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Fish Barrier Prioritisation – Daintree, Mossman, & Lower-Barron Catchments

Final Report

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Cover Image: From left to right, top to bottom; South Mossman River Causeway (BarID: 1273, Rank 6), Granite Creek Causeway; Bloomfield River Catchment (BarID:603, Rank 1), Saltwater Creek; Mossman Basin (BarID1218, Rank 14), Dunne Road tidal flap barrier - Avondale Creek Estuary (BarID: 682 Rank 9), Post larvae Jungle Perch (*Kuhlia rupestris)* (diadromous*)*; Olufson Creek - Bloomfield River Catchment, Cooper Creek; Daintree Basin, Opal Cling Goby (diadromous) (*Stiphodon semoni);* fast flowing rocky substrate waterways - Daintree Basin, Juvenile Barramundi (*Lates calcarifer*) (diadromous).

Contents

Glossary

Diadromous	Diadromous fishes are truly migratory species whose distinctive characteristics include that they (i) migrate between freshwaters and the sea; (ii) the movement is usually obligatory; and (iii) migration takes place at fixed seasons or life stages. There are three distinctions within the diadromous category: catadromous, amphidromous, and anadromous.
Catadromous	Diadromous fishes which spend most of their lives in fresh water and migrate to sea to breed.
Amphidromous	Diadromous fishes in which migration between freshwater and the sea is not for the purpose of breeding but occurs at some other stage of the life cycle.
Anadromous	Diadromous fishes which spend most of their lives at sea and migrate to freshwater to breed.
Potamodromous	Fish species whose migrations occur wholly within freshwater for breeding and other purposes
Ontogenetic Migration	Migrations associated with specific life stages
Declared Downstream Limit	The lower-most freshwater reach of a stream, as determined by Queensland Department of Natural Resources and Mines (DNRM).

Acronyms

CS	Catchment Solutions
NRM	Natural Resource Management Group
WT	Wet Tropics
WQ	Water Quality
WQIP	Water Quality Improvement Plan
FBPP	Fish Barrier Prioritisation Process
GEP	Google Earth Pro
GIS	Geographic Information System
GPS	Global Positioning System
DDL	Declared Downstream Limit
DAF	Department of Agriculture and Fisheries
DNRME	Department of Natural Resources, Mines and Energy
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
TSS	Total Suspended Solids

Executive Summary

The objective of the Daintree to Lower-Barron fish barrier prioritisation (known here-in as DLBFBP) was to identify and assess the large number of anthropogenic barriers that prevent, delay, or obstruct fish migration within the Daintree, Mossman, and Lower Barron River catchments. Fish barriers identified through this process were ranked in order of priority, accounting for the cumulative impacts' barriers have on aquatic ecosystems, fisheries resources, economy, and the local community. This study was conducted in conjunction with the Murray and Lower Herbert Rivers Fish Barrier Prioritisation which focused on the southern Wet Tropics region.

Fish migration is an essential life-history adaptation utilised by many freshwater fish species in coastal catchments in the Wet Tropics region. Migration strategies between key habitats have evolved for a variety of reasons, including feeding and reproduction purposes, predator avoidance, nursery habitat utilisation, maintaining genetic diversity, and population dispersal. Barriers preventing connectivity located in the Daintree, Mossman, and Lower Barron River catchments (known here-in as 'the study area') impact fisheries' productivity and create environmental conditions favourable for invasive pest fish species. Significantly, approximately 70% of the Daintree to Lower Barron freshwater fish species undertake ontogenetic shifts in habitat use between estuarine and freshwater environments. Remediating barriers and maintaining connectivity between saltwater and freshwater is therefore critical to ensuring freshwater fish community condition and improving overall aquatic ecosystem health. This project aimed to address such issues, through identifying, ranking, and in time remediating fish passage barriers throughout the northern Wet Tropics region.

Explicitly, the overall aims of the project were to;

1. Systematically identify all potential barriers to fish passage in northern Wet Tropics coastal catchments.
2. Undertake catchment-scale river network GIS analysis of biological, geographic, and environmental characteristics associated with each potential barrier to produce a prioritised list for ground-truthing, i.e., visit the most important potential barrier sites first.
3. Perform fine-scale, site-specific barrier assessment to validate, score, and rank priority barriers based on fish passability, configuration, in-stream habitat availability, and flow characteristics.
4. Further refine and prioritise barriers based on social, ecological, and fisheries productivity criteria.
5. Produce a list of the top 30 priority ranked fish barriers in the northern Wet Tropics region showing remediation options and indicative costs.
6. Facilitate the adoption of fish barrier remediation projects by NRM groups, State, and Local governments.

The fish barrier prioritisation process involved identifying potential barriers using high-resolution aerial imagery across the three catchments. In total, 1,649 potential barriers were identified in the project area (2,797 km^2) at a rate of 1.69 potential barriers per km^2. A Geographic Information System (GIS) based stream network analysis tool (RivEx) was then used to rapidly assess and prioritise the high number of potential barriers using a collective optimisation rank-and-score approach. Importantly, key socioeconomic flow-on benefits of improving aquatic connectivity were considered, i.e., the degree to which remediation may increase fisheries productivity and/or conserve vulnerable species.

In many parts of the world, remediation of man-made barriers with appropriately designed fishways is one of the most successful management tools utilised by government agencies and NRM groups to help restore populations of fish impacted by barriers. Objectively choosing the ‘right’ barriers to remediate in order to obtain the greatest benefits requires a holistic prioritisation process. In this prioritisation assessment, the process guided the authors and Terrain NRM project staff to ground-truthing the top priority ranked potential barriers in order of importance. In total, 193 potential barriers were assessed in the field, resulting in 120 actual barriers and 73 sites not impacting connectivity e.g., bed level crossings and bridges. These results showed that 62% of potential barriers identified remotely via aerial imagery were found to be actual barriers impacting aquatic connectivity. The highest-ranking fish barrier was a redundant weir on Granite Creek located in the Bloomfield River Catchment, followed equally by the Mossman Mill Weir located on the South Mossman River and a causeway located on Martins Creek in the Daintree River Catchment sharing the 2nd highest priority. Appendix 1 includes a list of the top 30 priority ranked fish barriers in the study area, including a photo, fish passage option and estimated cost of remediation at each site.

The resultant FBP report and associated priority ranked fish barrier list will assist Terrain NRM, environmental groups, and State Government decision-makers in determining where to best allocate funding opportunities to ensure the greatest environmental and outcomes for the northern Wet Tropics region.

Introduction

Waterways in the Wet Tropics region are impacted by waterway barriers affecting water quality, connectivity, biodiversity, and sediment transport. The fish communities utilising freshwater ecosystems are a unique component of the world heritage listed natural values in the region and are particularly impacted by waterway barriers found throughout. While there are natural barriers to fish movement (e.g., waterfalls), agricultural and isolated urban development has resulted in the construction of numerous obstructions within streams and wetlands. Fish passage barriers such as dams, weirs, causeways, culverts, earthen bunds, tidal floodgates, weed chokes, and eutrophic habitats represent significant threats to the health of river systems by altering natural flow regimes and restricting the movement of aquatic fauna.

Coastal freshwater fish assemblages in Australia comprise a high proportion of diadromous species which require access between fresh and saltwater habitats. Many of these species are of the highest socioeconomic importance, being of key commercial, recreational, and cultural value, as well as being key assets within the trophic ecology of waterways. Species such as Jungle Perch, Mangrove Jack, Barramundi, Tarpon, Long-finned Eel, and Cling Gobies all migrate between freshwater habitats and the estuary at different stages of their lifecycle. The decline of many of these species throughout their natural range can be largely attributed to the proliferation of barriers to movement, and further compounded by the degradation of aquatic habitats.

Through modern insight and a greater understanding of various lifecycle requirements, fish passage restoration works have seen the remediation of many barriers. In most instances, the barriers are considered critical infrastructure and cannot be removed to improve connectivity. Fishways or fish ladders are generally identified as the key method to mitigate the impacts of barriers on ecological integrity. State legislation requires adequate fish passage provisions to be incorporated into new in-stream infrastructure. Additionally, an increasing number of existing barriers are having fishways retrofitted, often to the immediate benefit of the aquatic assemblages of the waterways they impede.

The objective of the *Daintree, Mossman, and Lower-Barron Rivers FBP* report was to identify, assess, and prioritise actions to remediate the large number of anthropogenic barriers that impede fish migration. Fish barriers identified through this process were ranked in order of priority, accounting for the interactive effects of biological, geographic, and ecological factors associated with each barrier. A final list of the top 30 priority-ranked waterway barriers has been produced detailing remediation options and indicative costs (Appendix 1).

The current prioritisation complements other FBPs conducted throughout the State over recent years. These include: the Greater Brisbane prioritisation (Moore et al 2018), Sunshine Coast prioritisation (Moore & McCann 2018), the Mackay Whitsunday prioritisation update (Power et al 2022), Fitzroy FBP update (Marsden 2019), the Herbert and Lower Murray prioritisation (Moore et al 2021), City of Gold Coast FBP (Moore & Power 2022) and Southern Gulf catchments prioritisation (O'Brian et al 2010).

The objectives for this project were to:

1. Acquire and process spatial data for stream barrier prioritisation.
2. Perform the Stage 1 spatial analysis (GIS) to provide a preliminary desktop ranking of priority barriers in preparation for ground-truthing
3. Undertake Stage 2 ground-truthing, focusing on priority barriers

4. Perform Stage 2 spatial analysis, removing non-barriers and incorporating physical barrier and site-specific stream condition information e.g., fish passage passability, stream flow, and in-stream habitat condition
5. Collate data from Stage 1 and 2 to produce the final priority ranked fish barrier list for the Daintree, Mossman, and Lower Barron River catchments.

Fish Migration

Fish that migrate are most often defined within the broad groups 'diadromous' and 'potamodromous'. Diadromy includes subgroups 'amphidromous', 'catadromous', and 'anadromous', many varying definitions for each of these are a frequent cause for confusion. To alleviate this, we have defined fish only in the broader categories of diadromous, potamodromous, and marine vagrants.

For the current study, the definition of diadromy has included fish species that migrate between marine and freshwater environments, and that this migration is important to maintain population distribution and aquatic ecosystem health. Fish that undertake migrations between these two contrasting environments must overcome significant physiological challenges, including overcoming the osmotic barrier between saltwater and freshwater. Migration can also impact the fitness and survival of fish, requiring energy allocation for swimming and increasing the risk of mortality during migration (Miles 2007). Fish that migrate between saltwater and freshwater environments do so at great cost, and therefore these migrations must be important.

For the purpose of this report, the term 'diadromous' is used for fish in which migration between estuarine and freshwater environments is obligate to (adapted from Mallen-Cooper 1998):

- Contribute to its abundance
- Maintain its natural distribution
- Maintain aquatic ecosystem health

Potamodromous fish are defined here as migrating wholly within and between freshwater habitats e.g.,Sooty Grunter (*Hephaestus fuliginous*). And the same requirements listed above are applied to their migrations within the bounds of freshwater. Additionally, there are some species listed as 'marine vagrants', these are fish that do not require access between fresh and saltwater for the reasons listed above, but often move between the two given the opportunity e.g., Pikey Bream (*Acanthopagrus berda).*

Many diadromous species are recognised as contributing significant societal values, comprising high-value commercial, recreational, and indigenous fisheries. Historically, Sea Mullet (*Mugil cephalus*) and Long-finned Eel (*Anguilla reinhardtii*) have been established as important food sources for indigenous people (Barnett & Ceccarelli 2007). Today, both Sea Mullet and Long-finned Eel form important fisheries, with Sea Mullet forming the second most important commercial inshore net fishery in Queensland (Williams 2002). Diadromous species are also important recreationally, particularly Barramundi (*Lates calcarifer*) (Figure 1), Jungle Perch (*Kuhlia rupestris)* (Figure 1), Mangrove Jack (*Lutjanus argentimaculatus*) (Figure 1), tarpon (*Megalops cyprinoides*), Sea Mullet (*Mugil cephalus*) and Giant Herring (*Elops hawaiensis*).

Figure 1: Diadromous fish species impacted by barriers; Mangrove Jack (*L. argentimaculatus*) (left), Jungle Perch (*K. rupestris*) (centre), and Barramundi (L. calcarifer) (right). Mangrove Jack and Barramundi form important recreational, commercial, and indigenous fisheries while Jungle Perch are a highly prized recreational fishing species & top-order predator within freshwater ecosystems.

Healthy, sustainable populations of these species can attract recreational fishers to local coastal communities, providing valuable social and economic benefits. This is demonstrated via fishing tourism throughout northern Australia which attracts many recreational anglers in the pursuit of Australia’s most iconic freshwater fish species, the mighty Barramundi. Barramundi are diadromous, spawning in nearshore marine habitats before their offspring utilise tidal movement to recruit into estuarine swamps as post-larvae (15-50 mm) (Russell and Garrett 1983). They remain in these intertidal habitats until they possess an ability to swim (50+ mm), before migrating upstream into freshwater creeks and wetlands. Wetlands provide ideal nursery habitats; with stable water levels, in-stream habitat, and abundant food resources. These wetland attributes enable Barramundi to grow rapidly and evade predators; increasing their chances of survival and reaching maturity, before migrating back to saltwater to breed. Therefore, ensuring connectivity between habitats is a critical component in managing aquatic environments, and crucial to securing the long-term sustainability of important fisheries that underpin the social fabric of many coastal Queensland communities.

Barriers to Fish Migration

Barriers to fish passage include any anthropogenic or environmental obstruction that prevents, delays, or impedes the free movement of fish. For the purpose of this prioritisation, environmental barriers such as weed chokes, waterfalls, low dissolved oxygen slugs, and water temperature barriers have not been included, even though anthropogenic factors may have contributed to their occurrence. Anthropogenic barriers identified in this prioritisation include structures such as box culverts, pipes, road crossings, weirs, dams, streamflow gauging structures, floodgates, barrages, and bunds (or ponded pastures) (Figure 2). These structures have been built for a variety of purposes such as irrigation supply, flow gauging and regulation, stock watering, urban and industrial supply, flood mitigation, prevention of tidal incursion, road crossings or simply for urban beautification and recreation facilities (Marsden et al. 2003).

Figure 2: Barrier structures: a) pipe culvert causeway (Waterfall Creek), b) tidal floodgates (Mandam Creek) c) road causeway & apron drop (Frances Creek), d) rocky weir (Lagoon Creek), e) box culvert road crossing and concrete apron drop (Waterview Creek catchment, f) V-notch DNRME stream gauging weir (Warrill Creek).

Barriers which create velocities greater that 0.5m/sec generally impede or prevent the movement of fish according to the best available modelling and evidence to date. The swimming abilities of fish play a critical part in understanding the effects of barriers (Wang 2008). Physiology, size, developmental stage, and morphology all influence the ability of fish to ascend past barriers (Koehn & Crook 2013). Generally, juvenile (Rodgers et al. 2014) and small-bodied fish (Domenici 2001) possess weaker swimming abilities than larger adult fish. This is because larger fish have more muscle to propel them through the water (Tillinger & Stein 1996). Significantly, the vast majority of migrating native fish in coastal Queensland catchments comprise juvenile diadromous and small-bodied species (McCann & Power 2017; Power 2016; Moore 2016; Moore & Marsden, 2008).

The small size of migrating fish is further highlighted by fishway evaluation monitoring studies undertaken in central-north and south-east Queensland (QLD). In central-north QLD, the median size of native fish recorded successfully ascending the Gooseponds (Janes Creek, Mackay) and Alligator Creek (Townsville) rock ramp fishways during low flow conditions equated to just 31 mm (n= 35,924 at a catch rate of 27,422 per day) and 34 mm (n= 927 at a catch rate of 252 per day) respectively. In south-east QLD, the median size of native fish recorded successfully ascending Slacks Creek, Bremer, and South Pine River rock-ramp fishways during low flow conditions equated to just 25 mm (n= 6,548 fish at a catch rate of 1,385 per day), 34 mm (n= 16,401 fish at a catch rate of 4,075.5 fish per day) and 30 mm (n= 5,070 at a catch rate of 1,406.7 fish per day) respectively. Fishway sampling data in the FBP study area is not available, however, the study area comprises many of the same fish species recorded in the fishway evaluation monitoring studies mentioned above. It's likely that the median size of migrating fish throughout the DLBFBP region is also comparable, predominantly comprising juvenile diadromous and small-bodied fish species.

The potential impact of small head loss barriers on coastal fish communities is further exacerbated when these results are categorised by migration class, i.e., proportion of individual diadromous fish undertaking life-cycle dependant migrations. Of the 35,924 individual fish recorded successfully ascending the Gooseponds rock-ramp fishway, 85% of individuals were diadromous fish undertaking life-cycle dependant migrations, while correspondingly, 96% of the individuals monitored ascending the Bremer River rock- ramp were diadromous.

The swimming abilities of different fish species plays a critical role in their ability to ascend fishways. Mallen-Cooper (1989) tested the swimming abilities of two iconic and recreationally important diadromous fish species, Barramundi (*Lates calcarifer*) and Australian Bass (*Percalates novemaculeata*) through a vertical-slot fishway, and found that juvenile Barramundi (43 mm) were only able to navigate velocities of around 0.66 m/sec, while Australian Bass (40 mm) were able to navigate slightly faster velocities of around 1.04 m/sec. Watson *et al*., 2019 tested the 'burst' speed (Usprint) of *H.compressa* within the size range 44 – 78 mm and found that they could attain a mean Usprint of 0.51 m/sec.

