Relative condition of the freshwater fish community in the Macleay Basin: North Coast New South Wales Ecohealth Program

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Sampling was undertaken within the guidelines outlined in Animal Care and Ethics Permit No. 98/14.

SUMMARY

Relative condition of the freshwater fish community in the Macleay Basin: North Coast New South Wales Ecohealth Program.

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SUMMARY:

Many of the streams and rivers throughout Australia have experienced considerable change since European settlement, including those along the continent's eastern seaboard. The aim of this current study was to determine the relative health of the fish communities in the Macleay Basin as part of the North Coast Ecohealth Program. Fish were sampled at 27 sites throughout the Macleay Basin between 16th December 2014 and 18th February 2015, using combinations of electrofishing, seine netting and bait trapping. The analytical procedures developed for the Murray-Darling Basin Authority's *Sustainable Rivers Audit* and NSW *Monitoring Evaluation and Reporting* (MER) programs were used to derive fish health indicators representing Expectedness, Nativeness, Recruitment and Overall Condition for each site. In total 27,119 fish were caught (n = 25,446) or observed (n = 1,673) across all sites and for all methods combined. By number and in biomass, the long-finned eel (*Anguilla reinhardtii*) was by far the most abundant of the large-bodied species captured. The alien eastern mosquitofish (*Gambusia holbrooki*) dominated the catch among the small-bodied species. In total, 24 species of fish were caught across all sites in the Macleay Basin, including 18 of the 'expected' 25 native freshwater species, three estuarine species, and two alien species. The Expectedness Indicator value for the majority of sites sampled was either "Good" or "Excellent" (Figure 3; Table 7). However, four sites rated as only "Moderate" and the Oaky Power Station site scored a rating of "Poor". In general Nativeness was high at most sites, with 15 scoring a rating of "Excellent", eight a "Good" and three a "Moderate". However, the alien eastern mosquitofish was by far the most abundant of any the species sampled and it was also one of the more widespread having been caught in all altitudes except in the Upland Zone and at 16 of the 27 sites sampled. The high Expectedness and Nativeness scores suggest that the overall structure of the fish community in the Macleay Basin has changed little since European settlement; particularly in the lower altitude reaches of the system. In general, the Recruitment Indicator values were considerably lower than the other indices; "Moderate" in the Coastal Plains, Lowlands, Midlands and Slopes zones, and "Very Poor" in the Upland and Highland zones. Whilst the recruitment scores can likely be partly explained by natural spatio-temporal variation in recruitment as is common among coastal fishes, they also reflect the poor state of the fish community across the upper reaches of the Macleay. This was further evidenced by the lower Expectedness and Nativeness scores across the upper catchments. The weighted average scores for the Basin as a whole were: Expectedness "Good" 69.5 (CL = 68.63-73.72), Nativeness 'Good" 79.4 (CL = 75.83 – 82.57), and Recruitment "Poor' 32.3 (CL = NA). The Overall Fish Condition (Ndx-FS) score was 48.8, giving the Macleay Basin fish community an overall rating of "Moderate". The current study is the first comprehensive survey of fish in the Macleay Basin. As such the data presented effectively provides a baseline against which future samples can be compared, rather than being a definitive indicator of the long-term health of the basin.

KEYWORDS:
Freshwater fish, health metrics, Expectedness, Nativeness, Recruitment

1. BACKGROUND

The current report is one in a series that describe the relative health of the freshwater fish communities in the various basins across the North Coast of New South Wales (NSW) region as part of the North Coast Ecohealth program.

The health of river systems is controlled by many endogenous and exogenous factors. Whilst the deterioration in the condition of a river can in some cases be a result of natural phenomenon, most often anthropogenic influences are the underlying cause (Carpenter *et al*. 1992; Karr 1999; King *et al*. 2003). Like most countries throughout the world, many of the streams and rivers across Australia have experienced considerable change due to anthropogenic disturbance. Since European settlement, rural and urban development has seen the entrainment and over extraction of water from many of Australia's rivers, particularly those in Australia's south-east (Walker 1985; Kingsford 2000; Gehrke and Harris 2001). Riparian and instream disturbances have further exacerbated the problems created by altered flow regimes (Crook and Robertson 1999; Pusey and Arthington 2003; Rutherford *et al*. 2004). Pollution and the introduction of alien species (Koehn 2004) have also become an increasing issue in many systems. The end result has been a dramatic decline in the health of most Australian rivers and in the biota that live within them, including the fish communities.

Determining the relative health of riverine fish communities can be problematic. The distribution and abundance of individual species can vary both spatially and temporally, making accurate assessments at the site or even catchment scale difficult. In some cases this variability can be natural (Bilby *et al*. 2003), such as when individual species migrate to different parts of a system as part of their normal life-history (Tsukamoto *et al*. 2009), or where the abundance of a short lived species is in flux within the boom-bust cycle that epitomises the nature of many of these types of fishes (Balcombe and Arthington 2009). It therefore becomes difficult to resolve the difference between what might be considered "normal" and what has been significantly changed due to anthropogenic influences (Jackson *et al*. 2001; Roset *et al*. 2007). For this reason, fish have not always been considered a particularly suitable indicator for measuring the health of a river system. However, a recent paradigm shift in the field of bio-indicator theory has resulted in fish now being considered a key indicator of watershed health. While the reasons for this change in thinking are numerous, some of the key ones are: many species of fish are long-lived; fish are ubiquitous in that they live across a wide variety of habitats; most fish species are well studied and therefore are generally well understood; fish are diverse in that they exhibit a wide range of feeding habitats, reproductive traits and tolerances to environmental perturbations; most fish species are easily identifiable; and individual species within a watershed differ in their tolerance to the amount and types of pollution they can tolerate (Grabarkiewicz and Davis 2008).

As a result of this ever growing understanding of fish population dynamics, there have now been many studies undertaken throughout the world to determine the health of rivers using fish as an indicator. These studies have ranged from assessments of fish communities in relatively small streams and lakes, up to large basin-wide studies over many 1000's of km^2 (e.g. Jackson and Harvey 1997; Noble *et al*. 2007; Kang *et al*. 2009; Davies *et al*. 2010). Within Australia, programs such as the *NSW River Survey* (Harris and Gehrke 1997) and the *Murray-Darling Sustainable Rivers Audit* (Davies *et al*. 2010), have seen the development and refinement of standardised sampling and analyses techniques that are now used to assess the health of fish communities across many parts of the continent. These same protocols have most recently been used in implementing the the NSW Natural Resources *Monitoring Evaluation and Reporting* (MER) Program (Muschal *et al*. 2010). The aim of the MER program was to provide a co-ordinated approach to measuring progress towards NSW natural resource condition targets (NSW Government 2010). However, while these programs provided insights into the relative health of many of the river systems across NSW, detailed assessments of the condition of fish communities within individual drainage basins are still lacking.

The North Coast Bioregion extends along the north-east coast of NSW from Newcastle in the south to the Queensland border in the north. The region covers an area of just under six million hectares and is

considered sub-tropical along the coast, through to an almost temperate climate in the uplands along its western boundary (Anon 2011). In general, the rivers throughout the region are relatively short and steep, with the larger systems rising along the top of the Great Dividing Range and flowing in an easterly direction to the Pacific Ocean. The North Coast is also one of the fastest growing regions in Australia. Projected human population growth of ~6% is expected over the period from 2010 to 2020 (Anon 2010). Whilst the majority of rivers are largely unregulated, many are experiencing increasing anthropogenic pressure. Traditionally, the agricultural sector has been the main user of water from the rivers throughout much of the region, but with growth and an ever increasing human population there has been growing utilisation of rivers as a source of potable water.

There have been few detailed studies of fish communities at the catchment or basin scale throughout the North Coast Bioregion. The NSW MER Program (Muschal *et al.* 2010) saw a broader approach implemented that attempts to assess river health, including condition of freshwater fish communities, at larger scales across the entire North Coast. MER sampling covering the North Coast region was undertaken in 2006-07, 2009-10 and 2012-13. More recently, the Local Land Services North Coast (LLSNC) (formerly Northern Rivers Catchment Management Authority) initiated its Ecohealth Program, which aimed to undertake a detailed assessment of water quality, macro-invertebrates, riparian vegetation, estuarine vegetation and the fish communities at the basin scale. To date Ecohealth sampling has been undertaken in the Bellinger-Kalang, Hastings, Coffs Coast, Clarence and Richmond regions and basins. Sampling of the freshwater fish community was undertaken in all but the Coffs Coast region and Richmond Basin (Gilligan 2010; Butler *et al*. 2012; Butler *et al*. 2014). There are plans to expand the Ecohealth Program to include a number of other systems throughout the North Coast including the Nambucca and Tweed basins and to repeat sampling in the Hastings Basin and Coffs Coast region.

As part of the North Coast Ecohealth Program, the aim of this current study was to describe the relative health of the freshwater fish communities in the Macleay Basin.

2. METHODS

2.1. Study area

The Macleay Basin is the located in the north-east of NSW and covers an area of ~11,450 km^2. The Basin is formed by the Great Dividing Range at its western and north-western boundaries, by the Snowy Ranges and the Macleay Hills along its north-eastern boundary, and the Banda Banda Plateau and the hills of the Maria River State Forest to the south (White 2000). The rivers and streams of the Macleay Basin are largely unregulated, with only a small number of weirs, dams and road crossings throughout the smaller headwater tributaries. The three main sub-catchments within the Basin are the Macleay, the Chandler and the Apsley. The Macleay River is the longest river in the Basin at ~300 km, extending from the tablelands near the city of Armidale and entering the ocean at South West Rocks, north of Kempsey. Other major rivers and creeks include: Five Day, Dungay, Toorumbee creeks across the lower reaches; Georges, Apsley, Chandler, Styx, Yarrowitch, Tia across the mid-upper region; and the Gara River and Rockvale Creek, which are primarily in the upper reaches.

The climate across the lower regions of the Macleay Basin is considered on the whole subtropical to warm temperate, whilst the higher altitude areas are cooler and are considered to be almost temperate in nature (Bureau of Meteorology 2013). Average annual rainfall ranges from ~1100 mm at Kempsey in the lower reaches, up to ~1500 across the mid valley reaches, and down to ~800 mm at Armidale on the tablelands. In general, the higher falls are in January through March across the lower and mid reaches, whilst across the tablelands the highest falls occur in November through December (Bureau of Meteorology 2013). Like most basin systems across the North Coast region, the Macleay is subject to frequent and often large flooding events. Because the basin is naturally funnel-shaped, intense rainfall in the upper catchment combined with steep grades and contributions from various side streams results in dramatic stream rises over short periods of time (Dutton 2002). In general, normal West to East weather fronts crossing the Great Divide and summer storms result in small river rises and local flooding, whilst major flood events usually occur in winter and are a result of an interaction between tropical and monsoonal systems and sub-tropical high pressure systems creating low pressure systems, depressions and tropical storms along the coast (Dutton 2002).

