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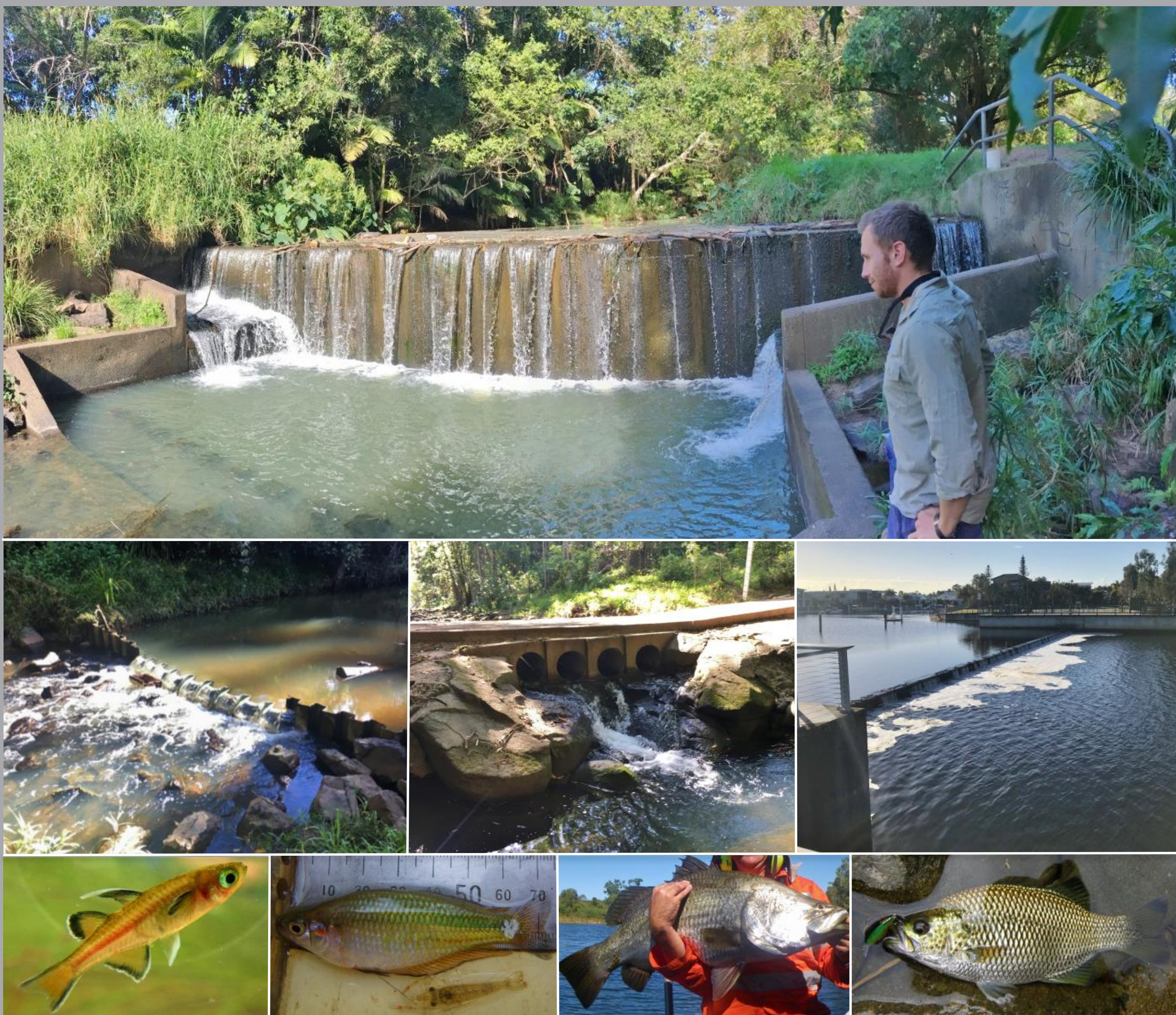

Sunshine Coast Council Fish Barrier Prioritisation

October 2018

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Cover images: top left to bottom right (fish barriers); Petrie Creek weir in Nambour (5th highest priority ranked fish barrier in SCC), Coochin Creek DNRME stream gauging weir (highest priority ranked fish barrier in SCC), Shady Lane pipe culvert causeway on the upper Mooloolah River (32nd highest priority ranked fish barrier in SCC), tidal weir on Lamerough Creek, Pelican Waters (2nd highest priority ranked fish barrier in SCC) and images of fish species residing in SCC waterways (left to right): honey blue-eye (*P. mellis*) (threatened fish species), crimson-spotted rainbowfish (*M. duboulayi*), barramundi (*L. calcarifer*) and jungle perch (*K. rupestris*).

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Glossary

Diadromous: Diadromous fishes are migratory species whose distinctive characteristics include that they (i) migrate between freshwater and saltwater; (ii) their movement is obligate to maintain species distribution and ecosystem health; and (iii) migration takes place at fixed seasons or life stages. There are three distinctions within the diadromous category, including: catadromy, amphidromy and anadromy.

- **Catadromous** - Diadromous fishes which spend most of their lives in freshwater and migrate to saltwater to breed.
- **Amphidromous** - Diadromous fishes in which migration between the saltwater and freshwater (or vice versa) is not for the purpose of breeding, however 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 – Movement between various habitats associated with specific life-history stages.

Potential barrier – A barrier identified within a stream through the use of GIS, however has not been ground-truthed to assess the true impacts and extent of the barrier.

Headloss – The difference (or 'loss') of water surface height between an upstream and downstream water body bisected by a barrier

Declared downstream limit – The lower-most freshwater reach of a stream, as determined by Queensland Department of Natural Resources and Mines.

Acronyms

SCC - Sunshine Coast Council

CS - Catchment Solutions

NRM - Natural Resources Management

SCCFBP - Sunshine Coast Council Fish Barrier Prioritisation

GIS - Geographic Information Systems

GEP - Google Earth Pro

DDL - Declared Downstream Limit

DAF - Department of Agriculture and Fisheries

DNRME - Department of Natural Resources, Mines and Energy

GPS - Global Positioning System

EPBC - Environment Protection and Biodiversity Conservation

RRF - Rock-ramp fishway

Preamble

Fish passage barriers such as dams, weirs, causeways, culverts, earthen bunds and floodgates represent significant threats to the health of river systems through altering natural flow regimes and causing impassable barriers to aquatic fauna. Anthropogenic obstructions are widespread in the highly urbanised coastal catchments throughout Australia and have been implicated in the decline of many iconic native fish species, in particular, migratory diadromous species.

Diadromous species which require unimpeded access between fresh and saltwater habitats are often of the highest socioeconomic importance, being of key commercial and recreational value, as well as being key ecological assets within the trophic ecology of their associated waterways. Species such as Australian bass, barramundi, jungle perch, long- finned eel, mangrove jack, freshwater mullet and sea mullet have all been found to adhere to strict migratory life-cycle strategies which require unimpeded access between inland freshwater habitats and the estuary. The decline of many of these species throughout their natural range can be largely attributed to the proliferation of movement barriers, and further compounded by the resultant diminished available habitat and poor water quality.

Through modern insight and a greater understanding of various life-cycle requirements, fish passage restoration works have seen the remediation of many barriers, with fishways or fish ladders identified as the key method to offset the impacts of barriers on ecological integrity. Various fishway designs are becoming increasingly factored in to waterway developments, with many identified historical barriers having retrofitted fishways constructed, often to the immediate benefit of the aquatic assemblages of the waterways they impede.

Executive Summary

The objective of the Sunshine Coast Council Fish Barrier Prioritisation (SCCFBP) was to identify and assess the large number of anthropogenic barriers that prevent, delay or obstruct fish migration in Sunshine Coast Council (SCC) coastal catchments. Fish barriers identified through this process were ranked in order of priority, accounting for the cumulative impacts' barriers have on the environment, fisheries resources, economy and local community.

