	-1.8e-01	0.04	weak negative
Lower Murray	Recruit abundance	0.04	-6.8e-01	0.77	no association
	Adult distribution	-8.2e-01	-2.1e+00	0.39	weak negative
Murrumbidgee	Recruit abundance	6.0e-03	-1.1e-01	0.13	no association
	Adult distribution	-1.4e-01	-3.4e-01	0.07	weak negative
Common carp					
Edward-Wakool	Recruit abundance	0.30	0.04	0.57	strong positive
	Adult abundance	-1.6e-01	-2.6e-01	-6.8e-02	strong negative
	Fulton’s K condition	-3.2e-06	-2.0e-05	1.0e-05	no association
Goulburn	Recruit abundance	0.54	-6.8e-01	1.79	no association
	Adult abundance	-8.6e-01	-1.2e+00	-4.8e-01	strong negative
Gwydir	Recruit abundance	0.14	0.08	0.20	strong positive
	Adult abundance	0.01	-3.0e-03	0.03	moderate positive
	Fulton’s K condition	4.9e-07	-5.4e-06	8.6e-06	no association
Lachlan	Recruit abundance	0.12	0.05	0.19	strong positive
	Adult abundance	-3.1e-02	-5.5e-02	-4.9e-03	strong negative
	Fulton’s K condition	4.3e-06	-1.7e-05	5.7e-05	no association
Lower Murray	Recruit abundance	0.60	-2.5e-01	1.47	weak positive
	Adult abundance	-5.0e-01	-7.3e-01	-2.6e-01	strong negative
Murrumbidgee	Recruit abundance	0.14	0.01	0.27	strong positive
	Adult abundance	-8.3e-02	-1.2e-01	-3.9e-02	strong negative
	Fulton’s K condition	7.8e-06	-7.5e-06	3.4e-05	no association
Eastern gambusia					
Edward-Wakool	Recruit abundance	-5.2e-02	-4.4e-01	0.39	no association
	Adult distribution	-2.0e-01	-4.3e-01	0.02	moderate negative
Goulburn	Recruit abundance	-7.1e-01	-2.5e+00	1.22	no association
	Adult distribution	-3.6e-01	-1.4e+00	0.71	no association
Gwydir	Recruit abundance	0.07	-1.1e-02	0.15	moderate positive
	Adult distribution	-1.2e-01	-1.9e-01	-6.2e-02	strong negative
Lachlan	Recruit abundance	6.3e-03	-1.0e-01	0.11	no association
	Adult distribution	-9.2e-02	-1.6e-01	-2.8e-02	strong negative
Lower Murray	Recruit abundance	-3.3e-01	-1.5e+00	0.84	no association
	Adult distribution	-3.7e-01	-1.0e+00	0.27	weak negative
Murrumbidgee	Recruit abundance	-2.7e-02	-2.2e-01	0.18	no association
	Adult distribution	-1.1e-01	-2.2e-01	1.9e-03	strong negative

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Golden perch					
Edward-Wakool	Spawning occurrence	-1.9e-02	-4.6e-02	8.3e-03	weak negative
	Adult abundance	0.03	-4.3e-02	0.10	no association
	Fulton's K condition	-5.5e-06	-2.7e-05	8.4e-06	no association
	Adult distribution	0.08	-1.8e-01	0.31	no association
Goulburn	Spawning occurrence	-1.3e-02	-2.4e-01	0.20	no association
	Adult abundance	0.27	-2.3e-02	0.54	moderate positive
	Fulton's K condition	4.6e-05	-2.1e-05	1.4e-04	weak positive
	Adult distribution	0.69	-4.5e-01	1.94	weak positive
Gwydir	Adult abundance	-1.1e-02	-2.2e-02	-6.3e-04	strong negative
	Fulton's K condition	-2.6e-06	-1.5e-05	2.7e-06	no association
	Adult distribution	-5.8e-02	-1.1e-01	-3.1e-03	strong negative
Lachlan	Spawning occurrence	-1.7e-02	-1.1e-01	0.07	no association
	Adult abundance	-6.3e-04	-1.9e-02	0.02	no association
	Fulton's K condition	2.1e-06	-2.3e-05	4.5e-05	no association
	Adult distribution	-5.3e-03	-6.7e-02	0.06	no association
Lower Murray	Spawning occurrence	0.10	-2.0e-02	0.23	moderate positive
	Adult abundance	0.14	-3.6e-02	0.32	moderate positive
	Fulton's K condition	2.5e-05	-1.5e-05	1.0e-04	no association
	Adult distribution	0.35	-3.8e-01	1.07	no association
Murrumbidgee	Spawning occurrence	7.6e-03	-5.4e-02	0.06	no association
	Adult abundance	0.02	-1.2e-02	0.05	weak positive
	Fulton's K condition	4.0e-06	-1.2e-05	2.8e-05	no association
	Adult distribution	0.04	-7.2e-02	0.16	no association
Murray cod					
Edward-Wakool	Recruit abundance	0.10	-7.4e-02	0.27	weak positive
	Adult abundance	0.08	4.5e-03	0.16	strong positive
	Fulton's K condition	-1.4e-06	-1.7e-05	1.4e-05	no association
	Adult distribution	0.21	-3.1e-02	0.46	moderate positive
Goulburn	Recruit abundance	0.97	0.12	1.80	strong positive
	Adult abundance	0.45	0.14	0.74	strong positive
	Fulton's K condition	3.1e-05	-1.7e-05	9.7e-05	weak positive
	Adult distribution	1.10	-6.7e-02	2.31	moderate positive
Gwydir	Recruit abundance	-1.2e-01	-1.6e-01	-6.8e-02	strong negative
	Adult abundance	-2.0e-02	-3.2e-02	-6.1e-03	strong negative
	Fulton's K condition	7.8e-06	-1.9e-06	4.4e-05	moderate positive
	Adult distribution	-4.5e-02	-9.6e-02	0.01	moderate negative

