Southeast Queensland estuarine fish surveys and reporting 2023

January 2024 Report to Healthy Land and Water

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January 2024

Executive summary

Coastal seascapes comprise a diversity of complex habitats that support fish species of significant cultural, economic and ecological significance. The importance of these seascapes leads to an increasing desire to better protect and/or enhance these ecosystems. Ongoing monitoring that tracks the functioning and health of ecosystems and the landscapes in which they sit are therefore crucial to optimising coastal management. Monitoring of these diverse and changing systems requires specific indicators that effectively identify links between the changes in physical metrics and the ecology of ecosystems. This has, in many settings, led to an increased desire for the use fish assemblages as indicators of ecosystem health within coastal seascapes.

Understanding the drivers of fish distributions is often a priority for stakeholders due to their significance for biodiversity and local fisheries, and their importance in maintaining the ecological functioning of estuaries. Despite this, quantitative descriptions of fish assemblage patterns in space and time are unclear in many settings. Similarly, it has been previously highlighted that incorporating fish assemblages into long-term monitoring program can potentially be challenging and inconsistent due to this lack of understanding. Given these challenges, Healthy land and Water and University of the Sunshine Coast collaborated on a three-year project from 2020-2023 to quantify and benchmark patterns in key fish indicators across southeast Queensland's estuaries. This resulted in a framework designed to incorporate estuarine fish assemblage metrics into the Healthy Land and Water Ecosystem Health Monitoring Program and associated Report Card. This report details the results of estuarine fish monitoring in southeast Queensland for 2023 (i.e. the first full round of monitoring after the benchmarking period), and uses the same approaches and models developed during the initial three-year project, thereby ensuring consistency in survey and grading approaches. Given this, the objectives of the 2023 round of sampling are to:

1. To quantify fish assemblages in 13 estuaries in southeast Queensland in 2024.

2. To ascertain consistency in the approaches established in Gilby et al. (Under review) again in 2024, thereby ensuring the efficacy of the approach and it's robustness for the potential 2024 rollout of the program.

Estuarine fish monitoring in southeast Queensland now represents a significant body of work, with four years of surveys comprised of up to ten replicates of six estuarine habitats (seagrass, mangroves, saltmarsh, unvegetated muds and sands, rocky outcrops and log snags) throughout 13 estuaries for n = 2440 sites in total and 628 sites in 2023. At each site, a 30 minute underwater camera deployment recorded fish assemblages within that habitat, resulting in a total of 1220 hours of video footage being collected and analysed across all years, and 314 hours for 2023. We used the *MaxN* statistic to quantify fish assemblages from this footage, and then calculated fish species richness, quantified as the maximum number of individual species observed in any single video frame. We used six indicator metrics including fish species richness and the abundance of five indicator species whose abundance differed significantly between years, habitats and estuaries; yellowfin bream *Acanthopagrus australis*, sea mullet *Mugil cephalus*, estuary perchlet *Ambassis marianus*, luderick *Girella tricuspidata* and Moses perch *Lutjanus russelli*. These selected indicators were modelled spatially using generalised additive models (GAMs). Individual estuaries were scored according to the percentage of sites that achieved above the predicted values predicted by GAMs.

Average percentage agreement value across all estuaries was 30.9%, increasing the average percentage agreement value by 14.5% from 2022 values. Albert River and Logan River were the only two estuaries to not improve on last years values (scoring 0% and 3.6%, down from 5.2% and 4.1%, respectively). Conversely, Maroochy River, Mooloolah River, Noosa River and Tallebudgera Creek more than doubled their percentage agreement values compared to the 2022 values (scoring 48.7%, 43.4%, 46.9% and 63.0%, up from 23.5%, 7.6%, 18.7% and 23.9%, respectively). Overall, Tallebudgera Creek scored the highest percentage agreement score in 2023, achieving 63.0%, followed by Maroochy River (48.7%) and Nerang River (47.2%). Three species accounted for 69.6% of the total fish abundance; estuary perchlet, yellowfin bream and sea mullet, with all three of these species being consistently found in the top 10 species identified across all years of survey so far.

Based on these findings, we have identified key conclusions for this year's monitoring as well as recommendations for future study;

- The methods established during the benchmarking period remain strong for monitoring estuarine fish in Southeast Queensland, with models being robust to the environmental condition changes detected in 2023.
- 11 out of 13 estuaries have shown signficant recovery since the region-wide flooding in 2022, with six estuaries achieving the highest percentage agreement scores in 2023 across all years of survey; Maroochy (48.7%), Nerang (47.2%), Noosa (46.9%) Pine (26.0%), Pumicestone (25.7%) and Tallebudgera (63.0%).
- Given these patterns, and exciting recovery of estuarine fish following region-wide flooding in 2022, we reccomend continuing the monitoring methodology and framework as described.

Introduction

Fish hold high cultural, ecological and economic importance throughout the southeast Queensland region, (Barker and Ross 2003; Teixeira et al. 2021; Whitfield et al. 2022). Fish support important ecological functions (e.g. herbivory and scavenging), and are significant economically due to many species being of high commercial and recreational value (Webley et al. 2015). For example, luderick *Girella tricuspidata* and black rabbitfish *Siganus fuscescens* are important herbivores that remove algae from light sensitive habitat (such as seagrass) (Henderson et al. 2019) ensuring adequate sunlight for sufficient growth of benthic plants. Piscivores such as Moses perch *Lutjanus russellii* help to maintain ecosystem health and resilience by removing carrion, thereby assisting in maintaining a more consistent water quality (Olds et al. 2018; Porter and Scanes 2015). Southeast Queensland experiences some of the highest rates of recreational and commercial fishing activities throughout Queensland (Teixeira et al. 2021; Webley et al. 2015). Species such as yellowfin bream *Acanthopagrus australis* and sand whiting *Sillago ciliata* are consistently among the most targeted species by recreational fishers (Teixeira et al. 2021). The importance of these species dictates that disentangling the drivers of their distributions is crucial to prioritising coastal management efforts such as restoration, conservation or fisheries management. Previous research has found that fish movements respond to a variety of changes within estuarine ecosystems including changes in water quality, catchment land use modifications and in-stream habitat condition and extent. However, these findings are often the outcomes from small-scale sampling or once off sampling events (Costa et al. 2018; Henderson et al. 2020). Transitioning short-term projects into ongoing long-term monitoring programs allows for distributions of these important species to be tracked alongside biophysical and ecological changes in ecosystems.

Collaboration between Healthy Land and Water (HLW) and University of the Sunshine Coast (UniSC) has resulted in large-scale monitoring of estuarine fish assemblages throughout southeast Queensland to better identify links between changes in physical metrics and the ecology of these ecosystems. This collaboration resulted in the inclusion of estuarine fish assemblage metrics as new indicators in the Ecosystem Health Monitoring Program (EHMP) from 2022, with the broad aim of providing crucial information on what actions can be taken to protect, manage and restore habitats that will support estuarine fish communities. This project has now been running for four years, including a three year benchmarking period between 2020 and 2022, and now a one year survey to commence ongoing monitoring in 2023. This four-year survey period has resulted in over 1200 hours of footage from 2440 replicates which has resulted in a significantly robust dataset. Although previous research has identified significant challenges and inconsistencies when incorporating fish assemblages into long-term monitoring programs (Desmond et al. 2002; Raposa et al. 2003), we found previously that the development of robust methodologies within the benchmarking period is crucial to optimising potential long-term monitoring plans. The data collected throughout the benchmarking period was crucial in extracting meaningful temporal and spatial patterns in estuarine fish assemblages that can now be used to help managers and stakeholders to create and maintain ongoing monitoring frameworks for estuarine and coastal fish assemblages in southeast Queensland (Gilby et al. Under review).

Identifying important, abundant and consistent indicators that can be used to monitor changes to the biophysical and ecology of ecosystems in ongoing long-term monitoring is essential to the success of the monitoring program (Margules and Pressey 2000). Collaborative approaches between HLW and UniSC have established robust methodology over several years of research to quantitatively assign system-specific grades based off annual estuarine fish assemblages surveys. Due to the success of the procedures used throughout the benchmarking period, these grades have been incorporated into the EHMP. For this report, we survey fish assemblages within 13 estuaries and six different coastal ecosystems (seagrass, mangroves, saltmarsh, unvegetated muds and sands, rocky outcrops and log snags) throughout southeast Queensland and grade them using the ‘percentage agreement approach’ established in Gilby et al. (Under review), thereby ensuring the efficacy of the approach and its robustness for ongoing monitoring.

Methods

Study region and estuaries

Fish assemblages were quantified in 13 estuaries along 220 km of coastline in southeast Queensland (Figure 1, Table 1). Southeast Queensland is an ideal region to test for how fish assemblages are influenced by variations in environmental conditions because estuaries in this region varies significantly both within and between estuaries in natural remnant land (e.g. mangrove, seagrass and saltmarsh) and levels of urbanisation (Figure 1). These variations in environmental conditions allows us to effectively test how the area, connectivity and distribution of estuarine habitats structure fish communities throughout Southeast Queensland. Similarly, estuaries within this region have been thoroughly monitored by Healthy Land and Water for several decades (Healthy Land and Water 2023). This monitoring program has collected substantial, robust data on water quality, habitat condition and extent, key animal abundances (including freshwater fish and invertebrates) and socio-economic considerations for all estuaries and their catchments, freshwater bodies and coastal bays within the region. This information is consolidated into an annually-released report card which elicits significant public interest (Healthy Land and Water 2023).

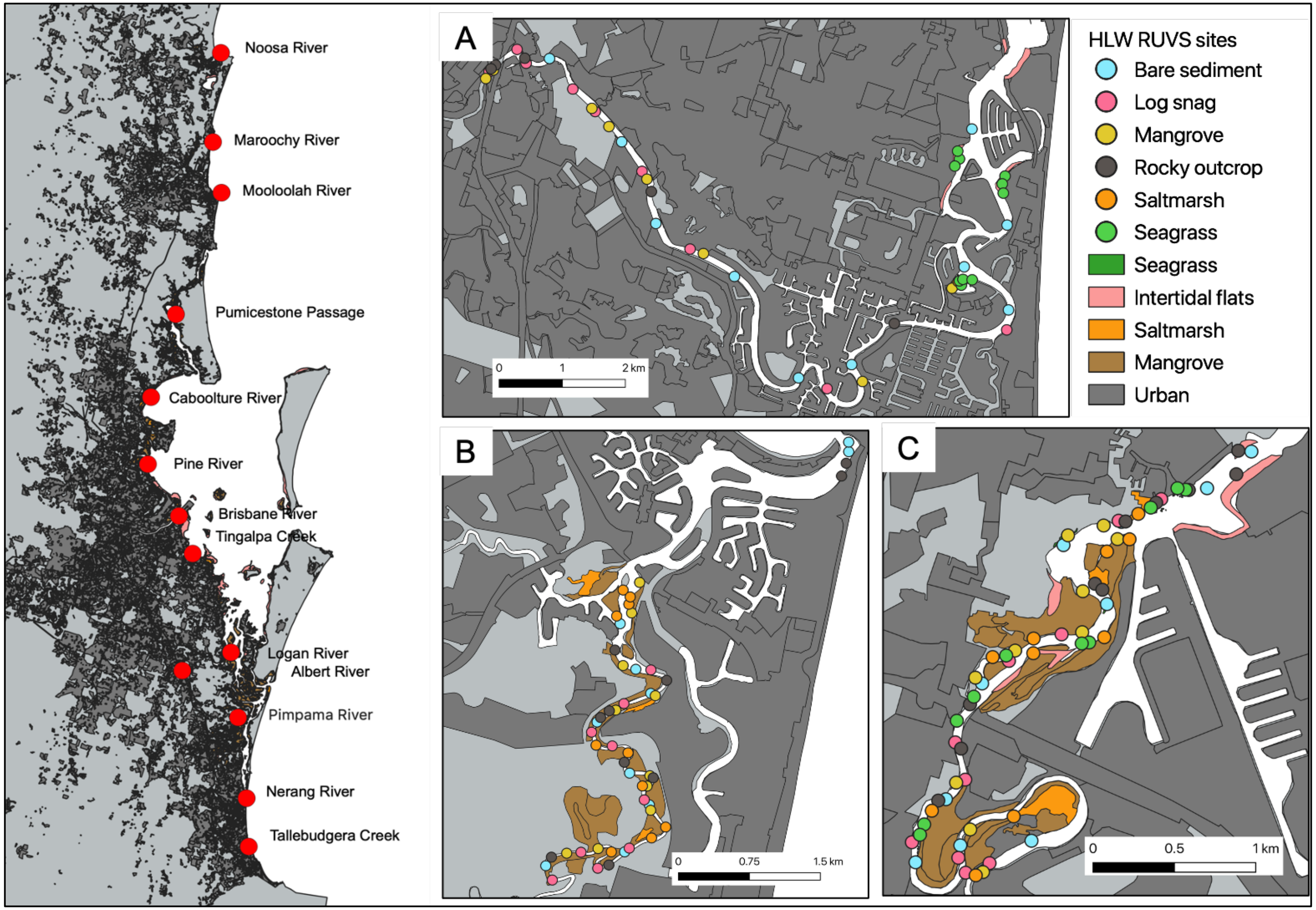

Figure 1 Map of the study region of southeast Queensland and focal estuaries, including example insets of A) Nerang River, B) Mooloolah River and C) Tallebudgera Creek, showing the variations in estuarine ecosystem extent and the distributions of sites throughout the estuaries.