Fish migration is an essential life history adaptation utilised by many freshwater fish species in the SCC region. Migration strategies between key habitats have evolved for a variety of reasons, including feeding and reproduction purposes, predator avoidance, nursery habitat utilisation and maintaining genetic diversity. Barriers preventing connectivity in the SCC region impact fisheries' productivity and create environmental conditions favourable for invasive pest fish species. Significantly, almost half of the SCC 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 SCC region.

Explicitly, the overall aims of the project were to;

1. Systematically identify all potential barriers to fish passage in SCC coastal catchments.
2. Undertake catchment-scale 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 barriers first.
3. Perform fine-scale, site specific barrier assessment to validate, score and rank priority barriers based on passability, configuration, in-stream habitat availability and flow conditions.
4. Further refine and prioritise barriers based on economic, social and fisheries productivity criteria.
5. Produce a list of the top 20 priority ranked fish barriers in the SCC region showing remediation options and indicative costs
6. Facilitate the adoption of fish barrier remediation by Local Governments and NRM groups

The fish barrier prioritisation process involved identifying potential barriers using high resolution aerial imagery across the SCC region. In total, 3825 potential barriers were identified in the project area (1,303 km^2) at a rate of 2.9 potential barriers per km^2. Geographic Information System (GIS) software was then applied 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, e.g. jungle perch, Honey blue-eye and Oxleyan pygmy perch.

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 to ground-truthing the top priority potential barriers in order of importance. The resultant SCCFBP report and associated priority ranked fish barrier list will assist SCC, natural resource managers and State Government decision makers in determining where to best allocate funding opportunities to ensure the greatest environmental and socioeconomic outcomes for the SCC region.

Introduction

The majority of freshwater fish species found in the SCC region migrate at some stage during their life history. Some of these migrations are short and confined wholly within freshwater habitats, while some migrations occur across vast distances and between varying habitats, including between estuarine and freshwater environments. Of the 44 native freshwater fish species found to occur in the SCC region (See 'Freshwater Fish Communities Overview', pp. 21- 24), over half (55%) require unimpeded access between freshwater and estuarine habitats to complete their life cycle and/or maintain species distribution.

Migration strategies between key habitats have evolved for a variety of reasons, including;

- Feeding and reproduction purposes,
- Avoidance of predators,
- Utilisation of nursery areas,
- Dispersal – to avoid being trapped in drying waterholes,
- Maintain genetic diversity, and
- Removing parasites.

The following Sunshine Coast Fish Barrier Prioritisation (SCCFBP) has been developed to assess and rank fish passage barriers having the greatest impacts on freshwater fish communities of the SCC region. Low passability barriers located within close proximity to the tidal interface on high ordered waterways have the greatest impact on freshwater fish community condition in coastal Queensland catchments. This is largely due to the ability of these barriers to prevent or impede juvenile diadromous species from undertaking longitudinal life-cycle dependant migrations upstream into important nursery habitats. A single low passability barrier located on the tidal interface has the potential to exclude up to 24 of the 44 native freshwater fish species known to occur in the SCC region (Rolls et al. 2013; 2014).

As fish barriers located close to the estuarine interface have significant impacts on aquatic ecosystem health and fish population distribution, the SCCFBP scoring system has been designed to ensure these types of barriers are prioritised. Barriers located in headwater reaches remain important to remediate, particularly if vulnerable fish species occur in these locations and this is accounted for in the prioritisation process. These headwater barriers have the greatest impact on movements of potamodromous fish species, which are able to complete their life-cycle wholly within freshwater, thus reducing the overall impact of such barriers.

The consequences of tidal interface barriers on diadromous fish species are well understood, but their impacts on displaced potamodromous species can also be significant. Tidal interface barriers eliminate the salinity gradient which occurs in natural waterways, and therefore removes important physiological stressors (increasing salinity) that may prevent potamodromous species from moving into downstream reaches of waterways. Depending on the size of the waterway, the removal of the salinity gradient potentially results in tens of thousands of individuals being displaced over barriers during flow events into saltwater environments, where they potentially perish without unimpeded connectivity back to freshwater.

Many Sunshine Coast diadromous fish species sit on top of the aquatic food web as top order predators within freshwater environments and therefore play important roles in maintaining the balance of aquatic biodiversity. In coastal QLD waterways with unimpeded connectivity, two diadromous species; long-finned eel (*Anguilla reinhardtii*) and jungle perch (*Kuhlia rupestris*) generally inhabit the entire river continuum, including lower, middle and headwater river reaches. Their position at the top of the trophic food web, combined with their wide-ranging distribution within waterways along the QLD coastline suggests they would also play important roles influencing predator-prey relationships. Therefore, it's plausible to suggest that well connected waterways with healthy native freshwater fish communities comprising top order, diadromous, predator species would be more resilient to threats posed by pest fish. This is further supported by the concept that fish barriers excluding key migratory native species from certain habitats potentially contributes towards conditions favouring the proliferation of pest fish populations (Stoffels 2013).

The impact of coastal barriers on freshwater fish communities is confounded in situations where barriers create lentic environments i.e. weir pools. Coastal freshwater fish species prefer lotic environments exhibiting a diversity of in-stream habitats typified by pools, runs and riffles. Weir pools created by barriers mediate and diminish lotic habitats, creating impounded lentic environments favoured by invasive pest fish species such as tilapia (*Oreochromis mossambicus*) and carp (*Cyprinus carpio*) (Koehn and Kennard 2013). Therefore, fish barriers not only directly impact upstream freshwater fish community composition through exclusion of diadromous fish species, but also impact indirectly through the establishment of inferior habitat conditions (e.g. lentic habitats) that favour pest fish species and reduce native potamodromous fish abundance and diversity.

In addition to their ecosystem service value, diadromous species are also recognised as contributing significant societal values, comprising high value commercial, recreational and Indigenous fisheries. Historically, sea mullet (*Mugil cephalus*) (Figure 1) and long-finned eels (*Anguilla reinhardtii*) have been established as important food sources for indigenous people (Barnett and Ceccarelli, 2007). Today, both sea mullet and long-finned eels form important commercial fisheries, with sea mullet forming the most important commercial inshore net fishery in South-East Queensland (Williams, 2002). Diadromous species are also important recreationally, in particular Australian bass (*Percalates novemaculeata*), jungle perch (*Kuhlia rupestris*, Figure 1), mangrove jack (*Lutjanus argentimaculatus*), tarpon (*Megalops cyprinoides*) sea mullet (*M. cephalus*) and freshwater mullet (*Trachystoma petardi*) (Figure 1). Healthy, sustainable populations of these species have the ability to attract fisherman to local coastal communities, providing valuable social and economic benefits. Ensuring connectivity between habitats is therefore 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.

Figure 1. Diadromous fish species impacted by barriers: sea mullet (*M. cephalus*) (top left), freshwater mullet (*T. petardi*) (bottom left) and jungle perch (*K. rupestris*) (right). Sea and freshwater mullet (sampled from the Bremer River) form important recreational, commercial and indigenous fisheries, while jungle perch are a highly prized recreational fishing species.

Objectives

Due to the large project area and high number of barriers encountered within the project boundaries, it was important to accurately prioritise potential barriers so funding resources could be utilised in the most appropriate manner. A desktop GIS analysis approach was established as the most efficient way to conduct a comprehensive fish barrier analysis. The initial utilisation of GIS enabled the prioritisation process to assess thousands of potential barriers and systematically rank them in order of importance.

The initial GIS process allowed managers undertaking the prioritisation to set an achievable target of potential barriers to be ground-truthed in stage two of the process, i.e. top 200 potential barriers. The availability of resources typically determines the size of the inventory, if resources are unlimited then all potential barriers could be ground-truthed. Due to the large geographic area, high numbers of barriers and restricted funding streams for fisheries based riverine restoration projects, this level of ground-truthing is rarely achievable. Therefore, the ability of GIS to rapidly assess large amounts of geo-spatial vector data for each potential barrier and produce a list of the top ranked barriers after stage one is critical to the prioritisation's success, as it allows resources to be directed towards evaluating the most important potential barriers first.