It must be noted that the swimming performance data mentioned above was collected under laboratory conditions. Fishway monitoring data collected in the field suggests that some fish species can navigate greater velocities than has been recorded under controlled conditions. For example, sampling of a rock-ramp fishway on Fursden Creek in central Queensland showed that juvenile Empire Gudgeon (*H. compressa)* within the size range of 15-82 mm were recorded passing through ridge slot velocities of 1.6 m/sec (Moore & Fries 2021). At Bremer River in South East Queensland, Striped Gudgeon (*Gobiomorphus australis*) (44 mm) and Sea Mullet (*Mugil cephalus)* (55 mm) were recorded negotiating ridge slot velocities of 2.1 m/sec and pool velocities of 0.4 m/sec. Similarly, a fishway monitoring study undertaken by Power et al. (2016) on a rock-ramp fishway on the Condamine River in South West Queensland recorded small Gudgeon (*Hypseleotris sp.*), Rainbowfish (*Melanotaenia sp.*), Bony Bream (*Nematalosa erebi*), and Spangled Perch (*Leiopotherapon unicolor*) negotiating ridge slot velocities of 2.0 m/sec and pool velocities up to 1.5 m/sec. The ability of fish to navigate faster velocities through rock-ramp fishways compared to smooth-sided vertical-slot fishways and laboratory flumes can be explained by the high degree of geometrical diversity of rock-ramps as a result of their irregular forms (rocks), which create interstitial spaces and micro-eddies (Wang 2008).

The stream velocities Australian fish species can traverse are lower in comparison with their northern-hemisphere counterparts such as adult Atlantic Salmon, which can traverse velocities of at least 2.4 m/sec (Mallen-Cooper 1989). Unfortunately, many early Australian fishway designs were based on northern hemisphere designs and the swimming abilities of salmonids (Mallen-Cooper 1996), which have the added capability of 'leaping' past small barriers (Thorncraft & Harris 2000). These fishways have drops between pools, velocities, and turbulence far in excess of what coastal Queensland fish communities are capable of ascending regularly and have themselves become fish barriers e.g., Luscombe Weir (Albert River), Berrys Weir (Bremer River) and Marian Weir (Pioneer River) (Figure 3). McCann and Moore (2017) measured the velocity of a pool and weir fishway constructed in the 1960s on the Bremer River (Berrys Weir) and recorded a velocity of 3.3 m/sec at the fishway exit (Figure 3. white circle), which is substantially faster than what our native fish can traverse, and potentially even faster than the velocities adult Atlantic salmon can withstand.

Figure 3: Showing northern hemisphere 'salmonid' style fishway designs exhibiting hydraulic conditions in excess of the swimming abilities of most native freshwater fish species. a) Denil fishway located on Luscombe Weir (Albert River, Queensland) showing steep gradient and excessive velocities (note baffles removed). b) Showing the bottom section of the Mt Crosby weir pool and weir fishway (Brisbane River). Note the inadequate fishway entrance with excessive turbulence associated with the large water surface

drop and shallow entrance pool and c) Pool and weir fishway located on the Bremer River (Berrys Weir). The exit of this style of fishway has a 600 mm high drop and velocities during base flows of 3.3 m/sec.

Ecophysiology and Barrier Type

Ecophysiology determines the ability of fish to successfully ascend past various types of barriers. What comprises a barrier for one species or age class may not necessarily apply to others. For instance, a 200 mm vertical drop on the downstream side of a damp, but not flowing culvert apron, will more than likely prevent the passage of juvenile Barramundi (*Lates calcarifer*). However, the unique climbing abilities of juvenile Long-finned Eel (*Anguilla reinhardtii*) enable them to ascend ≥200 mm damp vertical surfaces (Jellman 1977). Other barrier characteristics such as velocity and turbulence affect fish swimming ability in different ways. To counteract the natural variability in flow conditions, fish exhibit different swimming modes. Generally, these modes fall within three widely recognised categories (adapted from Domenici & Blake 1997):

- Sustained - swimming >200 minutes
- Prolonged - swimming 15 seconds - 200 minutes
- Burst - swimming <15 seconds

Burst speed is used by fish to traverse fast velocities (see Ch. 6 in Webb 1984) and one that fish species would most commonly use when attempting to migrate over small head loss barriers (<120 mm) and through box culverts during medium and high flow conditions (Watson et al. 2019). Burst speed is an energetically expensive and aerobic form of swimming, and as such cannot be sustained for long periods. Therefore, less obvious barriers such as culverts and pipes become problematic for juvenile and small-bodied fish when stream flow conditions through smooth-surfaced structures exceed 0.5 m/sec (Watson et al. 2019). Generally, barriers can be defined into 7 types:

- <u>Water surface drop</u> - Vertical drop off the downstream side of road crossings, weirs and culvert aprons that are greater than 200 mm (Figure 4)
- <u>Turbulence</u> - The motion of water having local velocities and pressures that fluctuate randomly. This is often observed downstream of culvert aprons, weirs, pipes and poorly designed fishways (Figure 4), without proper provision of pool depth. Turbulence is most often encountered during medium and high flow conditions
- <u>Velocity</u> - When the speed of water is in excess of the swimming capabilities of fish attempting to pass the obstruction (generally greater than 0.5m/sec). High velocities often occur through pipes and culverts and downstream of weirs and regulators during medium and high flow events (Figure 4)
- <u>Water Depth</u> - Shallow water depth of 5 mm – 100 mm depending on species, size, and morphology. Larger-bodied demersal species are most affected. Shallow water is often experienced during low flow conditions across road crossings, through culverts and across culvert aprons (Figure 4)
- <u>Behavioural</u> - Darkness, shadows and reduced light conditions inside culverts/pipes, and under low bridges (Figure 4)
- <u>Chemical</u> - Low dissolved oxygen slugs, often experienced during the first flow events in the lead up to summer (Oct-Dec) in waterways and wetlands. Particularly common in catchments with high proportions of intensive land use. Other chemical impacts include acid sulphate soil discharge and high temperatures associated with channel modification, i.e., channel straightening and widening works combined with the removal of riparian vegetation
- <u>Physical obstruction</u> – a complete or partial obstruction of the stream channel. This could include a dam wall, weir, bund, weed choke (e.g., Hymenachne), or built-up sediment. These may be a seasonal or tidal barrier, with high flows required for 'drown out'.

Figure 4: Left to right: Culvert causeway displaying high velocity flows through the pipes and two water surface drops; off the downstream extent of the pipe onto the apron, and from the apron to the waterway, showing a water surface drop barrier (centre) and showing a behavioural barrier due to insufficient light within the low-set culverts and velocity and turbulence (black polygon) barriers on the downstream extent of the structure due to a culvert aperture <40% of stream width (Coomera River, SEQ).

Barrier Passability

Barrier passability, sometimes referred to as barrier transparency, describes the extent to which in-stream barriers impede fish passage (Kemp & O'Hanley 2010). Passability formed an integral part of the current DLBFBP scoring criteria when assessing barriers in the field. Barrier passability can be complicated, with many dynamic temporal and spatial eco-physical characteristics influencing the extent and magnitude of barriers at different scales (Bourne et al 2011) The four underlying characteristics of barrier passability include:

- Fish physiology – biology, species, size, and swimming ability
- Waterway – stream size, stream slope, stream reach, temperature, and dissolved oxygen
- Stream flow – duration and volume
- Barrier type – box and pipe culverts, weirs, dams, flooded causeways, bunds, and sand dams
- Barrier size – The latitudinal and longitudinal extent of the barrier within the waterway as well as its height in relation to the bank height

For the purpose of the current DLBFBP, passability was simplified based on barrier type.

1. Dams, weirs, and bunds
2. Culverts (box and pipe) and floodgates

Dams, Weirs, and Bunds

Larger structures require higher flows to drown out and allow unimpeded fish passage. Higher flows are less frequent which leads to larger dams, weirs, and bunds having a greater impact on fish passage than smaller ones. Passability scores were assigned based on the degree of impact at each barrier site. For dams, weirs, and bunds this was achieved by using head loss as a proxy for passability (i.e., the higher the dam/weir the greater the score).

Culverts and Floodgates

Determining impacts on passability requires assessment of three main features associated with each structure:

1. Structure aperture as a proportion of the bank full cross-sectional area of the waterway
2. Structure height measured from streambed invert on the downstream side to the top of the causeway (e.g., road deck to downstream invert level)
3. Headloss – the difference between water levels on the upstream and downstream side of the structure

Culvert configurations with a small aperture (opening) in relation to the cross-sectional area of the stream score high (e.g., 300 mm pipe culvert located within an 8 m wide stream). In these instances, stream velocities are likely to be in excess of the swimming abilities of many native fish, particularly juvenile diadromous and small-bodied species which possess lower burst speeds. Structure height is a proxy for how frequently the barrier 'drowns out'. Drown out conditions occur when the water levels on the upstream and downstream sides of the structure are equal. Drown out conditions occur more frequently for low head structures e.g., 0.5 m high causeway and provides an increased level of passability for fish attempting to migrate past the barrier during the drown-out period.

Head loss acts as a proxy for barriers comprising a water surface drop off the downstream extent of the culvert apron. Native fish are poor 'leapers', and therefore a drop off the culvert apron greater than 100 mm and/or high enough to create air pockets in stream flows over the apron significantly impacts the ability of fish to enter culverts. Upon entering smooth-sided concrete culverts, fish are often required to negotiate high velocities. Engineers typically design a longitudinal fall throughout culvert structures, as they attempt to move water as quickly as possible past the structure. This fall also increases head loss and therefore forms an important component in the assessment of barriers. Below are typical criteria for low, medium, and high passability structures.

Low Passability (Figure 5)

- Rarely drowns out (e.g., average <5% of flow duration)
- Examples:
    - Dams and weirs >2 m head loss
    - Causeway >2 m high with culvert <20%, bankfull stream width & head loss >1m

Medium Passability (Figure 5)

- Occasionally drowns out (e.g., average 5-50% flow duration)
    - Culvert velocities exceed swimming ability during medium & high-flow events
    - Shallow water surface barrier during low flows (culverts)
    - Weir, causeway, bund wall, sand dam: 0.3 - 2 m head loss
    - Culverts/pipes that span <60 % of bankfull stream width

High Passability (Figure 5)

- Frequently drowns out (>50% of flow duration)
- Examples:
    - Culverts/pipes that span >60 % of bankfull stream width
    - Wet causeway <0.3 m
    - Barrier only for small proportion of flow events, i.e., high flows (full-width culverts) and very low flows (shallow water surface)

Figure 5. Examples of low (left), medium (mid) and high (right) passability fish barriers.

Study area

The study area included all watercourses within the Daintree, Mossman, and Lower-Barron River catchments. The Lower-Barron River catchment was separated from the upper catchment by Barron River Falls, a 125m high waterfall cascade impassable to almost all fish with the exception of Eel species (*Anguilla sp.*) which is suspected to navigate this natural barrier via the surrounding rocks and vegetation (J. Donaldson 2022 Personal Communication, 07 October). The Daintree catchment is the largest (2,107 km^2), followed by the Mossman (441 km^2) and the smallest being the Lower-Barron (249 km^2) (Land use data herein was derived from the QLD land use mapping programme 2013, QLD Government).

Each of the three catchment areas include larger permanent streams originating in mountainous rainforests and smaller coastal streams which are often ephemeral (only flowing during the wet season). Large perennial waterways of the Daintree catchment include the Daintree and Bloomfield Rivers and Cooper and Stewart Creeks. Large waterways of the Mossman basin include the Mossman and Mowbray Rivers and Saltwater and Whyanbeel Creeks. The Lower-Barron catchment encompasses the downstream reach of the Barron River, and the large tributary of Freshwater Creek.

Land use in the Daintree and Mossman catchments differs substantially from the Lower-Barron due to the urbanisation of Cairns city and surrounding suburbs. The Daintree catchment comprises 56% natural vegetation, 32% forestry, 7% grazing, and 2% sugarcane cropping. The Mossman catchment comprises 76% natural vegetation and 10% sugarcane cropping. The Lower Barron catchment comprises 63.4% natural vegetation, 14.7% natural vegetation grazing, 6.7% sugarcane cropping, and 6.7% urban/residential.

The three catchments included in this study present a unique environmental context unmatched globally. They include streams originating in the Wet Tropics World Heritage listed rainforest, meandering through highly diverse mangrove forests, and discharging directly into the World Heritage listed Great Barrier Reef Marine Park. The study catchments form a large part of the Wet Tropics region, which is characterised by high rainfall ranging from 1800mm to 8000mm annually (average of ~1980mm/yr.) and high average temperatures (27.5°C). Larger streams originate in the mountainous (~1000m elevation) rainforest slopes and meander through relatively short catchments (e.g., 24km – Mossman River). The Daintree River is the largest in the study area extending approximately 140km.

The high rainfall conditions provide permanent flow to many of these streams. Although, there is still distinct seasonality in rainfall and flow conditions with most rainfall occurring from December to April during the monsoon. Flooding is a common occurrence in the study area. There are some 1190km^2 of wetlands present within the catchments. Stream morphology varies from rock and cobble based enclosed canopy streams to exposed clay-based modified channels draining sugarcane cropping.

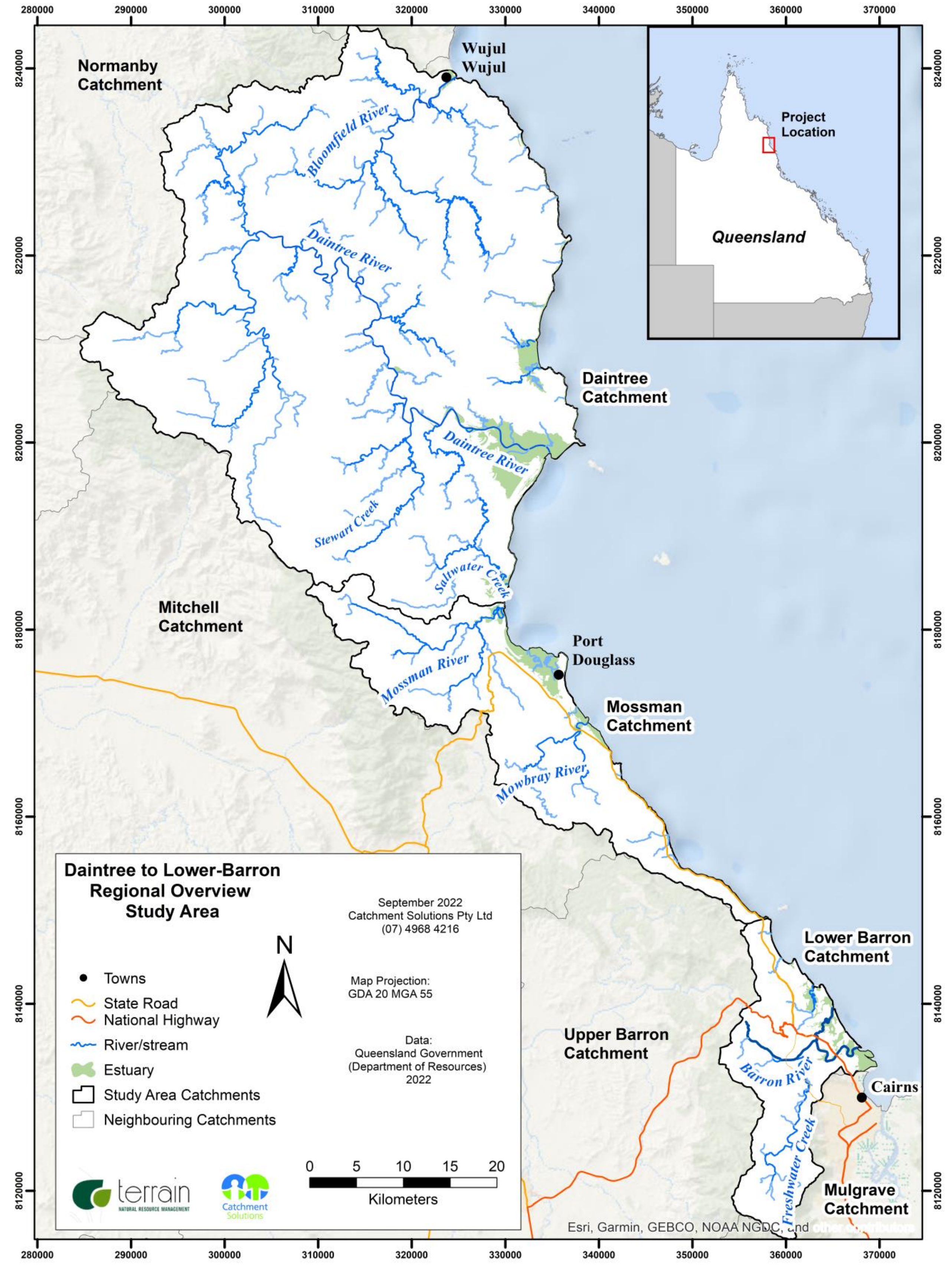

Figure 6. Daintree, Mossman, and lower Barron River catchments with boundary delineations used in the barrier prioritisation process.

Impacted fish community

In undertaking a fish passage barrier prioritisation in the Daintree, Mossman, and Lower Barron River catchments, it was fundamental to the overall project outcomes to have a sound understanding of the fish species present within the region. Having this understanding is critical when evaluating potential fish passage barriers. This is because different life cycles, breeding strategies, and the migration characteristics of the species that inhabit these waterways can exacerbate the impacts of certain barrier characteristics. This is particularly significant when it comes to understanding the diadromous fish species present within a catchment, which typically undertake migrations between marine, estuarine, and freshwater ecosystems (Harris 1988; Rolls et al. 2014).

A native species list was created from current verified records and published literature of species identified in the waterways within the project area. At least one hundred species are known to inhabit these waterways, including diadromous, potamodromous, and opportunistic freshwater inhabitants (marine vagrants). Many of the species found here are biologically dependant on both freshwater and marine/estuarine habitats (e.g., diadromous). This means they migrate between these ecosystems to breed, maintain population distribution, and sustain healthy populations e.g., Barramundi. Some of the species found here are biologically dependant on freshwater habitats and migrate between reaches of the freshwater streams to complete their lifecycles e.g., potamodromous.