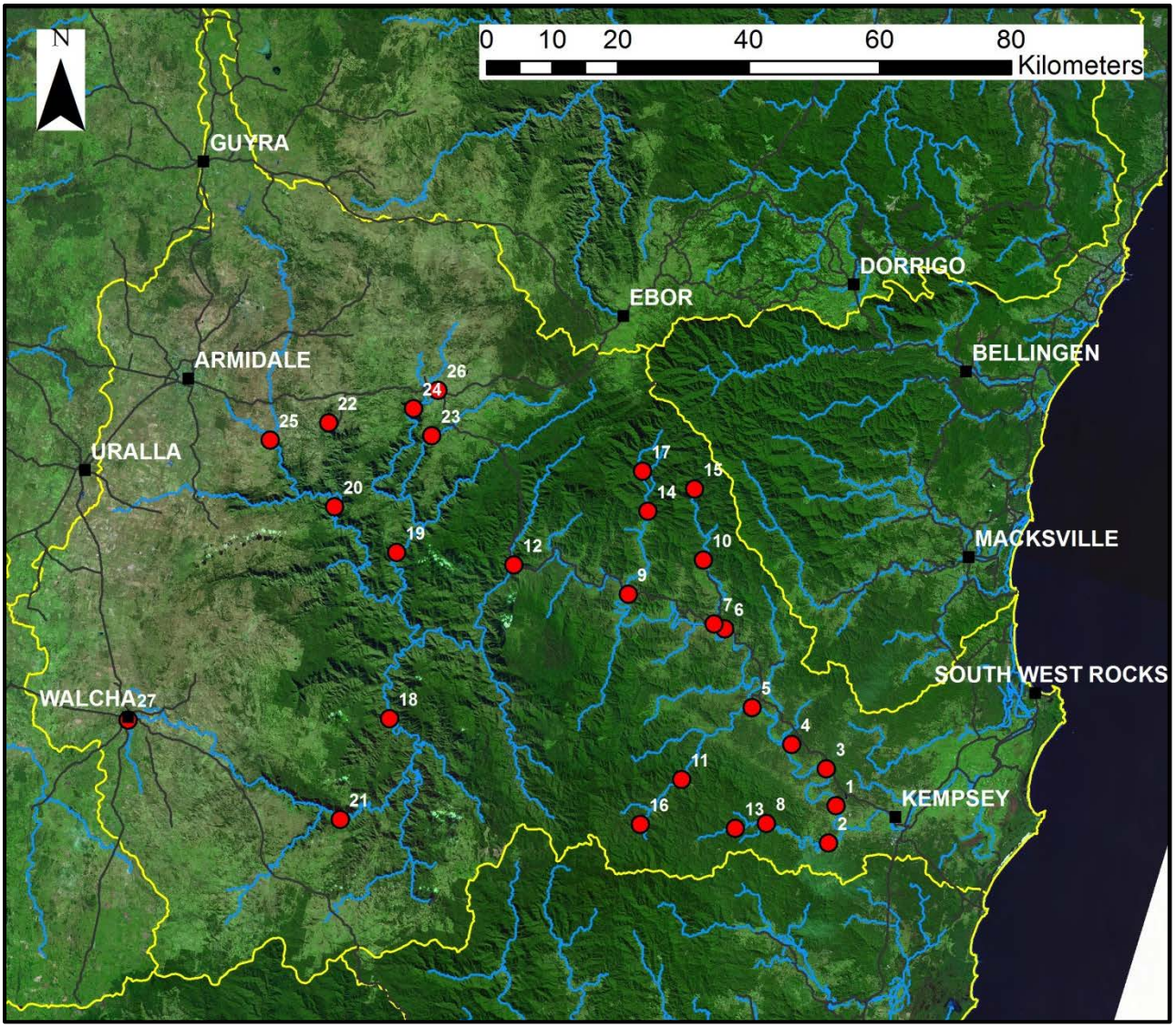

Figure 1. Sites sampled to determine the health of freshwater fish across the Macleay Basin. NB[#] full site details in Table 1 below.

Table 1. Sites and methods used to sample the freshwater fish in the Coastal Plains, Lowland, Midland Slopes, Upland and Highland altitude zones across the Macleay Basin.

Site	River	CEM Site Number	Latitude	Longitude	Altitude	Zone	River Style	Stream Reach Condition	Electrofishing Effort	Seine
Sherwood Bridge	Macleay River	1	-31.05860	152.73089	10	Coastal Plains	Planform controlled, low sinuosity, gravel	Moderate	Medium boat	✓
Battles Outlet	Dungay Creek	2	-31.11031	152.72169	15	Coastal Plains	Planform controlled, low sinuosity, gravel	Moderate	Small boat	✓
Turners Flat	Macleay River	3	-31.00848	152.71283	16	Coastal Plains	Planform controlled, low sinuosity, gravel	Moderate	Medium boat	✓
Temagog Bridge	Macleay River	4	-30.97721	152.65431	27	Coastal Plains	Planform controlled, low sinuosity, gravel	Moderate	Medium boat	✓
Dowling Falls Road	Parrabel Creek	5	-30.92948	152.58824	50	Lowland	Planform controlled, low sinuosity, gravel	Moderate	Backpack	✓
Bellbrook	Macleay River	6	-30.82344	152.53812	60	Lowland	Planform controlled, low sinuosity, gravel	Moderate	Medium boat	✓
Nulla Nulla Bridge	Nulla Nulla Creek	7	-30.81755	152.52029	68	Lowland	Planform controlled, low sinuosity, gravel	Poor	Backpack	✓
Wittitrin	Dungay Creek	8	-31.08786	152.62129	74	Lowland	Planform controlled, low sinuosity, gravel	Moderate	Backpack	✓
Comara	Five Day Creek	9	-30.78298	152.38122	98	Lowland	Planform controlled, low sinuosity, gravel	Poor	Small boat/backpack	✓
Slim Dustys	Nulla Nulla Creek	10	-30.73083	152.49834	111	Midland	Planform controlled, low sinuosity, gravel	Poor	Backpack	✓
Holis Flat	Parrabel Creek	11	-31.03378	152.48161	130	Midland	Planform controlled, low sinuosity, gravel	Moderate	Small boat/backpack	✓
D/S Georges Ck	Macleay River	12	-30.75064	152.19666	136	Midland	Bedrock controlled, gravel	Moderate	Small boat/backpack	✓
Duneight Crossing	Dungay Creek	13	-31.09725	152.57211	137	Midland	Gorge	Good	Backpack	✓
Postmans Trail	Five Day Creek	14	-30.66739	152.40557	156	Midland	Planform controlled, low sinuosity, gravel	Poor	Small boat/backpack	✓
Nulla Nulla 3	Nulla Nulla Creek	15	-30.63355	152.47795	225	Slopes	Gorge	Good	Backpack	✓
Toorumbee Junction	Parrabel Creek	16	-31.09868	152.41934	230	Slopes	Planform controlled, low sinuosity, gravel	Good	Backpack	✓
Five Day Ck Causeway	Five Day Creek	17	-30.61282	152.39392	231	Slopes	Gorge	Good	Backpack	✓
Apsley Gorge	Apsley River	18	-30.97063	152.01113	250	Slopes	Bedrock controlled, gravel	Good	Backpack	✗
Halls Peak	Chandler River	19	-30.74146	152.00929	261	Slopes	Bedrock controlled, gravel	Good	Backpack	✓
Glenmore	Macleay River	20	-30.67441	151.90343	327	Slopes	Gorge	Good	Backpack	✗
Enfield North	Apsley River	21	-31.11238	151.93924	448	Upland	Gorge	Good	Backpack	✗
Straits Goldmine	Bakers Creek	22	-30.56742	151.89117	580	Upland	Gorge	Moderate	Backpack	✗
Oaky Power Station	Oaky River	23	-30.57750	152.06060	624	Upland	Gorge	Good	Backpack	✗
Wollomombi Gorge	Chandler River	24	-30.54243	152.02478	670	Upland	Gorge	Good	Backpack	✗
Blue Hole	Gara River	25	-30.59510	151.79959	921	Highland	Planform controlled, low sinuosity, gravel	Poor	Small boat	✓
Chandler Bridge	Chandler River	26	-30.51585	152.06250	926	Highland	Gorge	Moderate	Backpack	✓
Old Trout Hatchery	Apsley River	27	-30.98852	151.59330	1043	Highland	Meandering, fine grained	Moderate	Medium boat/backpack	✓

2.2. Sample sites

Site selection for the Macleay Ecohealth Program was largely a desktop process, undertaken in consultation among an expert group of aquatic ecologists, hydrologists, geologists and natural resource managers. The first step in the process was to identify the scale (in this case the minimum catchment size) at which reporting was to occur. Once this was established, the next step was to identify the main stem streams within which sampling was to be undertaken. The main stem stream within each sub-catchment was then divided by altitude zone using criteria similar to those used to define the stream network for the SRA and MER programs (Davies *et al.* 2008). Altitude was used to stratify site selection to account for the natural changes in fish community composition at different altitudes, and because of the predominance and importance of diadromous fishes in coastal rivers. The altitude zones used were: coastal plain (2-30 m ASL), lowland (31-100 m ASL), midland (101-200 m ASL), slopes (201-400 m ASL), upland (401-700 m ASL), and highland (>701 m ASL). The same altitude zones were used to provide boundaries to assist in creating reference condition estimates for fish across the basin (*Section 2.1.4.1*). Not all altitudinal zones were represented in all sub-catchments due to their location in the landscape and/or because of access issues. Each altitude zone was further divided into *stream lengths* on the basis of River Style®. Geomorphic condition within each *steam length* was then used to identify upstream and downstream reach boundaries within which individual sampling sites were selected. River Style® and geomorphic condition (based on the River Styles® assessment of the Macleay Basin carried out by Alluvium Consulting (2012)) were considered two of the more important parameters in the site selection process, as both are known to strongly influence the condition and availability of aquatic habitat and river health (Chessman *et al.* 2006). A minimum of three sampling sites per main stem stream were selected within each of the sub-catchments chosen so as to allow reporting at the sub-catchment scale.

Fish were sampled at 27 sites throughout the Macleay Basin between 16th December 2014 and 18th February 2015; in the Apsley, Chandler, Gara, Oaky and Macleay rivers, and Bakers, Dungay, Five Day, Nulla Nulla and Parrabel creeks. Sites ranged from 10 m ASL up to 1043 m ASL and included reaches in the Coastal Plains (4), Lowland (5), Midland (5), Slopes (6), Upland (4) and Highland (3) altitude zones (Table 1). River Style® at sampling sites across the lower sections of the Macleay tended to be dominated by planform waterways, with all sites in the Coastal Plains and Lowlands identified as planform controlled, low sinuosity and gravel dominated. Contrastingly, in the upper reaches the dominate Riverstyle® was confined valley-gorge, with a small number of sites falling in partly confined valley – bedrock or planform controlled reaches (Alluvium 2012) (Table 1). Stream condition at sites was generally either good (n = 10) or moderate (n = 11), with a low small of reaches within the Lowland (n = 2), Midland (n = 2) and Highland zones (n = 1) considered to be in poor condition (Alluvium 2012) (Table 1).