The SCCFBP involves a three-stage rapid assessment process that ensures available financial resources are efficiently utilised to identify and prioritise barriers having the greatest impact on fish migration. The rapid assessment process comprehensively evaluates fishery, economic, social and eco-system benefits of barrier remediation. This is achieved by applying a multi-faceted approach, initially utilising the efficiency and unique decision-making capabilities of an automated GIS process. The advantage of GIS during the first stage of the prioritisation revolves around its capacity to assess wide-ranging temporal and spatial habitat characteristics associated with thousands of potential barriers over a large geographic area. Following the validation of high-ranking potential barriers, further assessment and prioritisation of actual barriers is undertaken using scoring and ranking methods in stage two and three. Important geospatial characteristics fundamental to a potential barrier scoring high in the first stage (GIS) of the prioritisation include:

- Potential barriers located on low gradient high ordered waterways,
- Potential barriers located in close proximity to the sea,
- 1st barrier located longitudinally along the waterway,
- Large amount of connected habitat upstream of the potential barrier,
- Low proportion of intensive land use within the sub-catchment.

Explicitly, the overall aims of the project were to;

1. Systematically identify all potential barriers to fish passage in the SCC region
2. Undertake catchment-scale 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 barriers first
3. Perform fine-scale site specific barrier assessment to validate, score and rank priority barriers based on passability, configuration, in-stream habitat availability and flow conditions
4. Further refine and prioritise barriers based on economic, social and fisheries productivity criteria.
5. Produce a list of the top 20 priority ranked fish barriers in the SCC region showing remediation options and indicative estimated costs
6. Facilitate the adoption of fish barrier remediation by SCC, State and Federal Governments and Natural Resource Managers

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 process, 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 process include structures such as box culverts, pipes, road crossings, weirs, dams, stream flow 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) Road causeway & concrete apron (Elimbah Creek), b) tidal floodgates (Behm Creek), c) V-notch stream gauging weir (Warrill Creek), d) Sheet pile and gabion basket weir (Warrill Creek), e) pipe culvert causeway (Albert River) and f) Tidal barrage (Caboolture River).

Barriers impact fish communities in many ways, with some barriers such as significant head loss dams forming complete blockages, whereas other structures such as culverts present partial or temporary barriers, restricting passage during particular flow events (e.g. small, medium or high flows). Even small vertical drops downstream of road crossings and culvert aprons (≥200 mm) are sufficient to form barriers for many fish, particularly juvenile and small bodied species. Often single structures possess multiple barrier types. It is common for culvert crossings to possess physical water surface drop barriers due to stream bed erosion on the downstream extent of culvert aprons, while hydraulic velocity barriers are often created when stream flows pass through their smooth internal surfaces. Perched culverts or those without low flow channels installed below bed level can result in insufficient water depth barriers (low flows are spread out across multiple culvert barrels).

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 and 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 and Stein, 1996). Significantly, the vast majority of migrating native fish in coastal Queensland catchments comprise juvenile diadromous and small bodied species (McCann and Power 2017; Power 2016; Moore 2016; Moore and Marsden 2008). The small size of migrating fish is further highlighted by fishway evaluation monitoring studies undertaken recently in the Greater Brisbane region. 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.

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 6,548 individual fish recorded successfully ascending the Slacks Creek rock-ramp fishway, 97% 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.

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 negotiate velocities of around 0.66 m/sec, while Australian bass (40 mm) were able to negotiate slightly faster velocities of around 1.04 m/sec. Rodgers et al. (2014) tested the prolonged swimming performance of empire gudgeon (*H. compressa*), a small-bodied diadromous species (32 - 77 mm) and found that they were only able to sustain swimming speeds of ≤0.10 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 the majority of fish species are able to negotiate greater velocities than has been recorded under controlled conditions. For example, sampling of a rock-ramp fishway on the Bremer River in south-east Queensland showed that juvenile empire gudgeon (*Hypseleotris compressa)* (34 mm), 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 negotiate faster velocities through rock-ramp fishways compared to smooth sided vertical-slot fishways can be explained by the high degree of geometrical diversity of rock-ramps as a result of their irregular forms (rocks) used in their construction, which create interstitial spaces and micro-eddies (Wang 2008).

The stream velocities Australian fish species are able to negotiate are lower in comparison with their northern-hemisphere counterparts such as adult Atlantic salmon, which are able to negotiate 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 and Harris 2000).

These fishways have drops between pools, velocities and turbulence far in excess of what coastal Queensland fish communities are capable of ascending on a regular basis and have themselves become fish barriers e.g. Luscombe Weir (Albert River), Mt Crosby Weir (Brisbane River) and Berrys Weir (Bremer River) (Figure 3). McCann and Moore (2017) measured the velocity of a pool and weir fishway constructed in the 1960's 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 are able to negotiate, 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, QLD) 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 & 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 passage of juvenile sea mullet (*Mugil cephalus*). However, the unique climbing abilities of juvenile long-finned eels (*Anguilla reinhardtii*) enables them to ascend up and over ≥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 and Blake 1997):

- Sustained – swimming more than >200 minutes
- Prolonged – 15 seconds -200 minutes, and
- Burst - <15 seconds

Burst speed is used by fish to negotiate fast velocities (Webb 1984; Ch. 6) 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. Burst speed is an energetically expensive and aerobic form of swimming, and as such cannot be sustained for long periods. This is why 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 0.1 m/sec (Rodgers et al. 2014). Generally, barriers can be defined into 6 types:

- Water surface drop – Vertical drop off downstream side of road crossings, weirs and culvert aprons that are greater than 200 mm in waterways close to the freshwater/estuarine interface and 300 mm in headwater/high gradient streams (Figure 4).
- Turbulence – 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 3), without proper provision of pool depth. Turbulence is most often encountered during medium and high flow conditions.
- Velocity – When the speed of water is in excess of the swimming capabilities of fish attempting to pass the obstruction. High velocities often occur through pipes and culverts and downstream of weirs and regulators during medium and high flow events (Figure 4).

- Water Depth – 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).
- Behavioural – Darkness, shadows and reduced light conditions inside culverts/pipes, and under low bridges (Figure 4).
- Chemical – 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.

Figure 4. Left to right: Culvert causeway displaying a water surface drop, shallow water surface (through culvert and on apron) and velocity barrier (during medium- high flow conditions) exacerbated due to a culvert diameter <60% of stream width; Pipe causeway displaying velocity and behavioural barriers (insufficient lighting in pipe) and water surface drop barrier.

Barrier Passability

Barrier passability, sometimes referred to as barrier transparency, describes the extent to which in-stream barriers impede fish passage (Kemp an O'Hanley, 2010), and forms an integral part of the current SCCFBP scoring criteria when assessing barriers in the field. Barrier passability can be extremely 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, swimming ability
- Waterway – stream size, stream slope, stream reach, temperature, dissolved oxygen
- Rainfall – precipitation duration and volume
- Barrier type – culverts, pipes, weirs, dams, road crossings, bund walls, sand dams, etc.

For the purpose of the current SCCFBP, barrier passability was simplified into three categories.[1]

Low Passability (Figure 5)

- Rarely drowns out (e.g. average 1 or less flow event/yr),
- Dams and weirs >2 m head loss,
- Causeway >2 m high with pipe/culvert configuration <10 %, bankfull stream width & head loss >1m.

Medium Passability (Figure 5)

- Occasionally drowns out (e.g. average 2-5 times/yr)
- Velocities through culverts/pipes exceed swimming ability of fish during medium and 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 (most flow events)
- Culverts/pipes that span >60 % of bankfull stream width
- 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. Left to right: low passability barrier, medium passability barrier, high passability barrier.

[1] It is imperative that experienced fisheries ecologists who understand local waterways, barrier types, fish biology and species expected to occur at a site scale within the study region assess these criteria.