Table 1 List of study estuaries, the local council and HLW report card region in which they are located, and the approximate maximum distance to be surveyed upstream. # distance from the estuary mouth to the upstream tidal limit. *distance surveyed in Pumicestone Passage is the full north-south length of the Passage, and not an upstream distance.

Estuary	Council	HLW Report Card Region	Upstream survey distance #
Albert River	Logan City Council	Albert	16 km
Brisbane River	Brisbane City Council	Brisbane	77 km
Caboolture River	Moreton Bay Regional Council	Caboolture	20 km
Logan River	Logan City Council	Logan	31 km
Maroochy River	Sunshine Coast Council	Maroochy	20 km
Mooloolah River	Sunshine Coast Council	Mooloolah	9 km
Nerang River	Gold Coast City Council	Nerang	19 km
Noosa River	Noosa Shire Council	Noosa	27 km
Pimpama River	Gold Coast City Council	Pimpama-Coomera	16 km
Pine River	Moreton Bay Regional Council	Pine	11 km
Pumicestone Passage	Sunshine Coast Council/Moreton Bay Regional Council	Pumicestone Catchment	34 km*
Tallebudgera Creek	Gold Coast City Council	Tallebudgera-Currumbin	7 km
Tingalpa Creek	Redland City Council	Redland	13 km

Following the methods used in previous years of surveys, six key coastal ecosystems were chosen as focal habitats for this study; mangrove forests, seagrass meadows, salt marsh, rocky outcrops, log snags, and unvegetated muds and sands. We used the same sites as previous years of survey wherever possible, with up to ten sites of each ecosystem chosen in each estuary where the distribution of the ecosystem permits (Figure 1). If the site was no longer present (e.g. seagrass distributions vary year to year or log snags may be washed away due to increased water flow), another site was selected in a similar seascape position to ensure 10 consistent replicates were surveyed. Sites were positioned a minimum of 50 m apart to allow for greater spatial independence between sites. This rule determined the number of replicates of some ecosystems in some estuaries. For example, in a hypothetical estuary where only a single, small (<50 m long) patch of seagrass is present, then only one site could be surveyed in this estuary. The sites were positioned along the full estuarine gradient from the mouth of the estuary to the upstream limit of tidal influence. This distance varied between estuaries, ranging from 7 km in the shortest estuary (Tallebudgera Creek) to

77 km in the longest estuary (Brisbane River) (Table 1). Similarly, this distance aligns with the most upstream estuarine survey points in the ecosystem health monitoring program thereby allowing water quality data to support estuarine fish assemblages surveys (Healthy Land and Water 2023).

Fish assemblage surveys

We used 30 min deployments of remote underwater video stations (RUVS) to survey fish assemblages at each site. RUVS are constructed of a GoPro camera recording in high definition (1080p), fixed to a weight and buoyed at the surface for retrieval and to ensure the rope does not enter the video's field of view during recording. The use of unbaited cameras are preferred for this study over baited camera techniques to avoid the confounding effects of bait drawing fishes from other habitats. Such approaches are increasingly used for the study of fishes and fish-habitat associations in coastal ecosystems (see Bradley et al. 2017; Sheaves et al. 2016). RUVs placed in structured (i.e. rocky outcrops, log snags) and vegetated habitats (i.e. mangrove forests and seagrass meadows) were positioned obliquely along the edge of the habitat, thereby recording fish moving in and out of the habitat and preventing the habitat itself (e.g. mangrove pneumatophores, seagrass blades) from obscuring the camera field of view.

RUVS were deployed from the mouth of the estuary to the most upstream EHMP estuarine point. These deployments were conducted in the timeframe 2 hrs either side of high tide, maximising water quality and ensuring intertidal habitats are inundated. Up to 12 RUVS were deployed at any given time (following the incoming tide) ensuring neighbouring sites were predominantly surveyed within the same 30 minute time frame. This minimised the likelihood that the same fish may be counted across two RUVS, and further enhanced spatial independence between sites. All surveys were conducted in the austral winter and spring in 2023. This period was selected to coincide with periods of maximum water clarity within the region, and to avoid times when significant rainfall in the surrounding catchment might become the overwhelming driver of fish distributions. Overall, 628 sites surveyed in 2023, aligning closely with previous years (Table 2).

Fish assemblages were quantified from videos using the standard *MaxN* metric; the maximum number of any species observed in any single video frame. *MaxN* therefore ensures individuals are not counted more than once at each site and is considered a conservative index of relative abundance (Stobart et al., 2015). From here, fish species richness was calculated by counting the number of unique species at each site.

Table 2 The number of sites within each ecosystem within each of the study estuaries that were surveyed and included in the last 4 years of reporting (2020 – 2023).

Estuary	**Unvegetated muds and sands**				**Log snags**				**Mangroves**				**Rocky structures**				**Saltmarsh**				**Seagrass**				
	2020	*2021*	*2022*	*2023*	*2020*	*2021*	*2022*	*2023*	*2020*	*2021*	*2022*	*2023*	*2020*	*2021*	*2022*	*2023*	*2020*	*2021*	*2022*	*2023*	*2020*	*2021*	*2022*	*2023*	**Total**
Albert River	10	10	10	10	10	9	9	10	10	9	9	10	3	3	2	3	1	1	1	1					131
Brisbane River	8	8	8	8	10	9	6	10	10	10	8	10	10	10	7	10	2	2	1	2					149
Caboolture River	10	9	8	10	10	10	8	10	10	9	9	10	2	2	2	2	10	9	9	10					159
Logan River	10	9	10	10	10	8	8	10	10	7	8	10	10	8	9	10	10	10	10	10					187
Maroochy River	10	10	10	10	10	10	10	10	10	10	10	10	1	1	1	1	10	10	10	10	6	5	6	6	187
Mooloolah River	10	10	10	10	9	9	10	9	10	10	10	10	10	10	10	10	10	10	10	10					197
Nerang River	10	10	9	10	10	10	9	10	9	9	9	9	5	5	5	5	1	1	1	1	10	10	10	10	178
Noosa River	10	10	10	10	9	9	9	9	10	10	10	10	10	10	9	10	10	10	10	10	10	11	8	10	234
Pimpama River	10	9	9	10	10	10	6	10	10	10	10	10	3	3	3	3	10	10	7	10	5	5	5	5	183
Pine River	10	10	10	10	10	10	10	10	10	10	10	10	7	6	7	7	10	10	11	10	2	1	1	2	194
Pumicestone Passage	10	7	10	10	10	10	10	10	10	10	10	10	10	9	10	10	10	8	9	10	10	10	9	10	232
Tallebudgera Creek	10	10	10	10	10	10	10	10	10	10	10	10	10	8	9	10	10	9	10	10	10	10	8	10	234
Tingalpa Creek	10	9	10	10	9	8	9	9	10	9	10	10	6	5	6	6	10	10	9	10					175
Total	128	121	124	128	127	122	114	127	129	123	123	129	87	80	80	87	104	100	98	104	53	52	47	53	2440

Environmental variables

Previous surveys of coastal and estuarine fish in Southeast Queensland have highlighted the importance of several landscape features that are consistently found to support abundant and diverse estuarine fish assemblages (Gilby et al. 2018a; Goodridge Gaines et al. 2022; Henderson et al. 2021). Consequently, we included a suite of environmental variables quantifying the proximity to and area of vegetated estuarine habitats and urban structures, as well as the proximity to the estuary mouth (Table 3A). We used QGIS to quantify the spatial variables within this study and chose to quantify area of these variables using 500m buffers (QGIS Development Team 2022b). This buffer size was chosen due to previous studies in the region finding consistent effects of these buffer distances in explaining fish distributions and assemblages (Gilby et al. 2018b; Gilby et al. 2017; Olds et al. 2012). Similarly, this distance relates most closely to the likely maximum range of most species in our assemblage over a single tidal cycle within this region.

We included a suite of water quality metrics including chlorophyll-a concentration, dissolved oxygen and turbidity in our analysis (Table 3B). These values were derived from the EHMP where water quality data for each system is quantified in standardised monthly surveys, and combines these values into annual medians for the report card. For this study, both the annual median values and the average across the three and six months prior to the surveys being conducted were used within the analysis for each of the years the survey was conducted. We incorporated a range of values that quantify water quality values over different time frames to look at whether fish are being significantly driven by long- and short-term changes to in stream water quality. Because sampling points for water quality monitoring did not precisely match fish sampling sites, water quality values were interpolated across estuaries using inverse distance weighting (IDW) interpolations in QGIS (QGIS Development Team 2022b).

Table 3 List of environmental variables used for analyses, their definitions and data sources. Seagrass area was not considered as very few sites had any seagrass within 500m of them. Nitrogen and phosphorous concentrations were not considered as they typically correlate strongly with turbidity and ChlA concentration, and fish do not respond directly to them. No variables included in final models correlated greater than r=0.578. * indicates variables that were included in the final model.

Variable	**Data source and definition**	**Covariance**
A- Seascape variables		
Distance to estuary mouth*	The distance (in m) of each site to the centre of channel at the estuary mouth, as a fish would swim. Calculated using NearMap (NearMap 2022) aerial imagery in QGIS (QGIS Development Team 2022a).	
Distance to* and area of* mangroves	The distance to (in m) and area of (in m^2, within a 500 m buffer) mangroves at each site. Mangrove mapping layers sources from the Queensland Government (2022).	
Distance to and area of saltmarsh	The distance to (in m) and area of (in m^2, within a 500 m buffer) saltmarsh at each site. Saltmarsh mapping layers sources from the Queensland Government (2022).	Both measures correlated strongly (Distance r=0.7, Area r=0.67) with distance to mouth, and so were excluded from analyses.
Distance to and area of seagrass	The distance to (in m) and area of (in m^2, within a 500 m buffer) seagrass at each site. Seagrass mapping layers created using NearMap (NearMap 2022) aerial imagery in QGIS (QGIS Development Team 2022a) and then ground truthed (per Goodridge Gaines et al. 2022).	Both measures correlated strongly (Distance r=0.8, Area r=0.963) with distance to mouth, and so were excluded from analyses.
B- Water quality variables		
Chlorophyl A (ChlA) concentration at sampling and for the previous 12 months*	The concentration of ChlA at each site from a local water quality monitoring program (EHMP 2022). Quantified as the ChlA concentration both 1 month before sampling, and the median values for all of the preceding 12 months, and included separately in models.	ChlA concentrations at sampling and for the previous 12 months corelated strongly (R=0.62), and so values at sampling were removed (as 12 months medians are a key regional monitoring focus).
Turbidity for the previous 12 months*	The turbidity of water at each site, measured in nephelometric turbidity units (NTU) from a local water quality monitoring program (EHMP 2022). Quantified as the median water column turbidity values for all of the preceding 12 months. We did not include the prior month turbidity as we control for this in sampling- if water clarity is low, sampling did not occur.	
Dissolved oxygen saturation at sampling* and for the previous 12 months*	The saturation of dissolved oxygen at each site, measured as a percentage from a local water quality monitoring program (EHMP 2022). Quantified as the dissolved oxygen saturation both 1 month before sampling, and the median values for all of the preceding 12 months, and included separately in models.	

Statistical analysis

Broad patterns across year, estuary and habitat for 2023 surveys

We used multivariate generalised linear models (ManyGLM) in the *mvabund* package (Wang et al. 2012) of R (R Core Team 2024) to quantify fish assemblages from the 2023 sampling round against the main effects of estuary (fixed factor, 13 levels) and habitat (fixed factor, 6 levels). These results were visualised using a non-metric multidimensional scaling ordination plot (nMDS) showing A) dissimilarity of 2023 sites and B) vectors for indicator species identified in the benchmarking period.

Average indicator metrics between estuary, habitat and year

We summarised the average (+/- standard error) species richness of fish and abundance of indicator species per habitat, estuary and year for each estuary in R; indicator species were sea mullet *Mugil cephalus*, estuary perchlet *Ambassis marianus*, yellowfin bream *Acanthopagrus australis*, luderick *Girella tricuspidata* and Moses perch *Lutjanus russellii* .

Grading schemes

We used the percentage agreement approach (as identified in Gilby et al (Under review)) which calculated the percentage of sites within each estuary in each year which achieves observed values above the predicted values. Predicted values for sites were calculated for each indicator species and metric based on the best-fit GAMs identified in Gilby et al (Under review) and using the raw environmental metrics for each 2023 site and the best-fit model for each indicator metric (using predict.gam in mgcv, best fit GAMs detailed in Gilby et al (Under review); see Table 4) (Wood 2022). For example, water quality variables that were included in the best-fit models for each GAM were reprojected using 2023 water quality data, thereby standardising for changes occurring between years for these environmental variables. This process calculates the value that metrics should take, on average, given the environmental conditions at each site. We then calculated the difference between the predicted values (based off the benchmark period) and the observed value (based on the 2023 data) of each metric at each site, with negative numbers indicating values lower than predicted, and positive numbers indicating values higher than predicted.

Table 4 Best fit generalised additive models (GAMs) describing patterns in species richness and the abundance of five indicator species in estuaries across southeast Queensland over the three years benchmarking period. ‘Significant ecosystems’ indicate the ecosystems for which model terms resulted in significant model sites within each best-fit environmental variable. Unlisted ecosystems were therefore not significantly correlated with values for that variable. I= variable importance.