2.3. Field methods

Electrofishing was undertaken at all sites and included small and medium boat mounted electrofishing (3.5 kW or 5 kW Smith-Root electrofisher), backpack electrofishing (Smith Root model LR20) or a combination of both. Float tubes were used in combination with backpacking at sites inaccessible by boat where it was too deep for standard backpack fishing (up to a maximum depth of ~2 m). Boat electrofishing consisted of 12 x 90 second operations per site, while backpack electrofishing consisted of 8 x 150 second operations. At sites where both boat and backpack sampling was required, the number of operations of each method used was proportional to the area of navigable versus wadable habitat. Boat electrofishing involved a series of ~10 second power-on and power–off operations, with successive operations undertaken on alternate banks while moving in an upstream direction. Backpack electrofishing involved sampling all areas accessible to the stationary operator, before the operator moved approximately 3 m upstream and repeated the process. All boat and backpack electrofishing was undertaken by a minimum of two operators, with three operators used at medium boat sites.

Ten unbaited traps were deployed for a minimum of 1.5 hours at each site; undertaken at the same times as electrofishing activities. Traps were distributed haphazardly throughout the site in water depths of 0.5 – 1 m. Seine netting was also undertaken at all but six sites; two sites in the slopes zone and four in the highland zone (Table 1). The extreme trekking required to reach these sites as well as the large boulder substratum and incised nature of the river channel made seining impractical. Six seine hauls were undertaken at all other sites using a net measuring 5 m in length, 1.8 m in height and with a 5 mm mesh. Each seine operation involved one sampler remaining stationary on the bank, whilst the other hauled the net at full extension from bank to bank in a semi-circle action; starting downstream of the stationary sampler and working upstream into the flow.

All fish were identified to species level, measured to the nearest millimetre and released onsite. Voucher specimens were retained for laboratory identification where an individual or individuals could not be positively identified in the field. Length measurements were taken as fork length for species with forked tails and total length for all other species. Where large catches of a species occurred, a sub-sample of individuals were measured and examined for each gear type. The sub-sampling procedure involved measuring all individuals in each operation until at least 50 individuals had been measured. The remainder of individuals in that operation were measured but any individuals of that species from subsequent operations of that gear type were only counted. Because of the large numbers of fish caught by the seine, 20 individuals were also measured in all operations even after a count of 50 had been reached, primarily to ensure the accuracy of biomass estimates. Fish that escaped capture, but could be positively identified were also counted and recorded as “observed”.

a)

Figure 2. Selection of sites sampled from across the various altitude zones in the Macleay Basin: Sherwood Bridge (a) and Temagog Bridge (b) (Coastal Plains); Parrabel Creek (c) and Dungay Creek (d) (Lowland); Nulla Nulla Creek (e) (Midland) and Five Day Creek (f) (Slopes); Oaky Creek (Power Station) (g) (Upland) and Apsley Gorge (h) (Highland).

2.4. Data Analyses

2.4.1. Reference Condition and Recruitment

The predicted pre-European fish community of the Macleay Basin was derived using the Reference Condition for Fish (RC-F) approach used by the Sustainable Rivers Audit (SRA) and NSW Monitoring, Evaluation and Reporting (MER) programs (Tables 2 and 3). The RC-F process involves using available historical and contemporary data, museum collections and expert knowledge to estimate the probability of collecting each species at any randomly selected site within an altitude zone if it were sampled using the standard sampling protocol prior to 1770 (Davies *et al.* 2008). Estuarine/marine vagrants were allocated an arbitrary RC-F probability of capture of 0.05, rare species (collected at $0 < 0.2$ of samples) an RC-F of 0.1, occasional species (collected at $0.21 < 0.7$ of samples) an RC-F of 0.45 and common species (collected at $0.71 < 1.0$ samples) an RC-F of 0.85 (RC-F scores being the median capture probability within each category).

The definition of a recruit was derived using a similar process as that applied in the SRA and MER programs (Dean Gilligan unpublished data). For large-bodied and generally longer lived species (>three years), an individual was considered to be a recruit if its body length was less than that of a one-year-old of the same species. For small-bodied and generally short-lived species that reach sexual maturity in less than one year, recruits were considered to be those individuals that were less than the species known average length at sexual maturity. The recruitment lengths used for both large- and small-bodied species were derived from published scientific literature or by expert opinion where that was not available (Table 4).

2.4.2. Metrics, Indicators and the Overall Fish Condition Index.

Using the methods described by Robinson (2012), eight fish metrics were derived from the data collected at each site. The eight metrics were then aggregated to produce three fish condition indicators and these indicators were then used to derive an overall Fish Condition Index (*SRA ndxFS*). Metric and indicator aggregation was done using Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) using the rules sets developed by Davies *et al*. (2010).

The Expectedness Indicator (*SR-FI*$_e$) represents the proportion of native species that are now found within the basin, compared to that which was historically present. The Expectedness Indicator is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). The two metrics were aggregated using the Expectedness Indicator Expert Rule set (Carter 2012). The Nativeness Indicator (*SR-FI*$_n$) represents the proportion of native versus alien fishes within the river. The Nativeness Indicator is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). The three metrics were aggregated using the Nativeness Indicator Expert Rule set (Carter 2012). The Recruitment Indicator (*SR-Fi*$_r$) represents the recent reproductive activity of the native fish community within each altitude zone. The Recruitment Indicator is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (RC-F corrected), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three metrics were aggregated using the Recruitment Indicator Expert Rule set (Carter 2012).

The three indicators were combined using the Fish Index Expert Rule set (Carter 2012) to calculate an overall Fish Condition Index (*SRA ndxFS*). The Fish Index Expert Rules analysis is weighted as $SR\text{-}FI_e > SR\text{-}FI_r > SR\text{-}FI_n$. The output generated by the Expert Rules analysis is scaled between 0 and 100, with higher values representing a 'healthier' fish community. The index was then partitioned into five equal bands to rate the condition of the fish community; "Excellent" (81-100), "Good" (61-80), "Moderate" (41-60), "Poor" (21-40), or "Very Poor" (0-20).

Table 2. Freshwater fish species predicted to have occurred in the Macleay Basin prior to European colonisation. Descriptions of predominance within altitude zones correspond to RC-F categories for the Murray Darling Basins Sustainable Rivers Audit program and are used to generate fish condition metrics.

Species	Common name	Coastal Plains	Lowlands	Midlands	Slopes	Uplands	Highlands
Anguilla australis	Short-finned eel	Occasional	Occasional	Occasional	Occasional	Occasional	Occasional
Anguilla reinhardtii	Long-finned eel	Common	Common	Common	Common	Common	Common
Arrhamphus sclerolepis	Snub-nosed garfish	Rare	Rare				
Galaxias maculatus	Common jollytail	Rare					
Galaxias olidus	Mountain galaxias			Rare	Rare	Common	Common
Galaxias sp. (A, F)	Climbing galaxias	Rare	Rare	Rare	Rare	Rare	Rare
Gobiomorphus australis	Striped gudgeon	Common	Common	Occasional	Rare		
Gobiomorphus coxii	Cox's gudgeon	Common	Common	Common	Common	Occasional	Rare
Hypseleotris compressa	Empire gudgeon	Common	Occasional	Occasional	Occasional	Rare	
Hypseleotris galii	Firetailed gudgeon	Common	Common	Occasional	Occasional	Occasional	Rare
Hypseleotris spp.	Unidentified gudgeon	Occasional	Occasional	Occasional	Occasional	Occasional	Rare
Melanotaenia duboulayi	Duboulay's rainbowfish	Common	Common	Common	Common		
Mogurnda adspersa	Purple spotted gudgeon	Rare	Rare	Rare	Rare	Rare	Rare
Mordacia mordax	Short-headed lamprey	Rare					
Mordacia praecox	Nonparasitic lamprey	Rare	Rare	Rare	Rare		
Mugil cephalus	Sea mullet	Common	Common	Occasional	Rare		
Neoarius graeffei	Blue catfish	Rare	Rare				
Notesthes robusta	Bullrout	Common	Occasional	Occasional	Rare		
Percalates novemaculeata	Australian bass	Occasional	Occasional	Occasional	Rare		
Philypnodon grandiceps	Flat-headed gudgeon	Common	Common	Common	Occasional	Occasional	Rare
Philypnodon macrostomus	Dwarf flat-headed gudgeon	Occasional	Common	Common	Occasional	Occasional	Rare
Potamalosa richmondia	Freshwater herring	Common	Common	Common	Rare		
Pseudomugil signifier	Southern blue-eye	Common	Occasional	Rare			
Retropinna semoni	Australian smelt	Common	Common	Common	Common	Occasional	Rare
Tandanus tandanus	North Coast freshwater catfish	Common	Common	Common	Common	Occasional	Rare
Trachystoma petardi	Freshwater mullet	Common	Common	Occasional	Occasional		

Table 3. Fish species predominately found in estuarine-marine waters predicted to have occurred within freshwater habitats in the Macleay Basin prior to European colonisation.

Species	Common name	Coastal Plains	Lowlands	Midlands	Slopes	Uplands	Highlands
Acanthopagrus australis	Yellowfin bream	Rare					
Afurcagobius tamarensis	Tamar goby	Vagrant					
Ambassis jacksoniensis	Port Jackson glassfish	Vagrant					
Ambassis marianus	Estuary glassfish	Rare					
Arenigobius bifrenatus	Bridled goby	Vagrant					
Argyrosomus japonicus	Mulloway	Vagrant					
Aseraggodes macleayanus	Narrow banded sole	Vagrant					
Brachirus nigra	Black sole	Vagrant					
Carcharhinus leucas	Bull shark	Vagrant					
Caranx sexfasciatus	Big-eye trevally	Vagrant					
Chanos chanos	Milkfish	Vagrant					
Dasyatis fluviorum	Estuary stingray	Vagrant					
Elops hawaiiensis	Giant herring	Vagrant					
Gerres subfasciatus	Silver biddy	Vagrant					
Girella tricuspidata	Luderick	Vagrant					
Gnathanodon speciosus	Golden trevally	Vagrant					
Gobiopterus semivestitus	Glass goby	Vagrant					
Herklotsichthys castelnaui	Southern herring (sprat)	Vagrant					
Hippichthys penicillus	Beady pipefish	Vagrant					
Hyporhamphus australis	Eastern sea garfish	Vagrant					
Liza argentea	Gold-spot mullet	Rare					
Lutjanus argentimaculatus	Mangrove jack	Vagrant					
Marilyna pleurosticta	Banded toadfish	Vagrant					
Megalops cyprinoides	Ox-eye herring	Vagrant					
Monodactylus argenteus	Silver batfish	Vagrant					
Mugilogobius platynotus	Flat-backed mangrove goby	Vagrant					
Myxus elongatus	Sand mullet	Vagrant					
Paramugil georgii	Fantail mullet	Vagrant					
Percalates colonorum	Estuary perch	Rare					

Table 3 cont. Fish species predominately found in estuarine-marine waters predicted to have occurred within freshwater habitats in the Macleay Basin prior to European colonisation.