Fish Passage Remediation

Complete barrier removal is generally the first remediation option. However, this is generally only a viable option if the structure is redundant. In most circumstances, the barrier structure (legal or illegal) 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 migrate as larger bodied adults, whereas many coastal QLD species migrate as juveniles 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 >4 m such as dams and significant head loss weirs located on large rivers e.g. Murray River. These fishways generally entail fish lifts (elevator-style fish ladders) and large vertical-slot type fishways. Often costing millions of dollars, these fishways are usually out of the feasible realm of local government and community groups rehabilitation efforts. The second and most common fishway types are generally designed for barriers <4 m in height. These include nature like rock-ramps, bypass channels, pre-cast concrete cone ramps, vertical-slot, denil and vertical and horizontal culvert baffle fishways. For detailed descriptions of common fish passage remediation options utilised in Australia, see Appendix 2- Fish Passage Remediation Options (pp. 53- 62).

Sunshine Coast Regional Overview

The project area across the Sunshine Coast region covers over 3,500 km^2 incorporating 4 major coastal catchments including the Noosa, Maroochy, Mooloolah and Pumicestone catchments. Figure 6 displays a regional map of the Sunshine Coast which also shows the defined project boundary. The spatial stream layer depicted on the map is the Queensland Government (DAF) Waterways for Waterway Barrier Works layer, which is a colour coded into categories based on the level of risk any waterway barrier would pose to fisheries resources on each particular stream i.e. green streams equal low risk, while purple streams equal major risk.

The Sunshine Coast region is one of the most rapidly developing and populated regions in Queensland, accommodating almost 366 000 residents, with a further 200 000 residents expected in the next 20 years (Queensland Government Statisticians Office 2018). Despite the many areas of exceptional biodiversity in the upper reaches and associated national parks of the Sunshine Coast hinterland, the majority of the lower reaches have been cleared or heavily modified due to urbanisation and the pressures associated with population growth (Queensland Government 2017). Generally, current land usage is dominated by residential, industrial and commercial development, whilst in the regional districts agricultural land and transport corridors further fragment native wildlife habitats. Infestations of the region by introduced species is also recognised to place further pressure on native flora and fauna.

Due to the intensive land use, the overall water quality of most of the regions systems has declined. Clearing of native forests and riparian vegetation has contributed to the decline in water quality and has also had detrimental impacts on in-stream habitat such as woody debris and vegetation overhangs. De-stabilisation of the river banks and surrounding plains has resulted in extensive erosion and regular sediment run-off following heavy precipitation throughout the region, with high nutrient and pollutant loading causing eutrophication throughout many systems. Run-off has also been dramatically intensified through the extent of impenetrable surfaces such as rooves and roads, deflecting water as opposed to absorbing it.

Water storage infrastructure throughout the region for domestic, industrial and agricultural supply usage is extensive, with Seqwater owning and operating a number of water storage facilities in the area including;

- Cooloolabin Dam (Cooloolabin)
- Ewen Maddock Dam (Landsborough)
- Poona Dam (Yandina)
- Wappa Dam (Yandina)
- South Maroochy Intake Weir (Yandina)

Whilst undoubtedly serving a purpose for societal welfare, these large, significant head loss barriers pose a threat to the aquatic communities of the catchments they impede (Poff et al. 1997). Not only do they form impassable barriers and fracture longitudinal connectivity, but barriers also impact the natural flow regimes of waterways (Kennard and Balcombe 2014). Changes such as reduced stream flow frequency, diminished flow magnitudes and changes in seasonal flow timings all have confounding impacts on native aquatic assemblages (Lytle and Poff 2004). Seqwater's owned and operated water storage facilities are only a snapshot of the total number of fish passage barriers in the Sunshine Coast region, with many other gauging stations, weirs, causeways and culvert crossings are known to significantly obstruct fish passage within the region.

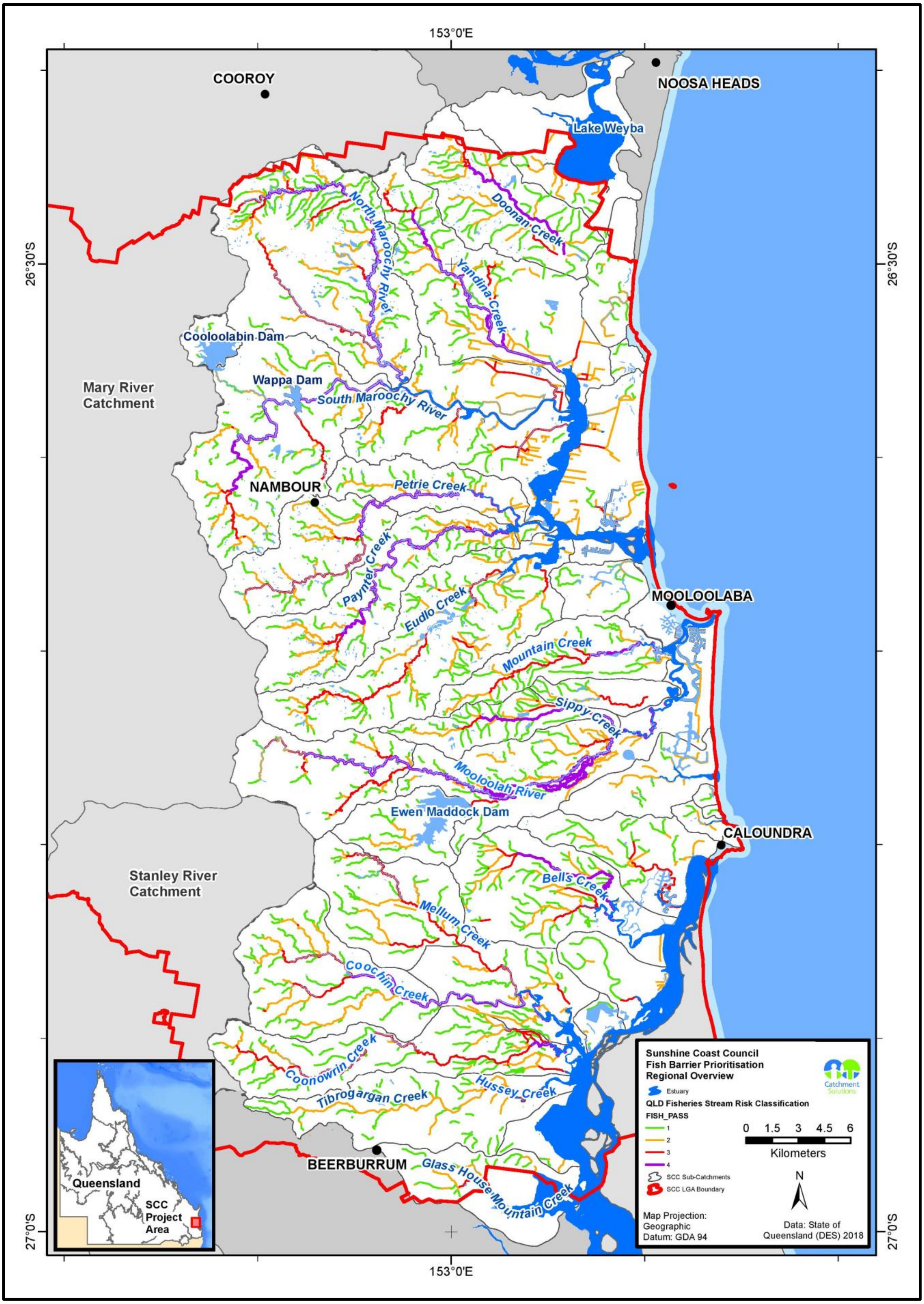

Figure 6. Sunshine Coast regional overview, with project area boundary shown

Fish Migration

For the current study, the definition of diadromy has included fish species that migrate between estuarine and freshwater environments, and that this migration is important to maintain population distribution and aquatic ecosystem health. Fish which undertake migrations between these two contrasting environments have to 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 which 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 in order to (adapted from Mallen- Cooper 1999):

- Contribute to its abundance,
- Maintain its natural distribution,
- Maintain aquatic ecosystem health, and
- For those species of fisheries importance; maintain sustainable fisheries

Sunshine Coast Freshwater Fish Communities Overview

In undertaking a fish passage barrier prioritisation in the Sunshine Coast region, 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, as knowledge on the biological processes and different life-cycle approaches which drive the species that inhabit these waterways, can potentially intensify the impacts of certain barrier types. This is particularly significant when it comes to understanding the diadromous fish species present within a catchment, which undertake the greatest migrations throughout a system (Harris 1988; Rolls et al. 2014).