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Lachlan	Recruit abundance	-2.1e-02	-6.6e-02	0.02	no association
	Adult abundance	0.02	8.4e-05	0.04	moderate positive
	Fulton's K condition	4.8e-06	-1.9e-05	6.0e-05	no association
	Adult distribution	0.03	-3.5e-02	0.09	no association
Lower Murray	Recruit abundance	0.48	-1.3e-02	0.99	moderate positive
	Adult abundance	0.27	0.07	0.45	strong positive
	Fulton's K condition	3.1e-05	-2.4e-06	8.5e-05	weak positive
	Adult distribution	0.66	-5.5e-02	1.38	moderate positive
Murrumbidgee	Recruit abundance	0.04	-4.6e-02	0.12	no association
	Adult abundance	0.05	1.0e-02	0.08	strong positive
	Fulton's K condition	7.5e-06	-4.2e-06	2.5e-05	no association
	Adult distribution	0.10	-2.5e-02	0.21	moderate positive
Murray-Darling rainbowfish					
Edward-Wakool	Recruit abundance	0.26	6.5e-03	0.52	strong positive
	Adult distribution	0.34	0.07	0.61	strong positive
Goulburn	Recruit abundance	1.98	0.81	3.16	strong positive
	Adult distribution	2.18	0.87	3.49	strong positive
Gwydir	Recruit abundance	-1.4e-01	-2.1e-01	-7.7e-02	strong negative
	Adult distribution	-1.5e-01	-2.3e-01	-7.5e-02	strong negative
Lachlan	Recruit abundance	0.01	-5.2e-02	0.08	no association
	Adult distribution	0.03	-4.0e-02	0.10	no association
Lower Murray	Recruit abundance	1.04	0.31	1.75	strong positive
	Adult distribution	1.20	0.44	2.02	strong positive
Murrumbidgee	Recruit abundance	0.12	-5.1e-03	0.24	moderate positive
	Adult distribution	0.13	6.7e-03	0.27	moderate positive
Silver perch					
Edward-Wakool	Spawning occurrence	-3.7e-02	-8.3e-02	0.01	moderate negative
Goulburn	Spawning occurrence	-2.9e-01	-6.5e-01	0.13	moderate negative
	Spawning occurrence	-2.9e-01	-6.5e-01	0.13	weak negative
Lachlan	Spawning occurrence	-1.2e-01	-2.7e-01	0.05	moderate negative
Lower Murray	Spawning occurrence	-1.4e-01	-3.5e-01	0.09	weak negative
Murrumbidgee	Spawning occurrence	-7.6e-02	-1.8e-01	0.03	weak negative
Community compositional metric					
Edward-Wakool		2.7e-03	-3.2e-03	8.3e-03	no association
Goulburn		0.02	-9.5e-03	0.04	weak positive
Gwydir		-1.1e-03	-2.9e-03	3.2e-04	weak negative
Lachlan		2.0e-04	-1.5e-03	1.9e-03	no association

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Lower Murray		0.01	-6.4e-03	0.03	weak positive
Murrumbidgee		1.5e-03	-1.5e-03	4.7e-03	no association

Appendix C Statistical tables for all analyses

C.1 Analysis: Spawning presence

Table C.1 Estimate of the effect of Commonwealth environmental water on recruitment rates of golden perch and silver perch, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown.