Species	Common name	Coastal Plains	Lowlands	Midlands	Slopes	Uplands	Highlands
Platycephalus fuscus	Dusky flathead	Vagrant					
Pristis zijsron	Green sawfish	Vagrant					
Pseudogobius sp.9	Blue-spot goby	Vagrant					
Redigobius macrostoma	Largemouth goby	Vagrant					
Rhabdosargus sarba	Tarwhine	Vagrant					
Scatophagus argus	Spotted scat	Vagrant					
Selenotoca multifasciata	Striped scat	Vagrant					
Sillago ciliata	Sand whiting	Vagrant					
Tetractenos glaber	Smooth toadfish	Vagrant					

Table 4. Lengths (mm) used to delineate new recruits for the fish species sampled in the Macleay Basin. Values represent the length at 1 year of age for longer lived species and the age at sexual maturity for species that reach maturity within 1 year. Presence or absence of recruits for each species and the number of sites recruits were sampled at is also shown. Dark shading indicates alien species.

	Common Name	Recruitment Indicator Length (mm)	Recruits Present	No. of sites where recruits sampled (total no. of sites where species caught)
Small-bodied species	Unidentified hardyhead	50	✓	1 (1)
	Mountain galaxias	35	✓	3 (5)
	Mosquitofish	20	✓	15 (16)
	Striped gudgeon	68	✓	19 (21)
	Cox's gudgeon	68	✓	19 (22)
	Empire gudgeon	66	✓	11 (12)
	Firetail gudgeon	32	✓	15 (16)
	Hypseleotris sp.	35	✓	1 (1)
	Duboulay's rainbowfish	38	✓	10 (13)
	Flathead gudgeon	42	✓	4 (7)
	Dwarf flathead gudgeon	31	✓	7 (9)
	Southern blue eye	23	✓	9 (13)
	Australian smelt	37	✓	22 (23)
Large-bodied species	Yellowfin bream	130	×	0 (1)
	Long-finned eel	250	✓	9 (26)
	Common goldfish	117	✓	4 (4)
	Nonparasitic lamprey	100	×	0 (1)
	Sea mullet	180	✓	3 (5)
	Bullrout	50	×	0 (5)
	Dusky flathead	180	✓	0 (0)
	Australian bass	156	✓	2 (10)
	Freshwater herring	72	×	0 (3)
	Freshwater catfish	92	✓	3 (9)
	Freshwater mullet	180	×	0 (4)

3. RESULTS

3.1. General findings

In total, 27,119 fish were caught (*n* = 25,446) or observed (*n* = 1,673) across all sites and for all methods combined. By method, captures were: 20,981 by seine net, 3,963 (1,673 observed) by all electrofishing methods combined, and 502 in bait traps. From a total of 24 species (13 small-bodied and 11 large-bodied) caught and/or observed, catches by each method ranged from 23 by all electrofishing techniques combined, 14 by seine netting, and eight by bait traps. By number, the long-finned eel (*Anguilla reinhardtii*) (*n* = 697) was the most abundant of the large-bodied species captured (those species attaining maximum lengths >200 mm), followed by the sea mullet (*Mugil cephalus*) (*n* = 76) and the alien common goldfish (*Carassius auratus*) (*n* = 49) (Table 5). The long-finned eel and sea mullet also had the first and second highest biomass respectively among the large-bodied species sampled, whilst Australian bass (*Percalates novemaculeata*) had the third highest. Of the small-bodied species (those species attaining maximum lengths <200 mm), the alien eastern mosquitofish (*Gambusia holbrooki*) dominated the catch (*n* = 17,490), followed by Australian smelt (*Retropinna semoni*) (*n* = 2,626), and southern blue-eye (*Pseudomugil signifier*) (*n* = 1,030). The eastern mosquitofish also had the highest biomass among the small-bodied species, whilst Cox's gudgeon (*Gobiomorphus coxii*) and striped gudgeon (*Gobiomorphus australis*) had the second and third highest respectively.

There was considerable variation in total catch and in total biomass among sites as well as among altitude zones. By number, the highest catch was recorded at the Old Trout Hatchery site in the upper Apsley River (*n* = 7,893), whilst the lowest was at the Oaky Power Station site on the Oaky River (*n* = 27) in the upper reaches of the northern section of the Basin (Table 5). The highest biomass was also recorded in the upper section of the basin but at the Blue Hole on the Gara River, whilst the Old Trout Hatchery site recorded the second highest. The lowest biomass was recorded at the Toorumbee and Parrabel Creek Junction. By altitude zone, the general trend was for average catch for all species to be higher among sites in the lower reaches of the basin, decline somewhat in the Slopes and Upland zones, before increasing again in the Highland reaches. If only native species are considered, a similar trend is apparent for the lower and mid sections of the basin, but the catch progressively declined thereafter, with the Highland sites recording the lowest average catches for natives of all six altitude zones. In overall numbers, the highest average (±SE) catch was in the Highland zone at 4,137 ± 1,878 (native only = 75 ± 20.3), whilst the lowest was in the Upland zone at 206 ± 103.5. No alien species were recorded at any of the sites sampled in the Upland zone. Similarly, the highest average biomass when all species were included was in the Highland Zone, followed by the Coastal Plains and Midland zones, whilst the Upland zone had the lowest average biomass. Species richness tended to follow a more consistent trend, with the numbers of species caught at sites declining as altitude increased. The highest species richness was recorded at Sherwood Bridge and Battles Outlet sites (*n* = 17) in the Coastal Plains altitude zone, while the lowest species richness was recorded downstream of the Oaky Creek Power Station in the Oaky River, where only mountain galaxias (*Galaxias olidus*) and long-finned eel were caught. By altitude zone, the Coastal Plains sites averaged the highest species richness at 12.7 ± 1.43, and the Upland sites the lowest at 3.3 ± 0.5.

Table 5. Numbers of fish caught from sites in the Coastal Plains (CP), Lowland (LL), Midland (ML), Slopes (SLP), Upland (UP) and Highland (HL) altitude zones across the Macleay Basin. Counts represent total catch for all methods combined. Individual species sampled by each gear type represented by electrofishing □, seine netting ○, and bait traps #. Dark shading denotes introduced species.

		CP				LL					ML					SLP						UP				HL			
		Sherwood Bridge	Battles Outlet	Turners Flat	Temagog Bridge	Dowling Falls Road	Bellbrook	Nulla Nulla Bridge	Wititirin	Comara	Slim Dusty's	Holis Flat	D/S Georges Creek	Duneight Crossing	Postmans Trail	Nulla Nulla 3	Toorumbee Junction	Five Day Creek Cway	Apsley Gorge	Halls Creek	Glenmore	Enfield North	Straits Goldmine	Oaky Power Station	Wollombi Gorge	Blue Hole	Chamdler Bridge	Old Trout Hatchery	**Total**
Small-bodied species	Unidentified hardyhead o	7																											**7**
	Mountain galaxias □ o															10		1						16		30	9		**66**
	Eastern mosquitofish □ o #	277	120 0	536	153	451	335	741		173			1022	128	3				38		274					2151	2238	7770	**17490**
	Striped gudgeon □ o #	10	35	144	8	28	6	46	25	51	28	7	17	1	16	15	4	8	3	7	3	4							**466**
	Coxes gudgeon □ o #	3	2	12	1	21	3	1		15	18	6	2	2	22	74	11	56	18	15	8	34	11		162				**497**
	Empire gudgeon □ o #	39	41	66	3		9	31		4	6		31	1	11					6									**248**
	Firetail gudgeon □ o #		2		3	3	2	55	56	3	14	57	1	331	12	9	150	205			1								**904**
	Hypseleotris spp. o □ #																											74	**74**
	Duboulay's rainbowfish □ o #		21			16		1	55	62	13	200	5	64	131			2	1	285									**856**
	Flathead gudgeon □ o	1	3								38	3				15									16		22		**98**
	Dwarf flathead gudgeon o #	1	13						15		18			48	11			15	1	6									**128**
	Southern blue-eye □ #	10		4	2	13		32	16	215	372	100	2	129	133			2											**1030**
	Australian smelt o □ #	21	53	12	49	16	11	102	43	157	170	96	92	8	104	313	113	125	13	664	5	385	65		9				**2626**
Large-bodied species	Yellowfin bream □	1																											**1**
	Long- finned eel □	32	62	17	14	47	10	9	20	4	12	55	20	20	13	23		47	38	13	25	66	8	11	40	61	4	26	**697**
	Common goldfish □ o #												8								15					3		23	**49**
	Nonparasitic lamprey □															1													**1**
	Sea mullet □	38	9		16		4	9																					**76**
	Bullrout □	1	2	1			1						1																**6**
	Australian bass □	3	7	3	6		2					1	9		13				1	1									**46**
	Freshwater herring □		20				7																						**27**
	Dusky flathead □	0																											**0**
	Freshwater catfish □		1		1			1		5		2			9				1	2	14								**36**
	Freshwater mullet □	3			5		4						4																**16**

Total	447	147 1	795	261	595	394	1028	230	689	689	527	1214	732	478	460	278	461	114	999	345	489	84	27	227	2245	2273	7893

3.2. Expectedness Indicator

In total, 24 species of fish were caught across all sites in the Macleay Basin, including native freshwater and estuarine species, as well as a small number of alien species. Of the native freshwater species, 18 of the 'expected' 25 were sampled at one or more sites across the Basin as a whole. Those native freshwater species that were expected to occur but were not sampled were: short-finned eel (*Anguilla australis*) snub-nosed garfish (*Arrhamphus sclerolepis*), common jollytail (*Galaxias maculatus*), climbing galaxias (*Galaxias* sp. B), southern purple-spotted gudgeon (*Mogurnda adspersa*), short-headed lamprey (*Mordacia mordax*) and blue catfish (*Neoarius graeffei*). Only three of the 38 marine-estuarine vagrant species that could have possibly been sampled were caught or observed; yellowfin bream (*Acanthopagrus australis*), an unidentified hardyhead species (most likely *Atherinosoma microstoma*) and one dusky flathead (*Platycephalus fuscus*) that was observed but not caught. All three species were recorded at the Sherwood Bridge site in the lower Macleay River (Table 5). The occurrence of individual species varied considerably both at the site scale as well across altitude zones. At the site scale, long-finned eel were the most widespread of the native freshwater species sampled having been caught at all sites sampled, whilst Australian smelt (*Retropinna semoni*) (n = 23) and the two of the larger gudgeon species, Cox's gudgeon (*Gobiomorphus coxii*) (n = 22) and striped gudgeon (*Gobiomorphus australis*) (n = 21), were also relatively widespread (Table 5).