This region is also home to several vagrant species which are usually found in estuaries but are known to enter lower reaches of freshwater waterways. Of the 98 known and likely present species, over half (60%) undertake movements between saltwater and freshwater habitats, comprising 33 diadromous species and 26 marine vagrants. The remaining species include 34 potamodromous species which undertake migrations wholly within freshwater and 5 species for which their migration characteristics are unknown. Many of the native species found in the region's streams are socially, culturally, and economically valuable. Species including Barramundi (*L. calcarifer*), Jungle Perch (*K. rupestris*), Sea Mullet (*M. cephalus*), and Mangrove Jack (*L. argentimaculatus*) are all key diadromous species targeted by recreational, indigenous, and commercial fishers.

The number and type of barriers within aquatic ecosystems and the distance to the first low-passability barrier in each stream can often be an important factor impacting the health of a particular waterway's fish assemblage. The cumulative impact of barriers along streams can reduce upstream fish diversity, particularly for diadromous species, and in some instances may cause localised extinctions upstream of the barrier (Bunn and Arthington 2002). Therefore, the amount of connected in-stream habitat longitudinally from the tidal interface to the first barrier is extremely important.

The number of in-stream barriers located within streams significantly reduce the ability of diadromous species to reach upstream nursery or spawning areas. Diadromous species may be able to use intermittent high flow conditions that 'drown out' barriers, enabling them to ascend upstream, but only if they are present at the barrier when the barrier experiences these conditions, and additionally possess swimming abilities sufficient to ascend the drowned-out barrier. The likelihood of the 'right' conditions prevailing at the next upstream barrier, and consequently the next after that, is reduced each time. The cumulative impact of barriers and the amount of connected in-stream habitat between barriers are critically important factors influencing the composition and health of fish communities in the study area.

Table 1. Fish species recorded and likely present and measured swim speeds in the Daintree, Mossman and Lower Barron River catchments, North Queensland. Note: letters after scientific name refer to species with a fish image in Figure 10 below. (CE) – Critically Endangered, * – Invasive

Migratory status / Scientific name	Common name	Swim speed max (m/s)	Reference
Diadromous			
Ambassis miops	Flagtail Glassfish		
Ambassis vachellii	Vachell's Glassfish		
Anguilla australis	Southern Shortfin Eel		
Anguilla obscura	Pacific Shortfin Eel		
Anguilla reinhardtii (I)	Longfin Eel	0.75a - 1.40b	a) Langdon & Collins 2000, b) Rolls & Sternberg 2015
Awaous acritosus (F)	Roman-nose Goby	0.45a	a) Pusey et al. 2004
Brachirus selheimi	Freshwater Sole		
Bunaka gyrinoides	Greenback Guavina		
Butis butis	Crimsontip Gudgeon		
Chanos chanos (O)	Milkfish		
Eleotris melanosoma	Black Spine-cheek Gudgeon		
Eleotris fusca	Brown Spine-cheek Gudgeon		
Elops hawaiensis (S)	Giant Herring		
Gerres filamentosus (G)	Threadfin Silverbiddy		
Giuris margaritacea (D)	Snakehead Gudgeon	0.22a	a) Pusey et al. 2004
Glossogobius aureus	Golden Flathead Goby		
Glossogobius bicirrhosus	Bearded Flatheat Goby		
Glossogobius giuris (Q)	Tank Goby		
Glossogobius illimis	False celebes Goby		
Hypseleotris compressa (N)	Empire Gudgeon	1.00a	a) Rolls & Strenberg 2015, b) Pusey et al. 2004, c) Rodgers et al. 2014, d) Watson et al 2019
Kuhlia marginata	Darkmargin Flagtail		
Kuhlia rupestris (A)	Jungle Perch		
Lates calcarifer (B)	Barramundi	1.40a	a) Rolls & Sternberg 2015, b) Mallen-Cooper 1992
Lutjanus argentimaculatus (H)	Mangrove Jack		
Megalops cyprinoides (E)	Tarpon		
Mesopristes argenteus	Silver Grunter		
Monodactylus argenteus (L)	Diamondfish		
Mugil cephalus	Sea Mullet	1.26	Peterson 1975
Mugilogobius wilsoni	Wilson's Mangrove Goby		
Neoarius graeffei	Blue/salmon Catfish		
Notesthes robusta (C)	Bullrout	1.40a	a) Rolls & Sternberg 2015, b) Pusey et al. 2004
Ophiocara porocephala	Spangled Gudgeon		
Pseudomugil signifer	Pacific Blue Eye	1.30a	a) Rolls & Sternberg 2015, b) Watson et al 2019
Redigobius balteatus	Rhinohorn Goby		
Redigobius bikolanus (U)	Speckled Goby	0.38a	a) Pusey et al. 2004, b) Watson et al 2019
Redigobius chrysosoma	Spotfin Goby		

Sicyopus discordipinnis	Papuan Sicyopus		
Scatophagus argus (P)	Spotted Scat		
Selenotoca multifasciata (K)	Striped Scat		
Sicyopterus lagocephalus	Blue Streamgoby		
Stiphodon pelewensis (T)	Daintree Cling Goby		
Terapon jarbua	Crescent Perch		
Toxotes chatareus (M)	Seven Spot Archerfish		
Yarica hyalosoma	Humpack Cardinalfish		
Potamodromous			
Ambassis agassizii	Agassiz's Glassfish	0.39	Kern et al 2018
Ambassis macleayi	Macleay's Glassfish		
Amniataba percoides	Banded Grunter	1.40a	a) Rolls & Sternberg 2015, b) Pusey et al. 2004
Cairnsichthys bitaeniatus	Daintree Rainbowfish		
Craterocephalus stercusmuscarum	Flyspecked Hardyhead	1.40a	a) Rolls & Sternberg 2015, b) Bice & Zampatti 2005, c) Watson et al 2019
Glossamia aprion	Mouth Almighty	0.84a	a) Pusey et al. 2004
Hephaestus fuliginosus	Sooty Grunter	0.43a	a) Pusey et al. 2004
Hephaestus tulliensis	Khaki Grunter		
Leiopotherapon unicolor	Spangled Perch	0.75a	a) Rolls & Sternberg 2015, b) Pusey et al. 2004, c) Watson et al 2019
Melanotaenia maccullochi	McCulloch's Rainbowfish		
Melanotaenia nigrans	Yalgurnda (Black-banded Rainbow)		
Melanotaenia splendida	Eastern Rainbowfish		
Melanotaenia splendida splendida	Eastern Rainbowfish	0.56a	a) Pusey et al. 2004
Melanotaenia trifasciata	Banded Rainbowfish		
Mogurnda adspersa	Southern Purple-spotted Gudgeon	0.70a	a) Rolls & Sternberg 2015, b) Pusey et al. 2004, c) Watson et al 2019
Mogurnda mogurnda	Northern Purple-spotted Gudgeon		
Nematalosa erebi	Bony Bream		
Neosilurus ater (J)	Black Catfish		
Neosilurus hyrtlii	Hyrtl's Catfish	0.50a	a) Rolls & Sternberg 2015
Oxyeleotris lineolata	Sleepy Cod		
Synclidopus hogani	Freshwater Sole		
Tandanus tandanus	Freshwater Catfish	1.40a	a) Rolls & Sternberg 2015, b) Pusey et al. 2004, c) Watson et al 2019
Tandanus tropicanus	Wet Tropics Tandan		
Pest fish			
*Amphilophus labiatus **	Green Terror		
*Gambusia holbrooki **	Mosquitofish		
*Oreochromis mossambicus **	Tilapia		
*Poecilia reticulata**	Guppy		
*Tilapia mariae**	Black Mangrove Cichlid		
*Xiphophorus hellerii **	Swordtail		
*Xiphophorus maculatus**	Platy		
Marine vagrant			
Ambassis dussumieri	Barehead Glassfish		
Ambassis interrupta	Longspine Glassfish		

Ambassis nalua	Scalloped Perchlet
Amniataba caudavittata	English Wyandotte
Apocryptodon madurensis	Peppered Mudskipper
Awaous ocellaris	Goby
Bathygobius fuscus	Dusky Frill Goby
Caranx sexfasciatus	Bigeye Trevally
Carcharhinus leucas	Bull Shark
Cynoglossus puncticeps	Spotted Tongue Sole
Gerres erythrourus	Short Silverbiddy
Microphis brachyurus	Short-tail Pipefish
Mugilogobius mertoni	Chequered Mangrove Goby
Mugilogobius notospilus	Freshwater Mangrove Goby
Neopomacentrus taeniurus	Freshwater Demoiselle
Pristis zijsron (CE)	Green Saw-fish
Schismatogobius hoesei	Scaleless Goby
Taenioides anguillaris	Bearded Worm Goby
Terapon puta	Spinycheek Grunter
Terapon theraps	Banded Grunter
Toxotes jaculatrix	Banded Archerfish
Zenarchopterus buffonis	Northern River Garfish
Unknown migratory status	
Glossogobius bellendenensis	Mulgrave Goby
Glossogobius circumspectus	Circumspect Goby
Guyu wujalwujalensis	Bloomfield River Cod
Hippichthys spicifer	Banded Freshwater Pipefish
Ophisternon gutturale (R)	Swamp Eel

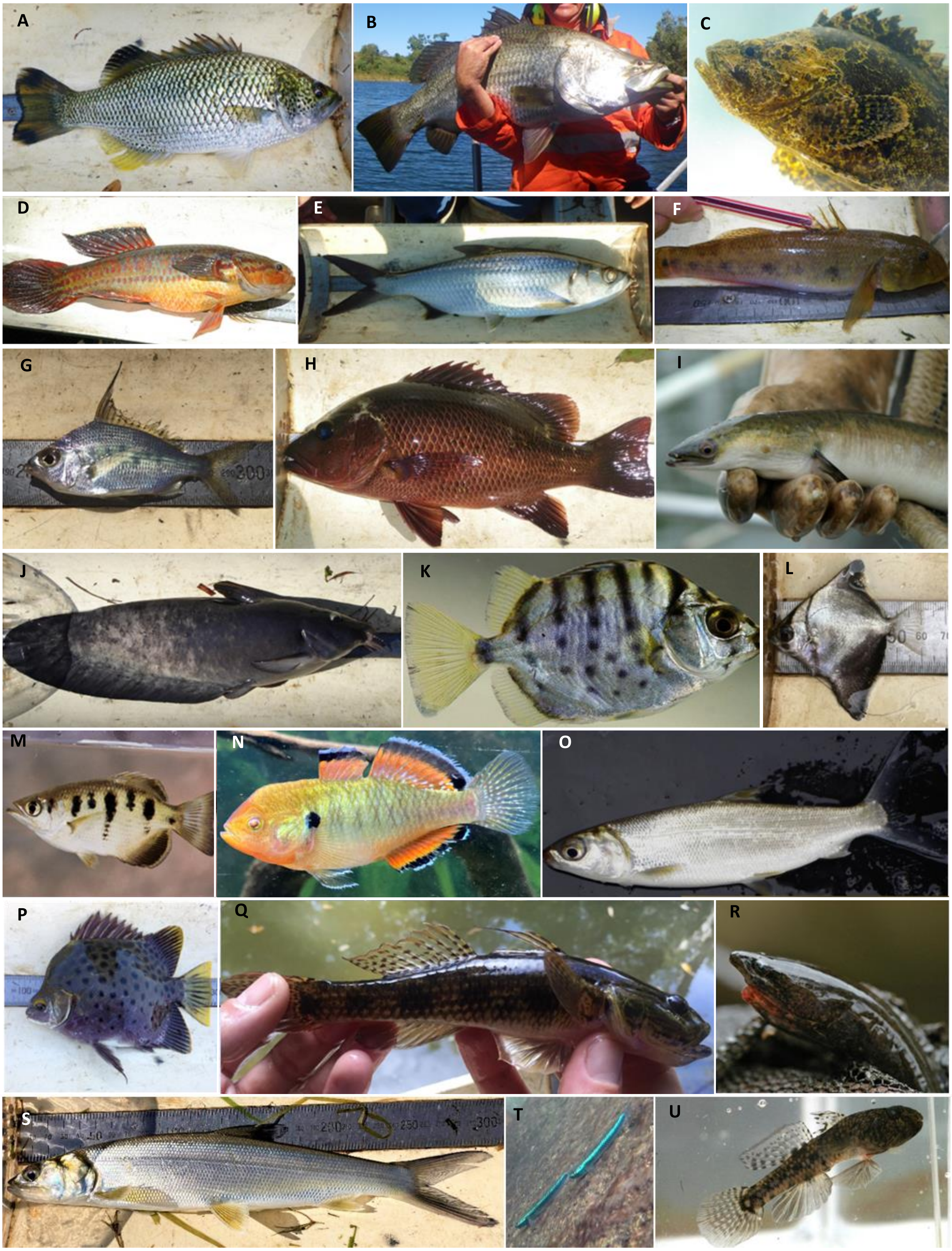

Figure 7. Showing a selection of freshwater fish species occurring within the study area. See Table 1 for common and species name. Note: Capital letter provides a reference to each species in Table 1 (located after the scientific name).

Methods

Stage 1: Catchment Scale GIS Analysis and Prioritisation

The first stage of the barrier prioritisation process involved extensive desktop-based identification. All potential barriers within the study area were identified using high-resolution aerial imagery (20 cm resolution captured in 2018, Google Earth Pro and Queensland Globe datasets captured across the past 10 years ranging from 15 cm to 60 cm resolution). A dataset based on the GeoScience Australia 1:100,000 drainage network of Queensland (where 1:100,000 coverage exists) and 'Queensland canal lines' layers were joined and utilised as the 'base' waterway data layer while identifying potential barriers. This process involved tracing each individual watercourse and drainage line to visually identify potential barriers. Potential barriers were defined by the presence of an anthropogenic structure crossing or likely protruding into a mapped watercourse or drainage line. Structures included road crossings, bridges, weirs, bunds, earth dams, culverts, tidal barrages, flood gates, flow control structures, and gauging weirs. A unique point shapefile identifier was snapped to the watercourse line at the location of each potential barrier.

Occasionally, potential barrier point shapefiles were assigned along a waterway when likely barrier attributes were detected, but a structure was not visible. Key barrier traits in these scenarios include dead trees, which have potentially drowned and died due to the ponding of water caused by a downstream barrier, and large, lentic bodies of water that are out of character with the rest of the waterway. On occasions when river reaches were fully enclosed by canopy cover, potential barrier waypoints were assigned where well-used vehicle tracks appeared to enter one side of a waterway and exit on the other side on a similar trajectory. This is often a sign indicating a structure, e.g., causeway or bed level crossing. A desktop GIS process was then undertaken to efficiently investigate spatiotemporal habitat characteristics associated with each potential barrier on a whole of catchment basis.

Each potential barrier waypoint created in ArcMap (GIS) was assigned a unique geo-referenced identification number that remained with the potential barrier throughout the process. Each identification number contains its own geospatial dataset that stores location and geometry data for each potential barrier. Potential barriers were then assessed against six geospatial questions relating to the barrier's position in the catchment, available upstream habitat, stream hierarchy (Strahler stream order) proportion of intensive land use (e.g., intensive cropping) in the sub-catchment, number of potential barriers downstream, and distance to the estuary.

The specialized river network GIS processing tool 'RivEX' (Hornby 2015) was used to analyze the stream network layer, apply attributes, perform quality control, calculate the distance between potential barriers, distance to the estuary, the distance of stream network upstream of the potential barrier, and number of downstream barriers along the stream network. Each potential barrier was then assigned a score (i.e., 1 - 5) depending on how well the criteria were answered for each question. Scores for all questions were combined and totaled and the final rank after Stage 1 was determined, i.e., the highest total score becoming the highest-ranking potential barrier after Stage 1. The following attributes were fundamental for a potential in-stream barrier to be given a high score in Stage 1 of the prioritisation process:

- Located on a high-ordered stream
- Minimal or no potential barriers downstream
- A substantial length of stream network (habitat) upstream of the potential barrier
- A large area of available upstream distance (habitat) to the next barrier or top of the catchment
- Good sub-catchment condition, i.e., minimal intensive land-use practices

- Barrier located in lower reaches or on the tidal interface, i.e., close to the estuary

Scoring criteria and questions for Stage 1 provided a preliminary assessment of priority barriers for further investigation in Stage 2 (ground truthing). As resources and time are limited, it was not possible to ground truth all potential barriers identified. The scoring criteria and questions used in Stage 1 are listed and described below.

1. Stream Hierarchy/Stream Order

In this study, stream order was used as a proxy for water permanence and productivity potential of watercourses within the network. In practice, parts of the network attributed as stream order 0 are typically drainage features such as gullies, paddock drains and steep mountainous creeks. These features are often ephemeral with water flows occurring only during rainfall and for a short period (hours to days) after rain events. They are therefore less valuable as habitat for most species of fish (although they do contribute to the overall productivity of downstream watercourses and are accounted for in this respect in question 3). Conversely, watercourses attributed with stream orders 5-8 have multiple smaller streams discharging into them and they often span large distances across lower elevations in the catchment. Generally, these high-ordered waterways provide permanent water, providing excellent fish habitat throughout many life stages. Large-ordered waterways also provide a wide variety of habitat types and support a greater diversity of fish species when compared with smaller waterways. Waterways within the project boundaries were classified into five separate classes based on Strahler stream order. Scores were assigned to potential barriers based on the stream order they were situated on (Table 2). Potential barriers on high-ordered waterways (5-8) score highest. Potential barriers located on drainage features scored lowest.

Table 2: Strahler stream order categories and associated scores.