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Golden perch							
Edward-Wakool	-0.019	-0.046	0.008	-0.042	0.001	-0.031	-0.004
Goulburn	-0.013	-0.243	0.197	-0.183	0.160	-0.110	0.114
Lachlan	-0.017	-0.108	0.075	-0.086	0.056	-0.061	0.033
Lower Murray	0.104	-0.020	0.235	0.013	0.210	0.033	0.162
Murrumbidgee	0.008	-0.054	0.064	-0.035	0.057	-0.023	0.037
Silver perch							
Edward-Wakool	-0.037	-0.083	0.012	-0.070	0.002	-0.058	-0.011
Goulburn	-0.294	-0.651	0.126	-0.562	0.035	-0.452	-0.066
Lachlan	-0.124	-0.271	0.053	-0.242	0.006	-0.191	-0.029
Lower Murray	-0.141	-0.347	0.086	-0.298	0.038	-0.237	-0.021
Murrumbidgee	-0.076	-0.179	0.028	-0.145	0.014	-0.122	-0.019

C.2 Analysis: Recruits analysis (young-of-year) using abundance data

Table C.2 Estimate of the effect of Commonwealth environmental water on recruitment rates, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Species/Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	0.30	0.04	0.57	0.08	0.50	0.15	0.43
Goulburn	0.54	-0.68	1.79	-0.40	1.55	-0.10	1.18
Gwydir	0.14	0.08	0.20	0.09	0.19	0.11	0.17
Lachlan	0.12	0.05	0.19	0.07	0.18	0.09	0.16
Lower Murray	0.60	-0.25	1.47	-0.08	1.27	0.19	1.08
Murrumbidgee	0.14	0.01	0.27	0.04	0.25	0.07	0.21
Eastern gambusia							
Edward-Wakool	-0.05	-0.44	0.39	-0.38	0.26	-0.28	0.14
Goulburn	-0.71	-2.51	1.22	-2.11	0.75	-1.74	0.14
Gwydir	0.07	-0.01	0.15	0.00	0.13	0.02	0.10

Species/Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Lachlan	0.01	-0.10	0.11	-0.08	0.09	-0.05	0.06
Lower Murray	-0.33	-1.48	0.84	-1.20	0.60	-0.99	0.19
Murrumbidgee	-0.03	-0.22	0.18	-0.18	0.14	-0.14	0.07
Carp gudgeon							
Edward-Wakool	0.03	-0.22	0.29	-0.17	0.22	-0.10	0.16
Goulburn	0.02	-1.09	1.22	-0.95	0.84	-0.55	0.62
Gwydir	-0.01	-0.06	0.04	-0.05	0.03	-0.04	0.02
Lachlan	-0.00	-0.07	0.06	-0.05	0.05	-0.04	0.03
Lower Murray	0.04	-0.68	0.77	-0.54	0.57	-0.35	0.39
Murrumbidgee	0.01	-0.11	0.13	-0.09	0.10	-0.06	0.07
Murray cod							
Edward-Wakool	0.10	-0.07	0.27	-0.03	0.24	0.02	0.19
Goulburn	0.97	0.12	1.80	0.34	1.65	0.57	1.42
Gwydir	-0.12	-0.16	-0.07	-0.15	-0.08	-0.14	-0.09
Lachlan	-0.02	-0.07	0.02	-0.06	0.01	-0.04	0.00
Lower Murray	0.48	-0.01	0.99	0.10	0.89	0.22	0.74
Murrumbidgee	0.04	-0.05	0.12	-0.03	0.10	-0.00	0.08
Murray-Darling rainbowfish							
Edward-Wakool	0.26	0.01	0.52	0.06	0.45	0.13	0.39
Goulburn	1.98	0.81	3.16	1.05	2.87	1.41	2.58
Gwydir	-0.14	-0.21	-0.08	-0.19	-0.09	-0.18	-0.11
Lachlan	0.01	-0.05	0.08	-0.04	0.06	-0.02	0.05
Lower Murray	1.04	0.31	1.75	0.49	1.61	0.65	1.37
Murrumbidgee	0.12	-0.01	0.24	0.02	0.21	0.06	0.18
Bony herring							
Edward-Wakool	0.12	-0.17	0.42	-0.12	0.34	-0.03	0.27
Goulburn	0.43	-1.01	1.76	-0.66	1.47	-0.30	1.10
Gwydir	0.02	-0.05	0.09	-0.03	0.08	-0.02	0.06
Lachlan	0.04	-0.04	0.12	-0.02	0.10	-0.00	0.07
Lower Murray	0.34	-0.70	1.22	-0.34	1.14	-0.18	0.78
Murrumbidgee	0.06	-0.09	0.21	-0.06	0.16	-0.01	0.14
Australian smelt							
Edward-Wakool	1.00	0.51	1.52	0.59	1.38	0.72	1.23
Goulburn	5.37	3.07	7.68	3.54	7.15	4.01	6.41
Gwydir	-0.07	-0.15	0.02	-0.14	-0.00	-0.11	-0.03
Lachlan	0.22	0.10	0.36	0.12	0.32	0.16	0.29
Lower Murray	3.19	1.74	4.61	2.08	4.32	2.32	3.79
Murrumbidgee	0.51	0.28	0.77	0.31	0.70	0.37	0.62