The Expectedness Indicator value for the majority of sites sampled across the Macleay Basin was either "Good" or "Excellent" (Figure 3; Table 7). However, four sites rated only "Moderate" and the Oaky Power Station site on the Oaky River rated as "Poor". Scores at the site scale ranged from 95.8 at the Sherwood Bridge site on the lower Macleay in the Coastal Plains altitude zone, down to 36.2 at the Oaky Power Station site in the Upland zone. The high score at Sherwood was a result of the capture of 15 native species, whilst at Oaky Power Station only two species, mountain galaxias and long-finned eels were caught. By altitude, sites on average (±SE) in the Coastal Plains (90.9 ± 2.85), Midlands (91.6 ± 0.90) and Slopes (89.7 ± 3.29) rated as "Excellent". The two higher altitude zones (Upland (51.6 ± 5.81) and Highland (47.4 ± 2.70)) had an overall rating of "Moderate", whilst the Lowland sites were on average 74.3 ± 4.22, giving it an overall rating of "Good".

3.3. Nativeness Indicator

Only two of the 24 fish species sampled across the Macleay Basin were alien; eastern mosquitofish (*Gambusia holbrooki*) and common goldfish (*Carassius auratus*) (Figure 4; Table 7). However, the eastern mosquitofish was by far the most abundant of all the species sampled (n = 17,490). It was also one of the more widespread having been caught at 16 of the 27 sites sampled and was present in all altitude zones except the Upland Zone. Contrastingly, goldfish were relatively low in number (n = 49) and were only caught at four sites scattered amongst the Midland, Slopes and Highland zones (Table 5). Despite the numbers of eastern mosquitofish caught, the generally high Nativeness scores for most sites reflects the relatively low biomass of alien compared to native species across the Macleay Basin as a whole. Of the 27 sites sampled, 15 scored a rating of "Excellent", eight as "Good" and three as "Moderate" (Table 7). Of those sites that scored an "Excellent", no alien species at all were caught at 11 of the 16 (Table 5). By altitude, the Lowland (82.7 ± 6.64), Midland (94 ± 5.90), Slopes (93.9 ± 5.22) and Upland (100) zones rated as "Excellent", whilst the Coastal Plains rated as "Good" (75.8 ± 1.82). In the Highland zone, the average was much lower (53.3 ± 3.33), giving it an overall rating of "Moderate". The lower rating for the Highland zone was due to the low numbers of natives in comparison to the high abundances of eastern mosquitofish and common goldfish (Table 5).

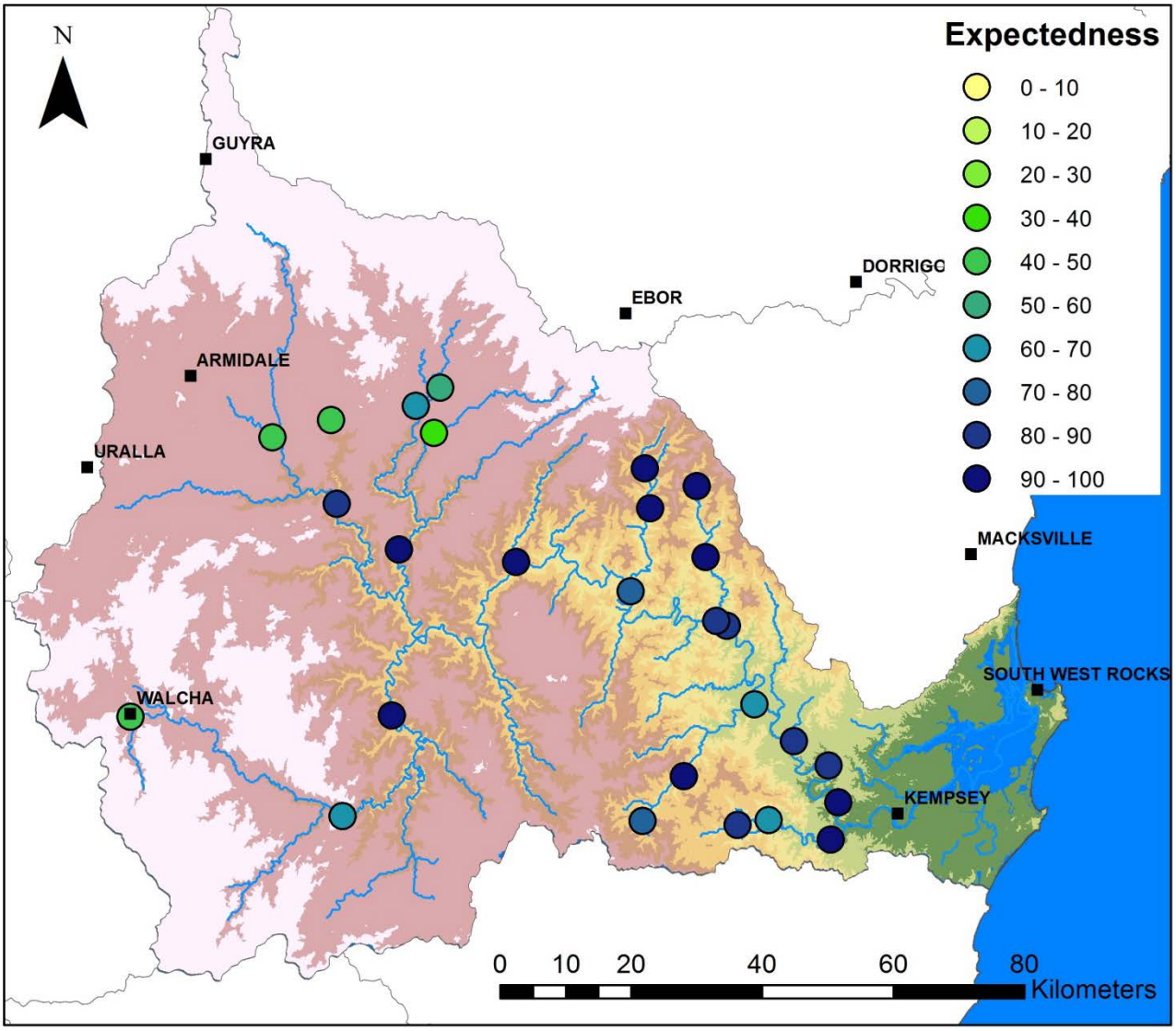

Figure 3. Expectedness Indicator ($SR - FI_e$) scores for the fish assemblages at the 27 sites sampled across the Macleay Basin. Yellow shading reflects very poor condition, while dark blue shading reflects fish assemblages in excellent condition. Altitude zones represented by: coastal plains, lowlands, midlands, slopes, uplands and highlands.

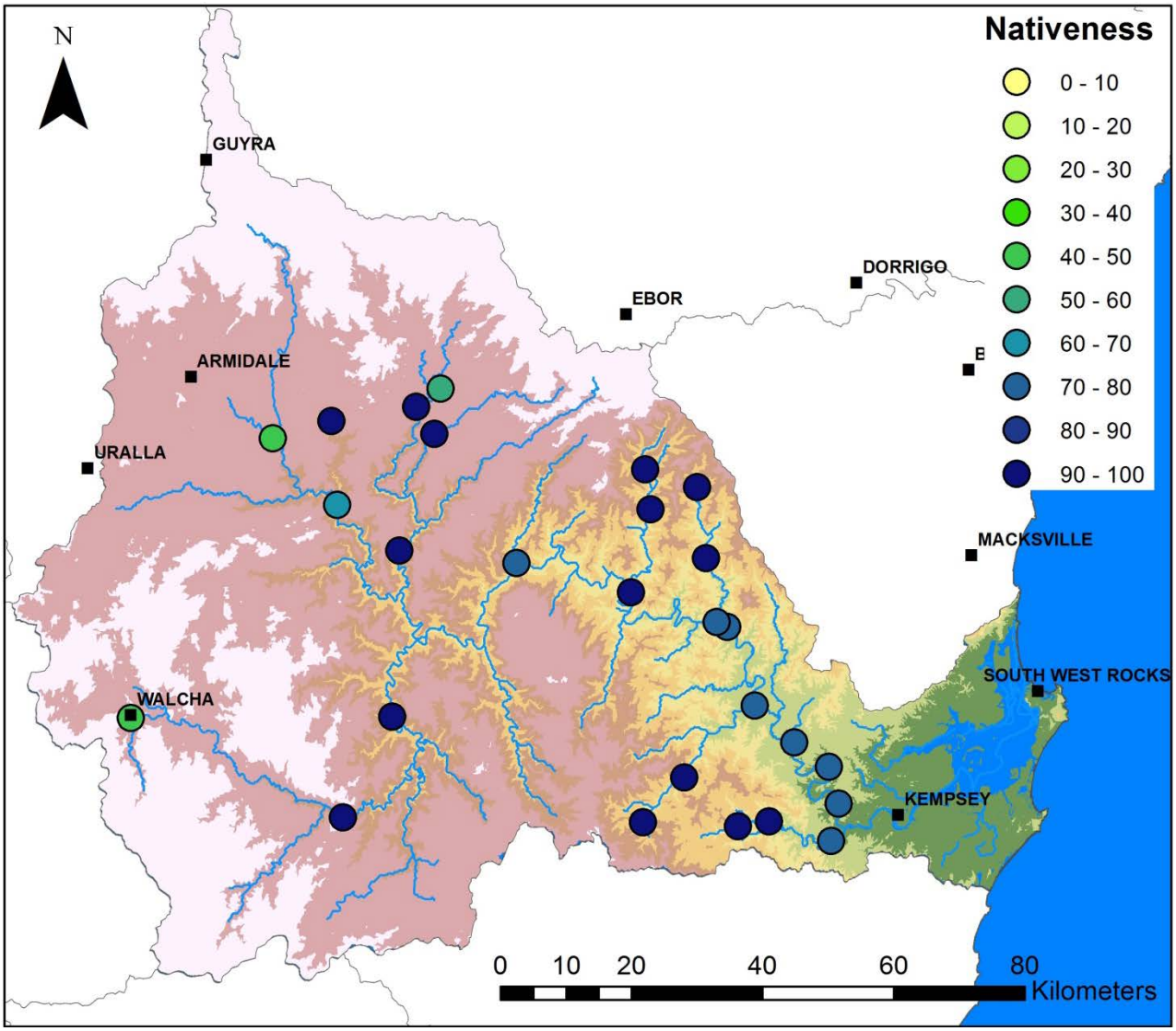

Figure 4. Nativeness Indicator ($SR - FI_n$) scores for the fish assemblages at the 27 sites sampled across the Macleay Basin. Yellow shading reflects very poor condition, while dark blue shading reflects fish assemblages in excellent condition. Altitude zones represented by: coastal plains, lowlands, midlands, slopes, uplands and highlands.