Option	Stream Order	Score
a.	Strahler stream orders 5-8	10
b.	Strahler stream orders 4	8
c.	Strahler stream order 3	5
d.	Strahler stream order 2	2
e.	Strahler stream order 1	1
f.	Drainage feature or Strahler stream order 0	0

2. Number of Potential Barriers Downstream

The number of potential barriers downstream assists in the prioritisation of barriers occurring in series along the same watercourse. Because passability is unknown in Stage 1, all barriers are assumed to be impassible in most conditions. Therefore, the first barrier in each series is the most important to the migration of diadromous species at this stage of the analysis. The score was calculated as the number of potential barriers downstream along the stream network, e.g., the first potential barrier upstream from the source (sea) receives a score of 6, the next barrier upstream receives a score of 5, the 6th barrier receives a score of 1 (Table 3).

Table 3: Number of potential barriers downstream and associated scores.

Option	Number of Barriers Downstream	Score
a.	0	8
b.	1	6
c.	2	5
d.	3	4
e.	4	3
f.	5	2
g.	6	1

3 Upstream Catchment Excluded by the Potential Barrier

Accumulation of stream network upstream of barrier to the top of the catchment. Calculated as the cumulative length of the stream network (including drainage features) upstream of the potential barrier (Table 4). This question is a proxy for allochthonous inputs into the system (nutrients, woody debris) and stream flows. This differs from stream order, as stream order is not always representative of catchment size.

Table 4: Accumulated distance scoring criteria.

Option	Accumulated Distance (km)	Score
a.	>100	5
b.	50 - 100	4
c.	10 - 50	3
d.	5 - 10	2
e.	<5	1

4 Distance to Next Barrier Upstream

The upstream length of accessible stream habitat, i.e., the distance from the potential barrier to the next potential barrier upstream, or to the top of the catchment (if there are no barriers), indicates the amount of habitat made available upon remediation, e.g., 15 km's of stream length (habitat) from barrier 1 to barrier 2, then barrier 1 receives a score of 2 (Table 5).

Table 5: Stream length to the next barrier or top of catchment categories and associated score.

Option	Stream Length (km) to the Next Barrier/or Top of Catchment	Score
a.	>20	3
b.	2-20	2
c.	<2	1

5 Catchment Condition - Proportion of Intensive Land Use

Catchment condition is an important factor as it is often linked to the risk of degraded habitats and poor water quality occurring, and broader ecosystem health. Intensive land uses such as cropping result in increased discharge of sediments, nutrients, and pesticides into waterways. Furthermore, they often coincide with the removal of riparian vegetation, straightening of creeks, and excavation of drains to remove water from the landscape more efficiently. These changes cumulatively reduce the quality and quantity of aquatic habitats available and may increase the risk of eutrophic conditions which can cause fish kills or create chemical barriers to migration. The proportion of intensive land use in the sub-catchment in which the potential barrier is located was therefore used as a proxy for catchment condition. In this study, 'intensive' land use included irrigated cropping, manufacturing and industrial, intensive animal husbandry, and residential. 'Non-intensive' land use categories included conservation and natural environment areas, plantation forestry, wetlands, estuaries, and natural vegetation grazing (Table 6).

Table 6: Showing the proportion (%) of intensive land use and associated scores for each category.

Option	Proportion (%) Intensive Land Use Within the Sub-Catchment	Score
a.	<30%	3
b.	30-60%	2
c.	>60%	1

6 Distance to Estuary

The distance to the estuary from each barrier provides a critical assessment of the impact on diadromous fish that require access between fresh and estuarine/marine waters to breed and/or maintain viable populations. Barriers located on, or close to the tidal interface are particularly problematic as they can exclude access between each of these ecosystems rather than simply reducing the amount of freshwater habitat available. This may prevent lifecycle completion for some species. For this assessment, the estuary was delimited by the highest astronomical tide (HAT) in most instances. Where stream features were consistent with estuarine habitat (i.e., presence of marine plants such as mangroves) the HAT limit was extended to represent those observed habitat features (Table 7).

Table 7: Criteria and associated scores for the measured distance between each barrier and the estuary.

Option	Distance to Estuary	Score
a.	In estuary or on the tidal interface	5
b.	<500m from tidal interface	4
c.	500m-2km	3
d.	2km-10km	2
e.	10km-20km	1
f.	>20km	0

Stage 2: Site-Specific Ecological Assessment

A priority ranked list of the most important potential barriers after Stage 1 was created following the GIS-based rapid assessment. This priority ranked list was then used to prioritise ground-truthing and assess the highest-ranking potential barriers during Stage 2. A total of 193 potential barriers were visited during Stage 2, this resulted in 120 barriers being confirmed and scored based on their passability, in-stream and riparian habitat, and stream flow. Additional information was collected at confirmed barrier sites to enable further prioritisation including site access (e.g., excavator, concrete truck) and landholder participation. Fish barrier scores acquired during ground-truthing were entered into a spatial database. Scores for Stage 1 and 2 were then totaled to obtain the final priority ranked score.

It should be noted that every barrier investigated on-ground was assessed based on the flow conditions present at the time. As conditions vary, the passability of each barrier will change. Therefore, the study can only prioritise remediation based on the probable impact of each barrier under similar flow conditions.

7 *Barrier Type and Passability*

Barrier type and passability were assessed based on the configuration of the barrier. Impoundment structures such as dams and weirs were scored separately from culverts. Dams and weirs were scored based on their height (head loss) alone, whereas culverts were scored according to their span across the waterway (aperture), total structure height, and head loss. Table 8 details scores attributed to various configurations. See the ‘Barrier Passability’ section on page 14 for more information.

Table 8: Criteria used to assess barrier passability for various barrier types and associated scores.

Option		Dam or Weir only (no culverts)	Score
a.		Dam or Weir 2 m + high	7
b.		Dam or Weir 1 - 2 m high	6
c.		Dam or Weir 0.5 - 1 m high	5
d.		Dam or Weir 0.25 - 0.5 m	4
e.		Dam or Weir <0.25 m	1
Box or Pipe Culverts			
Span			
A	a.	Culverts/pipes that span <20% of stream cross-sectional area	3
	b.	Culverts/pipes that span 20-40 % of stream cross-sectional area	2
	c.	Culverts/pipes that span 41 - 60% of stream cross-sectional area	1
	d.	Culverts/pipes that span >60% of stream cross-sectional area	0
Causeway/Structure Height			
B	a.	2 m +	2
	b.	1 - 2 m	1
	c.	0 - 1 m	0
Head loss			
C	a.	Head loss: 300 + mm	2
	b.	Head loss: 0 - 250 mm	1
	c.	Below Bed Level (no drop; upstream and downstream water levels equal)	0
***Notes: Head loss = difference between upstream and downstream water levels**			

8 Stream Condition

Stream condition was assessed by visual observation at the barrier site. This aimed to provide an approximate characterization of the ecological health of the surrounding riparian vegetation and the aquatic environment. Scoring was based on general observations of riparian clearing, presence of invasive weeds, erosion, and pollution (Table 9).

Table 9: Criteria used to assess stream condition at the barrier site and associated scores.

Option	Stream Condition	Score
a.	Pristine-undisturbed (no apparent clearing of riparian vegetation, no bank degradation, exotic weeds or pollution)	5
b.	Low disturbance (<25% of observable upstream areas degraded)	4
c.	Moderate disturbance (25-50% of observable upstream areas degraded)	3
d.	High disturbance (51-75% of observable upstream areas degraded)	2
e.	Very high disturbance (>75% of observable upstream areas degraded)	1

9 Water Supply

Assessment of streamflow characteristics was important in determining the permanence and quality of available habitat at the barrier site if remediation was to occur. Natural, permanent, and perennial flow regimes were scored highly given the increased chance of survival for any fish populations present. Ephemeral systems which are known to dry seasonally only provide habitat during part of the year and thus were scored lower (Table 10). The assessment of water supply was based on visual observations and local knowledge of each watercourse.

Table 10: Criteria used to assess water supply in the watercourse of each barrier and associated scores.

Option	Water Supply	Score
a.	Natural, permanent, perennial	5
b.	Natural, permanent via supplemented flow	4
c.	Stream occasionally dries up with refuge pools	3
d.	Stream dries seasonally with refuge pools	2
e.	Stream dries seasonally with no refuge pools	1

10 Habitat for Migratory Fish Species Upstream of Barrier Site

Habitat available for migratory fish upstream of the barrier was assessed by visual observations conducted during site visits. These observations included the presence and abundance of natural woody debris in the watercourse (particularly within the low-flow channel), the diversity of habitats, and the presence of aquatic macrophytes. Diverse and structurally complex habitats provide refuge for various sizes and life stages of fish and are critical to the survival and productivity of many species. Sites with diverse and abundant fish habitats were scored highly (Table 11).

Table 11: Criteria used to assess habitat for migratory fish upstream of the barrier and associated scores.

Option	Habitat for Migratory Fish Species Upstream of Barrier Site	Score
a.	Excellent - Diverse and abundant fish habitat (large woody debris, run, riffle and pool habitats, aquatic plants	5
b.	Good - Reasonable amount of suitable fish habitat	4
c.	Moderate - some suitable fish habitat present	3
d.	Poor - little suitable fish habitat	2
e.	Very poor - Scarce or no suitable fish habitat	1

11 Conservation Significance

Will improved connectivity have a positive impact on the conservation of listed species? Assessment criteria and scores for question 11 are displayed below in Table 12.

Table 12: Conservation significance criteria and associated scoring.

Option	Conservation Significance	Score
a.	EPBC Listed species present	2
b.	Only common or abundant species within the region are present	1

12 Distance to Next Significant Waterfall

The upstream length of accessible stream habitat to the next significant waterfall, i.e., the distance from the potential barrier to the next significant waterfall, or to the top of the catchment, indicates the amount of habitat made available upon remediation, e.g., 15 km's of stream length (habitat) from barrier 1 to next significant waterfall, then barrier 1 receives a score of 2 (Table 13). Waterfall data derived from Queensland's Spatial Catalogue with features captured or updated from the best available imagery. This dataset displays significant waterfalls, both named and un-named within the State of Queensland.

Table 13: Stream length to the next barrier or top of catchment categories and associated score.

Option	Stream Length (km) to the Next Significant Waterwall/or Top of Catchment	Score
a.	>100	5
	50.1-100	4
b.	20.1-50	3
c.	2-20	2
d.	1-2	1
e.	<1	0

Results

During Stage 1 potential barriers were ranked in order of priority in preparation for ground-truthing. Desktop barrier assessment resulted in the identification of 1,649 potential barriers (Figure 8).

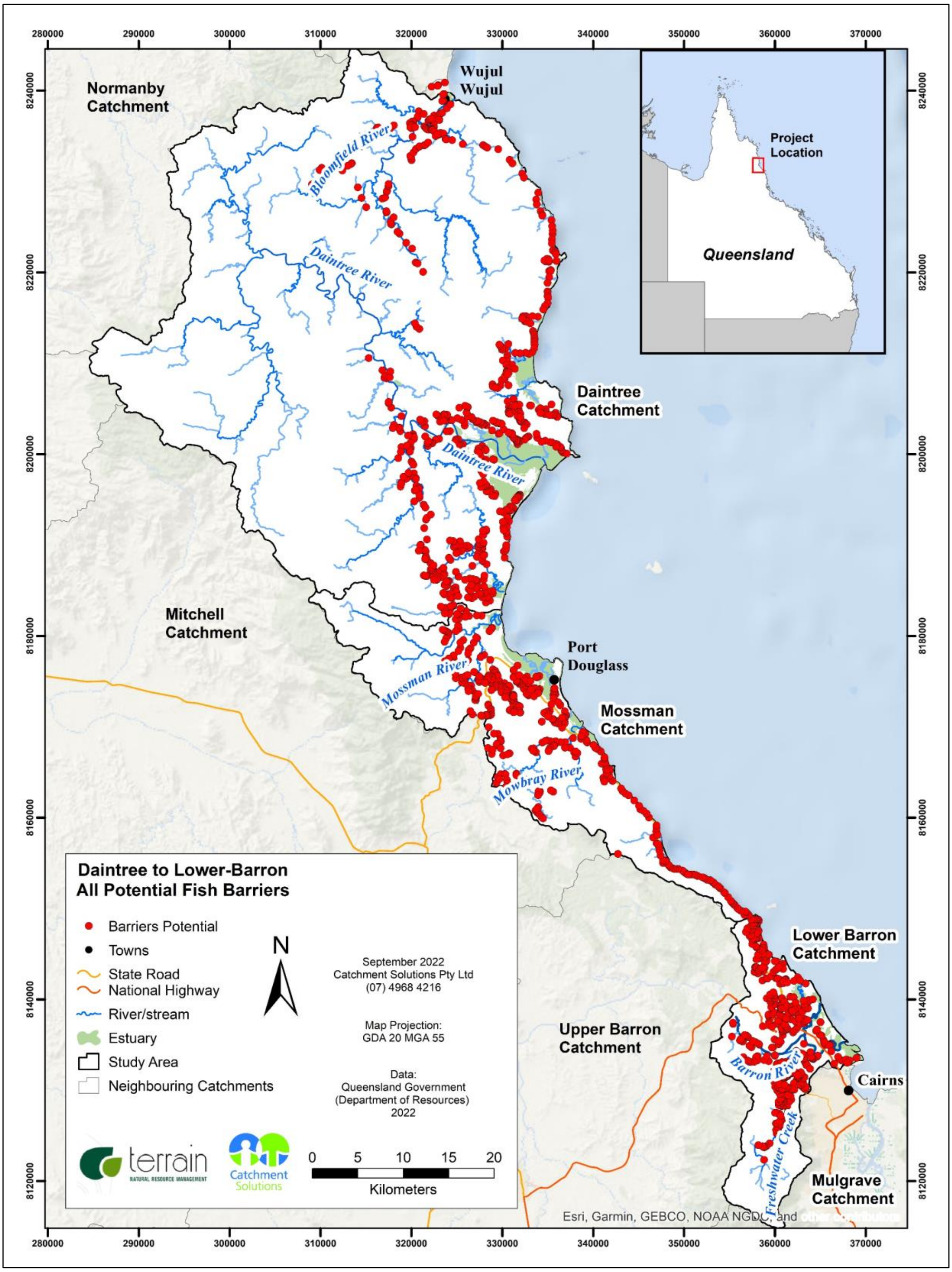

Figure 8: All potential fish barriers identified in the Daintree to lower Barron fish barrier prioritisation study, 2022.

Stage 2 -Ground-truthing

During Stage 2, 193 potential barriers were inspected and assessed in the field. 120 of the potential barriers visited (62%) were confirmed as barriers to fish passage. Most stream barriers were road causeways, typically with pipe and box culvert configurations (Figure 9). Typically, culverts were undersized (e.g., culvert aperture <60% of the full-channel width) and often vertical drops were present on the downstream side of the culvert apron (water surface drop barrier). Potential barriers validated in the field that were assessed as not impacting aquatic connectivity included bed level crossings, bridges, and natural features such as fallen trees (Figure 10).

Figure 9. Examples of typical fish barriers validated during ground-truthing by Terrain NRM (Lana Hepburn & Tom Crow), Wet Tropics Waterways (Richard Hunt and James Donaldson), and Catchment Solutions (Matt Moore) staff. From left to right; Causeways on Whyanbeel Creek (BarID:1278, Rank:21), Saltwater Creek (BarID:1218, Rank:14), and a tributary of Hutchinson Creek (Daintree Basin) (BarID:1801, Rank:56).

Figure 10. Typical non-fish barriers validated during ground-truthing. From left to right; Natural bed level crossing (Mowbray River), Bridge (Noah Creek), and a box culvert causeway encompassing the full stream width and constructed below bed level (Cooper Creek).

Following the removal of non-barriers and rescoring against Stage 2 criteria, barriers received their final rankings.

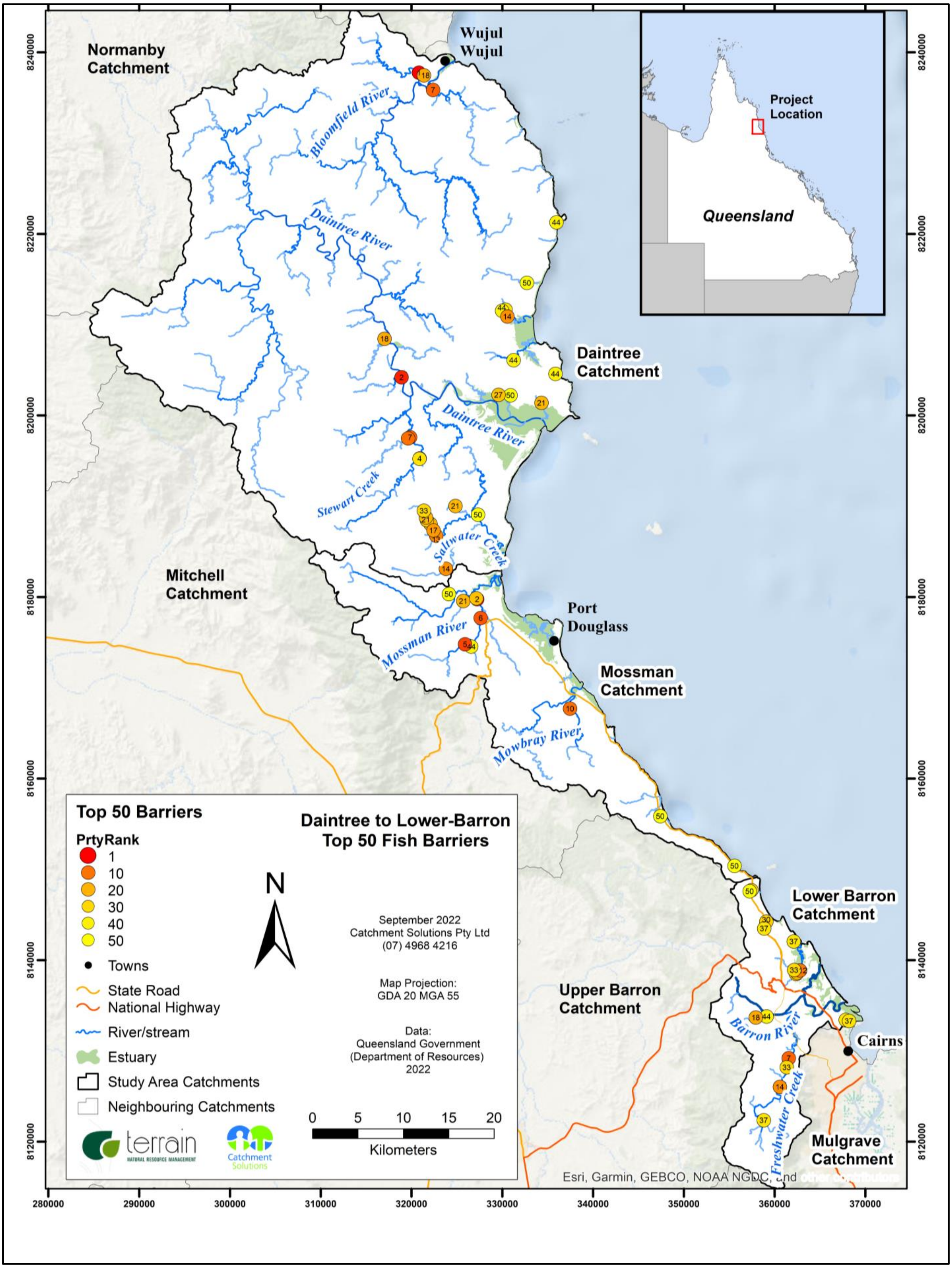

Figure 11: Top 50 priority ranked Daintree to Lower Barron fish barriers

Highest Ranking Barriers

1. Granite Creek, Bloomfield River Catchment

The highest priority barrier was a redundant causeway on Granite Creek in the Bloomfield River Catchment. (Figure 12). The causeway is located just upstream from the tidal interface. Riparian and instream habitat conditions at the site were in excellent condition. The Weir is approximately 1.5 m high and forms a low passability barrier. Complete removal is recommended, followed by a nature-like rock ramp fishway.