C.3 Analysis: Adult abundance

Table C.3: Estimate of the effect of Commonwealth environmental water on adult abundance, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	-0.16	-0.26	-0.07	-0.24	-0.08	-0.21	-0.11
Goulburn	-0.86	-1.24	-0.48	-1.14	-0.55	-1.08	-0.69
Gwydir	0.01	-0.00	0.03	0.00	0.03	0.01	0.02
Lachlan	-0.03	-0.06	-0.00	-0.05	-0.01	-0.04	-0.02
Lower Murray	-0.50	-0.73	-0.26	-0.69	-0.32	-0.62	-0.38
Murrumbidgee	-0.08	-0.12	-0.04	-0.12	-0.05	-0.10	-0.06
Murray cod							
Edward-Wakool	0.08	0.00	0.16	0.03	0.15	0.04	0.12
Goulburn	0.45	0.14	0.74	0.19	0.67	0.30	0.62
Gwydir	-0.02	-0.03	-0.01	-0.03	-0.01	-0.03	-0.01
Lachlan	0.02	0.00	0.04	0.01	0.04	0.01	0.03
Lower Murray	0.27	0.07	0.45	0.13	0.43	0.18	0.37
Murrumbidgee	0.05	0.01	0.08	0.02	0.07	0.03	0.06
Golden perch							
Edward-Wakool	0.03	-0.04	0.10	-0.03	0.08	-0.00	0.07
Goulburn	0.27	-0.02	0.54	0.06	0.49	0.12	0.41
Gwydir	-0.01	-0.02	-0.00	-0.02	-0.00	-0.02	-0.01
Lachlan	-0.00	-0.02	0.02	-0.02	0.01	-0.01	0.01
Lower Murray	0.14	-0.04	0.32	0.01	0.28	0.05	0.22
Murrumbidgee	0.02	-0.01	0.05	-0.00	0.04	0.00	0.03
Bony herring							
Edward-Wakool	0.20	0.02	0.38	0.05	0.33	0.11	0.29
Gwydir	-0.02	-0.05	0.01	-0.04	0.00	-0.03	-0.00
Lachlan	0.03	-0.02	0.08	-0.01	0.07	0.01	0.05
Lower Murray	0.69	0.23	1.12	0.36	1.05	0.45	0.91
Murrumbidgee	0.11	0.04	0.19	0.06	0.18	0.08	0.16

C.4 Analysis: Adult body condition

Table C.4 Estimate of the effect of Commonwealth environmental water on body condition, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown.

Species /Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Common carp							
Edward-Wakool	-0.000003	-0.000020	0.000010	-0.000015	0.000005	-0.000009	0.000002
Gwydir	0.000000	-0.000005	0.000009	-0.000003	0.000003	-0.000002	0.000001
Lachlan	0.000004	-0.000017	0.000057	-0.000011	0.000014	-0.000004	0.000007
Murrumbidgee	0.000008	-0.000008	0.000034	-0.000005	0.000027	-0.000002	0.000019
Murray cod							
Edward-Wakool	-0.000001	-0.000017	0.000014	-0.000012	0.000008	-0.000006	0.000003
Goulburn	0.000031	-0.000017	0.000097	-0.000005	0.000079	0.000007	0.000056
Gwydir	0.000008	-0.000002	0.000044	0.000000	0.000021	0.000001	0.000009
Lachlan	0.000005	-0.000019	0.000060	-0.000011	0.000015	-0.000003	0.000009
Lower Murray	0.000031	-0.000002	0.000085	-0.000001	0.000070	0.000002	0.000050
Murrumbidgee	0.000007	-0.000004	0.000025	-0.000003	0.000020	-0.000001	0.000015
Bony herring							
Edward-Wakool	0.000073	-0.000001	0.000218	-0.000000	0.000202	0.000003	0.000170
Gwydir	0.000009	-0.000015	0.000058	-0.000013	0.000026	-0.000004	0.000020
Lachlan	0.000004	-0.000561	0.000236	-0.000110	0.000210	0.000002	0.000096
Lower Murray	-0.000072	-0.000329	0.000158	-0.000296	0.000136	-0.000236	0.000038
Murrumbidgee	0.000017	-0.000069	0.000089	-0.000049	0.000076	-0.000029	0.000065
Golden perch							
Edward-Wakool	-0.000005	-0.000027	0.000008	-0.000021	0.000004	-0.000013	0.000001
Goulburn	0.000046	-0.000021	0.000138	-0.000006	0.000111	0.000009	0.000082
Gwydir	-0.000003	-0.000015	0.000003	-0.000008	0.000001	-0.000004	0.000000
Lachlan	0.000002	-0.000023	0.000045	-0.000015	0.000012	-0.000007	0.000005
Lower Murray	0.000025	-0.000015	0.000102	-0.000006	0.000078	-0.000002	0.000049
Murrumbidgee	0.000004	-0.000012	0.000028	-0.000009	0.000021	-0.000005	0.000013