3.4. Recruitment Indicator

The Recruitment Indicator scores tended to be relatively low at all sites and across all altitude zones in the Macleay Basin (Figure 5; Table 7). Recruitment rated as "Moderate" in the Coastal Plains, Lowlands, Midlands and Slopes zones, and as "Very Poor" in the Upland and Highland zones. The highest score of 48.8 was in the Coastal Plains, while the Upland and Highland zones rated the lowest at 16.1 (Table 7). By number, recruits from all species and across all sites combined represented ~42% of the total catch. At the altitude zone scale, the percentage of recruits in the sample averaged from 41% in the Coastal Plains down to 12% in the Lowland Zone. Whilst the recruitment scores for all zones were generally low, among the small-bodied species there was evidence of recent recruitment at a minimum of one site for all 11 native freshwater species sampled (Table 5). In general, recruits were sampled at the majority of sites where adults were caught among all of the smaller-bodied species (% average ± SE = ~81.7 ± 0.04). In contrast, among the large-bodied species, recruits were present among only four of the eight native freshwater species sampled. The species with no recruits present were: nonparasitic lamprey (*Mordacia praecox*), bullrout (*Notesthes robusta*), freshwater herring (*Potamalosa richmondia*) and freshwater mullet (*Trachystoma petardi*). Among the four large-bodied species where recruitment was evident, the ratio of sites that had adults only, compared to those with adults and recruits, was still relatively low, with recruits of three of the four species at less than 35% of sites where adults were sampled. There was evidence of recruitment in both alien species sampled. In the case of the eastern mosquitofish, recruits were caught at 15 of the 16 sites where it was sampled, while common goldfish recruits were caught at all four sites where it was sampled. The unidentified hardyhead was the only estuarine species of which recruits were sampled.

3.5. Overall Fish Condition

The Overall Fish Condition Indicator (*Ndx-FS*) scores for sites within the Macleay Basin were generally either "Good" or "Moderate" in the lower to mid sections of the Basin, and "Poor" or "Very Poor" in the upper reaches (Figure 6; Table 7). Of the 27 sites sampled, 17 scored a "Good" rating, two a "Moderate" rating, five a "Poor" rating, and two a rating of "Very Poor" (Table 7). Scores ranged from a maximum of 77.4 at three sites in the Midland zone, down to 17.8 at the Oaky Power Station in the Upland Zone (Table 7). The average rating for sites within the Coastal Plain was "Good" (70.6 ± 0.94), the Lowland "Good" (62.8 ± 2.93), the Midland "Good" (76.1 ± 1.25), the Slopes "Good" (68.1 ± 1.49), the Upland "Poor" (30.2 ± 4.84), and the Highland "Poor" (21.6 ± 1.90).

In general, the four indicator scores calculated for individual sites in the majority of cases is reflected in the overall Basin-wide weighted averages. The weighted average score is the average condition across the entire basin as a whole, based on average zone scores for each parameter weighted by intersected stream length within each zone. The overall rating and weighted average (95% confidence limits (CL)) scores for Recruitment, Nativeness and Expectedness were: Recruitment "Poor' 32.3 (CL = NA), Nativeness 'Good" 79.4 (CL = 75.83 – 82.57), and Expectedness "Good" 69.5 (CL = 68.63-73.72) (Table 6). The weighted average score for Overall Fish Condition (Ndx-FS) was 48.8 (CL = 47– 50.68), giving the Macleay Basin fish community an overall rating of "Moderate" (Table 6).

Table 6. Basin-wide weighted (average zone scores weighted by stream length within each zone) average and confidence limits (CL) for the Macleay Basin fish community.

	Recruitment	**Nativeness**	**Expectedness**	**Ndx-FS**
Weighted average	32.2	79.4	69.5	48.8
Lower 95% CL	NA.	75.83	68.63	47.00
Upper 95% CL	NA.	82.57	73.72	50.68
Rating	Poor	Good	Good	Moderate

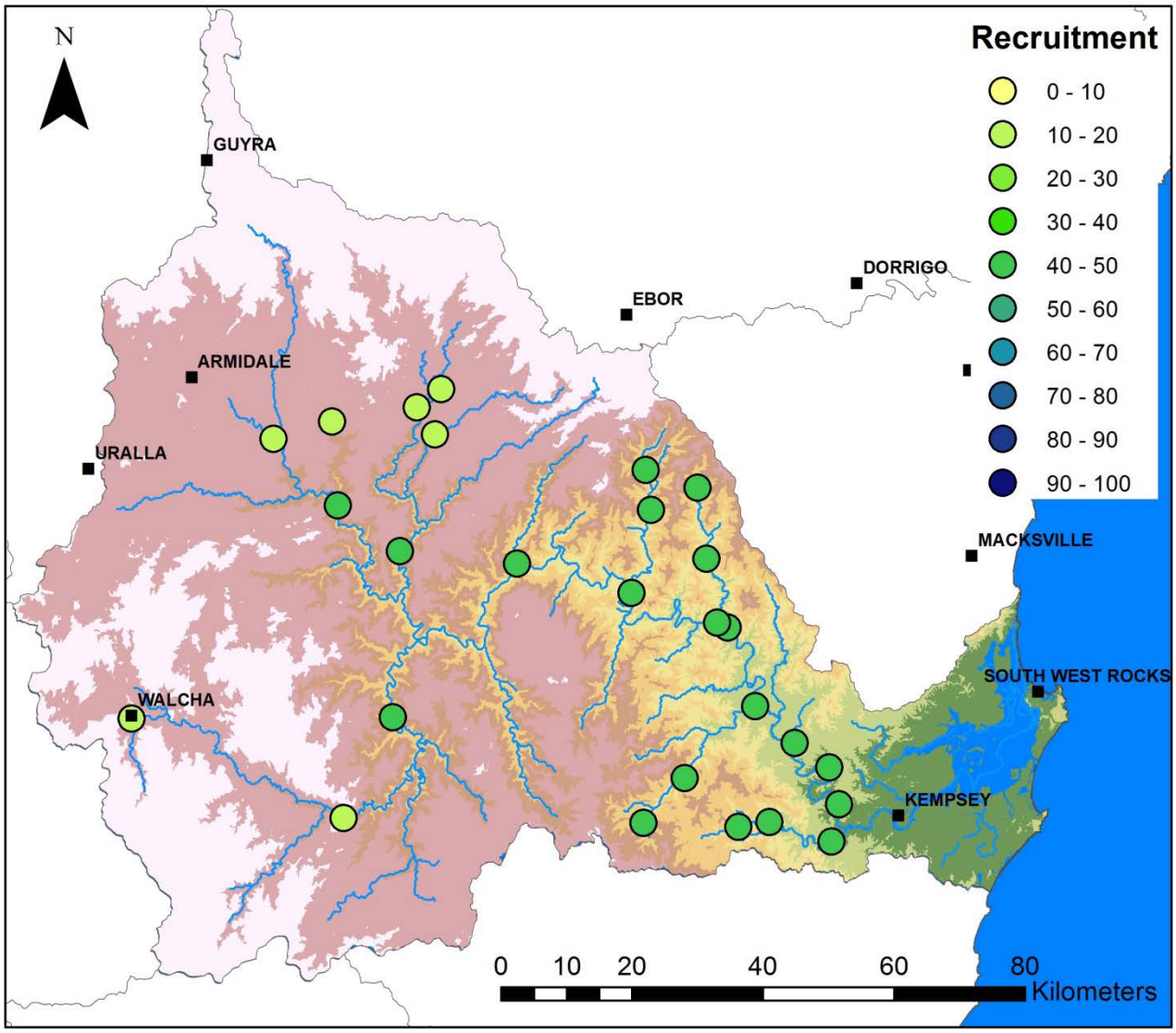

Figure 5. Recruitment Indicator (*SR-FI*$_r$) scores for the fish assemblages at the 27 sites sampled across the Macleay Basin. Yellow shading reflects very poor condition, while dark blue shading reflects fish assemblages in excellent condition. Altitude zones represented by: coastal plains, lowlands, midlands, slopes, uplands and highlands.

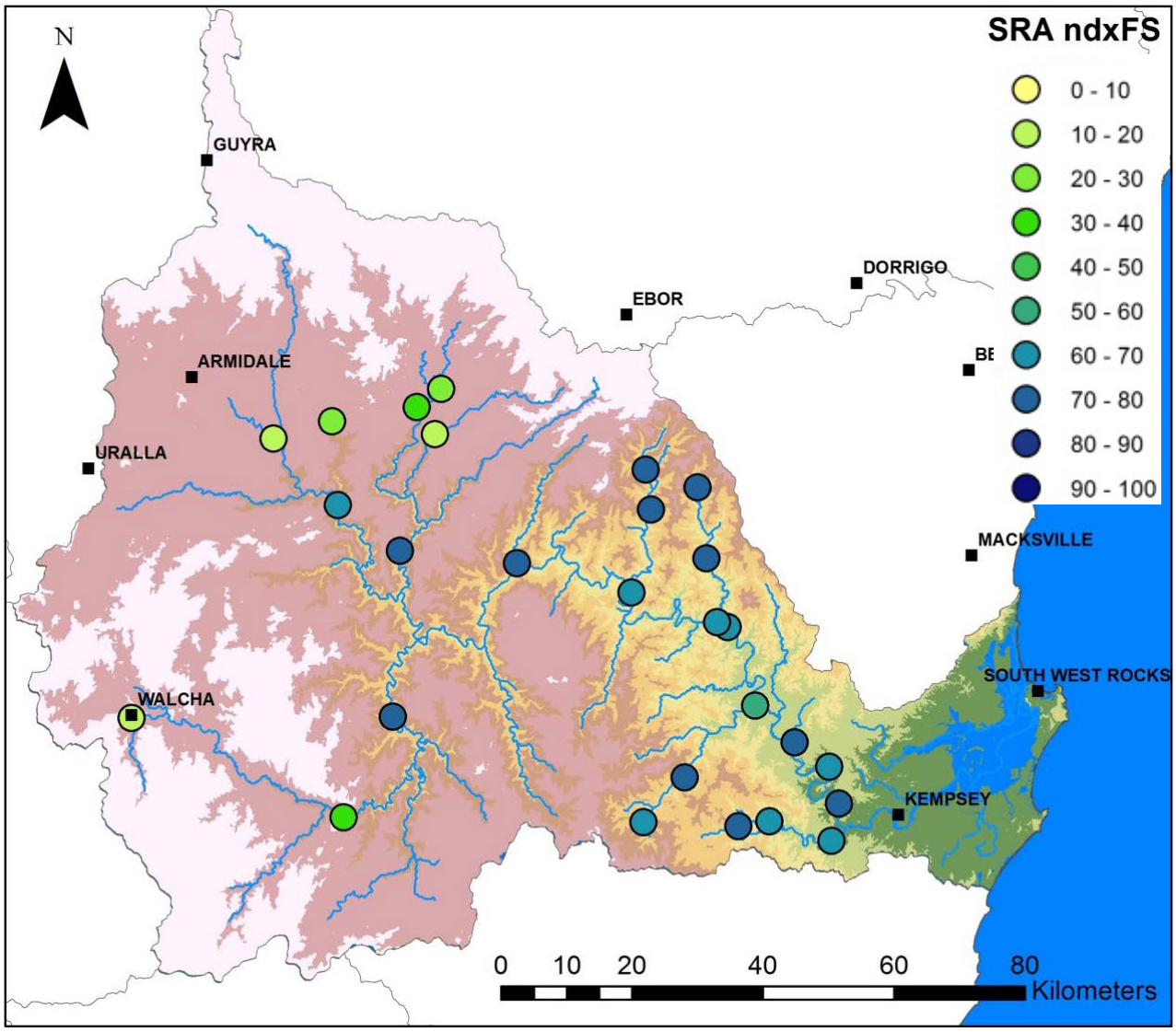

Figure 6. Overall Fish Condition Indicator (*SRA ndxFS*) scores for the fish assemblages at the 27 sites sampled across the Macleay Basin. Yellow shading reflects very poor condition, while dark blue shading reflects fish assemblages in excellent condition. Altitude zones represented by: coastal plains, lowlands, midlands, slopes, uplands and highlands.