Figure 12. Showing the highest priority ranked barrier (causeway) located on Granite Creek.

2. Mossman Mill Weir/Causeway, South Mossman River

Mossman Mill weir and causeway was the 2nd highest priority ranked fish barrier in the study (Figure 13).

Figure 13. Showing the 2nd highest priority ranked barrier on the South Mossman River

Discussion

The Daintree to Lower Barron River catchments are comprised of diverse aquatic habitats with numerous natural and anthropogenic factors impacting fish passage. High-priority fish barriers were identified across a range of unique ecosystem contexts. Significantly, barriers impacting connectivity were identified low down in the catchment in close proximity to the tidal interface on many of the region's waterways.

Barriers to fish passage located on or near the tidal interface have the greatest impact on the region's fish communities, particularly diadromous species, and in some instances may cause localised extinctions upstream of the barrier (Bunn & Arthington 2002). The reduction in distribution and abundance of many key socioeconomic diadromous fish species throughout much of their former range can be directly attributed to migration barriers, particularly low passability structures. Barriers blocking unimpeded connectivity along waterways reduce aquatic ecosystem health and the ability of waterways to maintain resilience in the face of ever-growing anthropogenic pressures such as poor water quality and pest fish.

Barrier passability is one of the most important metrics used to determine the impact of a particular barrier and formed a key component of the current fish barrier assessment. While some tidal interface barriers provide temporary opportunities for upstream passage (high passability) during the upper limits of high tides others provide minimal to no passage during normal stream flows e.g., Dunne Road tidal flap gate barrier on Avondale Creek (BarID 682 Rank 9). These low passability barriers have been scored high in the current assessment and remediation efforts to improve waterway connectivity should be prioritised at these sites.

Often the most appropriate remediation option for many waterway barrier sites is the construction of rock ramp fishways (Figure 14). Rock ramp fishways are aesthetically pleasing and designed to emulate natural rock riffles. As a result of their irregular forms (rocks), they provide a high degree of geometrical diversity which creates interstitial spaces and micro-eddies (Wang 2008). These assist weaker swimming juvenile diadromous fish species in successfully ascending upstream when compared to smooth-sided highly engineered fishways e.g., vertical slot. Further detail on Rock Ramp Fishways and alternative remediation options is provided in Appendix 2.

Figure 14. Showing rock ramp fishway constructed to remediate water surface drop barriers downstream from causeways; left Sandy Creek, Mackay (Palm Tree Road), and the Gooseponds (Janes Creek), Mackay City (right).

Approaches to Fish Barrier Remediation

Several approaches can be adopted when undertaking remediation works. This prioritisation ranks sites based on the environmental benefit of remediating a barrier in isolation. That is if a group can only undertake works at one site, which site would deliver the best outcomes for the funds available. An alternative approach may be to remediate a series of barriers within a single catchment. The rankings reported in this prioritisation do not consider the cumulative benefits of remediating barriers in series. Should this approach be adopted, it is recommended that the highest-ranking barrier within the catchment be remediated first if funds permit.

In general, the removal of a barrier that impedes fish passage should be considered the preferred option for remediation. There are instances, however, where the barrier is providing some benefit to fish communities and consideration should be given to choosing an appropriate remediation option that maintains that benefit. For example, ponded pastures are created when earth bunds are constructed on coastal plains. While modified, the wetlands which are created can provide valuable fish habitat and contribute to overall productivity. Removing the bund may improve connectivity at the cost of upstream fish habitat. An alternative approach may be to retrofit a fishway to the bund to improve connectivity while maintaining the upstream fish habitat (Figure 15). Where the removal of a bund is to reinstate tidal waters to assist with the control of invasive weeds (e.g., Salvinia), then consideration may be given to lowering the bund to a level that allows tidal exchange but maintains some depth for fish refuge.

Figure 15. A rock ramp fishway constructed to remediate a road causeway (water surface drop) on Tedlands wetlands in Koumala, central QLD (left). Young of the year Barramundi recruits captured successfully ascending the fishway during post-construction monitoring (top right). This is the typical size of juvenile Barramundi undertaking life-cycle-dependent migrations from saltwater to freshwater. Thousands of juvenile Empire Gudgeon (and a few Barramundi) were recorded in a single trap set successfully ascending the fishway (bottom right). These Empire Gudgeon and Barramundi were migrating from saltwater to freshwater.

In most instances, the structures which form fish barriers are considered critical infrastructure and removal is not supported. Under these circumstances, the retrofit of a fishway is considered the most appropriate remediation action. Careful consideration needs to be given to the type of fishway used and fish passage specialists should be consulted to provide guidance.

In Queensland the retrofit of fishways to existing fish barriers is itself considered waterway barrier works and generally requires State approval. This process can be lengthy and adds to the costs of remediation works. Such cost should be factored into works budgets or funding applications. Once a site is identified for remediation it is recommended that pre-lodgement advice is sought from the State Assessment and Referral Agency, the coordinating department for State development permits.

Conclusions

Importance of Barrier Remediation and Removal

Remediation and identification of barriers to fish passage is a critical component of holistic fisheries management and ecosystem restoration. Remediating and removing high-priority barriers will likely result in immediate benefits to the productivity, diversity, and resilience of fish communities in Daintree to Lower Barron River catchments. Removal or remediation of barriers via appropriately designed fishways (Figures 16 & 17) will have immediate benefits for individual streams and wetlands. Although, there are likely to be even greater cumulative impacts realised from the remediation of multiple barriers within the study area. Cumulative and multiplicative benefits can result from population connectivity between waterways and catchments. For example, the increased available habitat area upstream of a remediated barrier is likely to result in increases in the local population of diadromous species. These are species that require upstream migration from coastal and estuarine ecosystems into freshwaters. Many of these populations of diadromous fish utilise nearshore marine waters to disperse their eggs and larvae, e.g., Barramundi and Empire Gudgeon. Therefore, an increase in this population in one stream will likely result in an increased supply of dispersed eggs and larvae, and therefore recruits to other nearby streams. Cumulatively, as many barriers are remediated, the local and regional supply of recruitment will improve. This is important for population and ecosystem resilience as in any given year, environmental variations will impact habitat suitability and accessibility due to the timing and duration of freshwater flows and flooding. Increases in the quantity of recruiting larvae and juvenile fish across space and time can take advantage of these variations, sustaining the regional population year-to-year.

Recommendations

- Undertake pre-barrier remediation monitoring to determine current impacts on fish communities at high-priority sites. Up to three sites could be monitored with specifically designed fish barrier traps (paired upstream and downstream monitoring) at one time. Recommend one week (5 days) of monitoring. Information can be used to determine the extent of impacts, inform business cases, and convey results to the local community. Additionally, this data can be used to make comparisons with post-fish barrier remediation monitoring to determine the benefit gained from fish passage works.
- Remediate high-priority fish barriers. The authors recommended selecting one high-visibility site to remediate in the first instance, including pre and post-fishway monitoring, to showcase the benefits of remediation to the local community, environment, fish populations and waterway health.
- Finish assessing high-priority barrier sites through an DLBFBP update. Several high-priority sites have not been assessed due to access difficulties.

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Appendix 1: Top 30 Priority Ranked Fish Barriers

Note: Fish barrier remediation costs are preliminary estimates only and are based upon similar fish passage projects undertaken by the authors. Costs may vary depending on remediation option, site constraints and potential approvals and engineering requirements.

Overall Priority Ranking	**1**	
Barrier ID	1603	
Stream Name	Granite Creek	
Location	15° 55.983'S	145° 19.568'E
Barrier Type	Redundant Causeway	
Barrier Name	U/S Rossville Bloomfield Rd	
Remediation Option	Removal/Partial Removal + Rock Ramp Fishway	
Approx. Cost of Fishway	$100-$350 k	

Overall Priority Ranking	**2**	
Barrier ID	992	
Stream Name	South Mossman River	
Location	16° 27.458'S	145° 22.907'E
Barrier Type	Weir + Dropboard Culvert	
Barrier Name/Info	Mossman Mill Weir	
Remediation Option	Rock Ramp (RR) Fishway/Bypass RR Fishway	
Approx. Cost of Fishway	$120 - $320 k	

Overall Priority Ranking	**2**	
Barrier ID	1460	
Stream Name	Martins Creek	
Location	16° 14.168'S	145° 18.335'E
Barrier Type	Culvert Causeway	
Barrier Name	Upper Daintree Rd	
Remediation Option	Rock Ramp Fishway/Fish Friendly Scour protection	
Approx. Cost of Fishway	$80-150 k	

Overall Priority Ranking	**4**	
Barrier ID	1437	
Stream Name	Stewart Creek	
Location	16° 19.027'S	145° 19.408'E
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Stewart Creek Rd	
Remediation Option	Culverts/Partial-width Rock Ramp Fishway	
Approx. Cost of Fishway	$150-$350 k	


Low flow. Image Credit: Lana Hepburn

Overall Priority Ranking	**5**	
Barrier ID	1022	
Stream Name	South Mossman River	
Location	16° 30.154'S	145° 22.170'E
Barrier Type	Causeway	
Barrier Name	Shannonvale Rd	
Remediation Option	Partial-width Rock Ramp Fishway + nib wall	
Approx. Cost of Fishway	$100 - $300 k	

Overall Priority Ranking	**6**	
Barrier ID	1273	
Stream Name	South Mossman River	
Location	16° 28.587'S	145° 23.105'E
Barrier Type	Causeway	
Barrier Name	Farm Access	
Remediation Option	Fish Friendly Scour Protection	
Approx. Cost of Fishway	$30-$90 k	

Overall Priority Ranking	**7**	
Barrier ID	487	
Stream Name	Freshwater Creek	
Location	16° 55.013'S	145° 41.997'E
Barrier Type	Causeway	
Barrier Name	Lower Freshwater Driveway	
Remediation Option	Fish Friendly Scour Protection	
Approx. Cost of Fishway	$50-$120 k	

Overall Priority Ranking	**7**	
Barrier ID	1444	
Stream Name	Cassowary Creek	
Location	16° 17.757'S	145° 18.828'E
Barrier Type	Pipe Causeway	
Barrier Name	Crystal Brook Road	
Fishway Type Needed	Box Culverts/Rock Ramp Fishway + High flow scour protection	
Approx. Cost of Fishway	BC:$120-$250 k/ RR: $60-$150 k	

Overall Priority Ranking	**7**	
Barrier ID	1635	
Stream Name	Woobadda River	
Location	15° 57.007'S	145° 20.430'E
Barrier Type	Box Culvert Causeway	
Barrier Name	Upper Daintree Rd/Not DAF ADR Compliant	
Fishway Type Needed	Bridge/Culverts	
Approx. Cost of Fishway	B: $2m +, BC: $500-$950 k	

Overall Priority Ranking	**10**	
Barrier ID	827	
Stream Name	Spring Creek	
Location	16° 34.045'S	145° 28.587'E
Barrier Type	Box Culvert Causeway	
Barrier Name	Mowbray River Rd/Not DAF ADR Compliant	
Fishway Type Needed	Culverts below bed level	
Approx. Cost of Fishway	$500 k- $1.2 m	

Overall Priority Ranking	**10**	
Barrier ID	1445	
Stream Name	Cassowary Creek	
Location	16° 17.828'S	145° 18.702'E
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Crystal Brook Rd	
Fishway Type Needed	Box Culverts/Rock ramp	
Approx. Cost of Fishway	BC: $150 - $350 k/ RR: $70-$120 k	

Image Credit: Richard Hunt

Overall Priority Ranking	**12**	
Barrier ID	682	
Stream Name	Avondale Creek/Estuary	
Location	16° 49.777'S	145° 42.735'E
Barrier Type	Tidal Flap Gates	
Barrier Name	Dunne Road	
Fishway Type Needed	Flap Gate Removal or Fish Friendly Tidal Activated Gate	
Approx. Cost of Fishway	$0-$80 k	

Example Auto-tidal gate to improve WQ & Fish Passage
Image Credit: Fish Habitat Network

Overall Priority Ranking	**13**	
Barrier ID	1275	
Stream Name	High Falls Creek	
Location	16° 23.656'S	145° 20.391'E
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Old Forestry Road	
Fishway Type Needed	Box Culverts/RckRamp	
Approx. Cost of Fishway	BC:$200-$550 k, RR:$60-$200 k	

Overall Priority Ranking	**14**	
Barrier ID	498	
Stream Name	Freshwater Creek	
Location	16° 56.699'S	145° 41.457'E
Barrier Type	Redundant Weir	
Barrier Name	Gamburra Park Weir	
Fishway Type Needed	Removal/Partial-width Rock Ramp Fishway	
Approx. Cost of Fishway	R:$60-$220 k, RRF:$80-$240 k	

Overall Priority Ranking	**14**	
Barrier ID	1218	
Stream Name	Saltwater Creek	
Location	16° 25.632'S	145° 20.974'E
Barrier Type	Culvert Causeway + Apon drop	
Barrier Name	O'Donoghue Road	
Fishway Type Needed	Partial-width Rck Ramp Fishway	
Approx. Cost of Fishway	$80 k -$240 k	

Overall Priority Ranking	14	
Barrier ID	1753	
Stream Name	Cooper Creek tributary	
Location	16° 10.593'S	145° 24.896'E
Barrier Type	Pipe Causeway	
Barrier Name	Cape Tribulation Rd	
Fishway Type Needed	Box Culverts	
Approx. Cost of Fishway	$150-$450 k	

Overall Priority Ranking	17	
Barrier ID	1884	
Stream Name	Whyanbeel Creek	
Location	16° 23.346'S	145° 20.218'E
Barrier Type	Bridge Scour Protection	
Barrier Name	Kingfisher Lane	
Fishway Type Needed	Fish Friendly Scour Protection/Rck Rmp Fway	
Approx. Cost of Fishway	FFSP:$40-90 k/RRF:$60-$180 k	

Overall Priority	18	
Barrier ID	640	
Stream Name	Stoney Creek	
Location	16° 52.568'S	145° 39.969'E
Barrier Type	Concrete Causeway	
Barrier Name	Stoney Creek Swimming Hole	
Fishway Type Needed	Rock Ramp Fishway	
Approx. Cost of Fishway	$80-$250 k	

Image Credit: Cody May

Overall Priority	**18**	
Barrier ID	1467	
Stream Name	Niau Creek	
Location	16° 11.874'S	145° 17.301'E
Barrier Type	Pipe Causeway + Apron Drop	
Barrier Name	Off Upper Daintree Rd	
Fishway Type Needed	Rock Ramp Fishway/Box Culverts	
Approx. Cost of Fishway	RRF:$80-$180k/BC:$150-$350 k	

Overall Priority	**18**	
Barrier ID	1606	
Stream Name	Olufson Creek	
Location	15° 56.153'S	145° 19.867'E
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Rossville Bloomfield Rd	
Fishway Type Needed	Box Culverts/Rock Ramp Fishway	
Approx. Cost of Fishway	BC:$200-450k/RRF:$40-$90k	


Juvenile Jungle Perch

Overall Priority	**21**	
Barrier ID	681	
Stream Name	Avondale Creek	
Location	16° 49.920'S	145° 42.561'E
Barrier Type	Tidal Pipe Causeway	
Barrier Name	Cattana Wetlands Tidal Interface	
Fishway Type Needed	Removal/Box Culverts	
Approx. Cost of Fishway	R:$40-$80k BC:$220-$380k	

Overall Priority	**21**	
Barrier ID	1276	
Stream Name	Whyanbeel Creek	
Location	16° 22.951'S	145° 20.040'E
Barrier Type	Redundant Causeway	
Barrier Name	Off Whyanbeel Rd	
Fishway Type Needed	Removal/Rock Ramp Fishway	
Approx. Cost of Fishway	R: $40-$80k, RRF:$70 -$140k	

Overall Priority	**21**	
Barrier ID	1278	
Stream Name	Whyanbeel Creek	
Location	16° 22.550'S	145° 19.766'E
Barrier Type	Pipe Causeway + Apron Drop	
Barrier Name	Driveway off Whyabeel Rd	
Fishway Type Needed	Rock Ramp Fishway/Box Culverts	
Approx. Cost of Fishway	RRF:$70-160k/BC: $120-220k	