When undertaking a review of the freshwater fish species present within the project area, it was decided that an approach would be taken to make the species list as current as possible. To do this, Queensland Government Ecosystem Health Monitoring Program (EHMP) data was obtained, which includes fish survey data from 110 surveyed waterways within the 14 catchments of South-east Queensland. These fish community surveys have been undertaken annually since 2003 and are used as grading criteria in the annual *‘Ecosystem Health Report Cards’* produced by the program. Species from these surveys identified from the Maroochy, Mooloolah, Noosa and Pumicestone catchments were collated, and cross referenced with catchment-specific species lists in ‘Freshwater Fishes of North-Eastern Australia’ (Pusey, Kennard and Arthington 2004) to generate a species list for the region. To this dataset, some additional species have also been added which are known to occur in this region, but which have not been surveyed, and these species will be noted with an asterisk.

The finalised list comprised of a total of 50 fish species (44 native) being identified within freshwaters of the Sunshine Coast region. This can be broken down into four species categories based on migration classifications (Table 1);

- 4 Marine vagrant species - Species which occasionally, through natural dispersal, will enter freshwater habitats for periods of time, however biologically are not obliged to do so.
- 20 Diadromous species - True migratory species which at some point, and often at regular intervals, require unimpeded access between fresh and saltwater to complete their life-cycle and maintain species distribution.
- 20 Potamodromous species - Species which migrate wholly within freshwater habitats, and can complete their entire life-cycle within these environments.
- 6 Pest fish species - These species are all potamodromous fish and exist wholly within freshwater environments, however were kept separate from native fish in their own classification.

This dataset displays the diverse range of species that exist within the Sunshine Coast's streams, over half (55%) of the native fish population found within freshwaters of the region require unimpeded access to estuarine habitats to maintain species distribution. The number and type of barriers within aquatic ecosystems and the distance to the first low-passability barrier in each high ordered stream can often be the limiting factor in determining the health of a particular waterway's fish assemblage. High ordered and connected lowland aquatic ecosystems in the region generally contain diverse and abundant fish communities, with a high proportion of diadromous species. The cumulative impact of barriers along high ordered steams has the ability to reduce upstream fish diversity, particularly 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. In summary, the greater the amount of connected in-stream habitat, the greater the diversity and abundance of diadromous species, ultimately resulting in better condition and more resilient fish communities.

The number of in-stream barriers located within streams significantly reduce the ability of diadromous species to reach upstream nursery 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. Additionally, juvenile life-stages of some diadromous fish species appear to favour the tail end of high flow conditions through to low flow conditions when undertaking their upstream migration. This may be due to juvenile species not possessing the same swimming abilities as adults, as they don't have the same muscle mass to propel them through the water. Therefore, 'drown out' conditions may predominantly favour stronger swimming returning adults. The cumulative impact of barriers and amount of connected in-stream habitat between barriers, are extremely important spatial attributes influencing the composition of Sunshine Coast fish communities.

It was determined that 70% of the native species found in the region's streams are deemed to be of socioeconomic importance through either (or a combination of) conservation status, commercial, recreational, indigenous and aquarium trade fisheries. Species including Australian bass (*P. novemaculeata*), barramundi (*L. calcarifer*), jungle perch (*K. rupestris*), sea mullet (*M. cephalus*) and freshwater mullet (*T. petardi*) are all key diadromous species with significant socioeconomic value. Further to this, two species present in the region are listed on the EPBC Act (1999), including the threatened Oxleyan pygmy perch (*N. oxleyana*) and the vulnerable Honey blue-eye (*P. mellis*). In addition to these two species, the status of freshwater mullet (*T. petardi*) is currently under review for potential listing of this species under the EPBC

Act (1999). This is due to significant declines in population abundance across its known range, with barriers to fish passage recognised as one of the key threatening processes. Figure 7 shows images of native fish species inhabiting SCC region waterways.

Figure 7. Showing fish species occurring in SCC waterways. See Table 1 for common and species name.

Table 1. Freshwater fish species recorded in Sunshine Coast waterways, including migration class, common name, species name and importance to commercial, recreational, indigenous or aquarium trade fisheries. Note: letters after common name refers to species with a fish image in Figure 7 above.

Migration Classification	Common Name	Species	Importance
Marine Vagrant (n= 4)	*Bull shark	*Carcharhinus leucas*	C, R
	Dusky flathead	*Platycephalus fuscus*	C, R, I
	Estuary glassfish (R)	*Ambassis marianus*	-
	Yellowfin bream (S)	*Acanthopagrus australis*	C, R, I
Diadromous (n= 20)	Australian bass (N)	*Percalates novemaculeata*	R, I, A
	Barramundi (K)	*Lates calcarifer*	C, R, I, A
	Bullrout (W)	*Notesthes robusta*	A
	Common silverbiddy (5)	*Gerres subfasciatus*	-
	Cox's gudgeon	*Gobiomorphus coxii*	-
	Empire gudgeon (D)	*Hypseleotris compressa*	A
	Freshwater mullet (V)	*Trachystoma petardi*	R, I
	Flathead goby	*Glossogobius giurus*	-
	Fork-tailed catfish (M)	*Arius graeffei*	I, A
	Jungle perch (H)	*Kuhlia rupestris*	R, I, A
	Lamprey species (3)	*Mordacia sp.*	-
	Large-mouth goby (F)	*Redigobius macrostoma*	-
	Long-finned eel (B)	*Anguilla reinhardtii*	C, R, I
	*Mangrove Jack (Y)	*Lutjanus argentimaculatus*	C, R, I, A
	Shortfin eel (2)	*Anguilla australis*	C, R, I
	Roman-nosed goby (6)	*Awaous acritosus*	-
	Sea mullet (Q)	*Mugil cephalus*	C, R, I
	Striped gudgeon (G)	*Gobiomorphus australis*	A
	Tamar goby	*Afurcagobius tamarensis*	-
	Tarpon (X)	*Megalops cyprinoides*	R, A
Potamodromous (n= 20)	Agassizi's glassfish (A)	*Ambassis agassizii*	A
	Australian smelt (J)	*Retropinna semoni*	A
	Bony bream (O)	*Nematalosa erebi*	-
	Crimson-spotted rainbowfish (L)	*Melanotaenia duboulayi*	A
	Dwarf flathead gudgeon (T,b)	*Philypnodon macrostomus*	-
	Eel-tailed catfish (8)	*Tandanus tandanus*	R, I, A
	Firetail gudgeon (E,1)	*Hypseleotris galii*	A
	Flathead gudgeon (T,a)	*Philypnodon grandiceps*	I
	Flyspecked hardyhead	*Craterocephalus stercusmuscarum*	A
	Honey blue-eye (Z)	*Pseudomugil mellis*	S
	Marjorie's hardyhead	*Craterocephalus marjoriae*	-
	Mouth almighty (10)	*Glossamia aprion*	A
	Ornate rainbowfish (P)	*Rhadinocentrus ornatus*	A
	Oxleyan pygmy perch	*Nannoperca oxleyana*	S
	Pacific blue-eye (C)	*Pseudomugil signifer*	A
	Purple-spotted gudgeon (9)	*Mogurnda adspersa*	A
	Rendahl's catfish (7)	*Porochilus rendahli*	I
	Spangled perch (U)	*Leiopotherapon unicolor*	I
	Swamp eel (4)	*Ophisternon sp.*	-
	Western carp gudgeon	*Hypseleotris klunzingeri*	-
Pest Fish (n= 6)	Goldfish	*Carassius auratus*	-
	Guppy	*Poecilia reticulata*	-
	Mosquitofish	*Gambusia holbrooki*	-
	Platy	*Xiphophorus maculatus*	-
	Swordtail	*Xiphophorus helleri*	-
	Tilapia	*Oreochromis mossambicus*	

Methods

SCCFBP Project Boundaries

The SCCFBP project boundary used for the current study was determined by SCC and incorporated eastern flowing coastal catchments originating in the Sunshine Coast hinterland (Note: western flowing streams including the headwaters of the Mary and Stanley River catchments were excluded, despite originating in the SCC region boundary). The project boundary extended from Glass House Mountain Creek in the south to Lake Weyba in the north and encompassed all urban and peri-urban areas within the SCC region.