Table 7. Expectedness Indicator, Nativeness Indicator, Recruitment Indicator, SRA ndxFS values and the corresponding ratings for fish at sites in the Coastal Plains (CP), Lowland (LL) and Midland (ML) altitude zones across the Macleay Basin.

	Site	Expectedness Index	Rating	Nativeness Index	Rating	Recruitment Index	Rating	SRA ndxFS	Rating
CP	Sherwood Bridge	95.8	Excellent	77.6	Good	46.9	Moderate	72.6	Good
	Battles Outlet	95.6	Excellent	70.9	Good	46.9	Moderate	69.8	Good
	Turners Flat	84.2	Excellent	75.3	Good	46.9	Moderate	68.4	Good
	Temagog Bridge	88.3	Excellent	79.3	Good	46.9	Moderate	71.7	Good
LL	Dowling Falls Road	65.1	Good	72.1	Good	47.1	Moderate	52.7	Moderate
	Bellbrook	86.6	Excellent	70.4	Good	47.1	Moderate	68.1	Good
	Nulla Nulla Bridge	80.3	Good	73.4	Good	47.1	Moderate	64.8	Good
	Wittitrin	65.1	Good	100	Excellent	47.1	Moderate	60.1	Moderate
	Comara	74.5	Excellent	97.9	Excellent	47.1	Moderate	68.4	Good
ML	Slim Dustys	92.1	Excellent	100	Excellent	48.8	Moderate	77.4	Good
	Holis Flat	92.1	Excellent	100	Excellent	48.8	Moderate	77.4	Good
	D/S Georges Creek	92.9	Excellent	70.4	Good	48.8	Moderate	71.1	Good
	Duneight Crossing	88	Excellent	99.5	Excellent	48.8	Moderate	77.2	Good
	Postmans Trail	92.7	Excellent	100	Excellent	48.8	Moderate	77.4	Good
SL	Nulla Nulla 3	94.4	Excellent	100	Excellent	42.6	Moderate	70.4	Good
	Toorumbee Junction	76.4	Good	100	Excellent	42.6	Moderate	65	Good
	Five Day Creek Causeway	94.8	Excellent	100	Excellent	42.6	Moderate	70.4	Good
	Apsley Gorge	94.8	Excellent	95.1	Excellent	42.6	Moderate	70.5	Good
	Halls Peak	94.8	Excellent	100	Excellent	42.6	Moderate	70.4	Good
	Glenmore	82.8	Excellent	68.1	Good	42.6	Moderate	62.1	Good
UL	Enfield North	60.6	Good	100	Excellent	16.1	Very Poor	37.9	Poor
	Straits Goldmine	49.1	Moderate	100	Excellent	16.1	Very Poor	27.2	Poor
	Oaky Power	36.2	Poor	100	Excellent	16.1	Very Poor	17.8	Poor
	Wollomombi Gorge	60.6	Good	100	Excellent	16.1	Very Poor	37.9	Poor
HL	Blue Hole	44.7	Moderate	50	Moderate	16.1	Very Poor	19.7	Very Poor
	Chandler Bridge	52.8	Moderate	60	Moderate	16.1	Very Poor	25.4	Poor
	Old Trout Hatchery	44.7	Moderate	50	Moderate	16.1	Very Poor	19.7	Very Poor

4. DISCUSSION

The relatively high species richness found in the current study suggests that the overall structure of the fish community in the Macleay Basin has changed little since European settlement. Of the ~26 native freshwater species thought to have occurred naturally throughout the basin pre-1770, 19 were captured during the current survey. In general, these number of species caught reflects to some degree previous sampling undertaken within the Macleay Basin, albeit not all in the one survey. In the first directed state-wide survey of the freshwater fish communities of NSW, Llwellyn (1983) sampled fives sites in the Macleay Basin in 1975-76 as part of the overall program. While the number of sites sampled was low, Llwellyn (1983) reported the capture of 15 species (14 native and one alien), with all but short-finned eel (*Anguilla australis*), western carp gudgeon (*Hypseleotris klunzingeri*) and climbing galaxias (*Galaxias* sp. (A, F)) also caught in the current study. Notable absentees from Llewellyn's (1983) catch were Australian bass (*Percalates novemaculeata*), freshwater mullet (*Trachystoma petardi*), freshwater herring (*Potamalosa richmondia*) and bullrout (*Notesthes robusta*) among the large-bodied species, as well as two gudgeon species (*Philypnodon macrostomus* and *Philypnodon grandiceps*) and the mountain galaxias (*Galaxias olidus*) among the small-bodied species. The absence of these and of the other species thought to have occurred pre-1770 from Llewelyn's (1983) sample was most likely a combination of the sampling techniques used, the relatively small number of sites sampled, and/or the life-history strategies of individual species meaning that they were possibly in different parts of the basin at the time of sampling.

More recent surveys across the Macleay Basin have captured similar numbers of species to that captured by Llwelyn (1983) and in the current study. The *NSW River Survey* (Harris and Gehrke 1997) caught 18 native freshwater species from the only two sites sampled in the Basin (one each in the Gara and Macleay rivers), all of which were also caught in the current study. Similarly, the three NSW MER survey rounds undertaken within the Macleay have caught 11 freshwater species from two sites, 19 from 13 sites and 14 from two sites in the 2006-07, 2009-10 and 2012-13 surveys respectively (NSW DPI Freshwater Fish Database, unpublished data). The two sites sampled in 2006-07 and 2012-13 were the same two sites sampled as part of the *NSW River Survey*. The only native freshwater species caught when catches of all three MER surveys are combined that was not caught in the current study was the short-finned eel. Whilst Llwelyn also reported short-finned eels in his study, the species is not considered particularly common in the freshwaters of northern NSW and is more abundant toward the southern end of its range in southern NSW, Victoria and Tasmania (Pusey *et al* 2004). As such, the species could almost be considered a vagrant rather than common in North Coast Rivers, meaning its appearance in samples is going to be rare.

As with the short-finned eel, the remaining six native freshwater species likely to have occurred historically in the catchment, but that were not captured in the current study, all have restricted distributions or are considered naturally rare (Table 3). These were snub-nosed garfish (*Arrhamphus sclerolepis*), common jollytail (*Galaxias maculatus*), climbing galaxias (*Galaxias* sp. (A, F)), purple-spotted gudgeon (*Mogurnda adspersa*), short-headed lamprey (*Mordacia mordax*) and blue catfish (*Neoarius graeffei*). Of these, the common jollytail, short-headed lamprey, purple-spotted gudgeon and the blue catfish have not previously been captured in the Macleay Basin but have been sampled in nearby drainages. The nearest confirmed records of common jollytail is in the Hastings River in the Hastings Basin to the south, and in Warrel Creek (a tributary of the Nambucca River) to the north. Similarly, purple-spotted gudgeon and blue catfish have been caught to the north in the Clarence Basin, but have never been recorded south of the Clarence. Likewise, the only record of short-headed lamprey on the NSW north coast is a single museum specimen collected in the Richmond River Basin in 1966 (Australian Museum record No: I.24282-001), with the species distribution mainly considered to the south of the Hawkesbury-Nepean Basin.

Of the remaining two species, snub-nosed garfish and climbing galaxias both have previously been recorded in the Macleay Basin but only in low numbers. Snub-nosed garfish are generally considered to widespread across the NSW north coast, but they are largely restricted to the coastal plains and are most frequently

only collected in freshwater near the tidal limits (21 - 69% of sampling sites within the coastal plain zone). Therefore it is not unexpected that they were not sampled in the current study given that there were only a few sites sampled in semi-tidal waters. There was also a low likelihood of sampling climbing galaxias species in the current study, given that very few steep gradient and forested headwater streams were sampled which is their preferred habitat (McDowall and Fulton 1996). However, whilst climbing galaxias occupies these habitats for the majority of it life, the species is generally considered to be catadromous, meaning it must migrate downstream to the estuary to spawn (McDowall and Fulton 1996). There are exceptions to this life-history strategy, with some land-locked populations capable of spawning and recruiting in freshwater lake environments, however this is rare. Recent intensive surveys specifically targeting Galaxias spp. across NSW (Raadik 2014), found climbing galaxias in only two rivers systems across the North Coast region and none at all were caught in the Macleay catchment (Tarmo Raadik pers. comm.). This suggests that if present within the system they are most likely in very few streams at best and where present are likely only in low abundance.

Only three estuarine species were caught or observed in the current study; yellowfin bream (*Acanthopagrus australis*), an unidentified hardyhead (*Craterocephalus* sp.) and dusky flathead (*Platycephalus fuscus*). Previous studies of the freshwater reaches of the Macleay Basin have also only reported low numbers of marine-estuarine species, with most catching none or only one. Llewellyn's (1983) 1975-76 survey of the basin returned no estuarine species, whilst in the *NSW River Survey* (Harris and Gehrke 1997) only one estuarine vagrant was caught, golden trevally (*Gnathanodon speciosus*). Similarly, the 2006-07 and 2012-13 NSW MER surveys (NSW DPI Freshwater Fish Database, unpublished data) reported no estuarine species in the Macleay. The two sites sampled in each of the two surveys were above 60 MASL meaning there was little chance of encountering estuarine vagrants. Unlike the other two NSW MER surveys, in 2009-10 13 sites were sampled across the Macleay Basin, including two in the Coastal Plains. However, only two individuals of the one estuarine species, yellowfin bream, were captured. The small numbers of marine-estuarine species caught in the current study and in previous studies in the Macleay Basin almost certainly reflects the lack of sampling sites within the tidal freshwater sections of the system.