Overall Priority	**21**	
Barrier ID	1484	
Stream Name	Doyle Creek	
Location	16° 15.754'S	145° 26.967'E
Barrier Type	Pipe Causeway	
Barrier Name	Farm Access Causeway	
Fishway Type Needed	Bed Level Crossing/Rock Ramp Fishway	
Approx. Cost of Fishway	BLC:$40-$70k, RRF:$70-$130k	

Overall Priority	**21**	
Barrier ID	1268	
Stream Name	Chinaman Creek	
Location	16° 21.878'S	145° 21.606'E
Barrier Type	Pipe Causeway	
Barrier Name	Kahana Rd	
Fishway Type Needed	Fish-Friendly Scour Protection/Rock Ramp Fishway	
Approx. Cost of Fishway	FFSP:$40-$70k/RRF:$50-$90k	

Overall Priority	**21**	
Barrier ID	1133	
Stream Name	Marr Creek	
Location	16° 27.558'S	145° 22.038'E
Barrier Type	Concrete Bridge Apron	
Barrier Name	Cane Rail Bridge	
Fishway Type Needed	Fish-Friendly Scour Protection/Rock Ramp Fishway	
Approx. Cost of Fishway	FFSP:$40-$60k/RRF:$50-$90k	

Overall Priority	**27**	
Barrier ID	1277	
Stream Name	Whyanbeel Creek	
Location	16° 22.724'S	145° 19.827'E
Barrier Type	Culvert Causeway	
Barrier Name	Driveway off Whyabeel Rd	
Fishway Type Needed	Rock Ramp Fishway/Box Culverts	
Approx. Cost of Fishway	RRF: $80-$140 k/BC:$150-$350 k	

Overall Priority	**27**	
Barrier ID	1511	
Stream Name	Unnamed Ck - Daintree Ferry Nth	
Location	16° 15.266'S	145° 24.324'E
Barrier Type	Culvert Causeway + Apron Drop	
Barrier Name	Cape Tribulation Road	
Fishway Type Needed	Fish Friendly Scour Protection/Rock Ramp	
Approx. Cost of Fishway	FFSP:$35-$50 k/RRF:$70-$90 k	

Overall Priority	**27**	
Barrier ID	1272	
Stream Name	Parker Creek	
Location	16° 27.407'S	145° 22.846'E
Barrier Type	Bridge Abutments	
Barrier Name	Mossman Mill	
Fishway Type Needed	Rock Ramp Fishway	
Approx. Cost of Fishway	RRF:$100-220k	

Overall Priority	**30**	
Barrier ID	1919	
Stream Name	Deep Creek	
Location	16° 46.847'S	145° 40.669'E
Barrier Type	Culvert & Apron Drop	
Barrier Name	Cottesloe Dr, Kewara Beach	
Fishway Type Needed	Rock Ramp & Horizontal Baffle	
Approx. Cost of Fishway	$50-$110 k	

Overall Priority	**30**	
Barrier ID	1978	
Stream Name	Sweet Creek	
Location	16° 44.968'S	145° 39.747'E
Barrier Type	Culvert Causeway + Apron Drp	
Barrier Name	Cook HWY Palm Cove	
Fishway Type Needed	Low flow investigation/Fish Friendly Rock Scour Protection	
Approx. Cost of Fishway	$45-$85 k	

Overall Priority	**30**	
Barrier ID	680	
Stream Name	Avondale Creek	
Location	16° 49.987'S	145° 42.497'E
Barrier Type	Redundant Culvert Causeway	
Barrier Name	Cattana Road	
Fishway Type Needed	Removal/Fish Friendly Scour Protection	
Approx. Cost of Fishway	R: $15-$30 k/$30-$40 k	

Overall Priority	**33**	
Barrier ID	2108	
Stream Name	Avondale Creek Tributary	
Location	16° 49.761'S	145° 42.378'E
Barrier Type	New Perched Culverts_Not DAF ADR Compliant	
Barrier Name	Dunne Rd - Adj Cattana Wetlands	
Fishway Type Needed	Rock Ramp Fishway/Culverts	
Approx. Cost of Fishway	RRF:$90-$170 k/C:$350-850 k	

Appendix 2

Fish Passage Remediation Options

Complete barrier removal is generally the first remediation option. However, this is often only a viable option if the structure is redundant. In most circumstances, the barrier structure (lawful or unlawful) exists for a reason (e.g. irrigation, water supply, transportation, etc.), and retrofitting a fishway is the only fish passage solution. There have been numerous fishway designs implemented in Australian waters over the years. Many of the original designs were based on northern hemisphere fish species such as Atlantic salmon, which are able to negotiate faster velocities and higher water turbulence than Australian native fish species. Further, unlike most Australian coastal freshwater fish species, many salmonid species possess an ability to leap past obstacles. Atlantic salmon migrate as larger bodied adults, whereas many coastal Queensland species undertake an upstream migration during their early life-history, typically as juveniles, but also post larvae and sub-adult stages, which makes ascending these early fishway designs virtually impossible. Unfortunately, this was not immediately recognised, resulting in a high proportion of fishways constructed between the 1960-80's that were inadequate for Australian fish passage rehabilitation; a legacy which today is still blocking fish migration in a number of systems on a daily basis.

Fortunately, fishways constructed today generally take into consideration the swimming abilities of Australian native fish, with a growing recognition that all fish species and size classes are catered for. Fishways can be broken into two main groups; highly engineered, expensive fishways for high barriers >5 m such as dams and high weirs located on large rivers e.g. Murray River. These fishways generally entail fish lifts or locks (elevator-style fish ladders) and large vertical-slot fishways. Often costing millions of dollars, these fishways are usually out of the feasible realm of local government and community group's rehabilitation efforts. The second and most common fishway types are generally designed for barriers <5 m in height. These include nature like rock-ramp, bypass channel, concrete cone ramp, vertical-slot, denil, and vertical and horizontal culvert baffle fishways.

Rock- Ramp fishways

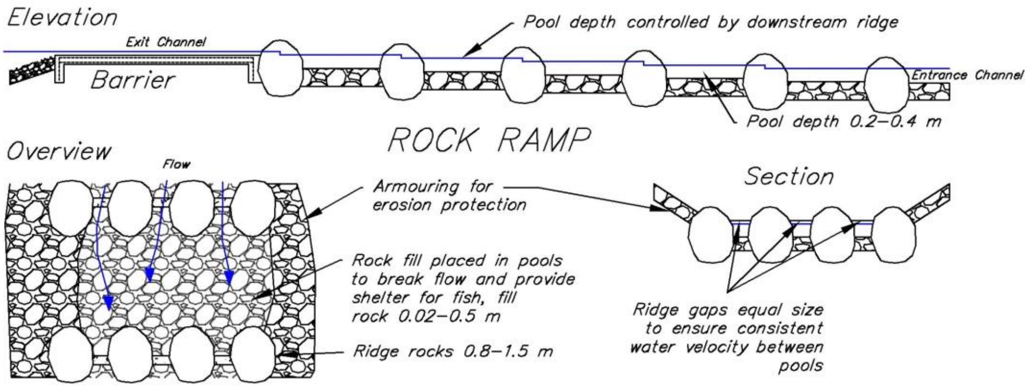
Rock-ramp fishways, or nature-like fishways, are the most common fishway type constructed in Queensland. Over the past decade, rock- ramps have been refined to suit the swimming abilities of native fish species and represent a low cost option to more formal fishway designs (Gebler 1988; Pasche et al 1995; Steiner 1995; Baumgartner and Lay 2002). They have proven to be effective fishways for the whole fish community, particualry weaker swimming juvenile diadromous and small bodied species (Table 1). The success of rock-ramps in passing small bodied species is largely due to the surface rougness, micro-eddies and flow complexity imparted by natural rock materials used to construct rock-ramps when compared to more structural, smooth-sided fishways (e.g vertical-slot, denil, etc.).

Figure 16. Nature like rock-ramp fishways: a) Full width (Gooseponds Ck, Mackay), b) Dog-leg (Lake Callemondah, Gladstone) c) Partial width (Tedlands Ck, Koumala)

In Australia, rock-ramps (Figure 16) are generally constructed on barriers up to 2.5 m in height, but could essentially be constructed on barriers much higher. Rock-ramp fishways are designed to mimic natural rock riffle stream conditions, with the added advantage of deep resting pools between ridges. Rock-ramps are generally constructed on a gradient of approximately <1:20 and designed to create a series of deep pools interspersed by rock ridges, with the falls between ridges usually set at between 60-90 mm, with smaller falls in lower river reaches and higher falls in headwater streams. Native fish utilise the deep pools between rock ridges to rest and regain their energy, before using their burst speed to negotiate the small falls between rocks to enter the next upstream pool. The natural materials (rock) used to construct rock-ramps provide interstitial spaces and surface irregularities which assist weaker swimming fish as they migrate upstream. Rock-ramps are aesthetically pleasing and their natural appearance means they blend into the surrounds of the natural stream environment. See table 14 below for a full list of advantages and disadvantages of rock-ramp fishways.

Table 14. Showing advantages, disadvantages and conceptual design of nature-like rock-ramp fishways

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Nature like Rock-ramp: Full width Partial width. Dog-leg Bypass Channel	Minimum Requirements: 1:20 - 1:30 grade Ridge rock height 1.2 m -1.8m Wall rock height 1.5 m -2.0 m wall 300 mm pool depth at cease to flow High flow & low flow slots Well graded rock mix to secure ridge and wall rocks Fibre-reinforced concrete to seal pools (small waterways/partial width designs)	Effective for the whole fish community, particularly juvenile diadromous and small bodied species Cost Effective Natural appearance High flows and low flows Reasonably high degree of redundancy (i.e. if partly blocked by debris, etc., will still function in rest of fishway) Good for downstream passage Simple construction	Entrance location needs to be considered or fish won't use the fishway. It needs to be suitable for different discharge flows / conditions. Require rock supply relatively close to site – cost consideration Construction needs to be well supervised by fish biologist experienced in fishway construction May requires maintenance–removal of debris (e.g. sticks) from the ridge slots



Cone Fishways

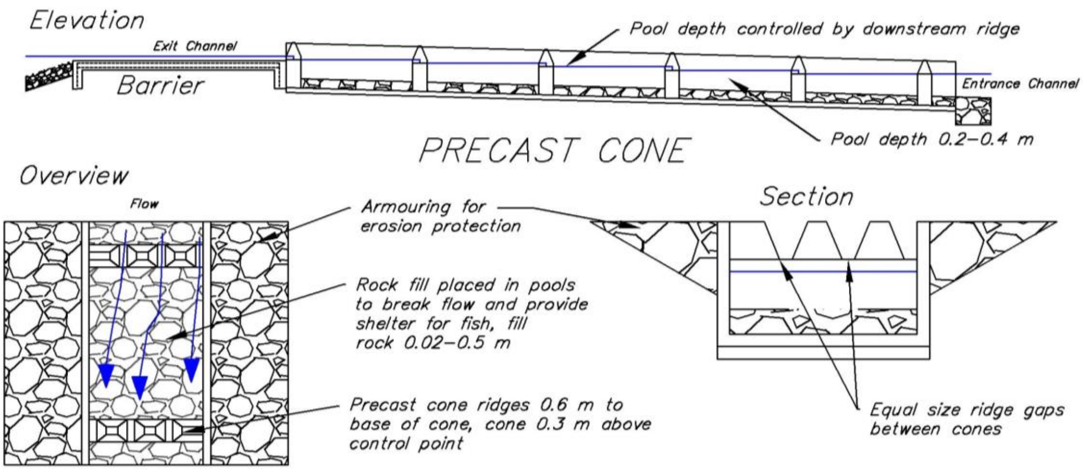
In an operational sense cone fishways are similar to rock-ramps, comprising of a series of pools interspersed at regular intervals by ridges within a channel on a minimum gradient of approximately 1:20. The main differences between the two fishway types, centers around the prefabrication of materials and unnatural appearance for cone fishways in comparison to the natural appearance of materials used for rock-ramps. Cone fishways have the added advantage of requiring less space than for rock-ramps and can be extremely useful when rock is in short supply e.g. Southern Gulf in northern Australia, as the side walls and cone ridge components can be prefabricated off site (Table 15). The highly engineered structural nature of cone fishways (Figure 17) ensures flow characteristics are also more consistent between ridges when compared to rock-ramps. Conversely, the smooth sided internal walls of cone fishways lack the surface roughness and micro-eddies associated with rock-ramps, which assist the migration of weaker swimming species.

The ridge components of cone fishways can be prefabricated using concrete or HDPE plastic. The pre-cast concrete or plastic cone ridges are inserted into a concrete channel creating a pool upstream and a small drop downstream. Generally, this type of fishway is more expensive to construct due to the cost of the pre-cast components and increased installation time when compared to rock-ramps.

Figure 17. Concrete cone fishway on Boundary Creek, Koumala; showing fish successful at ascending, top to bottom; juvenile Barramundi and Empire Gudgeon, Giant Herring & over one thousand juvenile Banded Scats & Threadfin Silver Biddy.

Table 16. Showing advantages, disadvantages and conceptual design cone fishways

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Concrete cone Full width Partial width. Dog-leg –	Consists of a channel with steps to form a hydraulic gradient of approximately 1:20 Steps have fabricated cones installed as ridges to create a pool upstream and a small drop downstream. Gaps between the ridge rocks afford passage for smaller fish at low flows. 300 mm pool depth at cease to flow High flow & low flow slots	Geometric design means that this can accurately control flow rate down fishway. Has been used elsewhere throughout Queensland with excellent results. Has a reasonably high degree of redundancy (i.e. if partly blocked by debris, etc, will still function in rest of fishway. All reinforced concrete components make this design less susceptible to damage during high flows	Entrance location needs to be considered or fish won't use the fishway. It needs to be suitable for different discharge flows / conditions. Precast components can be costly, however may be comparable to rock that has to be imported from long distance. Highly engineered appearance may not fit with the natural character of the waterway



Vertical-slot Fishways

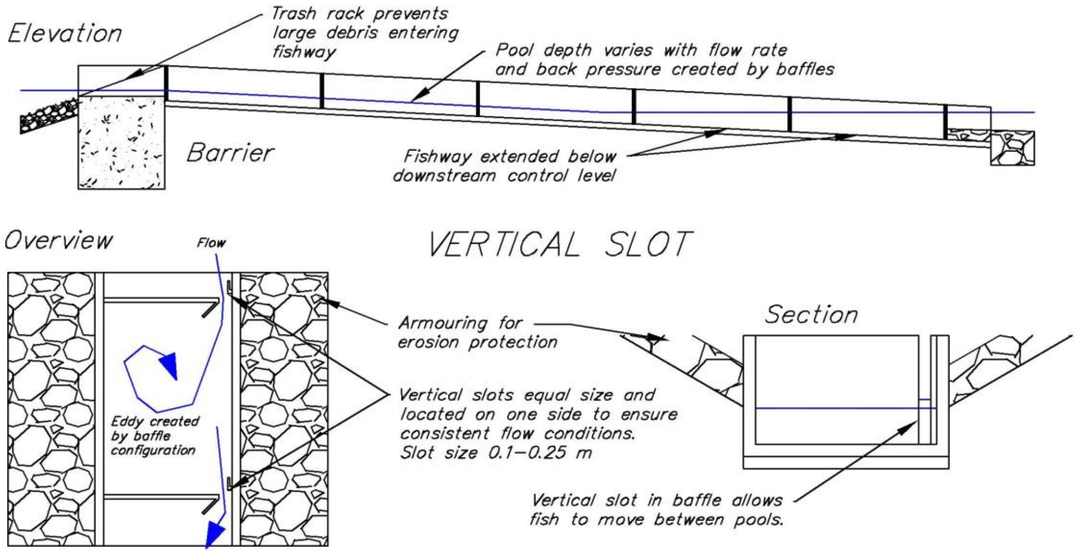
Vertical-slot fishways have been widely used throughout Australia and proven successful at passing a variety of species. Vertical-slot fishways operate by creating a series of pools separated by baffles that have a narrow vertical-slot on one side (Table 17). The baffles are installed into a concrete channel constructed on a minimum gradient of 1:20. As water travels through the fishway eddies are created by the baffles which form resting areas for the fish. As with the other fishway styles, the number of baffles needed is determined by the height of the barrier and the desired pool size. Typical pool size of vertical-slot fishways is 1- 2 m by the width of the concrete channel (1-2 m). As the vertical-slot extends the height of the baffle pool depth varies with flow rate, i.e. the more water travelling through the fishway, the greater the depth of the pools. As with the other fishways the entrance of a vertical-slot fishway is usually set below the level of the downstream control point to account for potential stream bed erosion.

Figure 18. Showing a vertical-slot fishway on Waterpark Creek, Byfield. Note: The partial width nature and small entrance of vertical-slot fishways means it may be difficult for fish to locate the entrance.

Vertical-slot fishways (Figure 18) are limited to partial width in all but very small streams. As with all partial width designs, entrance positioning and provisions for low flow conditions is important and 'dog-legs' are often incorporated into vertical-slot designs to ensure fish are able to locate the entrance. Vertical-slot fishways are more prone to clogging by debris. As this style relies on a single slot in each baffle, a build-up of debris can reduce the efficacy of the fishway and in some instances prevent fish from moving past the obstruction. Vertical-slot fishways are generally fitted with trash racks to prevent large debris from entering the fishway but are ineffective at preventing finer sediments e.g. sand.

Table 17. Showing advantages, disadvantages & design characteristics of Vertical-slot fishways.