Model	**Species richness**	**Sea mullet**	**Luderick**	**Moses perch**	**Yellowfin bream**	**Estuary perchlet**
Model Adjusted R2	0.34	0.1	0.26	0.3	0.17	0.29
Model R2	0.32	0.26	0.43	0.46	0.31	0.47
Ecosystem	χ^2=120.7, P<0.001	χ^2=13.57, P=0.02	χ^2=11.8, P<0.01	χ^2<0.001, P=1	χ^2=12.1, P<0.001	χ^2=390, P<0.001
Estuary	χ^2=212.17, P<0.001	χ^2=419.7, P<0.001	χ^2=99.7, P<0.001	χ^2=125.9, P<0.001	χ^2=13.1, P<0.001	χ^2=7174, P<0.001
Year	χ^2=195.9, P<0.001	χ^2=267.49, P<0.001	χ^2=16.1, P<0.001	χ^2=7.6, P<0.001	χ^2=31.1, P<0.001	χ^2=1630, P<0.001
Environmental variable	Mangrove area (I=0.55)	Distance to mangroves (I=1)	Distance to estuary mouth (I=0.98)	Distance to mangroves (I=1)	Distance to estuary mouth (I=0.46)	Mangrove area (I=1)
Significant ecosystems	Bare sediment (χ^2=15.9, P<0.001), rocky structures (χ^2=4.48, P=0.04)	Log snags (χ^2=21.9, P<0.001), mangroves (χ^2=128.2, P<0.001), rocky structures (χ^2=10.9, P<0.01), saltmarsh (χ^2=27, P<0.001), seagrass (χ^2=10, P<0.01)	Bare sediment (χ^2=6.6, P<0.01), log snags (χ^2=8.1, P<0.01), rocky structures (χ^2=6.6, P=0.01), seagrass (χ^2=12.1, P<0.01)	Log snags (χ^2=17.7, P<0.001)	Bare sediments (χ^2=8.4, P<0.001)	Log snags (χ^2=32.6, P<0.001), mangroves (χ^2=219.2, P<0.001), rocky structures (χ^2=143.4, P<0.001), saltmarsh (χ^2=685.2, P<0.001), seagrass (χ^2=154.3, P<0.001)

Environmental variable	Turbidity median (I=1)	Mangrove area (I=1)	Mangrove area (I=0.99)	ChlA median (I=0.97)	Turbidity median (I=0.96)	ChlA median (I=1)
Significant ecosystems	Log snags (χ^2=37.1, P<0.001), mangroves (χ^2=17.98, P<0.001), rocky structures (χ^2=9.1, P<0.01), saltmarsh (χ^2=17.74, P<0.001)	Bare sediments (χ^2=43.5, P<0.001), log snags (χ^2=13.9, P<0.01), mangroves (χ^2=10.5, P=0.001), rocky structures (χ^2=53.3, P<0.001), saltmarsh (χ^2=17.1, P<0.01)	Bare sediment (χ^2=15.6, P<0.001), log snags (χ^2=6.7, P=0.03), seagrass (χ^2=13.9, P=0.001)	Mangroves (χ^2=6.7, P=0.03), rocky structures (χ^2=9.5, P<0.01)	Bare sediments (χ^2=3.8, P=0.02), log snags (χ^2=15.2, P<0.001)	Log snags (χ^2=116.3, P<0.001), mangroves (χ^2=460.7, P<0.001), saltmarsh (χ^2=983.6, P<0.001), seagrass (χ^2=96.8, P<0.001)
Environmental variable	DO median (I=0.78)	DO median (I=1)	DO median (I=1)	DO median (I=1)	ChlA median (I=0.98)	DO median (I=1)
Significant ecosystems	Bare sediment (χ^2=17.2, P<0.001), mangroves (χ^2=6.5, P=0.01), saltmarsh (χ^2=5.8, P=0.02)	Bare sediments (χ^2=49.8, P<0.001), log snags (χ^2=47, P<0.001), mangroves (χ^2=22.2, P<0.001), rocky structures (χ^2=19.3, P<0.001), saltmarsh (χ^2=19, P<0.001), seagrass (χ^2=, P=0.05)	Bare sediment (χ^2=15.8, P=0.03), seagrass (χ^2=10.1, P<0.01)	Log snags (χ^2=13.4, P<0.001), mangroves (χ^2=11.5, P<0.01), rocky structures (χ^2=6.6, P<0.01)	Log snags (χ^2=6.2, P<0.01), saltmarsh (χ^2=4.4, P=0.03), seagrass (χ^2=4.9, P=0.03)	Log snags (χ^2=89, P<0.001), mangroves (χ^2=875.9, P<0.001), rocky structures (χ^2=25.1, P<0.001), saltmarsh (χ^2=1421.1, P<0.001), seagrass (χ^2=337.7, P<0.001)

Results

Fish assemblages: 2023

We found a significant effect of the interaction between estuary and habitat on the structure of fish assemblages in the estuaries of Southeast Queensland in 2023 (deviance=931, P=0.005) (Figure 2). In 2023, we identified a total of 9343 individual fish from 80 species with 46.5% of these individuals being classed as a harvested species within southeast Queensland (n= 4342). In 2023, sites were found to support an average diversity of 2.3 species, an average abundance of 14.9 individuals and an average harvested fish abundance of 6.9 individuals (Table 5). Seagrass meadows supported the highest fish diversity (3.2), total abundance (21.8) and abundance of harvested species (9.0) (Table 5). The most abundance species identified in 2023 surveys were estuary perchlet, followed by yellowfin bream and sea mullet (Table 5), constituting 41.7%, 16.3% and 11.5% percent of total abundance across all replicates, respectively.

Fish assemblages: 2020 - 2023

Over the four years of surveys from 2020 to 2023, we have identified 36719 individual fish from 103 species, with 41.7% of these individuals being of high commercial and recreational fisheries value (n = 13727). From the 103 species identified throughout the project, seven fish species were consistently found to be among the top ten most abundant species across all years of survey; estuary perchlet, yellowfin bream, southern herring *Herklotsichthys castelnaui,* sea mullet, common hardyhead *Atherinomorus vaigiensis,* common silverbiddy *Gerres subfasciatus* and diamond fish *Monodactylus argenteu)* (Table 6). There were seven species that were identified in the list of top ten most abundant species throughout 2020-2023 that are targeted by recreational and/or commercial fishers; yellowfin bream, southern herring, sea mullet, sand whiting *Sillago ciliata*, Australian sardine *Sardinops sagax*, and luderick. Similarly, two of these species, yellowfin bream and sea mullet, have previously been found to be in the top three most targeted species by recreational fishers in the 2020-2021 Queensland Recreational Fishing Survey (Teixeira et al. 2021).

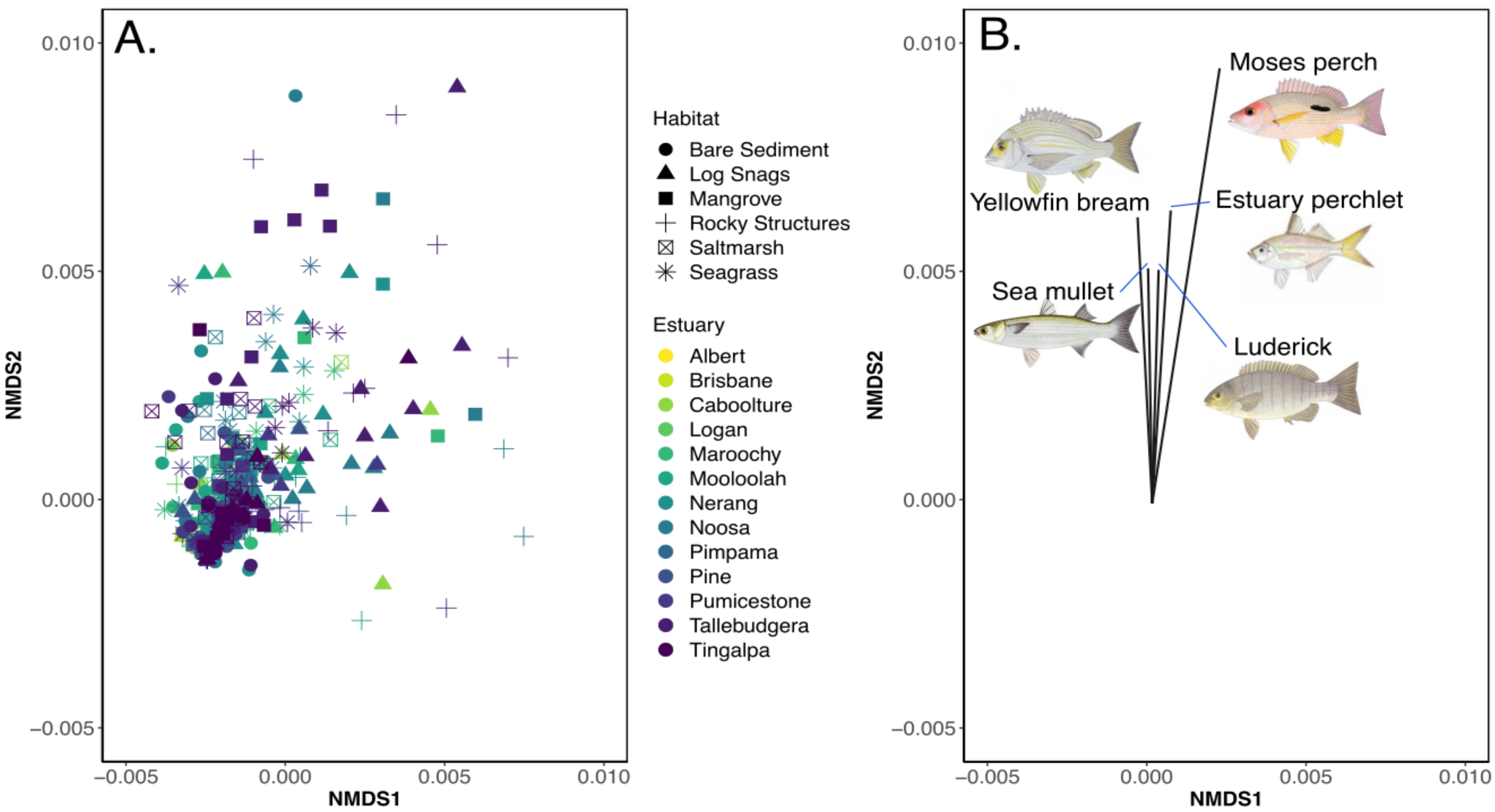

Figure 2 Non-metric multidimensional scaling ordination plot (nMDS) showing A) the 2023 RUVS sites by habitat (symbols) and estuary (colours) and B) the selected indicator species from the previous 3 years of benchmark surveys

Table 5 List of the average species richness, average fish abundance, average harvested fish abundance across the baseline years and the most recent 2023 surveys for all habitats combined as well as individual habitats.

Ecosystem	Average species richness		Average abundance		Average harvested abundance	
	2020-2022	2023	2020-2022	2023	2020-2022	2023
All habitats	1.6	2.3	15.1	14.9	5.2	6.9
Log snag	2.2	2.9	17.7	18.8	7.5	8.9
Mangrove	1.5	2.1	18.4	20.8	4.3	6.8
Rocky outcrop	1.9	2.6	17.3	11.5	5.5	8.1
Saltmarsh	1.6	2.5	16.4	16.1	5.7	7.7
Seagrass	1.9	3.2	20.1	21.8	4.4	9.0
Unvegetated muds and sand	1.0	1.4	4.4	3.4	3.5	2.8

Table 6 List of the most abundant species found (ordered from highest at the top of the table, to 10th at the bottom of the table) in estuarine fish surveys in SEQ between 2020-2023. Bold indicates species used as indicators in the benchmark reporting. * indicates harvested fish species

Benchmarking period			
2020	**2021**	**2022**	**2023**
Ambassis marianus	***Ambassis marianus***	***Ambassis marianus***	***Ambassis marianus***
Acanthopagrus australis*	***Acanthopagrus australis****	***Acanthopagrus australis****	***Acanthopagrus australis****
*Herklotsichthys castelnaui**	*Atherinomorus vaigiensis*	*Retropinna semoni*	***Mugil cephalus****
Mugil cephalus*	*Herklotsichthys castelnaui**	*Atherinomorus vaigiensis*	*Gerres subfasciatus*
Atherinomorus vaigiensis	*Gerres subfasciatus*	***Mugil cephalus****	*Herklotsichthys castelnaui**
Gerres subfasciatus	***Mugil cephalus****	*Gerres subfasciatus*	*Atherinomorus vaigiensis*
Monodactylus argenteus	*Retropinna semoni*	*Herklotsichthys castelnaui**	*Sillago ciliata**
Retropinna semoni	*Monodactylus argenteus*	*Monodactylus argenteus*	*Monodactylus argenteus*
*Sardinops sagax**	*Gobiidae spp*	*Sillago ciliata**	*Gobiidae spp*
*Sillago ciliata**	***Girella tricuspidata****	*Gobiidae spp*	***Girella tricuspidata****