Fish Barrier Prioritisation Process

In order to best achieve the defined objectives of the project, a three-stage selection criteria process used and developed by Moore and Marsden (2008) and Moore (2015) was refined and enhanced with the latest innovative river network analysis technology by Hornby (2015). The three stages involved evaluating the biological, social and economic benefits of providing unrestricted fish passage past barriers for the environment and local community. Note: All barriers are defined as 'potential' barriers until they have been validated in the field as 'actual' barriers in stage two of the process.

Stage 1. Catchment Scale: GIS Analysis – Spatial & Temporal Habitat Characteristics

Stage 1 of the barrier prioritisation involved identifying all 'potential' barriers within the study area using high resolution aerial imagery (Google Earth Pro (GEP) and Queensland Globe (QG)). Barrier information was also acquired from Local Government structure inventories and local community knowledge. A desktop GIS process was then undertaken to efficiently investigate spatio-temporal habitat characteristics associated with each potential barrier on a whole of catchment basis.

Stage 1 of the prioritisation process used a desktop computer running ArcMap 10.2 GIS software. Potential barrier waypoints (kml files) identified using high resolution aerial imagery were imported into ArcMap. Waypoints were assigned to obvious barriers such as weirs and likely potential barriers such as culverts and road crossings. Potential barriers were also assigned to bridges that extend over waterways. Although bridges usually extend over waterways and have no impact on fish passage, on occasions, actual barriers exist underneath the bridge. Waypoints were also assigned along waterways that indicated a barrier may be in place but a structure was not clearly 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 enclosed by dense 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 causeway of some description.

Each potential barrier waypoint created in GEP and imported into ArcMap was assigned a unique geo-referenced identification number that remained with the potential barrier throughout the three-stage process. Each identification number contains its own geo-spatial dataset that stores location and geometry data for each potential barrier. Potential barriers were then assessed against five geo-spatial questions relating to the barrier's position in the catchment, type and amount of available upstream habitat, stream hierarchy (Strahler stream order and gradient), proportion of intensive land use (e.g. cropping/grazing) and number of barriers downstream.

The 100K Queensland east-coast ordered drainage stream network was utilised as the 'base' waterway data layer while identifying potential barriers. All potential barriers on this stream network were assigned a unique waypoint. Fisheries QLD spatial waterway data layer '*Queensland waterways for waterway barrier works*' was utilised as the 'base' waterway data layer during GIS analysis in stage 1. This data layer is derived from the 100K Queensland east-coast ordered drainage stream network, however it includes additional data such as stream slope, flow regime, number of fish present, and fish swimming ability. This additional data was used to produce a stream network layer that categorises waterways based on the level of risk any waterway barrier would pose to fisheries resources on each particular stream. Four categories were created, with some categories having more than one stream order within each, i.e. the highest category 'Major' includes coastal stream orders 4-7, as barriers on these ordered waterways were equally determined to be a major risk to fisheries. At the other end of the scale the 'Low' risk category only included first ordered waterways that discharge directly into the estuary. First ordered waterways that did not intersect the estuary were deemed to have low fish habitat values and were removed from the classification.

The specialised river network GIS processing tool 'RivEX' (Hornby 2015) was used to analyse the 100K '*Queensland waterways for waterway barrier works*' stream network, apply attributes, perform quality control, calculate distance between barriers and calculate the 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 was answered for each question. Scores for all questions were combined and totaled and the final rank after stage 1 determined, i.e. highest total score becoming the highest-ranking barrier after stage 1. The following attributes were fundamental for a potential in-stream barrier to be given a high score in stage one of the selection criteria process:

- Located on a high ordered stream,
- Minimal to no barriers downstream,
- Good catchment condition, i.e. minimal intensive land use practices,
- Large area of *available* upstream habitat (distance to the next barrier or top of catchment),
- Barrier located in lower reaches, i.e. close to the sea

Question 1. Stream Hierarchy

Waterways within the SCCFBP project region were classified into five separate classes based on Fisheries QLD 'Waterway Barrier Works Stream Layer'. Scores were assigned to potential barriers based on the stream risk class they were situated on (Table 2). Potential barriers on major risk waterways score highest. Potential barriers located on first ordered waterways that did not discharge directly into estuarine environments were deemed low priority and were removed.

Table 2: The five stream classes and associated scoring system for Question 1.

Option	Stream classification (represented by colour code)	Stream characteristics	Score
a.	Purple (Major risk)	Strahler stream orders 4-7	10
b.	Red (High risk)	Strahler stream orders 2-3 with low gradient Strahler stream order 3 with medium gradient	5
c.	Amber (Moderate risk	Strahler stream order 3 with high gradient Strahler stream order 2 low/medium gradient	3
d.	Green (low risk)	Strahler stream order 2 with high gradient Strahler stream order 1 within tidal waters	1
e.	*Removed*	Strahler stream order 1 outside tidal waters	0 -removed

Question 2. Catchment Condition

Proportion (%) of intensive land use in each sub-catchment the potential barrier is located in. *Example* 'intensive' land use included; Irrigated cropping, manufacturing and industrial, intensive animal husbandry and residential. *Example* 'non-intensive' land use categories include; conservation and natural environment areas, plantation forestry, wetlands, estuaries and grazing native vegetation (Table 3).

Option	Proportion (%) Intensive land use within the sub-catchment	Score
a.	0%	5
b.	0.1 - 5%	4
c.	5.1 - 15%	3
d.	15.1 - 30%	2
e.	30.1 - 50%	1
f.	>50.1%	0

Table 3. Showing proportion (%) of intensive land use and associated scores for each category.

Question 3. Number of Potential Barriers Downstream

Number of potential barriers downstream along the stream network until the DDL. *Example:* the first potential barrier upstream from the DDL receives a score of 7. The next barrier upstream receives a score of 5. The 25th barrier receives a score of 0 (Table 4)

Table 4. Number of potentials barriers downstream and associated score.

Option	Number of barriers downstream	Score
a.	0	7
b.	1	5
c.	2 – 4	3
d.	5 – 9	2
e.	≥10	0

Question 4. Distance to Next Barrier Upstream

The total upstream length to the next potential barrier or top of catchment (if there are no barriers) i.e. amount of available upstream habitat if the barrier is remediated. *Example:* 15 km's of stream length (habitat) from barrier 1 to barrier 2, then barrier 1 receives a scores of 4 (Table 5).

Table 5. Stream length (km) 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.	≥25	5
b.	10 - 24.99	4
c.	5 - 9.99	3
d.	2 - 4.99	2
e.	0.5 - 1.99	1
f.	0 - 0.499	0

Question 5. Barrier's Geographical Position within the Sub-catchment

Question 5 determines the potential barrier's geographic position in the catchment and the amount of stream network inaccessible due to the barrier as a proportion of the total sub-catchment stream network (potential available habitat). This is derived by determining the stream length from the DDL to the potential barrier in question as a proportion (%) of the total stream length in the whole sub-catchment (Table 6). Barriers close to the tidal interface that prevent connectivity to the rest of the catchment score high.

Table 6. Distance (km) of sub-catchment upstream of barrier as a proportion (%) of total sub-catchment

Option	Distance (km) of sub-catchment upstream of barrier as a proportion (%) of total sub-catchment.	Score
a.	80 -100%	5
b.	50 -79.99%	4
c.	20 - 49.99%	3
d.	5 - 19.99%	2
e.	1 - 4.99%	1
f.	0 - 0.99%	0

Stage 2 – Fine Scale: Site- Specific Ecological Assessment

Stage 2 of the prioritisation involves field validation of the top ranked potential barriers (~200) after stage 1 of the process. To achieve this, a GPS (Garmin GPSmap76) tracking system was set up in conjunction with a laptop computer using OziExplorer mapping software. This was used to systematically locate the geographic position of each barrier in relation to uniquely identifiable locations (towns, roads, streams), allowing for efficient validation of potential barriers. Once a potential barrier was located and confirmed to be a barrier to fish passage, important information regarding the barrier's physical characteristics were collected. Important barrier parameters collated included: barrier type, number of culverts/pipes, head loss, length, height and width of structure and apron dimensions. Additional information such as photos and site constraint information was also acquired i.e. access for heavy machinery and structure owner, etc.