C.5 Analysis: Adult presence/distribution

Table C.5 Estimate of the effect of Commonwealth environmental water on body condition, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Eastern gambusia							
Edward-Wakool	-0.20	-0.43	0.02	-0.37	-0.02	-0.33	-0.10
Goulburn	-0.36	-1.38	0.71	-1.14	0.47	-0.96	0.09
Gwydir	-0.12	-0.19	-0.06	-0.17	-0.08	-0.16	-0.09
Lachlan	-0.09	-0.16	-0.03	-0.14	-0.04	-0.12	-0.06
Lower Murray	-0.37	-1.02	0.27	-0.85	0.14	-0.72	-0.07
Murrumbidgee	-0.11	-0.22	0.00	-0.20	-0.03	-0.17	-0.06
Carp gudgeon							
Edward-Wakool	-0.28	-0.71	0.16	-0.61	0.05	-0.49	-0.05
Goulburn	-1.33	-3.30	0.67	-2.89	0.19	-2.18	-0.18
Gwydir	0.00	-0.08	0.09	-0.07	0.07	-0.04	0.04
Lachlan	-0.07	-0.18	0.04	-0.15	0.02	-0.11	-0.01
Lower Murray	-0.82	-2.09	0.39	-1.82	0.07	-1.35	-0.13
Murrumbidgee	-0.14	-0.34	0.07	-0.30	0.02	-0.24	-0.03
Murray cod							
Edward-Wakool	0.21	-0.03	0.46	0.02	0.41	0.09	0.34
Goulburn	1.10	-0.07	2.31	0.16	2.01	0.54	1.73
Gwydir	-0.04	-0.10	0.01	-0.09	-0.00	-0.07	-0.01
Lachlan	0.03	-0.04	0.09	-0.02	0.08	0.00	0.06
Lower Murray	0.66	-0.05	1.38	0.07	1.20	0.26	1.00
Murrumbidgee	0.10	-0.03	0.21	0.01	0.20	0.03	0.15
Golden perch							
Edward-Wakool	0.08	-0.18	0.31	-0.11	0.27	-0.06	0.19
Goulburn	0.69	-0.45	1.94	-0.25	1.60	0.05	1.25
Gwydir	-0.06	-0.11	-0.00	-0.10	-0.01	-0.09	-0.03
Lachlan	-0.01	-0.07	0.06	-0.05	0.04	-0.04	0.02
Lower Murray	0.35	-0.38	1.07	-0.21	0.90	-0.01	0.71
Murrumbidgee	0.04	-0.07	0.16	-0.06	0.13	-0.01	0.10
Murray-Darling rainbowfish							
Edward-Wakool	0.34	0.07	0.61	0.14	0.56	0.21	0.47
Goulburn	2.18	0.87	3.49	1.13	3.13	1.50	2.81
Gwydir	-0.15	-0.23	-0.08	-0.22	-0.10	-0.19	-0.12
Lachlan	0.03	-0.04	0.10	-0.03	0.08	-0.01	0.06
Lower Murray	1.20	0.44	2.02	0.60	1.82	0.82	1.60

Species/ Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Murrumbidgee	0.13	0.01	0.27	0.02	0.23	0.06	0.19
Bony herring							
Edward-Wakool	0.15	-0.11	0.41	-0.05	0.36	0.00	0.27
Goulburn	2.12	0.63	3.46	1.07	3.22	1.45	2.86
Gwydir	-0.17	-0.27	-0.08	-0.24	-0.10	-0.22	-0.12
Lachlan	-0.01	-0.09	0.06	-0.07	0.04	-0.05	0.02
Lower Murray	0.98	0.19	1.80	0.34	1.58	0.59	1.42
Murrumbidgee	0.09	-0.04	0.22	-0.01	0.19	0.04	0.17
Australian smelt							
Edward-Wakool	0.39	0.20	0.57	0.25	0.53	0.28	0.47
Goulburn	1.61	0.75	2.47	0.85	2.21	1.14	2.02
Gwydir	0.03	-0.02	0.07	-0.01	0.06	-0.00	0.05
Lachlan	0.10	0.05	0.15	0.06	0.14	0.07	0.12
Lower Murray	1.05	0.51	1.58	0.64	1.46	0.78	1.31

C.6 Analysis: Community metric

Table C.6 Estimate of the effect of Commonwealth environmental water on community metric, by Selected Area
Estimates and 90%, 80%, and 60% credible intervals are shown

Selected Area	estimate	lower_90	upper_90	lower_80	upper_80	lower_60	upper_60
Community							
Edward-Wakool	0.00	-0.00	0.01	-0.00	0.01	-0.00	0.01
Goulburn	0.02	-0.01	0.04	-0.00	0.04	0.01	0.03
Gwydir	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00
Lachlan	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00
Lower Murray	0.01	-0.01	0.03	-0.00	0.02	0.00	0.02
Murrumbidgee	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00

C.7 Analysis: Predicting Commonwealth environmental water contribution on Murray cod and Murray-Darling rainbowfish recruitment at unmonitored areas across the Murray–Darling Basin

The table showing Basin-wise CEW effects with 60%, 80%, and 90% credible intervals for recruitment rates analysis is available on request to the author.