There are currently no species endemic to the Macleay Basin listed as threatened under the *Fisheries Management Act 1994*. However, as discussed previously, a number of species are considered naturally rare due to their cryptic nature, habitat preferences or simply because they are at the extremes of their natural distribution. Among these is the nonparasitic lamprey (*Mordacia praecox*), which until the current study has rarely been caught in NSW and only as far north as the Deua River to the south of Sydney (Australian Museum record No: I.37169-001). Lampreys are an ancient fish and along with the hagfishes, are the sole surviving representatives of jawless vertebrates (Potter 1996). Recent captures across south-east Queensland suggest lampreys may be more widely distributed than previously thought and that at least some rivers in Queensland may contain at least one previously undescribed species (Hoffman 2012). DNA from the Macleay lamprey is currently being analysed and may provide "the missing link" between the southern and northern groups. As such, further investigation is warranted within the Macleay to determine the extent and abundance of lamprey throughout the Basin, both to determine and describe where and what habitats they are using and to implement appropriate management actions if required.

The high Expectedness Indicator scores for the majority of sites in the current study suggest that the fish community in the Macleay Basin closely resembles that which would have been present prior to European settlement. Just over 80% of the 27 sites sampled scored either an "Excellent" or "Good" rating for Expectedness. Of the remaining sites, ~15% scored a "Moderate" rating, with only the Oaky Power Station site scoring a "Poor". In general, the overall trend was for scores to be lowest in the upper altitude zones, particularly in the Upland and Highland zones. These results most likely reflect the poor state of the upper sections of the Basin, with activities such as land clearing and stream modification on the plateau directly affecting the fish community (Benson and Ashby 2000). The two exceptions to this were the Enfield North and Wollomombi Gorge sites which both rated as "Good". Both sites are located in steep gorge country below the plateau and as such have been largely unaffected by anthropogenic influences. As with most river systems, there was a decreasing number of species caught across the Macleay Basin as altitude increased. In the Coastal Plains, species numbers caught at sites averaged (± SE) 12.8 (± 0.1.43), in the Lowlands 9 (± 1.82), in the Midlands 11.5 (± 0.85), in the Slopes 7.3 (± 0.91), in the Uplands 3.3 (± 0.48), and in the Highlands 4 (± 0.00). Very similar results were reported in the Bellinger (Gilligan 2010), Hastings (Butler

et al. 2012) and Clarence (Butler *et al.* 2014) Ecohealth surveys. Generally, decreasing stream order is associated with a decline in species diversity as well as in overall abundance (Platts 1979; Beecher *et al.* 1988; Gehrke and Harris 2001). This decline may reflect many factors, but is generally considered to be due to a decrease in the amounts of available habitat and a decline in the stability of the environment as stream order becomes lower (Harrel and Dorris 1968). Additionally, in coastal river systems such as those along the North Coast of NSW, the occurrence and abundance of diadromous species such as freshwater mullet, Australian bass and freshwater herring, declines in direct relation to increasing distant from the estuary.

Whilst the overall structure of the fish community has changed little across the Macleay Basin as a whole, there is evidence of at least some localised change at the site and even the altitude scale in some catchments. Overall, the weighted RC-F scores indicated that many of the sites sampled were relatively close to historical levels of species richness, however, nine species were caught at <50 % of sites where they may have occurred in the past, only five species were caught at >75% of sites where they may have occurred historically, and only one species (striped gudgeon) was caught at all sites where it was expected to occur. At the altitude scale, 17 of the native freshwater species sampled were caught within >50% and 14 within >75% of the zones in which they were likely to have occurred historically. Further sampling is required to confirm that there is a localised loss of some species in some areas; however, given that in general most species are occurring in at least some catchments, and if there is connectivity between sites or catchments where species are in low number or have become locally extinct and where there are good abundances, then recolonization will naturally occur given time.

The “Excellent” or “Good” Nativeness rating for the majority of sites in the current study suggests that alien species are most likely having little influence on the fish communities across the Macleay Basin. Only two alien species were caught, eastern mosquitofish (*Gambusia holbrooki*) and common goldfish (*Carassius auratus*), with the later only caught at four sites and in relatively low numbers. Contrastingly, however, eastern mosquitofish were caught at 15 of the 27 sites sampled and were in relatively high numbers at most sites, particularly in the Highland zone. The high abundance of eastern mosquitofish and the presence of small numbers of common goldfish, as well as the lack of native species, resulted in the “Moderate” rating for Nativeness for all three sites sampled in the Highlands. Both common goldfish and eastern mosquitofish are considered relatively ubiquitous across NSW. Sampling by Fisheries NSW (1977-current), has resulted in captures of common goldfish at 1162 sites in 27 drainage basins across the State, and eastern mosquitofish at 1667 sites in 41 drainage basins (Unpublished data, Fisheries NSW Freshwater Fish Database). Although common goldfish are a relatively benign alien species in that they are largely detrital and plant eaters and do not predate heavily on native fauna, eastern gambusia are considered more of a threat to biodiversity via predation and competition, including inter-specific interactions with both small and large bodied fish, and with many other native aquatic fauna as well (Komak and Crossland 2000; Harris 2013). As such, their presence should be considered an issue and whenever possible the public should be made aware of their presence in the Macleay Basin and be educated about the impacts that they have on native aquatic fauna.

Whilst the only alien species caught in the current study were eastern mosquitofish and common goldfish, other alien species have been captured or reported previously within the Macleay Basin including common carp (*Cyprinus carpio*), redfin perch (*Perca fluviatilis*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Common carp are present in the majority of inland waterways and several coastal drainages across NSW. Graham *et al*. (2005) reported the possible occurrence of common carp in the upper Macleay catchment, but qualified the suggestion by stating the report was only anecdotal and that follow up scientific surveys had failed to capture any specimens. It is likely given no carp were captured then or in subsequent surveys that what may have been observed were common goldfish. Redfin perch are moderately sized fish growing to 400-450 mm and 1-2 kg and are native to Eurasia (Harris 2013). The species was first introduced to Australia in 1862 and is considered a threat to aquatic biodiversity in Australia and it is also a vector for the epizootic haemopoietic necrosis virus which is pathogenic to some native fish (Harris 2013). Fisheries NSW have sampled redfin perch in two locations in the upper Macleay Basin, in the Gara River near Armidale in 1998 and in Mihi Creek to the south of Armidale in 2003 and 2004. Not known as a great disperser, generally redfin perch are deliberately moved to provide fishing opportunities or for use as bait. As such, if the species is still persisting in parts of the upper basin, the best

way to prevent their further dispersal is by targeted public education programs extolling the negative impact the species has on native fish.

No brown or rainbow trout were caught in the current study but both species have been sampled previously by Fisheries NSW in the upper basin (Unpublished data, Fisheries NSW Freshwater Fish Database; Cameron *et al.* 2012). Trout are produced and stocked annually throughout the higher altitude regions of NSW by two NSW Government hatcheries in the north and south of the state. The northern hatchery (L P Dutton Trout Hatchery) is located near the village of Ebor on the headwaters of the Serpentine River in the Macleay Basin. The hatchery produces in the vicinity of two million trout each year (Peter Selby, L P Dutton Hatchery Manager pers. com.), with most fish released across the New England region and into a small number of North Coast streams (>600 m ASL). The North Coast stockings include annual releases of ~200,000 rainbow and ~100,000 brown trout in a number of streams across the upper Macleay (Unpublished data, Fisheries NSW Stocking Database). These streams include among others the upper reaches of the Apsley, Styx, Tia, Oaky and Dykes rivers. While many of the streams stocked are considered marginal, in that during extreme summers water temperatures may exceed that preferred by trout, given the numbers stocked it is likely that both species persist in at least some systems year round. Recent sampling by Fisheries NSW in the upper north-western section of the Macleay Basin, including the upper Styx River, caught both species of trout in low numbers at a number of sites (Cameron *et al.* 2012). It is therefore likely that if more sampling had been undertaken in the current study in the smaller streams across the upper Macleay Basin, greater numbers of trout would have been caught.

The Recruitment Indicator scores for the Macleay Basin were considerably lower than either the Nativeness or Expectedness scores. All altitude zones rated as either "Moderate" (n = 4) or "Very Poor" (n = 2), suggesting recruitment in 2013-14 was much lower than expected throughout the entire Basin. This was particularly apparent at higher altitudes, with both the Upland and Highland zones scoring a lowly 16.1 out of a possible 100. Among the individual recruitment metrics (averaged across all species and all sites), the average proportion of sites per zone at which each species was recruiting ranged from 23% in the upland zone up to 62% in the midland zone, whilst the proportion of species that were captured within each zone that showed evidence of recruitment ranged from 67% in the upland zone up to 73% in the lowland and midland zones, with a weighted average of 71% (based on stream length within each zone). These results suggest that while the overall scores were low for recruitment, even within the worst zones recruits were still present at around a quarter of the sites where they were expected, and that across all zones less than a third of species were not recruiting where adults were present. This result is somewhat better than that reported for the Hastings Basin, where the proportion of sites at which species were recruiting was as low as 12%, while the catchment weighted average of the proportion of species in each zone that were recruiting was also lower at 62% (Butler *et al.* 2012). Contrastingly, the Clarence Basin was similar to the Macleay; with the proportion of sites at which species were recruiting also ranging up to 62%, whilst the weighted average for proportion of species that were captured within each zone that showed evidence of recruitment was only marginally lower at 69% (Butler *et al.* 2014).

Whilst the recruitment scores across the Macleay were relatively low, overall they were higher than that reported for the Hastings Basin (Butler *et al.* 2012) and with the exception of the upland and highland zones, were similar to that of the Clarence Basin (Butler *et al.* 2014). Butler *et al.* (2012, 2014) suggested that low recruitment numbers in the Hastings and Clarence were most likely due to a number of anthropogenic and natural factors. These factors could include natural effects such as variations in the availability of food, levels of predation, water temperature, discharge, habitat availability, etc. (Myers *et al.* 1997; Beesley *et al.* 2012) or anthropogenic influences such as man-made barriers preventing migration of adults and juveniles, excessive water extraction leading to fish passage issues or the destruction of breeding habitat etc. In most cases it is likely that two or more variables combine to bring about recruitment failure within years as well through time. To fully understand the processes that drive and ultimately dictate the failure or success of recruitment in dynamic river systems like those along the NSW North Coast will require multiple samples over multiple years to effectively determine the difference between years where natural variability is occurring as opposed to true long-term recruitment failure.

The overall rating of "Moderate" for the Macleay Basin is a representative assessment of the condition of the fish community at the time of sampling. The weighted average scores of "Good" for Expectedness and

for Nativeness suggest that the overall structure of the fish community in the Macleay Basin has changed very little since European settlement and remains in reasonable condition. Whilst the overall rating of "Poor" for Recruitment is low, recruits of all small-bodied and the majority of large-bodied freshwater species were captured somewhere in the basin. Additionally, by number, recruits represented over 40% of the total catch of freshwater native fish across the basin as a whole. As intended under the strategy of the Ecohealth program, longer-term trends will become more apparent for all health indices including Recruitment as sampling is repeated across multiple years. As the current study is the first detailed study of the freshwater fish of the Macleay Basin, the data presented effectively provides a baseline against which future samples can be compared.

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