Average indicator metrics between estuary, habitat and year

2023 Albert River results

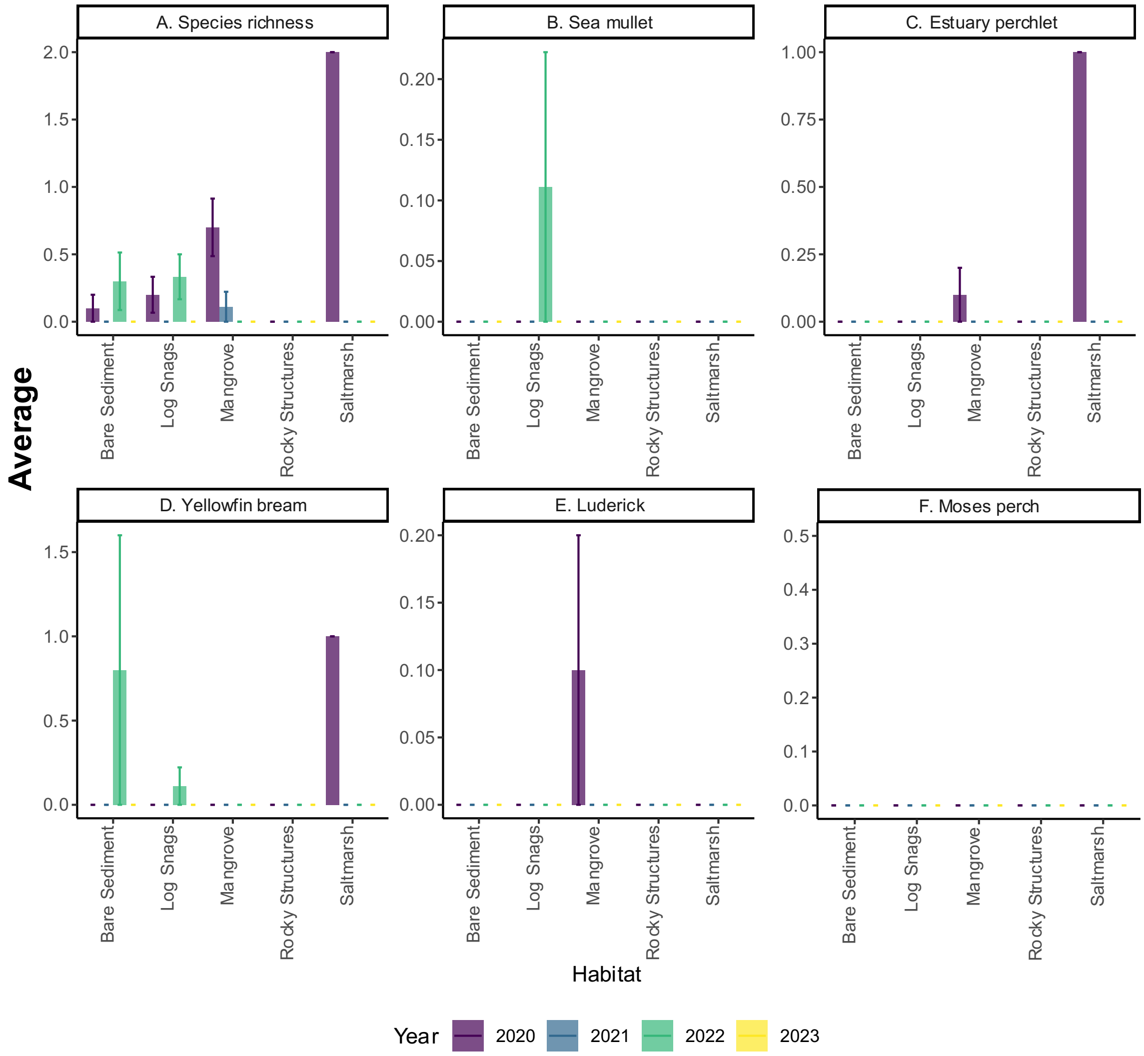

Figure 3 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Albert River per habitat for surveys completed annually between 2020 - 2023.

Albert River had higher average species richness and average estuary perchlet abundance at sites in mangrove and saltmarsh habitats in 2020 (Figure 3). Similarly, the average luderick abundance was higher at sites in mangroves in 2020. In comparison, the average sea mullet and yellowfin bream abundance was higher in 2022 at sites in log snags and bare sediments habitats, respectively. We found very low averages of both species richness and the abundance of indicator species in the 2023 surveys. There were no Moses perch identified in Albert River.

2023 Brisbane River results

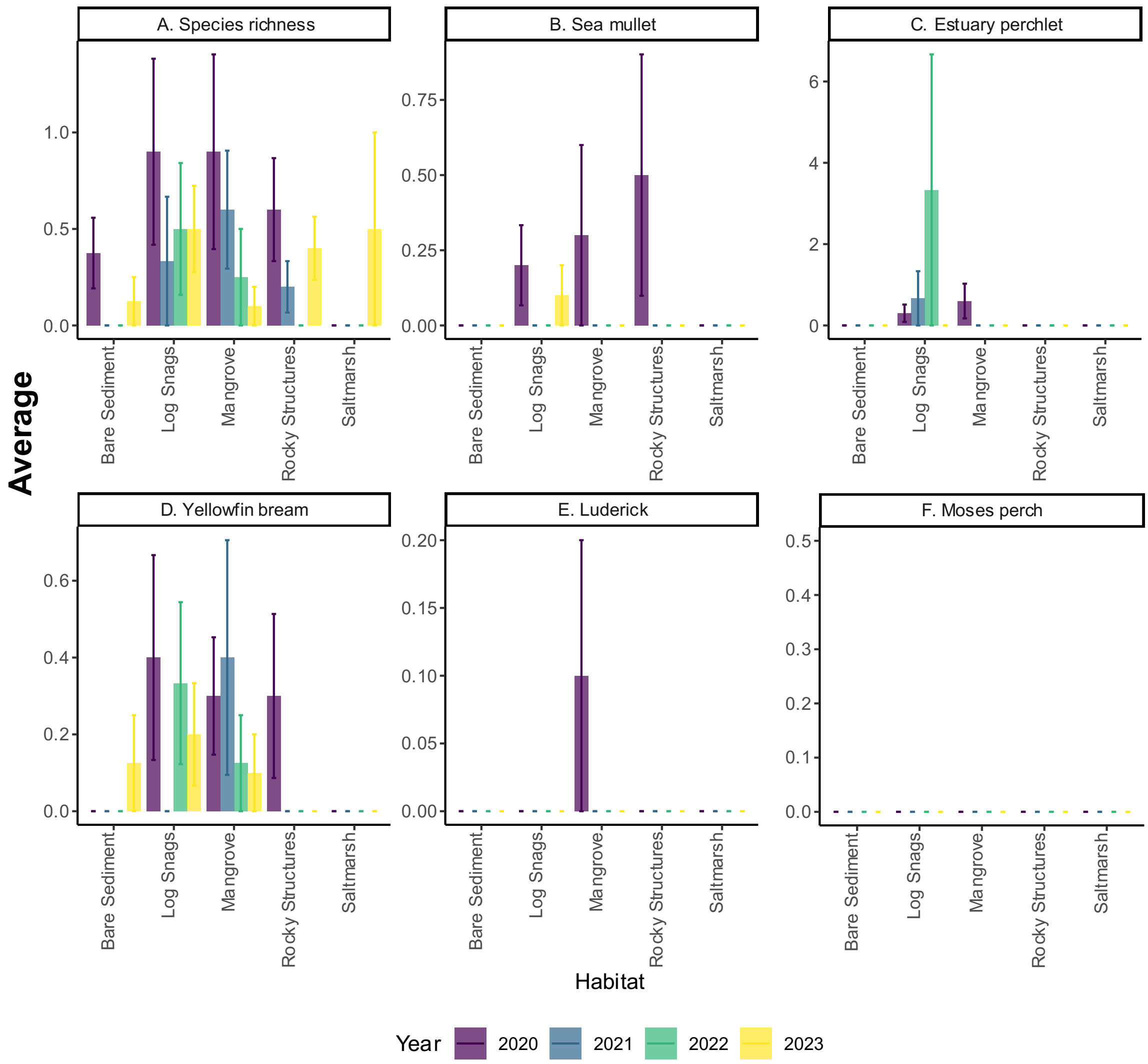

Figure 4 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Brisbane River per habitat for surveys completed annually between 2020 - 2023.

Brisbane River had higher average species richness and abundance of sea mullet, yellowfin bream and luderick throughout 2020, however these results varied between habitat (Figure 4). The average species richness at sites were found to improve after the 2022 floods in some habitats (bare sediment, rocky structures and saltmarsh), however the average species richness still remains lower than the 2020 averages (Figure 4). There were no Moses perch identified in Brisbane River.

2023 Caboolture River results

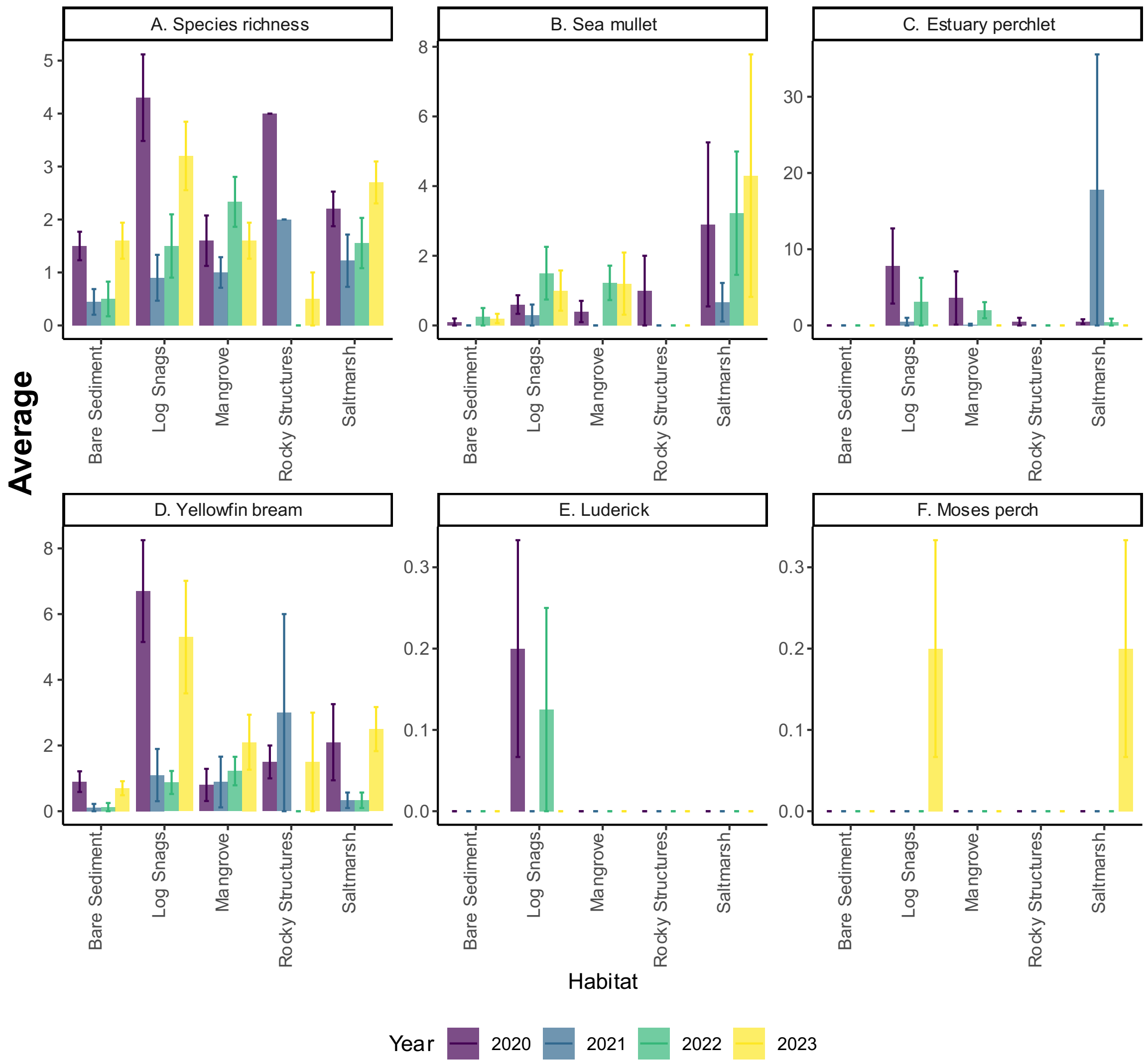

Figure 5 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Caboolture River per habitat for surveys completed annually between 2020 - 2023.s

Caboolture River had higher average species richness at both log snag and rocky structures in 2020, and bare sediment and saltmarsh in 2023 (Figure 5). Saltmarsh consistently supported higher average abundances of sea mullet across all years of survey (Figure 5). Similarly, log snags supported higher average abundances of luderick in 2020 and 2022 and average Moses perch abundance was highest in log snag and saltmarsh habitats in 2023 compared to other habitats (Figure 5).