Appendix D Table of Commonwealth environmental water effects

D.1 Summary table across all analyses

Table D.1 Confidence categories for statistical analyses

Confidence is the posterior probability that the value of a fish response is increased by the delivery of Commonwealth environmental water.

Value	Category	Description
0.00–0.05	strong negative	Greater than 95% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.05–0.10	moderate negative	90–95% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.10–0.20	weak negative	80–90% probability that response was lower with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.20–0.80	no association	Less than 80% probability that response was lower or higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.80–0.90	weak positive	80–90% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.90–0.95	moderate positive	90–95% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water
>0.95–1.00	strong positive	Greater than 95% probability that response was higher with Commonwealth environmental water than under a counterfactual scenario without Commonwealth environmental water

Table D.2 Estimate of the effect of Commonwealth environmental water on population processes for each focal species

The CEW effect is the difference in each response between the observed data (with CEW) and a counterfactual scenario (without CEW), averaged over all survey years. Positive values reflect increases in a response due to CEW. Lower and upper bounds are 10th and 90th percentiles over all survey years. Confidence is the posterior probability that the response is greater with than without CEW, with confidence categories assigning these values to broad classes as described in Table B.1. Selected Areas (abbreviated in the table) are Edward/Kolety–Wakool river systems, Goulburn River, Gwydir River System, Lachlan River System, Lower Murray River and Murrumbidgee River System, respectively. The Junction of Warrego and Darling rivers Selected Area is not included as it does not have a designated targeted indicator for fish and historically is not included in Basin-scale fish analyses.

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Australian smelt					
Edward-Wakool	Recruit abundance	1.00	0.51	1.52	strong positive
	Adult distribution	0.39	0.20	0.57	strong positive
Goulburn	Recruit abundance	5.37	3.07	7.68	strong positive
	Adult distribution	1.61	0.75	2.47	strong positive

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Gwydir	Recruit abundance	-6.8e-02	-1.5e-01	0.02	moderate negative
	Adult distribution	0.03	-1.6e-02	0.07	weak positive
Lachlan	Recruit abundance	0.22	0.10	0.36	strong positive
	Adult distribution	0.10	0.05	0.15	strong positive
Lower Murray	Recruit abundance	3.19	1.74	4.61	strong positive
	Adult distribution	1.05	0.51	1.58	strong positive
Murrumbidgee	Recruit abundance	0.51	0.28	0.77	strong positive
	Adult distribution	0.19	0.11	0.29	strong positive
Bony herring					
Edward-Wakool	Recruit abundance	0.12	-1.7e-01	0.42	no association
	Adult abundance	0.20	0.02	0.38	strong positive
	Fulton's K condition	7.3e-05	-1.4e-06	2.2e-04	weak positive
	Adult distribution	0.15	-1.1e-01	0.41	weak positive
Goulburn	Recruit abundance	0.43	-1.0e+00	1.76	no association
	Adult distribution	2.12	0.63	3.46	strong positive
Gwydir	Recruit abundance	0.02	-5.0e-02	0.09	no association
	Adult abundance	-1.9e-02	-4.6e-02	8.7e-03	weak negative
	Fulton's K condition	8.7e-06	-1.5e-05	5.8e-05	no association
	Adult distribution	-1.7e-01	-2.7e-01	-8.2e-02	strong negative
Lachlan	Recruit abundance	0.04	-4.0e-02	0.12	no association
	Adult abundance	0.03	-1.8e-02	0.08	weak positive
	Fulton's K condition	3.8e-06	-5.6e-04	2.4e-04	weak positive
	Adult distribution	-1.4e-02	-8.9e-02	0.06	no association
Lower Murray	Recruit abundance	0.34	-7.0e-01	1.22	no association
	Adult abundance	0.69	0.23	1.12	strong positive
	Fulton's K condition	-7.2e-05	-3.3e-04	1.6e-04	no association
	Adult distribution	0.98	0.19	1.80	strong positive
Murrumbidgee	Recruit abundance	0.06	-8.7e-02	0.21	no association
	Adult abundance	0.11	0.04	0.19	strong positive
	Fulton's K condition	1.7e-05	-6.9e-05	8.9e-05	no association
	Adult distribution	0.09	-3.7e-02	0.22	weak positive
Carp gudgeon					
Edward-Wakool	Recruit abundance	0.03	-2.2e-01	0.29	no association
	Adult distribution	-2.8e-01	-7.1e-01	0.16	weak negative
Goulburn	Recruit abundance	0.02	-1.1e+00	1.22	no association
	Adult distribution	-1.3e+00	-3.3e+00	0.67	weak negative