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Vertical-slot	Consists of a series of constructed cells with internal baffles that create pools and small head drops between each.	Good for large fish species. Good precedence examples of effective fishways. Can provide downstream passage. Can control hydraulic conditions reasonably well.	Small entrance aperture and limited attraction flows can make it difficult for fish to locate the entrance Single slot. Debris lodged in slot has the ability to impede fishway operation Sedimentation / debris issues following a flood or high flow event. Expensive to fabricate baffles and cast concrete Smooth sided walls and baffles may preclude smaller bodied fish species



Culvert Baffles

Vertical Baffles

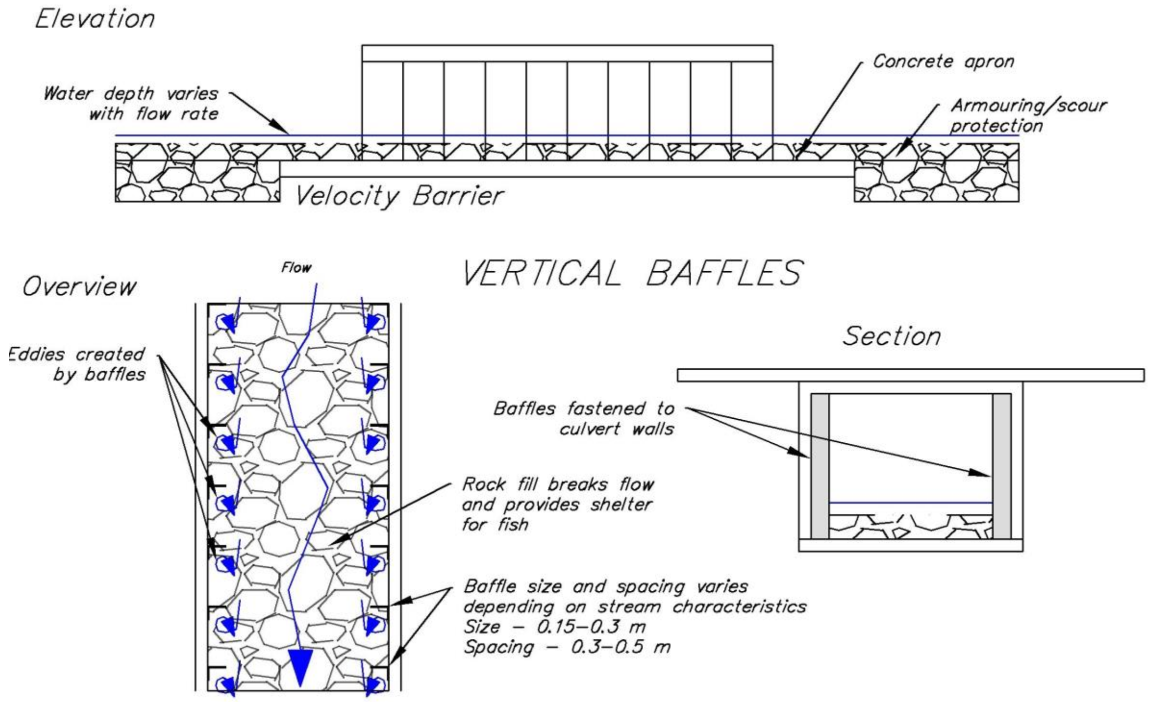
Vertical culvert baffles are an option for improving fish passage through box culverts. The relatively low cost and ability to easily retrofit to existing structures has seen the installation of baffles at many culvert structures throughout Queensland (Table 18). However, unlike horizontal baffles, they do not provide resting pools, which may potentially impact small-bodied, weaker swimming species, particularly over the long distances often experienced through culverts located under road transportation networks. Other potential deficiencies of vertical baffles include their ability to ameliorate shallow water surface barriers through culverts under low flow conditions, which can impact upstream passage of larger bodied species.

Baffle fishways consist of ‘L’ shaped panels that are fixed to the outer walls of the bank side culvert barrels (Figure 19). The baffles are designed to break flow and reduce water velocity through the barrels. As water passes the baffles, eddies are created on the downstream side and form small resting areas for the fish. The size of the baffles and spacing within the culvert vary depending on the position of the culverts within the system, stream characteristics and culvert configuration. Generally, baffles between 150-300 mm that extend from the base to the culvert roof and are spaced at 300-500 mm for the length of the barrel. Construction material also varies from low cost galvanised ‘C’ section purlins to fabricated stainless steel baffles that provide extra corrosion resistance. Regular maintenance checks are required for vertical baffles, particularly after flooding, as the baffles occasionally become dislodged, and new baffles retrofitted. Vertical baffles have also been known to corrode, requiring replacement. Advantages and disadvantages of vertical baffles including a conceptual diagram of a single barrel box culvert fitted with baffles is provided in Table 18.

Figure 19. a) Vertical culvert baffles with scour protection (Aims Rd, Townsville) b) Close up view of vertical baffles retrofitted to a culvert c) Vertical baffles in conjunction with a rock-ramp fishway (Sheepstation Creek, Ayr).

Table 18. Showing advantages, disadvantages and conceptual design of vertical culvert baffles

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Vertical baffles – culvert barrel/apron	Metal baffles fixed to the outer barrel walls and apron wing walls. Baffle protrusion into culvert barrel – 0.15-0.30 m Spacing between baffles – 0.3-0.6 m	Reduced laminar flow in high flow conditions. Minimizes sediment build-up. Good for downstream passage.	No resting pools. Reduced water conveyance capacity of culverts. Prone to damage from large debris. Corrosion may impact baffles over time No remediation of water surface barrier during low flow conditions



Horizontal Culvert Baffles

Horizontal culvert baffles (Figure 20) are a recent, innovative option for improving fish passage through box culverts. Monitoring has demonstrated that they are highly effective at passing fish, particularly juvenile species, with the fishway in Figure 10 recording a catch rate of 1,371 individual fish per day. Unlike vertical baffles, they provide resting pools for migrating fish (Table 19). Resting pools are important for native fish attempting to ascend past velocity barriers, particularly when these barriers occur for extended distances, such as through culverts located under road transportation networks. Resting areas are even more imperative for small-bodied species which don't possess the swimming abilities of larger bodied species (Rodgers et al., 2014; Domenici, 2001). This is because larger fish have more muscle to propel them through the water (Tillinger and Stein, 1996). Small bodied fish comprise the most common component of fish communities migrating upstream through coastal waterways in Queensland.

Conversely, larger bodied species are more susceptible to shallow water depth barriers often experienced through culverts during low flow conditions, whereby flows can be spread out across multiple culvert barrels. Retrofitting vertical baffles under these conditions would only minimally increase the depth of water through the culverts, and remediation of the water surface barrier would not be achieved. However, the ability of horizontal baffles to incorporate low and high flow slots in-conjunction with resting pools increases the depth of water through culverts, remediating the water surface drop barrier and providing increased fish passage for larger bodied species. The capital cost associated with horizontal baffles may be higher than for vertical baffles, however, this may be offset by the greater design life, improved fish passage and reduced likelihood of damage from flood flows i.e. vertical baffles are prone to dislodging after floods and are often impacted by corrosion over time, requiring replacement.

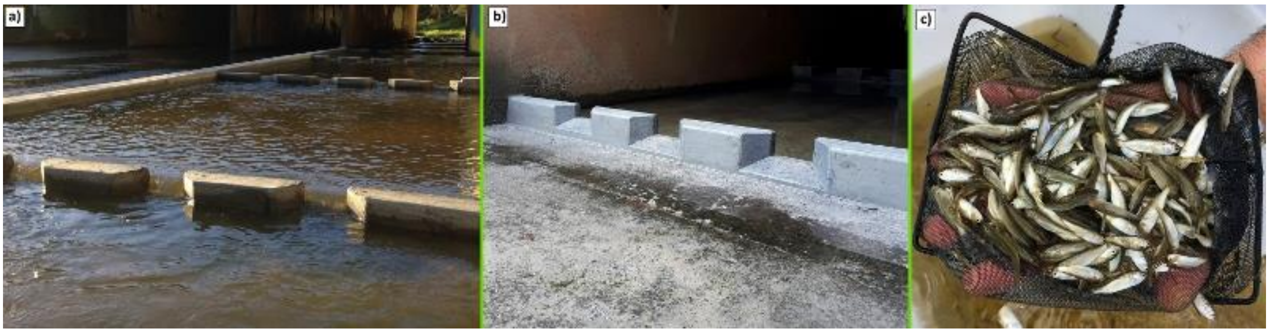
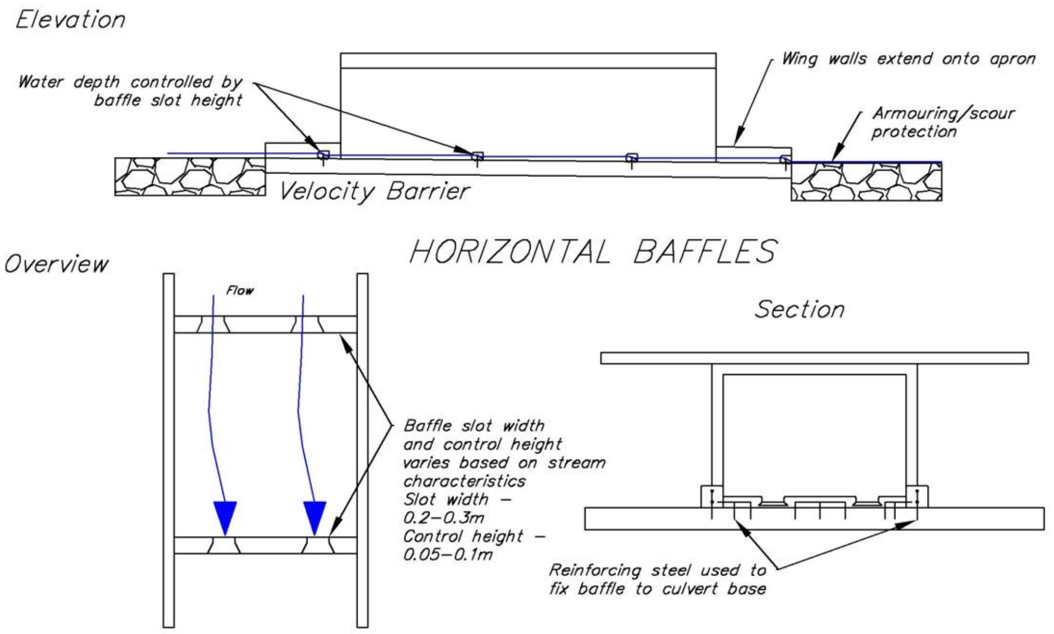


Figure 20. a) Retrofitted horizontal culvert baffles in operation under Paradise Road on Slacks Creek. Note: Nib wall to divert all base attraction flows down the fishway. Prior to remediating this barrier, the flow was spread out across four 2.4 m wide culvert barrels creating a shallow water surface barrier under base flow conditions. b) Horizontal baffles with the boxing recently removed c) Predominantly showing juvenile Sea Mullet and Striped Gudgeon captured successfully ascending through the horizontal culvert baffle fishway at catch rates of 256 and 793 individuals per day respectively.

In addition to the baffles, rock fill is commonly added to the floor of the culvert barrels. This creates a more natural bed and helps improve fish passage by further breaking up flow and providing shelter for fish as they move through the culverts. Culvert structures that consist of multiple barrels and are located on larger streams often incorporate a low flow channel. Low flow channels are formed by setting one or more barrel(s) at a lower level. All water is directed through this channel during periods of low flow and helps maintain an adequate depth for fish to swim past the structure.

Table 19. Showing advantages, disadvantages and conceptual design of horizontal culvert baffles

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Horizontal baffles – culvert barrel/apron	Formed/precast concrete baffle fixed to culvert floor. Baffle protrusion into culvert barrel – 0.2 - 0.5 m Spacing between baffles – 2.0 - 5.0 m	Resting pools provided. Minimal reduction in water conveyance capacity of culverts. All reinforced concrete components make this design less susceptible to damage during high flow. Remediates water surface barriers during low flows	Reduced functionality during high flow conditions. Potential for sediment build-up – maintenance consideration.



Fish Friendly Scour Protection

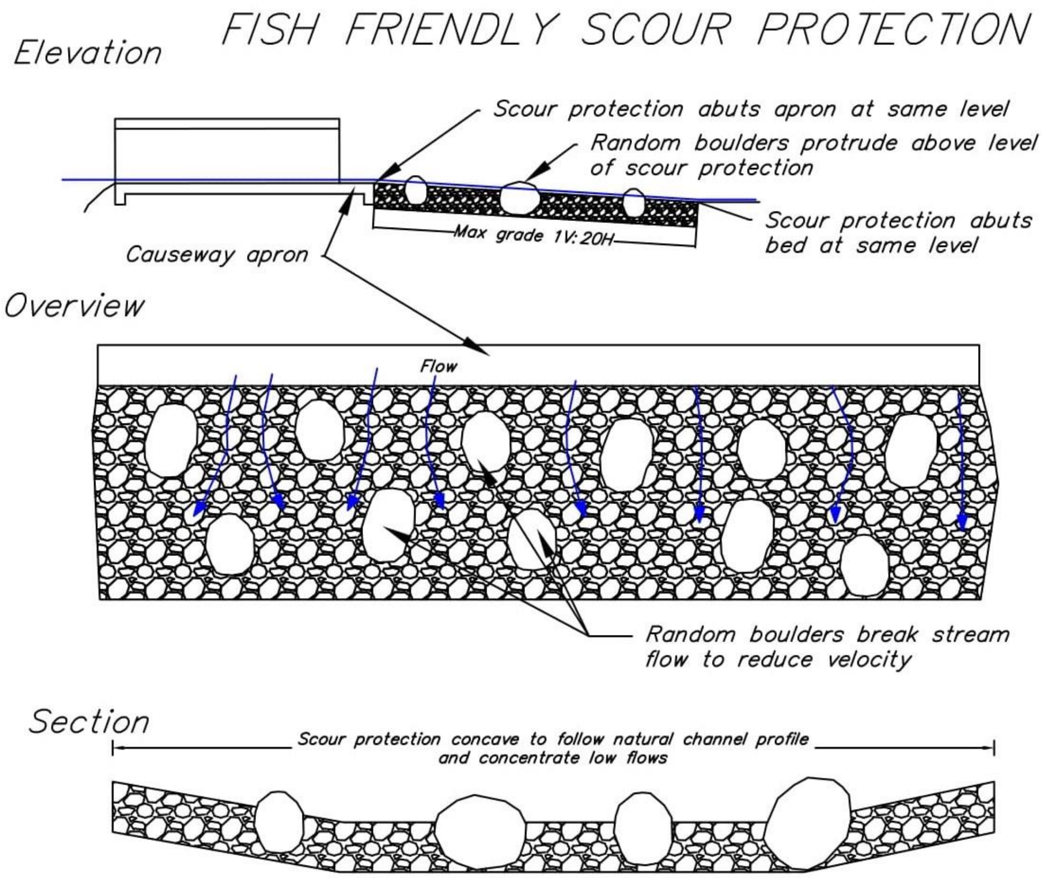
Fish friendly scour protection (FFSP) is generally used to remediate small vertical drops (<0.3m) on the downstream extent of culvert aprons and bed level crossings. On most occasions FFSP can occur under DAF's Accepted Development Requirements (ADR), and therefore precludes the requirement of a Development Approval (DA). There are many advantages of remediating barriers to fish passage under the ADR, including significant cost and time savings when compared to completing a DA. These cost savings can be more than $50,000. To meet the ADR, FFSP must (Adapted from DAF's Accepted development requirements for operational work that is constructing or raising waterway barrier works) :

- Abut the surface edge of the crossing at the same level (this is to ensure that there is no drop in elevation at the join).
- The stream bed must abut the scour protection at the same level (this is to ensure that there is no drop in elevation at the join),
- Installed at a gradient no steeper than 1 in 20 or the natural channel gradient, whichever is steeper,
- Incorporate a low flow channel,
- Use clean rocks (minimal fine material), at least 100 mm diameter,
- Ensure the rock armouring is not over compacted but left proud and uneven (track-rolled finish or rougher).

Figure 21. Left image: Pre-barrier remediation showing a bed-level crossing with a 300 mm vertical water surface drop on Palm Creek, Ingham. Right; Post-barrier remediation showing FFSP completed under the DAFs ADR. Note: Scour protection of various size rock (assist with interlocking) placed on a gentle gradient (1 high: 25 long), with a low flow channel. Larger rocks protruding from above the water level downstream from the crossing to reduce velocity and provide essential resting areas for migrating fish species.