2023 Logan River results

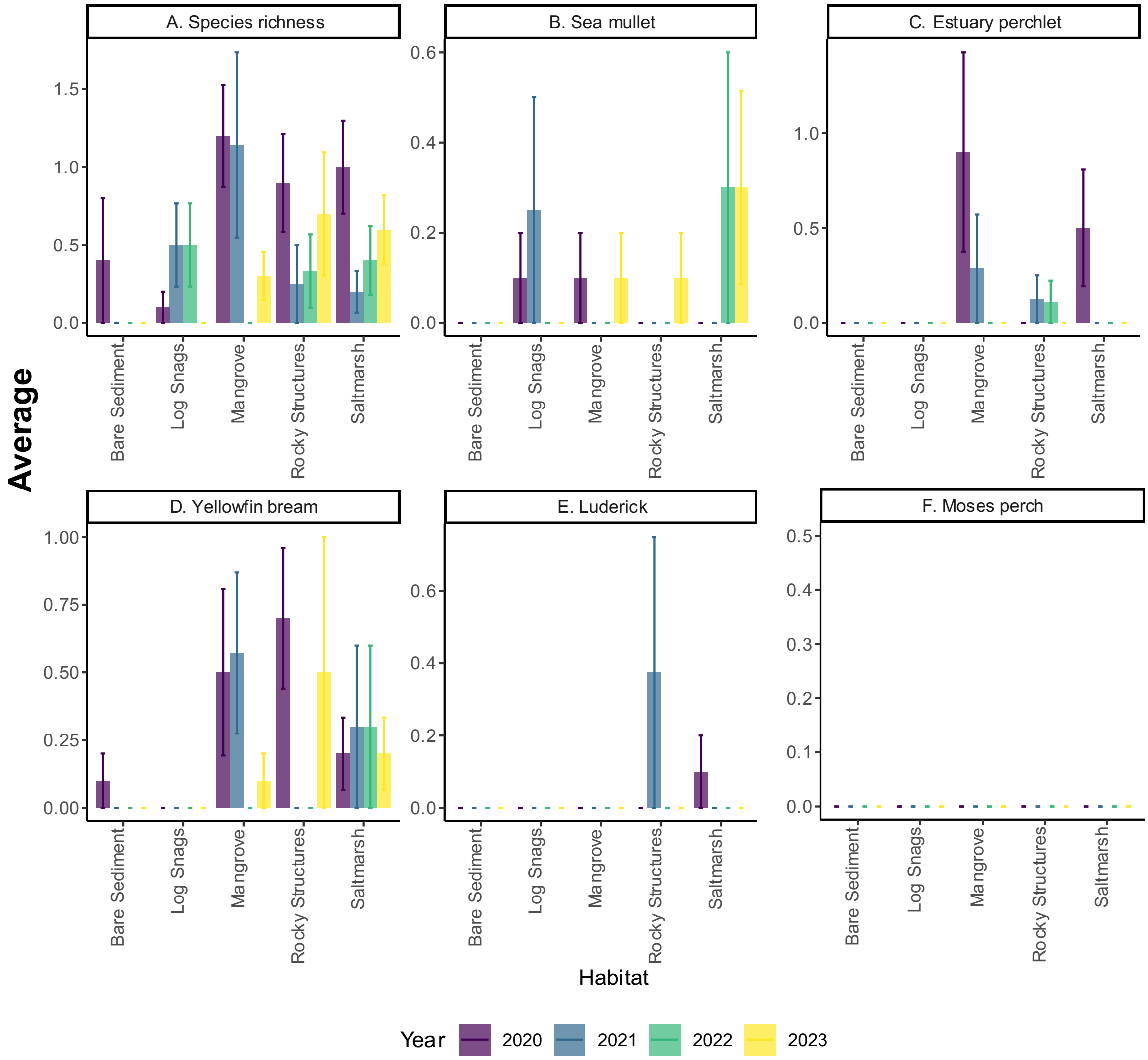

Figure 6 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Logan River per habitat for surveys completed annually between 2020 - 2023.

Logan River had higher average species richness at sites in bare sediment, mangrove, rocky structures and saltmarsh habitats, a higher average abundance of estuary perchlet at sites in mangrove and saltmarsh habitats and a higher average yellowfin bream abundance in rocky structures in 2020 (Figure 6). There were no Moses perch identified in Logan River.

2023 Maroochy River results

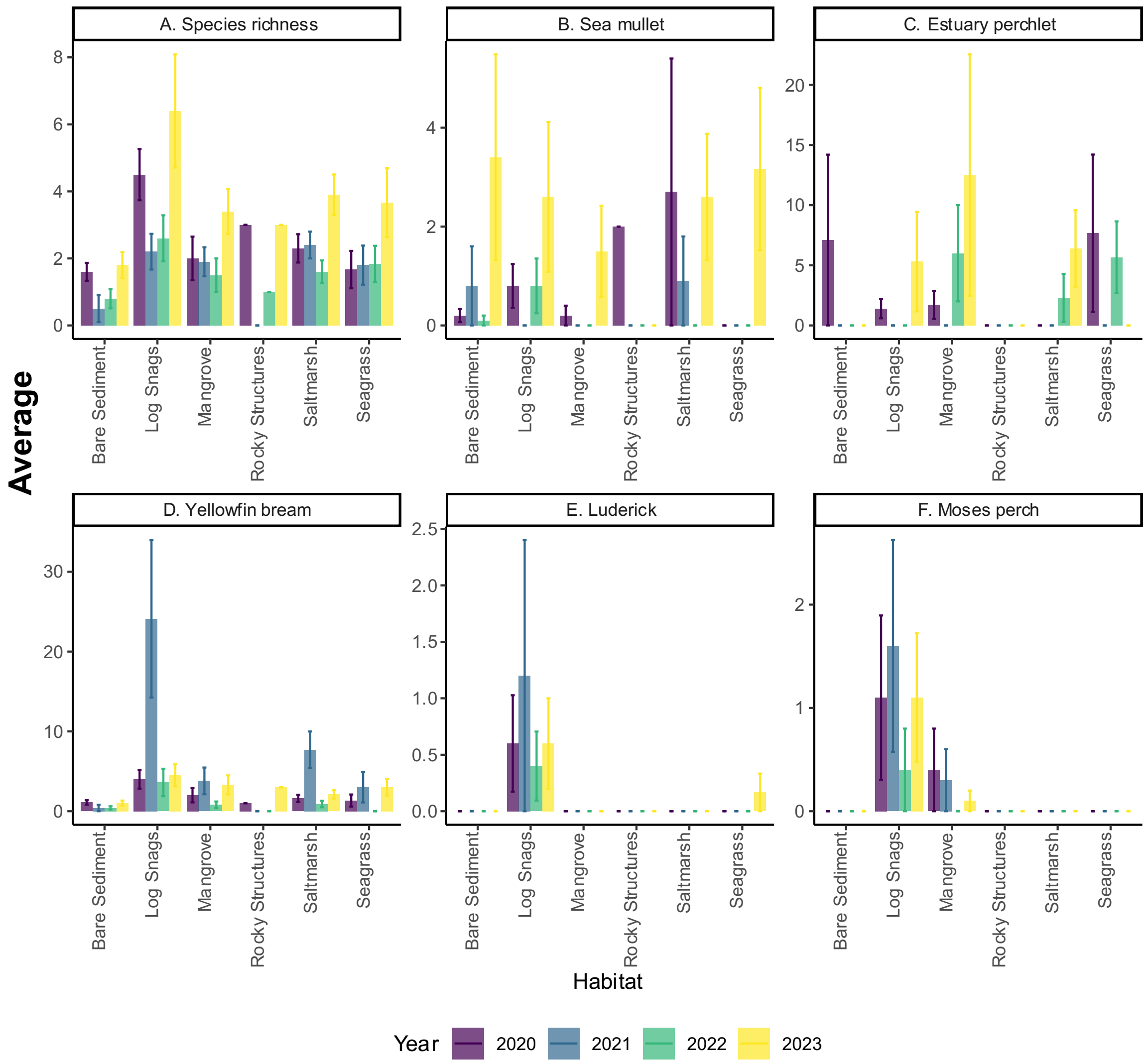

Figure 7 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Maroochy River per habitat for surveys completed annually between 2020 - 2023.

Maroochy River had higher average species richness across sites in all habitats except rocky structures in 2023 (Figure 7). Similarly, the average sea mullet abundance was highest in 2023 within bare sediment, log snag, mangrove and seagrass habitats. The average abundance of yellowfin bream, luderick and Moses perch were higher at sites in log snags habitat in 2021 compared to other habitats across all years of survey (Figure 7). Luderick were only identified in log snag habitats across all years of survey. Similarly, Moses perch were only identified in log snag and mangrove habitats.

2023 Mooloolah River results

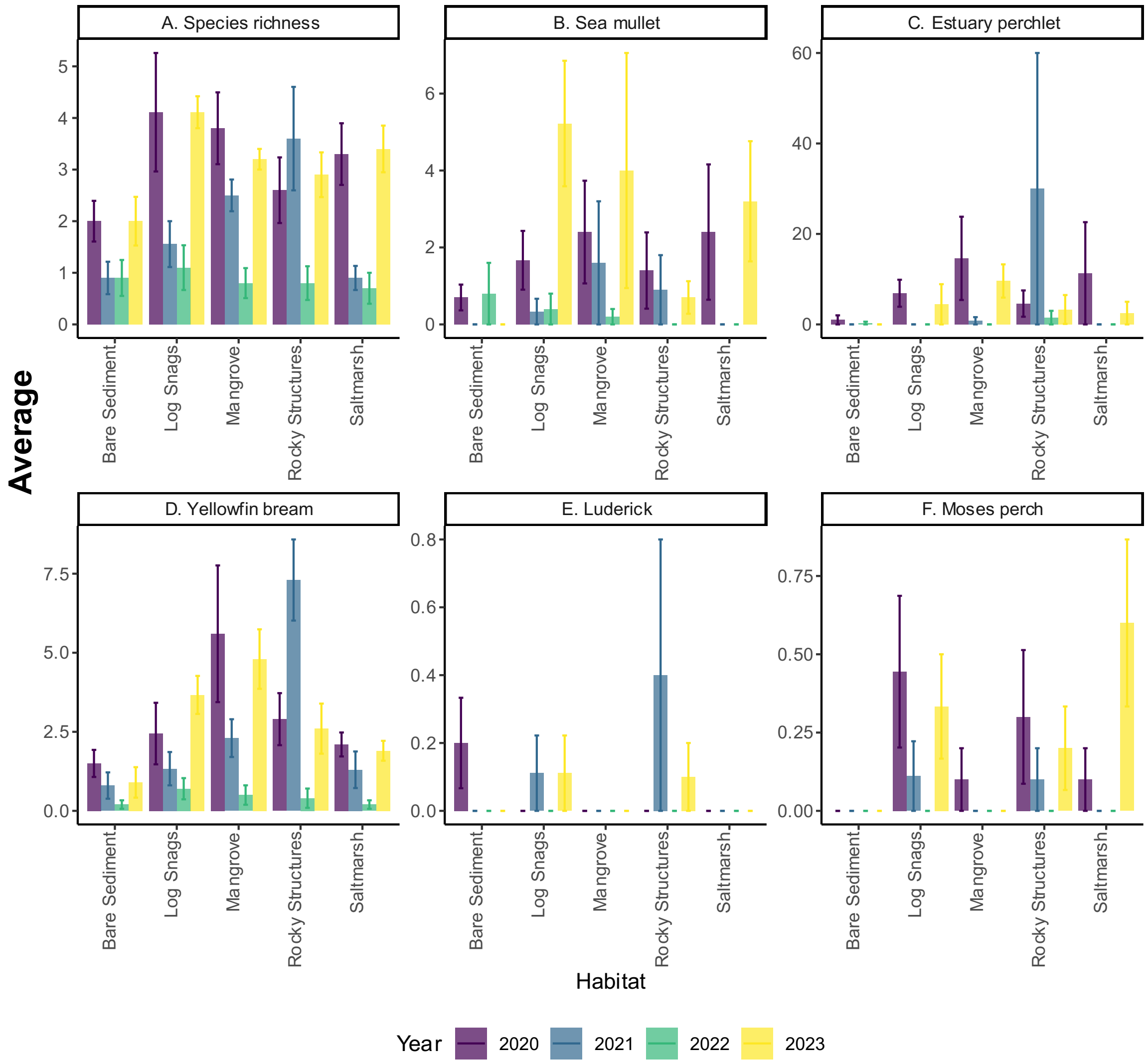

Figure 8 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Mooloolah River per habitat for surveys completed annually between 2020 - 2023.

Mooloolah River had the highest average species richness and average abundance of estuary perchlet and yellowfin bream in years 2020 and 2023 for all habitats excluding rocky structures (highest average species richness and average abundance of estuary perchlet and yellowfin bream were quantified in 2021) (Figure 8). The average abundance of sea mullet was highest in 2023 in log snag, mangrove and saltmarsh habitats, while the average luderick and Moses perch abundance remained consistently low across all habitats and all years (Figure 8).