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Gwydir	Recruit abundance	-1.0e-02	-5.9e-02	0.04	no association
	Adult distribution	2.5e-03	-8.5e-02	0.09	no association
Lachlan	Recruit abundance	-1.8e-03	-7.0e-02	0.06	no association
	Adult distribution	-6.6e-02	-1.8e-01	0.04	weak negative
Lower Murray	Recruit abundance	0.04	-6.8e-01	0.77	no association
	Adult distribution	-8.2e-01	-2.1e+00	0.39	weak negative
Murrumbidgee	Recruit abundance	6.0e-03	-1.1e-01	0.13	no association
	Adult distribution	-1.4e-01	-3.4e-01	0.07	weak negative
Common carp					
Edward-Wakool	Recruit abundance	0.30	0.04	0.57	strong positive
	Adult abundance	-1.6e-01	-2.6e-01	-6.8e-02	strong negative
	Fulton's K condition	-3.2e-06	-2.0e-05	1.0e-05	no association
Goulburn	Recruit abundance	0.54	-6.8e-01	1.79	no association
	Adult abundance	-8.6e-01	-1.2e+00	-4.8e-01	strong negative
Gwydir	Recruit abundance	0.14	0.08	0.20	strong positive
	Adult abundance	0.01	-3.0e-03	0.03	moderate positive
	Fulton's K condition	4.9e-07	-5.4e-06	8.6e-06	no association
Lachlan	Recruit abundance	0.12	0.05	0.19	strong positive
	Adult abundance	-3.1e-02	-5.5e-02	-4.9e-03	strong negative
	Fulton's K condition	4.3e-06	-1.7e-05	5.7e-05	no association
Lower Murray	Recruit abundance	0.60	-2.5e-01	1.47	weak positive
	Adult abundance	-5.0e-01	-7.3e-01	-2.6e-01	strong negative
Murrumbidgee	Recruit abundance	0.14	0.01	0.27	strong positive
	Adult abundance	-8.3e-02	-1.2e-01	-3.9e-02	strong negative
	Fulton's K condition	7.8e-06	-7.5e-06	3.4e-05	no association
Eastern gambusia					
Edward-Wakool	Recruit abundance	-5.2e-02	-4.4e-01	0.39	no association
	Adult distribution	-2.0e-01	-4.3e-01	0.02	moderate negative
Goulburn	Recruit abundance	-7.1e-01	-2.5e+00	1.22	no association
	Adult distribution	-3.6e-01	-1.4e+00	0.71	no association
Gwydir	Recruit abundance	0.07	-1.1e-02	0.15	moderate positive
	Adult distribution	-1.2e-01	-1.9e-01	-6.2e-02	strong negative
Lachlan	Recruit abundance	6.3e-03	-1.0e-01	0.11	no association
	Adult distribution	-9.2e-02	-1.6e-01	-2.8e-02	strong negative
Lower Murray	Recruit abundance	-3.3e-01	-1.5e+00	0.84	no association
	Adult distribution	-3.7e-01	-1.0e+00	0.27	weak negative

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Murrumbidgee	Recruit abundance	-2.7e-02	-2.2e-01	0.18	no association
	Adult distribution	-1.1e-01	-2.2e-01	1.9e-03	strong negative
Golden perch					
Edward-Wakool	Spawning occurrence	-1.9e-02	-4.6e-02	8.3e-03	weak negative
	Adult abundance	0.03	-4.3e-02	0.10	no association
	Fulton's K condition	-5.5e-06	-2.7e-05	8.4e-06	no association
	Adult distribution	0.08	-1.8e-01	0.31	no association
Goulburn	Spawning occurrence	-1.3e-02	-2.4e-01	0.20	no association
	Adult abundance	0.27	-2.3e-02	0.54	moderate positive
	Fulton's K condition	4.6e-05	-2.1e-05	1.4e-04	weak positive
	Adult distribution	0.69	-4.5e-01	1.94	weak positive
Gwydir	Adult abundance	-1.1e-02	-2.2e-02	-6.3e-04	strong negative
	Fulton's K condition	-2.6e-06	-1.5e-05	2.7e-06	no association
	Adult distribution	-5.8e-02	-1.1e-01	-3.1e-03	strong negative
Lachlan	Spawning occurrence	-1.7e-02	-1.1e-01	0.07	no association
	Adult abundance	-6.3e-04	-1.9e-02	0.02	no association
	Fulton's K condition	2.1e-06	-2.3e-05	4.5e-05	no association
	Adult distribution	-5.3e-03	-6.7e-02	0.06	no association
Lower Murray	Spawning occurrence	0.10	-2.0e-02	0.23	moderate positive
	Adult abundance	0.14	-3.6e-02	0.32	moderate positive
	Fulton's K condition	2.5e-05	-1.5e-05	1.0e-04	no association
	Adult distribution	0.35	-3.8e-01	1.07	no association
Murrumbidgee	Spawning occurrence	7.6e-03	-5.4e-02	0.06	no association
	Adult abundance	0.02	-1.2e-02	0.05	weak positive
	Fulton's K condition	4.0e-06	-1.2e-05	2.8e-05	no association
	Adult distribution	0.04	-7.2e-02	0.16	no association
Murray cod					
Edward-Wakool	Recruit abundance	0.10	-7.4e-02	0.27	weak positive
	Adult abundance	0.08	4.5e-03	0.16	strong positive
	Fulton's K condition	-1.4e-06	-1.7e-05	1.4e-05	no association
	Adult distribution	0.21	-3.1e-02	0.46	moderate positive
Goulburn	Recruit abundance	0.97	0.12	1.80	strong positive
	Adult abundance	0.45	0.14	0.74	strong positive
	Fulton's K condition	3.1e-05	-1.7e-05	9.7e-05	weak positive
	Adult distribution	1.10	-6.7e-02	2.31	moderate positive
Gwydir	Recruit abundance	-1.2e-01	-1.6e-01	-6.8e-02	strong negative
	Adult abundance	-2.0e-02	-3.2e-02	-6.1e-03	strong negative