Table 20. Showing advantages, disadvantages and conceptual design of fish friendly scour protection

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Fish Friendly Scour Protection	Well graded rock mix of various sizes to form an interlocking matrix Low gradient & low flow channel Larger rocks left protruding to provide resting areas	Cost effective Save time & resources (associated with Development Approvals) Low risk Minimal reduction in water conveyance capacity of culverts. Remediates water surface barriers during low flows	Rocks abutting the apron must not be higher than the apron. This would allow greater fish passage at the site by backing water through the culverts, reducing water velocity, increasing water depth and remediating the shallow water surface barrier Only suitable for bed level crossings with a vertical drop ≤300 mm



Appendix 3 – Top 131 Priority Ranked Barrier Table

Table 21: Showing top 131 priority ranked actual and potential fish barriers showing barrier ID, stream name, stage 1 and 2 scores, location, basin and final priority rank

Barrier ID	*Stream Name*	Scores Stage 1						Scores Stage 2						Total Score	Overall Priority Rank	Basin
		Q1: Stream Order	Q2: Num. Downstm Barriers	Q3: Upstrm Catchment (km)	Q4: Dist. to Next Barrier	Q5: Distance to Estuary	Q6: Intensive landuse (%)	Q7: Barrier Passability	Q8: Stream Condition Score	Q9: Stream Flow	Q10: Instrm Habitat	Q11. EPBC Species	Q12: Dist. to Sig Waterfall			
1603	*Granite Creek*	8	8	5	3	4	3	6	5	5	5	2	5	59	**1**	BLOOMFIELD
992	*South Mossman River*	8	8	5	2	5	2	6	5	5	5	1	5	57	**2**	MOSSMAN
1460	*Martins Creek*	8	8	5	3	5	3	6	4	5	4	1	5	57	**2**	DAINTREE
1437	*Stewart Creek*	8	8	5	3	2	3	6	4	5	4	1	5	54	**4**	DAINTREE
1022	*South Mossman River*	8	5	5	3	2	3	6	5	5	5	1	5	53	**5**	MOSSMAN
1273	*South Mossman River*	8	6	5	2	2	3	5	5	5	5	1	5	52	**6**	MOSSMAN
487	*Freshwater Creek*	8	8	5	1	2	3	6	4	5	4	1	4	51	**7**	BARRON
1444	*Cassowary Creek*	8	8	5	1	2	3	6	3	5	4	1	5	51	**7**	DAINTREE
1635	*Woobadda River*	8	8	5	1	4	3	4	5	3	4	1	5	51	**7**	BLOOMFIELD
827	*Spring Creek*	8	6	4	1	3	3	6	4	5	5	1	4	50	**10**	COOK
1445	*Cassowary Creek*	8	6	5	3	2	3	5	3	5	4	1	5	50	**10**	DAINTREE
682	*Avondale Creek Estuary*	5	8	3	1	5	2	7	4	5	5	1	3	49	**12**	BARRON
1275	*High Falls Creek*	5	8	4	2	2	3	5	4	5	4	1	4	47	**13**	NEWELL
498	*Freshwater Creek*	8	5	5	1	1	3	6	4	5	4	1	3	46	**14**	BARRON
1218	*Saltwater Creek*	5	8	3	3	1	3	5	5	5	5	1	2	46	**14**	NEWELL
1753	*Unnamed Ck_Cooper Ck Trib*	5	8	3	3	4	3	4	5	3	4	1	3	46	**14**	TRIBULATION
1884	*Whyanbeel Creek*	5	8	4	2	2	3	3	4	5	4	1	4	45	**17**	NEWELL
640	*Stoney Creek*	5	8	3	3	3	3	4	5	3	4	1	2	44	**18**	BARRON
1467	*Niau Creek*	5	6	5	1	2	3	6	4	5	4	1	2	44	**18**	DAINTREE
1606	*Olufson Creek*	5	8	3	3	3	3	3	5	3	4	1	3	44	**18**	BLOOMFIELD
681	*Avondale Creek*	5	6	2	1	5	2	6	4	5	4	1	2	43	**21**	BARRON
1133	*Marr Creek*	5	8	3	1	3	2	4	4	5	4	1	3	43	**21**	MOSSMAN
1268	*Chinaman Creek*	5	7	3	3	2	3	5	4	3	4	1	3	43	**21**	NEWELL
1276	*Whyanbeel Creek*	5	6	4	1	1	3	5	4	5	4	1	4	43	**21**	NEWELL
1278	*Whyanbeel Creek*	5	4	4	1	1	3	7	4	5	4	1	4	43	**21**	NEWELL
1484	*Doyle Creek*	5	8	3	1	3	3	7	3	3	3	1	3	43	**21**	DAINTREE
1272	*Parker Creek*	1	8	2	1	5	3	5	4	5	5	1	2	42	**27**	MOSSMAN

Barrier ID	*Stream Name*	Scores Stage 1						Scores Stage 2						Total Score	Overall Priority Rank	Basin
		Q1: Stream Order	Q2: Num. Downstm Barriers	Q3: Upstrm Catchment (km)	Q4: Dist. to Next Barrier	Q5: Distance to Estuary	Q6: Intensive landuse (%)	Q7: Barrier Passability	Q8: Stream Condition Score	Q9: Stream Flow	Q10: Instrm Habitat	Q11. EPBC Species	Q12: Dist. to Sig Waterfall			
1277	*Whyanbeel Creek*	5	5	4	1	1	3	5	4	5	4	1	4	42	**27**	NEWELL
1511	*Unnamed Ck*	5	8	3	2	4	3	4	4	3	3	1	2	42	**27**	DAINTREE
680	*Avondale Creek*	5	6	3	1	5	2	6	1	5	3	1	3	41	**30**	BARRON
1919	*Deep Creek*	5	8	3	1	3	2	4	3	5	4	1	2	41	**30**	COOK
1978	*Sweet Creek Trib*	5	6	3	1	3	2	7	4	3	4	1	2	41	**30**	COOK
396	*Unnamed Ck*	1	8	1	1	5	1	6	5	5	5	1	1	40	**33**	TRINITY
493	*Freshwater Creek*	8	1	5	1	2	3	1	4	5	5	1	4	40	**33**	BARRON
1894	*Whyanbeel Creek*	5	3	3	2	1	3	6	4	5	4	1	3	40	**33**	NEWELL
2108	*Avondale Ck Trib*	5	5	3	1	5	2	7	3	3	3	1	2	40	**33**	BARRON
401	*Unnamed Ck*	1	8	1	1	5	1	5	5	5	5	1	1	39	**37**	TRINITY
402	*Unnamed Ck*	1	8	1	1	5	1	5	5	5	5	1	1	39	**37**	TRINITY
574	*Freshwater Creek*	8	1	5	3	0	3	7	4	3	3	1	1	39	**37**	BARRON
818	*Moores Gully*	2	8	3	1	5	2	3	4	5	3	1	2	39	**37**	BARRON
1438	*Orsova Creek*	5	6	3	2	2	3	4	4	3	3	1	3	39	**37**	DAINTREE
1747	*Unnamed Ck_Cooper Ck Trib*	2	8	2	1	3	3	5	5	3	4	1	2	39	**37**	TRIBULATION
1921	*Deep Creek*	5	6	3	1	3	2	5	3	5	3	1	2	39	**37**	COOK
637	*Rocky Creek*	2	8	2	1	4	3	5	4	3	3	1	2	38	**44**	BARRON
1006	*Ball Creek*	5	4	3	1	2	3	5	3	5	3	1	3	38	**44**	MOSSMAN
1702	*Mason Creek*	5	8	3	2	4	3	2	4	2	2	1	2	38	**44**	TRIBULATION
1749	*Unnamed Ck_Cooper Ck Trib*	2	6	2	2	3	3	5	5	3	4	1	2	38	**44**	TRIBULATION
1779	*Unnamed Ck_Hutchinson Ck*	2	8	3	1	2	3	4	5	3	4	1	2	38	**44**	TRIBULATION
1812	*Unnamed Ck_Cow Bay*	5	8	3	1	3	3	4	4	3	2	1	1	38	**44**	TRIBULATION
1164	*Mossman River Trib*	5	6	3	2	2	2	5	3	3	3	1	2	37	**50**	MOSSMAN
1238	*Skeleton Creek*	5	6	3	1	3	3	4	3	3	3	1	2	37	**50**	NEWELL
1507	*Brown Creek*	2	8	3	2	3	3	3	4	3	3	1	2	37	**50**	DAINTREE

Barrier ID	*Stream Name*	Scores Stage 1						Scores Stage 2						Total Score	Overall Priority Rank	Basin
		Q1: Stream Order	Q2: Num. Downstm Barriers	Q3: Upstrm Catchment (km)	Q4: Dist. to Next Barrier	Q5: Distance to Estuary	Q6: Intensive landuse (%)	Q7: Barrier Passability	Q8: Stream Condition Score	Q9: Stream Flow	Q10: Instrm Habitat	Q11. EPBC Species	Q12: Dist. to Sig Waterfall			
1731	*Unnamed Ck_Noah Ck Trib*	1	8	1	2	4	3	6	5	2	2	1	2	37	**50**	TRIBULATION
1979	*Sweet Creek Trib*	5	5	3	0	3	2	6	4	3	3	1	2	37	**50**	COOK
2011	*Cascade Creek*	1	8	2	2	4	3	4	4	3	3	1	2	37	**50**	COOK
2054	*Unnamed Ck*	5	8	3	2	3	3	3	4	1	2	1	2	37	**50**	COOK
678	*Avondale Creek*	5	4	3	1	2	2	5	3	5	2	1	3	36	**57**	BARRON
1486	*Doyle Creek*	2	6	2	2	2	3	7	3	3	3	1	2	36	**57**	DAINTREE
1732	*Unnamed Ck_Noah Ck Trib*	2	8	2	2	4	3	5	4	1	2	1	2	36	**57**	TRIBULATION
1745	*Unnamed Ck_Cooper Ck Trib*	2	8	1	2	4	3	3	5	2	3	1	2	36	**57**	TRIBULATION
1746	*Unnamed Ck_Cooper Ck Trib*	2	8	1	2	4	3	3	5	2	3	1	2	36	**57**	TRIBULATION
1767	*Unnamed Ck_Hutch. Ck Trib*	2	8	2	2	2	3	4	5	2	3	1	2	36	**57**	TRIBULATION
1774	*Mackenzie Creek*	2	6	1	2	3	3	5	5	3	3	1	2	36	**57**	TRIBULATION
1801	*Unnamed Ck Hutchinson Ck Trib*	1	8	2	2	3	3	6	4	2	2	1	2	36	**57**	TRIBULATION
1817	*Unnamed Ck_Cow Bay*	5	6	3	1	3	3	6	4	2	2	1	0	36	**57**	TRIBULATION
1948	*Dead Mans Gully*	2	8	2	1	5	2	5	2	3	3	1	2	36	**57**	COOK
2078	*Grants Creek*	5	8	2	2	4	3	3	2	2	2	1	2	36	**57**	COOK
783	*Avondale Creek Trib*	5	4	3	1	3	2	6	2	3	3	1	2	35	**68**	BARRON
907	*Unnamed Ck*	5	6	3	1	4	2	3	3	3	2	1	2	35	**68**	COOK
1297	*Unnamed Ck Saltwater Ck Trib*	2	8	3	2	4	3	3	3	2	2	1	2	35	**68**	NEWELL
1465	*Unnamed Creek*	5	8	3	2	4	3	1	2	2	2	1	2	35	**68**	DAINTREE
1542	*Forest Creek*	5	6	3	2	2	3	1	4	3	3	1	2	35	**68**	DAINTREE
1563	*Luttra Creek*	2	5	3	2	3	3	4	3	3	3	1	3	35	**68**	DAINTREE
1640	*Idriess Creek*	2	8	2	1	5	3	4	3	2	2	1	2	35	**68**	BLOOMFIELD
1683	*Donovan Creek*	2	8	3	2	4	3	2	4	2	2	1	2	35	**68**	TRIBULATION
1754	*Unnamed Ck_Cooper Ck Trib*	2	8	2	2	4	3	3	5	1	2	1	2	35	**68**	TRIBULATION

Barrier ID	*Stream Name*	Scores Stage 1						Scores Stage 2						Total Score	Overall Priority Rank	Basin
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1796	*McLean Creek*	2	8	3	1	2	3	3	4	3	3	1	2	35	**68**	TRIBULATION
1800	*Buchanan Creek*	2	8	2	2	3	3	3	4	2	3	1	2	35	**68**	TRIBULATION
2012	*Spring Creek*	1	8	1	1	5	3	4	4	3	3	1	1	35	**68**	COOK
973	*Crees Creek*	2	8	3	1	4	2	3	3	2	2	1	3	34	**80**	COOK
1269	*Chinaman Creek Trib*	1	6	2	1	2	3	5	4	3	4	1	2	34	**80**	NEWELL
1703	*Mason Creek*	2	6	2	2	3	3	7	2	2	2	1	2	34	**80**	TRIBULATION
2051	*Unnamed Ck*	2	8	2	1	4	3	2	4	2	3	1	2	34	**80**	COOK
2104	*McLean Creek*	2	3	2	2	2	3	6	5	3	3	1	2	34	**80**	TRIBULATION
1483	*Unnamed Ck_Doyle Ck Trib*	2	8	2	2	3	3	1	4	2	3	1	2	33	**85**	DAINTREE
1548	*Forest Creek Trib*	2	8	3	2	2	3	1	3	3	3	1	2	33	**85**	DAINTREE
1855	*Thompson Creek*	5	5	3	3	3	3	1	2	2	2	1	3	33	**85**	BLOOMFIELD
2007	*Unnamed Ck*	2	8	1	2	5	3	1	4	1	3	1	2	33	**85**	COOK
784	*Avondale Creek Trib*	5	5	3	1	3	2	2	2	3	3	1	2	32	**89**	BARRON
1239	*Skeleton Creek*	2	5	3	1	3	3	3	3	3	3	1	2	32	**89**	NEWELL
1463	*Unnamed Creek*	2	8	2	2	5	3	1	2	2	2	1	2	32	**89**	DAINTREE
1464	*Unnamed Creek*	2	8	3	2	4	3	1	2	2	2	1	2	32	**89**	DAINTREE
1508	*Brown Creek Trib*	2	8	2	2	3	3	3	4	1	1	1	2	32	**89**	DAINTREE
1804	*Boggy Creek*	2	8	1	1	4	3	1	4	2	3	1	2	32	**89**	TRIBULATION
2109	*Cattana Wetlands*	1	5	2	0	4	2	5	4	3	4	1	1	32	**89**	BARRON
611	*Freshwater Creek Trib*	5	4	3	1	2	3	3	3	2	2	1	2	31	**96**	BARRON
780	*Atika Creek*	5	1	3	1	2	2	5	3	3	3	1	2	31	**96**	BARRON
1281	*Carson Creek*	2	6	3	1	3	2	2	3	3	3	1	2	31	**96**	MOSSMAN
1455	*Unnamed Creek*	2	8	2	2	3	3	2	2	2	2	1	2	31	**96**	DAINTREE
1479	*Unnamed Ck Cape Kimberley*	1	8	1	1	4	3	3	4	2	2	1	1	31	**96**	DAINTREE
1512	*Unnamed Ck*	1	8	1	1	4	3	2	4	2	2	1	2	31	**96**	DAINTREE
1524	*Forest Creek Trib*	1	5	2	2	3	3	3	4	2	3	1	2	31	**96**	DAINTREE
1596	*Keating Creek*	8	6	5	3	1	3	Not Assessed in Stage 2					5	31	**96**	BLOOMFIELD
1684	*Unnamed Creek*	1	8	1	2	4	3	2	4	1	2	1	2	31	**96**	TRIBULATION

Barrier ID	Stream Name	Scores Stage 1						Scores Stage 2						Total Score	Overall Priority Rank	Basin
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2106	*Cattana Wetlands*	2	5	2	2	4	2	3	3	2	4	1	1	31	**96**	BARRON
2107	*Cattana Wetlands*	1	4	2	1	4	2	4	4	3	4	1	1	31	**96**	BARRON
1565	*Luttra Creek Trib*	2	5	2	1	5	3	5	1	2	1	1	2	30	**107**	DAINTREE
1587	*Baird Creek*	8	6	5	3	0	3	Not Assessed in Stage 2					5	30	**107**	BLOOMFIELD
1712	*Unnamed Ck*	1	8	2	1	3	3	2	3	2	2	1	2	30	**107**	TRIBULATION
1863	*Unnamed Ck*	2	8	3	1	4	2	2	3	1	1	1	2	30	**107**	AMOS
2105	*Unnamed Ck_Brown Ck Trib*	0	8	2	2	2	3	5	3	1	1	1	2	30	**107**	
840	*Rocky Creek*	2	5	3	1	2	3	3	3	2	2	1	2	29	**112**	COOK
1458	*Sawmill Creek*	2	8	2	1	3	3	1	2	2	2	1	2	29	**112**	DAINTREE
1482	*Unnamed Ck Cape Kimberley*	1	8	1	2	3	3	1	4	1	1	1	2	28	**112**	DAINTREE
2013	*Unnamed Ck*	0	8	1	1	5	3	2	4	1	3	1	0	29	**112**	COOK
2039	*Unnamed Ck*	1	8	1	2	5	3	1	2	1	1	1	2	28	**112**	COOK
655	*Surprise Creek*	5	8	3	3	2	3	Not Assessed in Stage 2					3	27	**117**	BARRON
1379	*Unnamed Oxbow*	2	4	2	2	3	2	4	2	1	2	1	2	27	**117**	DAINTREE
677	*Avondale Creek Trib*	2	2	3	0	2	2	5	2	5	1	1	2	27	**117**	BARRON
546	*Unnamed Ck*	5	1	3	1	2	3	2	2	2	2	1	2	26	**120**	BARRON
905	*Unnamed Ck*	5	8	3	1	5	2	Not Assessed in Stage 2					2	26	**120**	COOK
1038	*Cassowary Creek*	5	6	5	1	2	2	Not Assessed in Stage 2					5	26	**120**	MOSSMAN
1106	*Ball Creek*	1	1	2	1	2	2	5	3	3	3	1	2	26	**120**	MOSSMAN
1748	*Unnamed Ck*	5	8	3	2	3	3	Not Assessed in Stage 2					2	26	**120**	TRIBULATION
1039	*Cassowary Creek*	5	5	5	1	2	2	Not Assessed in Stage 2					5	25	**125**	MOSSMAN
1040	*Cassowary Creek*	5	4	5	2	2	2	Not Assessed in Stage 2					5	25	**125**	MOSSMAN
1212	*Saltwater Creek*	5	6	4	1	2	3	Not Assessed in Stage 2					4	25	**125**	NEWELL
1249	*Skeleton Creek*	5	8	3	1	3	3	Not Assessed in Stage 2					2	25	**125**	NEWELL
1600	*Unnamed Ck*	5	6	3	3	2	3	Not Assessed in Stage 2					3	25	**125**	BLOOMFIELD
689	*Yorkeys Creek*	2	8	2	2	5	2	Not Assessed in Stage 2					2	23	**131**	BARRON
743	*Unnamed Ck*	2	1	3	1	2	2	5	2	1	1	1	2	23	**131**	BARRON
744	*Unnamed Ck*	2	1	3	1	2	2	5	2	1	1	1	2	23	**131**	BARRON

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