2023 Nerang River results

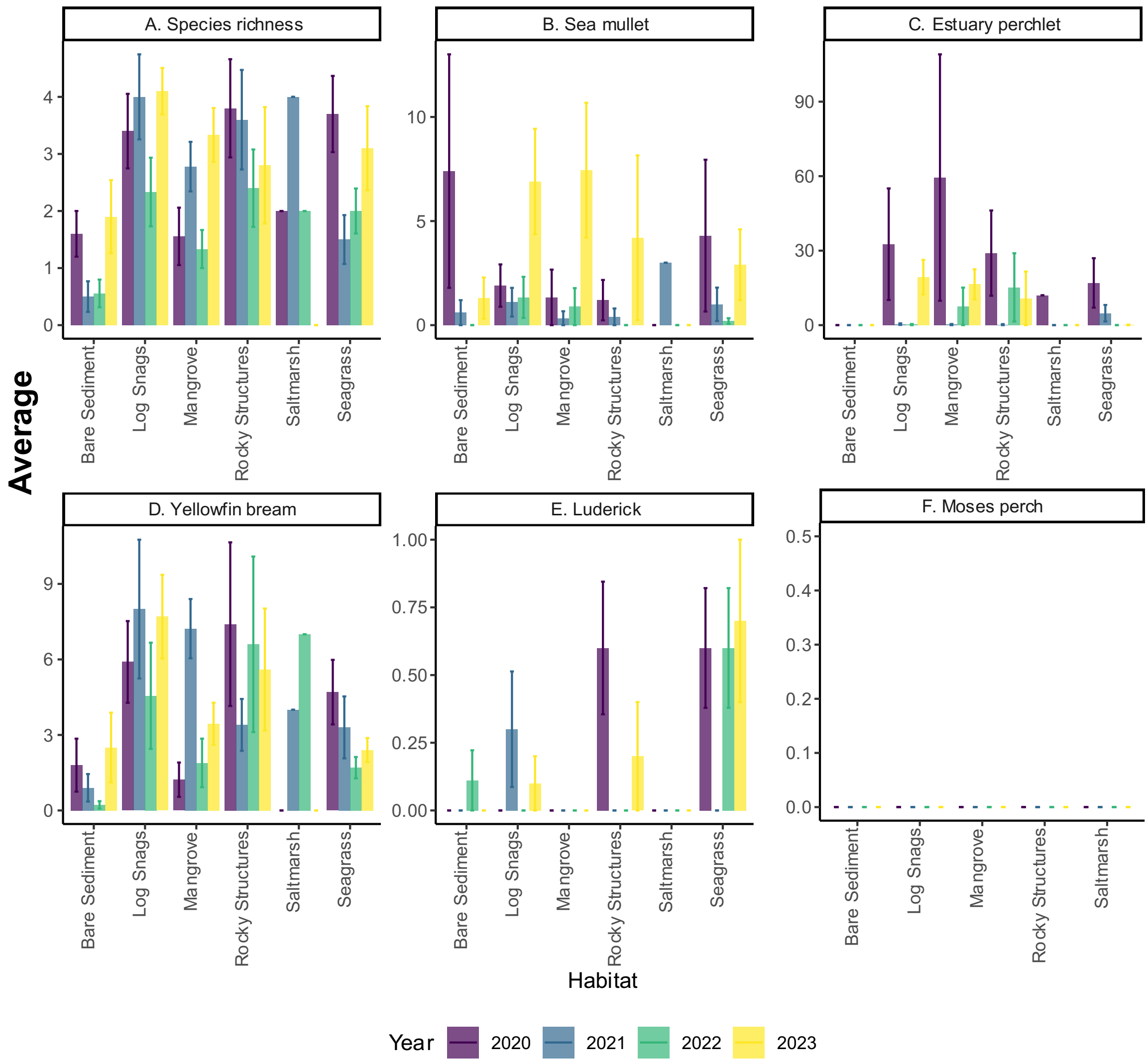

Figure 9 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Nerang River per habitat for surveys completed annually between 2020 - 2023.

Nerang River had varying results between habitat and year for average species richness and average abundance of yellowfin bream (excluding saltmarsh habitats in 2022 which had the highest average abundance of yellowfin bream), however species richness was generally lower in 2022 and in bare sediment habitats (Figure 9). The average sea mullet abundance was generally higher in 2020 and 2023 (again, excluding saltmarsh habitats in 2022), and the average abundance of estuary perchlet was consistently higher in 2020 for all habitat aside for bare sediment. There were no Moses perch identified in Nerang River.

2023 Noosa River results

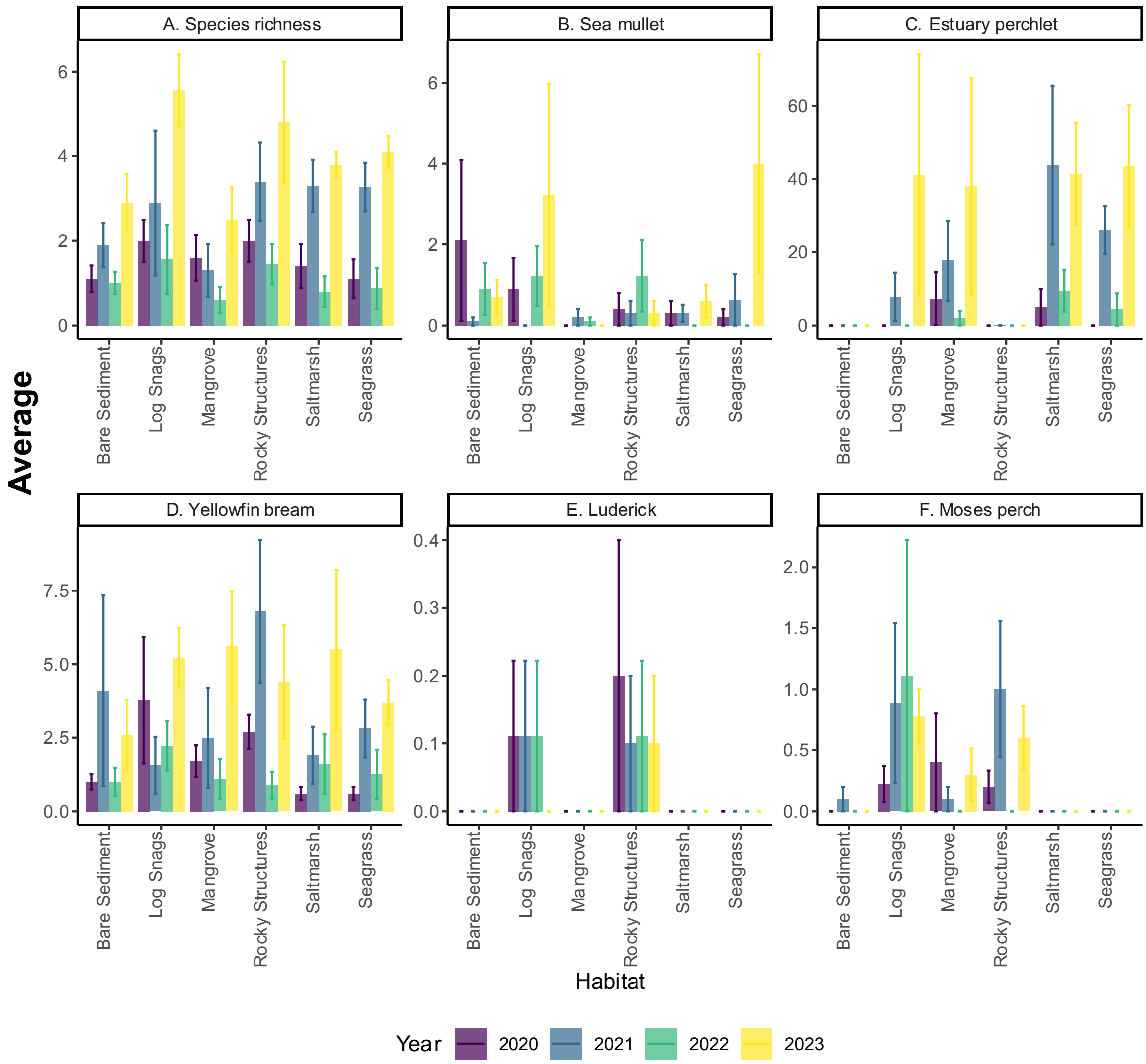

Figure 10 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Noosa River per habitat for surveys completed annually between 2020 - 2023.

Noosa River found consistent results of a higher average species richness in 2023 across all habitats (Figure 10). Similarly, the average yellowfin bream abundance was higher in log snag, mangrove, saltmarsh and seagrass habitats, with this average abundance in rocky structures and bare sediment habitats higher in 2021. Average estuary perchlet abundance was always higher in log snag, mangrove, saltmarsh and seagrass habitats compared to bare sediment and rocky structures, with luderick only found in log snag and rocky structure habitats (Figure 10).

2023 Pimpama River results

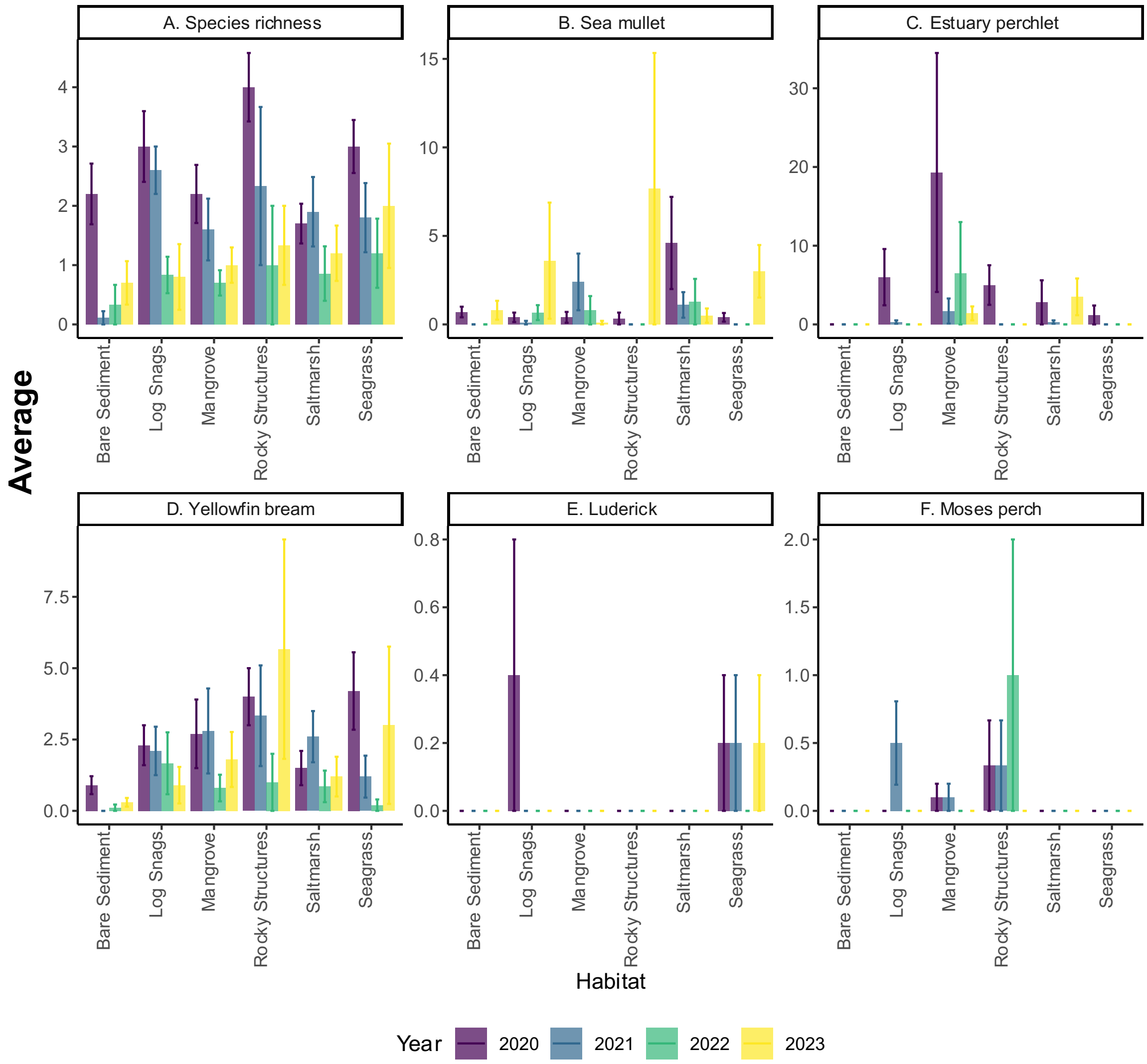

Figure 11 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Pimpama River per habitat for surveys completed annually between 2020 - 2023.

Pimpama River had a consistently higher average species richness in 2020 across all habitats, excluding saltmarsh habitat where the average species richness was higher in 2021 (Figure 11). The average yellowfin bream abundance was consistently higher at bare sediment, log snag, mangroves, saltmarsh and seagrass habitats in 2020 and 2021. The average species richness and abundance of sea muller, yellowfin bream and luderick were generally lower in 2022, with not luderick identified throughout the habitats in 2022 (Figure 11).