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
	Fulton's K condition	7.8e-06	-1.9e-06	4.4e-05	moderate positive
	Adult distribution	-4.5e-02	-9.6e-02	0.01	moderate negative
Lachlan	Recruit abundance	-2.1e-02	-6.6e-02	0.02	no association
	Adult abundance	0.02	8.4e-05	0.04	moderate positive
	Fulton's K condition	4.8e-06	-1.9e-05	6.0e-05	no association
	Adult distribution	0.03	-3.5e-02	0.09	no association
Lower Murray	Recruit abundance	0.48	-1.3e-02	0.99	moderate positive
	Adult abundance	0.27	0.07	0.45	strong positive
	Fulton's K condition	3.1e-05	-2.4e-06	8.5e-05	weak positive
	Adult distribution	0.66	-5.5e-02	1.38	moderate positive
Murrumbidgee	Recruit abundance	0.04	-4.6e-02	0.12	no association
	Adult abundance	0.05	1.0e-02	0.08	strong positive
	Fulton's K condition	7.5e-06	-4.2e-06	2.5e-05	no association
	Adult distribution	0.10	-2.5e-02	0.21	moderate positive
Murray-Darling rainbowfish					
Edward-Wakool	Recruit abundance	0.26	6.5e-03	0.52	strong positive
	Adult distribution	0.34	0.07	0.61	strong positive
Goulburn	Recruit abundance	1.98	0.81	3.16	strong positive
	Adult distribution	2.18	0.87	3.49	strong positive
Gwydir	Recruit abundance	-1.4e-01	-2.1e-01	-7.7e-02	strong negative
	Adult distribution	-1.5e-01	-2.3e-01	-7.5e-02	strong negative
Lachlan	Recruit abundance	0.01	-5.2e-02	0.08	no association
	Adult distribution	0.03	-4.0e-02	0.10	no association
Lower Murray	Recruit abundance	1.04	0.31	1.75	strong positive
	Adult distribution	1.20	0.44	2.02	strong positive
Murrumbidgee	Recruit abundance	0.12	-5.1e-03	0.24	moderate positive
	Adult distribution	0.13	6.7e-03	0.27	moderate positive
Silver perch					
Edward-Wakool	Spawning occurrence	-3.7e-02	-8.3e-02	0.01	moderate negative
Goulburn	Spawning occurrence	-2.9e-01	-6.5e-01	0.13	moderate negative
	Spawning occurrence	-2.9e-01	-6.5e-01	0.13	weak negative
Lachlan	Spawning occurrence	-1.2e-01	-2.7e-01	0.05	moderate negative
Lower Murray	Spawning occurrence	-1.4e-01	-3.5e-01	0.09	weak negative
Murrumbidgee	Spawning occurrence	-7.6e-02	-1.8e-01	0.03	weak negative
Community compositional metric					
Edward-Wakool		2.7e-03	-3.2e-03	8.3e-03	no association
Goulburn		0.02	-9.5e-03	0.04	weak positive

Species/Selected Area	Response	Commonwealth environmental water			Category
		Effect	Lower	Upper	
Gwydir		-1.1e-03	-2.9e-03	3.2e-04	weak negative
Lachlan		2.0e-04	-1.5e-03	1.9e-03	no association
Lower Murray		0.01	-6.4e-03	0.03	weak positive
Murrumbidgee		1.5e-03	-1.5e-03	4.7e-03	no association

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