Detailed ecological information on the stream (Table 13) and flow condition (Table 14), in-stream habitat condition for migratory fish upstream of the barrier (Table 15) and distance from the tidal interface (Table 16) were assessed. Barriers were assigned a score of 1- 5 for each of the ecological criteria. Scores were collated and added to stage 1 scores to obtain an overall score and rank after stage 2. The ecological questions and associated scoring system used to prioritise barriers in the second stage are as follows:

Question 6. Barrier Type

Assessment criteria for question 6 (barrier type) is displayed below in Table 7. Note: Dam or weir refers to all barriers with a water surface drop. The height of the barrier refers to the head-loss over the entire structure. Tidal barrage refers to a barrier located on the tidal interface and/or the tide reaches the barrier.

Table 7. Barrier type assessment criteria and associated score.

Option	Barrier Type	Score
a.	Tidal barrage or bund.	5
b.	Dam, weir or culvert apron drop >1.5 m high	4
c.	Dam, weir or culvert apron drop 0.8 m – 1.5 m high.	3
d.	Dam, weir or culvert apron drop <0.8 m high or culvert aperture <60% of bankfull stream width.	2
e.	Culvert aperture that spans >60% of bankfull stream width.	1
f.	No barrier – DO NOT SCORE REMAINING CRITERIA	

Question 7. Stream/Riparian Condition

Riparian corridor condition within 250 m upstream and downstream of the barrier were assessed on site. High quality, undisturbed sites are characterised by no apparent clearing of riparian vegetation or bed and bank degradation, invasive weeds, or visible pollution. Assessment criteria for this question is displayed below in Table 8.

Table 8. Stream/riparian condition assessment criteria and associated score

Option	Stream/Riparian Condition	Score
a.	High quality- undisturbed.	5
b.	Low disturbance (<25% of upstream habitats degraded as above).	4
c.	Moderate disturbance (25-50% of upstream habitats degraded as above).	3
d.	High disturbance (51-75% of upstream degraded).	2
e.	Very high disturbance (>75% of upstream degraded).	1

Question 8. Stream Flow Classification

Stream flow characteristics used to assess and score question 8 are displayed below in Table 9.

Table 9. Stream flow classification assessment criteria and associated score.

Option	Water Supply/Quantity	Score
a.	High stream permanence with perennial base flow.	5
b.	High stream permanent via supplemented flow.	4
c.	Stream very occasionally dries up with refuge pools.	3
d.	Stream dries seasonally with refuge pools.	2
e.	Stream dries seasonally with no refuge pools.	1

Question 9. In-stream Habitat Condition – For Migratory Species

In-stream habitat condition within 250 m upstream and downstream of the site were assessed on site. Assessment criteria options and scores are displayed below in Table 10.

Table 10. Upstream fish habitat condition for migratory species assessment criteria and associated score.

Option	Upstream Fish Habitat Condition	Score
a.	Excellent. Diverse and abundant fish habitat (i.e. large woody debris, pool-run-riffle habitats, macrophytes, undercut banks, deep pool refuge)	5
b.	Good. Reasonable amount of suitable fish habitat.	4
c.	Moderate amount of suitable fish habitat.	3
d.	Poor. Little suitable fish habitat.	2
e.	Very poor. Little or no suitable fish habitat.	1

Question 10. Proximity to Estuary

Proximity to estuary assessment criteria and scores (question 10) are displayed below in Table 11.

Table 11. Proximity to estuary assessment criteria and associated score.

Option	Proximity to Estuarine Habitats	Score
a.	In the estuary or on the tidal interface	5
b.	< 500 m from the tidal interface	4
c.	500 m – 2 kms from the tidal interface	3
d.	>2 kms - <5 kms from the tidal interface	2
e.	>5 kms from the tidal interface	1

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The third stage of the prioritisation process involved investigating the social, economic and fisheries productivity benefits of barrier remediation. Importantly, this stage considered the net benefits of improving connectivity versus the economic cost of remediation. This was achieved by assessing all ranked barriers after stage 2. Barriers that can be remediated with low cost fishways while increasing fisheries productivity or restoring vulnerable fish species score high, whereas barriers requiring technical and expensive fishways score lower. Similar to the previous stages of the prioritisation, each criterion contained a question with a range of answers. A separate score (1-5) was assigned for each answer. After all barriers had been analysed, scores were collated, with the highest scoring barrier becoming the top ranked barrier in the SCC region. The end result of the third stage is a priority ranked list of the top 50 barriers to fish migration in the region. See Appendix 1 for priority ranked list (top 50), including remediation cost and fishway type required.

The following attributes were fundamental for in-stream barriers to score well in this stage three:

- Low cost to remediate,
- Suitable site access for heavy machinery e.g. excavators & concrete pumping trucks,
- Landholder permission to remediate barrier,
- Fishway to benefit listed or restricted species,
- Fishway to benefit commercial and/or recreational and/or indigenous fisheries productivity

The social, economic and fisheries productivity questions and associated scoring system used to prioritise barriers in the third stage included:

Question 11. – Estimated Cost

Estimated cost to undertake fishway design, organisation, construction, supervision and approvals can be seen below in Table 12. Fishway monitoring *not* included in cost estimates.

Table 12. Estimated remediation cost assessment criteria and associated score.

Option	Estimated Remediation Cost	Score
a.	Low cost: <$40 k i.e. Removal, small rock-ramp (RR) or short culvert baffle (CB) fishway	5
b.	Low- moderate cost: $40 - $80 k i.e. Removal, medium RR, long CB or small cone (C) fishway	4
c.	Moderate cost: $81 - $120 k i.e. Removal, high RR/small-medium size C or VS fishway	3
d.	Moderate- high cost: $121 - $500 k i.e. Removal, by-pass RR, medium size C or VS fishway	2
e.	High cost: > $500 k i.e. Removal, large size technical fishway i.e. fish lift or VS fishway	1

Question 12. – Community & In-kind Support

What local community, financial or in-kind support is available? Community support may refer to local government/community, landcare or NRM group undertaking and/or prioritised to undertake rehabilitation projects along the waterway. Location of project must be in close proximity to barrier site or within sub-catchment. Access refers to the ability of heavy machinery to reach the site and/or landholder/asset owner permission to remediate barrier. Assessment criteria and scores for question 13 are displayed below in Table 13.

Table 13. Community and in-kind support assessment criteria and associated score.

Option	Community & In-kind Support	Score
a.	Easy access, good community, financial or in-kind support available	5
b.	Easy access, some community, financial or in-kind support available	3
c.	Easy access, no community, financial or in-kind support available	1
d.	No access or no community, financial or in-kind support available	0

Question 13. – Conservation Significance

Will improved connectivity have a positive impact on the conservation of listed species? Assessment criteria and scores for question 13 are displayed below in Table 14.

Table 14. Conservation significance assessment criteria and associated score.

Option	Conservation Significance	Score
a.	Listed species present.	5
b.	Species that are rare or restricted within the region (but not rare or restricted outside the region, i.e. jungle perch).	3
c.	Only common or abundant species within the region present.	1

Question 14. – Fisheries Productivity and Economic Benefits

Will the species benefited improve commercial harvest, recreational or indigenous fishing opportunities? Assessment criteria and scores for question 14 are shown below in Table 15.

Table 15. Fisheries Productivity and economic benefit assessment criteria and associated score.

Option	Fisheries Productivity & Economic Benefits	Score
a.	High benefit to commercial and/or recreational and/or indigenous fishery species.	5
b.	Moderate benefit to commercial and/or recreational and/or indigenous fishery species	3
c.	Small benefit to commercial and/or recreational and/or indigenous fishery species	1
d.	No benefit to commercial and/or recreational and/or indigenous fishery species	0

Question 15. – Barrier Passability

Barrier passability or barrier 'transparency' (Table 16). How often are fish potentially able to ascend past the barrier?