2023 Pine River results

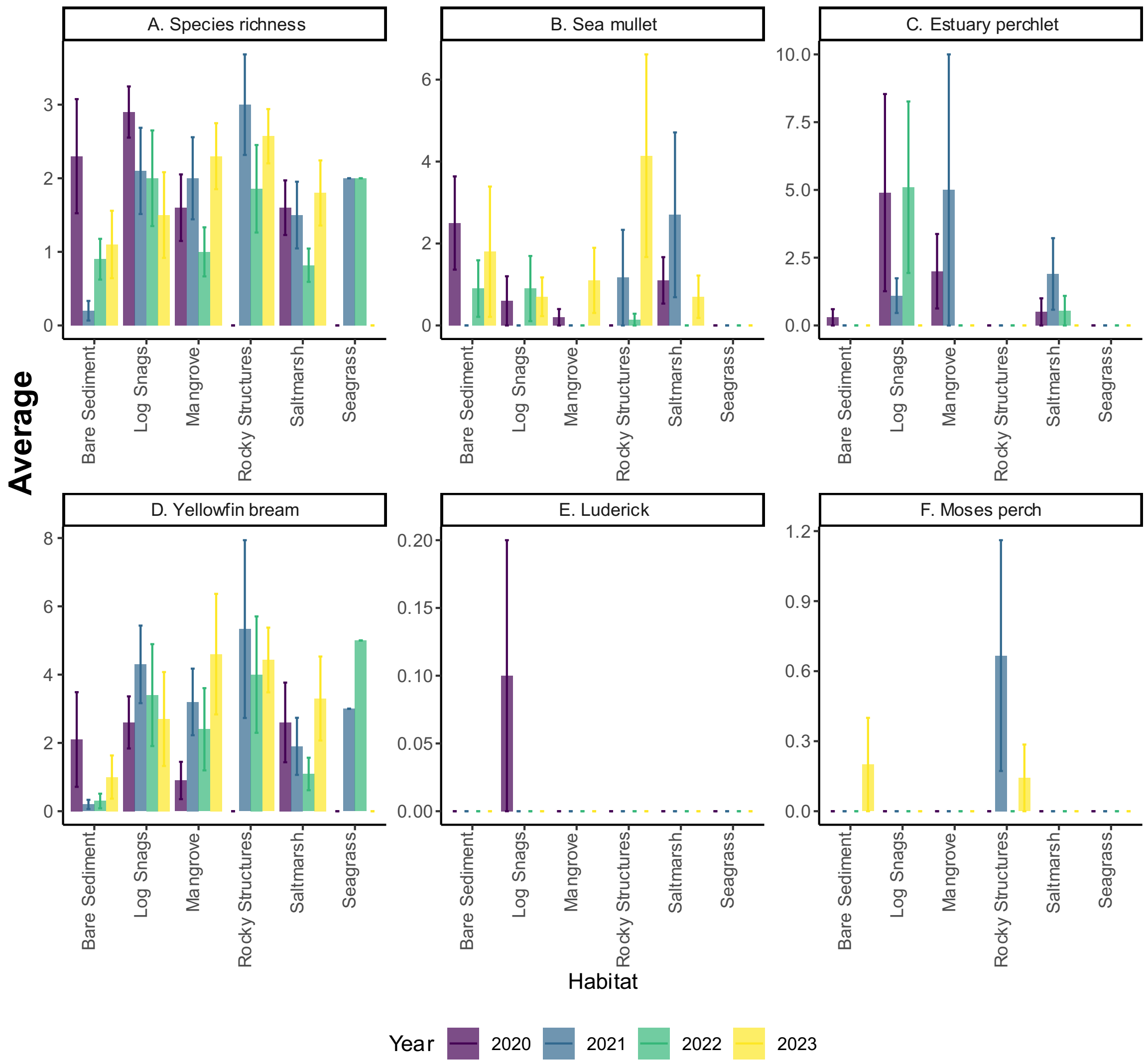

Figure 12 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Pine River per habitat for surveys completed annually between 2020 - 2023.

Pine River found varying results for the average species richness across habitat and year. The average yellowfin bream and sea mullet abundance varied greatly between habitat and year, however only a small number of mullet were identified in 2021, and only identified in rocky structures and saltmarsh habitats. Very few luderick and Moses perch were identified throughout all surveys and years, and estuary perchlet were identified throughout all years of surveys except 2023 as well as not being identified at rocky structures and seagrass habitats.

2023 Pumicestone Passage results

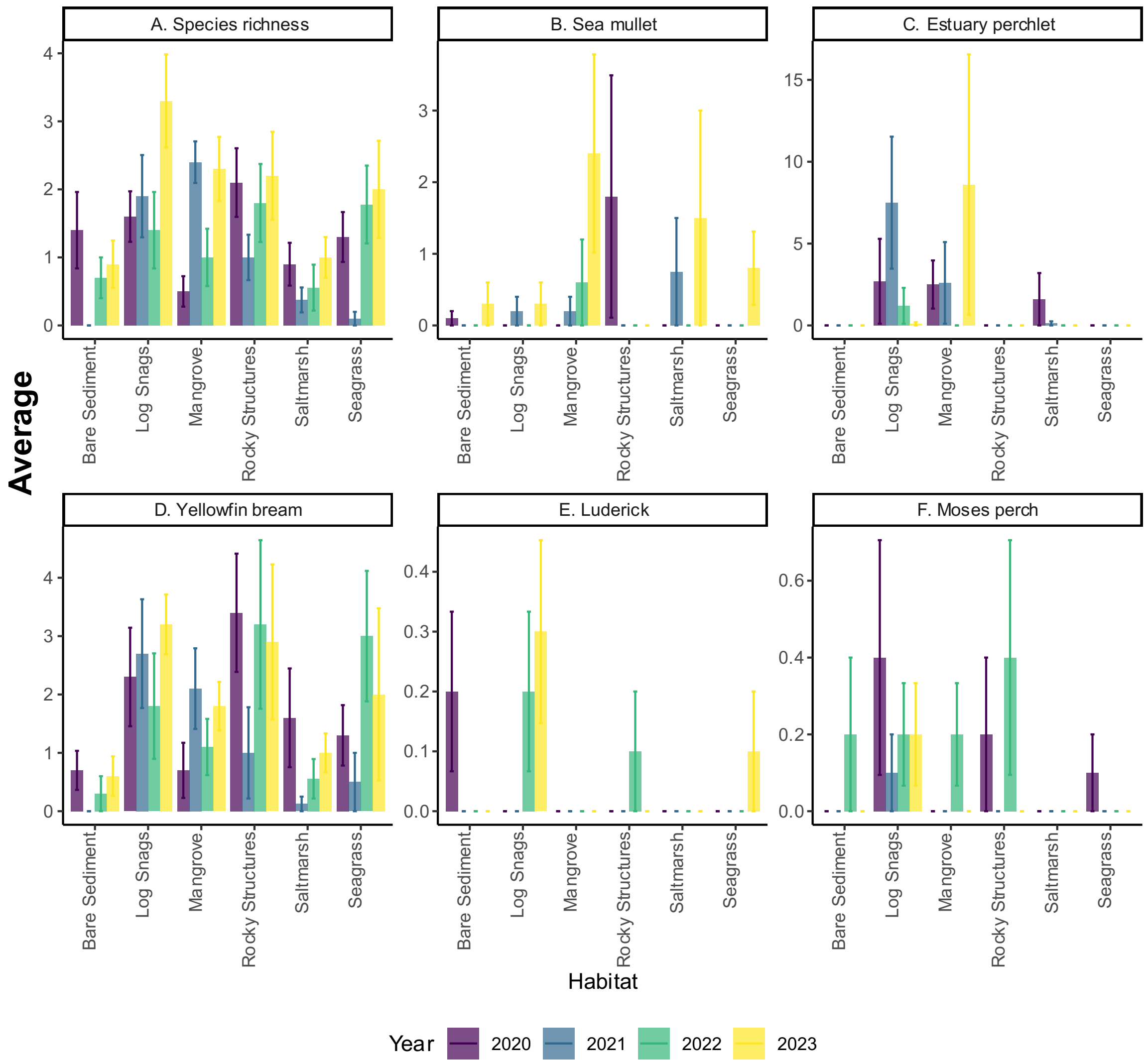

Figure 13 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Pumicestone Passage per habitat for surveys completed annually between 2020 - 2023.

Pumicestone Passage found log snags, mangroves, rocky structures and seagrass had higher average species richness compared to bare sediment and saltmarsh habitats in 2022 and 2023. Sea mullet were consistently identified in 2023 in all habitats except rocky structures, in comparison to the Moses perch which were only identified in log snag habitats in 2023. No luderick were identified in Pumicestone Passage in the 2021 round of surveys, and very few were identified in other years of sampling.

2023 Tallebudgera Creek results

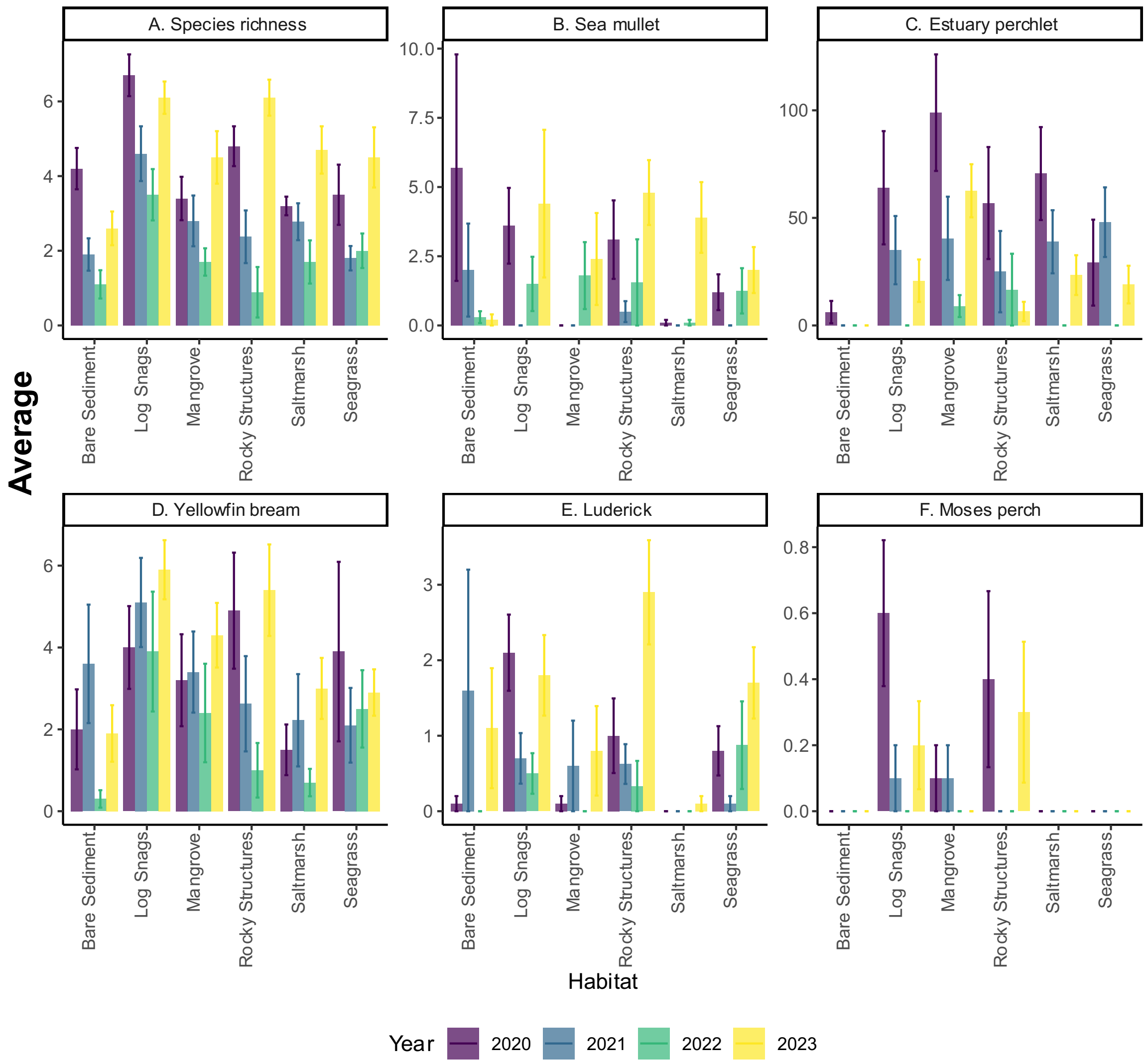

Figure 14 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Tallebudgera Creek per habitat for surveys completed annually between 2020 - 2023.

Tallebudgera Creek found consistently higher average species richness in 2020 and 2023 with a higher average species richness found in bare sediment and log snags in 2020, and a higher average species richness found in mangrove, rocky structures, saltmarsh and seagrass in 2023. These results differed for the average abundance of estuary perchlet with the highest average abundances more consistently identified in 2020 and 2021. No Moses perch were identified bare sediment and seagrass habitats across all surveys, not there were none identified across any habitat in the 2022 round of sampling.

2023 Tingalpa Creek results

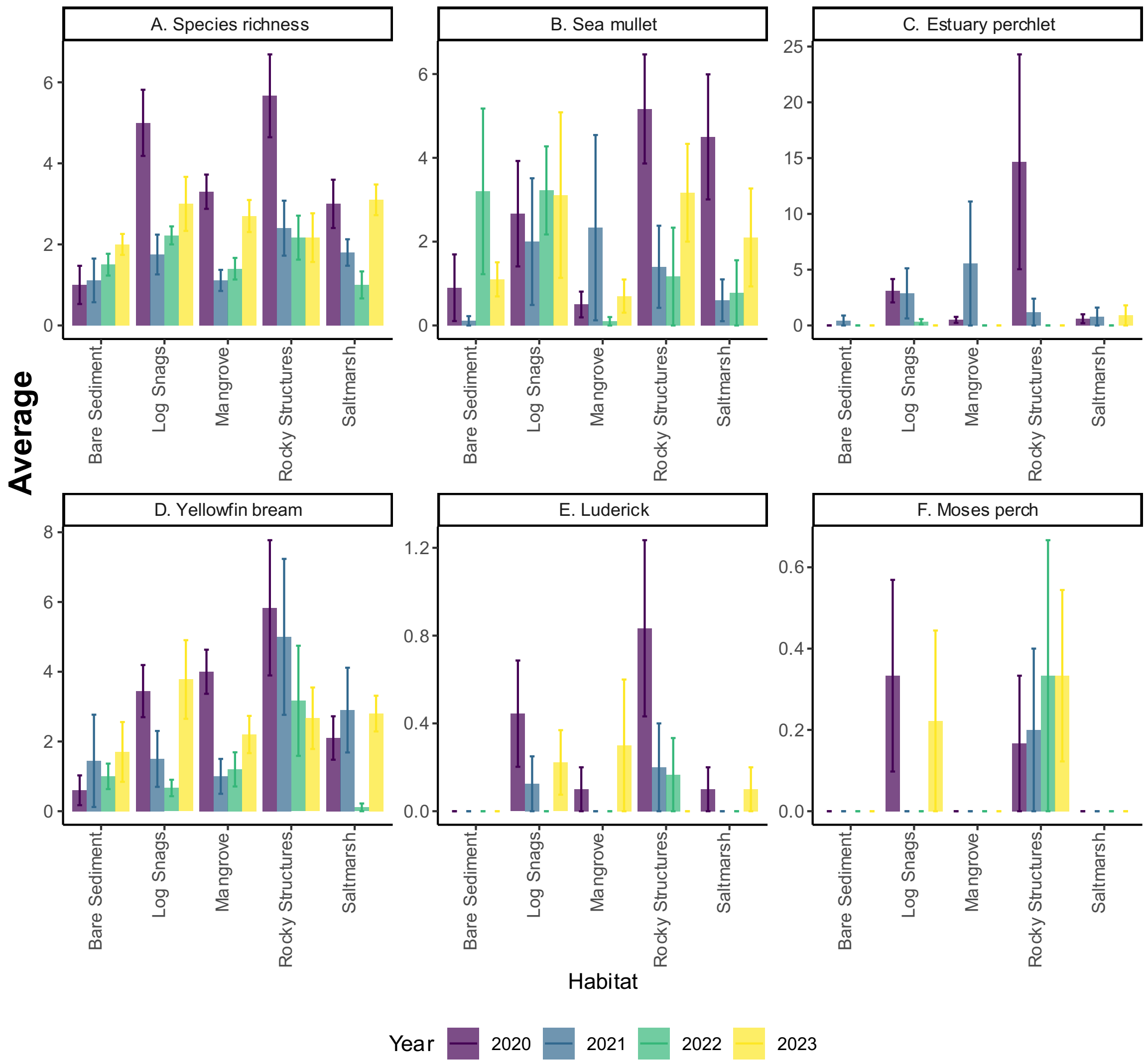

Figure 15 Average (+/- standard error) richness for A) species richness and the abundance of B) sea mullet, C) estuary perchlet, D) yellowfin bream, E) luderick and F) Moses perch in Tingalpa Creek per habitat for surveys completed annually between 2020 - 2023.

Tingalpa Creek a higher average species richness in 2020 in log snag, mangrove and rocky structure habitats and a higher average species richness in 2023 in bare sediment and saltmarsh habitats (Figure 15). The average abundance of sea mullet and yellowfin bream varied between habitat and year, while the average estuary perchlet abundance was higher in 2020 and 2021 across all habitats. Both luderick and Moses perch were not identified in bare sediment habitats across all years of survey, and varied in the average abundances throughout other habitats and years (Figure 15).

Grading results

Mean percentage agreement value across all sites and years (i.e. from 2020-2023) was 24.6%, with the average values for 2020 being 31%, 2021 being 20%, 2022 being 16.4% and 2023 being 30.9% (Figure 16, Table 7). In 2023, 11 out of 13 estuaries saw an increase in percentage agreement values from the previous year's surveys, with six estuaries recording their highest values across all years of survey; Maroochy River, Nerang River, Noosa River, Pine River, Pumicestone Passage and Tallebudgera Creek (Table 7). Four estuaries have more than doubled their percentage agreement values since 2022; Maroochy River, Mooloolah River, Noosa River and Tallebudgera Creek (Table 7). Tallebudgera Creek has recorded the highest percentage agreement value in 2020 (56.3), 2021 (41.9) and 2023 (63.0), with Nerang recording the highest percentage agreement value in 2022 (27.4) (Figure 16, Table 7). Conversely, Albert River, Brisbane River and Logan River remained consistently low throughout the entire study period, Albert River and Logan River failed to rebound at all, and Brisbane River recovered only slightly (and not to historically high values) following 2022 flooding. Albert River and Logan River have both the lowest (or equal lowest) percentage agreement value for that estuary since surveys began recording 0 and 3.6, respectively (Figure 16, Table 7).

Table 7 List of estuaries and their percentage agreement values over the predicted scores for the benchmarking period (2020-2022) and the 2023 surveys.

Estuary	**Benchmarking period**			**2023**
	2020	**2021**	**2022**	
Albert	7.6	0	5.2	0
Brisbane	11.9	2.5	2.6	3.3
Caboolture	36.6	12.7	26.0	32.7
Logan	9.6	5.3	4.1	3.6
Maroochy	37.2	23.1	23.5	48.7
Mooloolah	46.3	25.4	7.6	43.4
Nerang	42.8	31.4	27.4	47.2
Noosa	23.5	32.1	18.7	46.9
Pimpama	40.3	24.0	13.0	20.2
Pine	23.1	23.8	19.5	26.0
Pumicestone	20.7	13.1	18.6	25.7
Tallebudgera	56.3	41.9	23.9	63.0
Tingalpa	46.8	24.1	23.6	41.4
Average	**31.0**	**20.0**	**16.4**	**30.9**

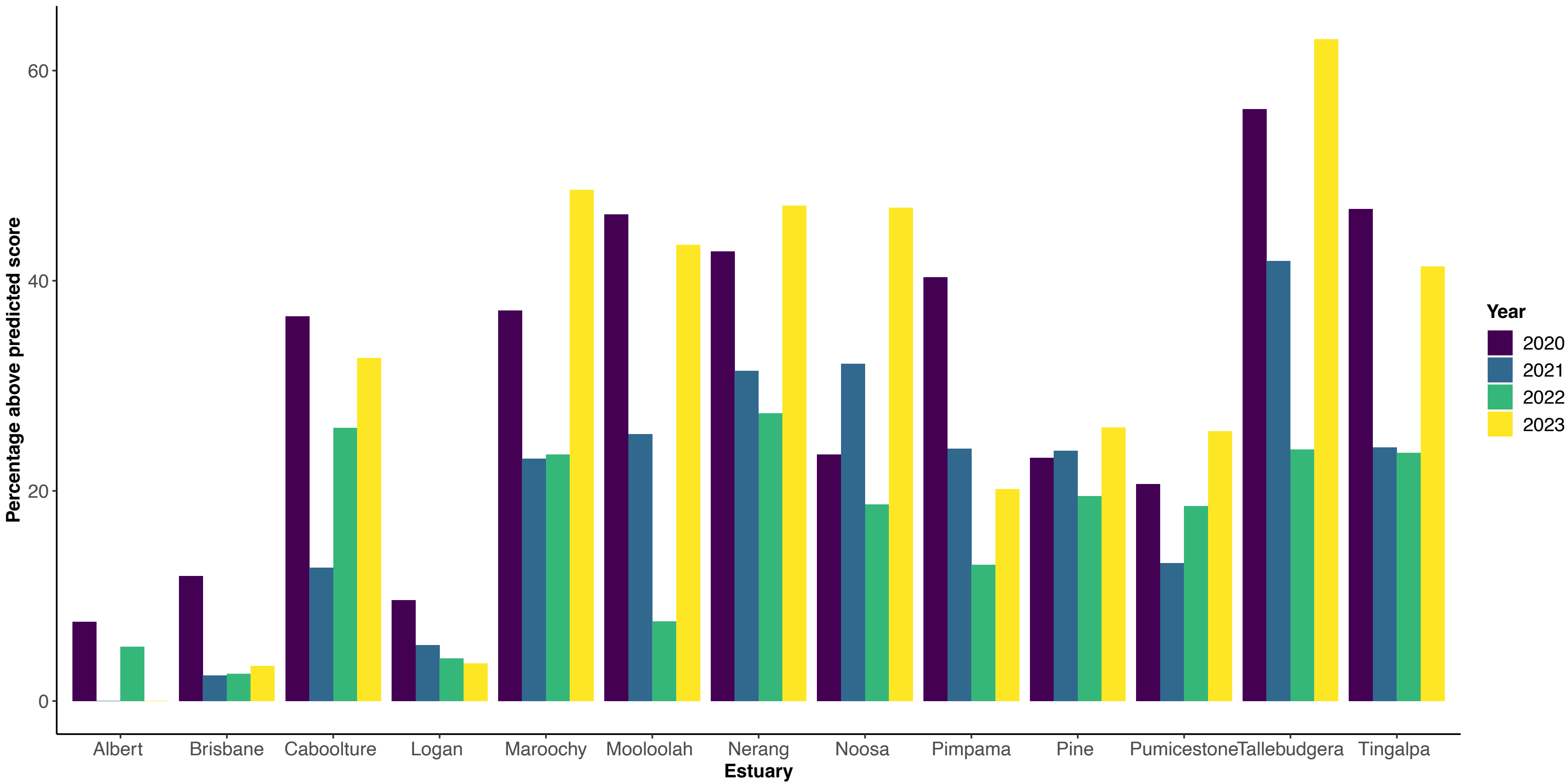

Figure 16 The percentage agreement value above the predicted score for individual estuaries over the survey period (2020 – 2023).

Discussion and conclusions

The methods established during the benchmarking period identified field methodologies, minotoiring frameworks and statistical models that effectively minotor change in estuarine fish in Southeast Queensland. The effectiveness of these procedures in detecting improvements in estuary grands across most systems in 2023 following flowing in 2022 reinforces the value and robustness of the models created throughout the benchmarking period. There were several key conclusions identified in 2023, with the most significant outcome relating to the recovery of fish assemblages throughout majority of the estuaries.

Recovery of estuarine fish assemblages following 2022 flooding

Most estuaries appear to be recovering since the region-wide flooding of early 2022, with 11 out of the 13 estuaries achieving a higher value compared to 2022, and six estuaries achieving their highest grade since surveys began in 2020; Maroochy River, Nerang River, Noosa River, Pine River, Pumicestone Passage and Tallebudgera Creek. All of these estuaries contain vast seagrass meadows either within the estuary itself (Maroochy River, Nerang River, Noosa River, Pumicestone Passage and Tallebudgera Creek) and/or the estuary is fed by a semi-enclosed embayment that contains vast seagrass meadows (i.e. Moreton Bay and Broadwater) (Pine River and Nerang River). This may either indicate a role of the seagrass in improvements, or that these estuaries have typically better water quality that allows the persistence of seagrass and therefore a greater capacity for ecosystems to rebound following impacts. In 2023 surveys, we found seagrass to be the most important habitat for supporting diverse and abundant fish assemblages because it supported the highest diversity and abundance of fish. Throughout this region, seagrass meadows have been previously found to respond to flooding in different ways, with seagrass meadows closer to the impacted estuary having higher rates of nutrient uptake compared to seagrass meadows further away which allowed for greater recovery post flood event (Gibbes et al. 2014; Maxwell et al. 2015). We identified that sea mullet went from being the fifth most common species in 2022 to the third most common species in 2023. Following 2022 flooding impacts, it is possible that the resuspension and turnover to nutrient enriched sediments, increasing food resources for detritivores fish species, such as the sea mullet.

The fact that fish assemblages in estuaries rebounded significantly following flooding in most estuaries, and many to their highest ever levels indicates two potential patterns. Firstly, fish assemblages in estuaries that are in relatively good condition rebound quickly, and certainly within one year of impacts being felt. Secondly, it is possible that smaller flood impacts that bring about significant increases in sediment and nutrients enhance the ecology of some estuaries, thereby returning energy and significant food sources to these habitats following flooding. This may, in some estuaries, lead to an enhancement of fish assemblages in the year following flooding. Crucially, this conclusion requires further testing, including quantifying whether these effects persist in surveys for 2024. Conversely, highly impacted, turbid estuaries showed little improvement in 2023, thereby indicating that these fish assemblages within these systems and ecosystems likely have little resilience to ongoing impacts.

Recommendations for ongoing monitoring

Due to the patterns, and the identification of the recovery of estuarine fish following the flooding which occurred in 2022, we reccomend the continuation of the estuarine fish monitoring methodology and framework as described in 2022 and then tested again in 2023 as an ongoing monitoring project. The ongoing monitoring of estuarine fish assemblages can effectively identify links between changes in physical metrics and the ecology of these ecosystems, providing robust information to stakeholders, and the management of these systems.

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