Table 16. Barrier Passability assessment criteria and associated score.

Option	Barrier Passability	Score
a.	**Low Passability** - Rarely drowns out (e.g. average 1 or less flow event per/yr), - Dams and weirs >1.5 m head loss, - Causeway >2 m high with culvert aperture <20% bank full stream width & head loss >1 m, i.e. raised culvert and/or raised culvert with apron drop	5
b.	**Medium Passability** - Occasionally drowns out (e.g. average 2-5 times per/yr), - Weir, causeway, raised culvert or culvert apron drop with head loss = 0.25 – 2 m, - Velocity through culverts may exceed swimming ability of fish during medium & high flows, - Culverts/pipes that span <40 % of bank full stream width	3
c.	**High Passability** - Frequently drowns out (most flow events), - Weir, causeway, raised culvert or culvert apron drop with head loss 0.12 - 0.25 m, - Culverts/pipes that span >40 % of bank full stream width, - Culverts - Barrier only for small proportion of flows i.e. velocity barrier during high flows only or shallow water surface barrier only during low base flows	1

Results

Stage 1 - Catchment Scale: GIS Analysis

A total of 3,826 potential barriers were identified (Figure 9) equating to 2.9 potential barriers per km^2 (total catchment area). Potential barriers located on first ordered waterways that did not discharge directly into estuarine environments were deemed low priority and were removed leaving 1,804 potential barriers that were assessed against stage 1 criteria. Two potential barriers received the equal highest stage 1 score of 28 out of a possible 32 points; which were the Coochin Creek DNRME stream gauging weir and a potential barrier located on the tidal interface of Bells Creek within the 'Stockland Aura' development area. Access to this site was not permitted at the time of ground truthing. Subsequent requests for information pertaining to this potential barrier from the developer (and other high-ranking potential barriers within this site) have not been granted.

Stage 2 - Fine Scale: Site-Specific Ecological Assessment

A total of 157 potential barriers were assessed in the field during the second stage of the prioritisation. Actual barriers to fish passage accounted for 72 (46%) of the field validated potential barriers, the remaining 85 non-barriers predominantly consisted of fallen strangler figs (Figure 8), bridges, bed level crossings (Figure 8), log jams and bed control structures. The 72 fish barriers were assessed against site specific ecological criteria set out for stage 2, before advancing to stage 3 of the prioritisation process. The equal highest scoring barriers in stage 2 of the process scoring 24 out of a possible 30 points, were the Lamerough Creek canal tidal causeway and a relic 1 m high weir on a tributary of Cornmeal Creek.


Figure 8. Showing example potential barriers identified via aerial imagery & assessed in the field as not affecting fish passage. Left; Fallen strangler fig, Right; bed level crossing over the upper Mooloolah River that meets Fisheries Queensland's Accepted Development provisions.

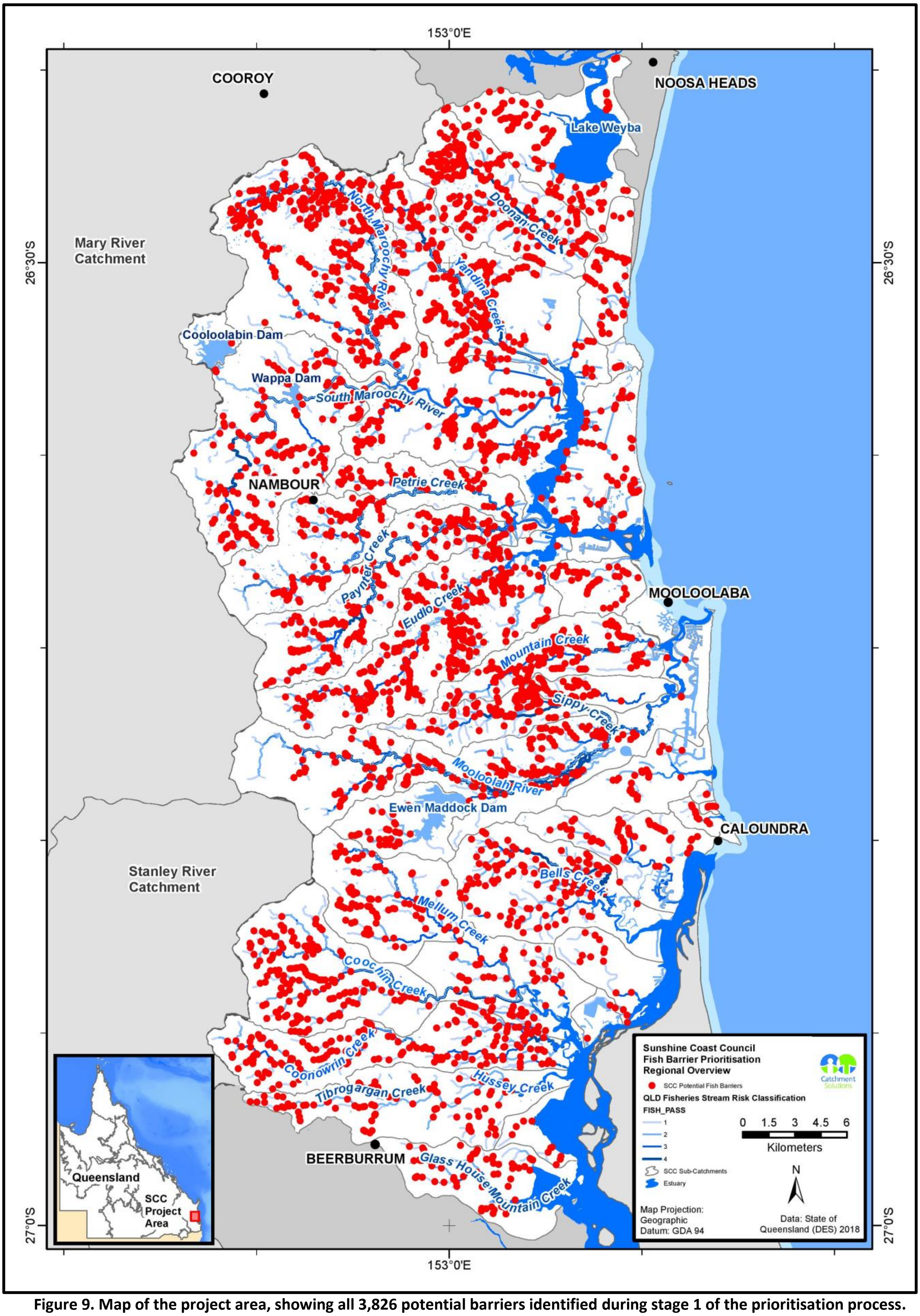

Figure 9. Map of the project area, showing all 3,826 potential barriers identified during stage 1 of the prioritisation process.

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The third and final stage involved assessing the top 72 ranked barriers after stage 2. The end product was a priority ranked list of the top 20 barriers to fish passage in the SCC region (see 'Top 20 Priority Ranked SCC Fish Barriers' below). The top-ranking barrier in stage 3 was the DNRME stream gauging weir on Coochin Creek (ID 276) with a score of 14 out of a possible 20 points. Scores for the three stages were totalled to acquire the final priority rank. The Coochin Creek DNRME gauging weir acquired the highest score after 3 stages (62 points) becoming the number one ranked priority fish barrier in the SCC region, followed by Lamerough Creek (canal) tidal weir with 60 points and an overall rank of second. A tidal pipe causeway on Sippy Creek and a pedestrian causeway on Lamerough Creek each scored 58 points and an overall rank of equal third, followed by the Tibrogargan Creek causeway (SCC Water Quality test site) and Petrie Creek weir in Nambour, each with a score of 56 points and an overall rank of equal fifth. The location and priority rank of the top 50 barriers is shown in Figure 10. Details of the top 20 priority ranked barriers including remediation options and indicative estimated costs are provided below under section 'Top 20 SCC Priority Ranked Fish Barriers'.

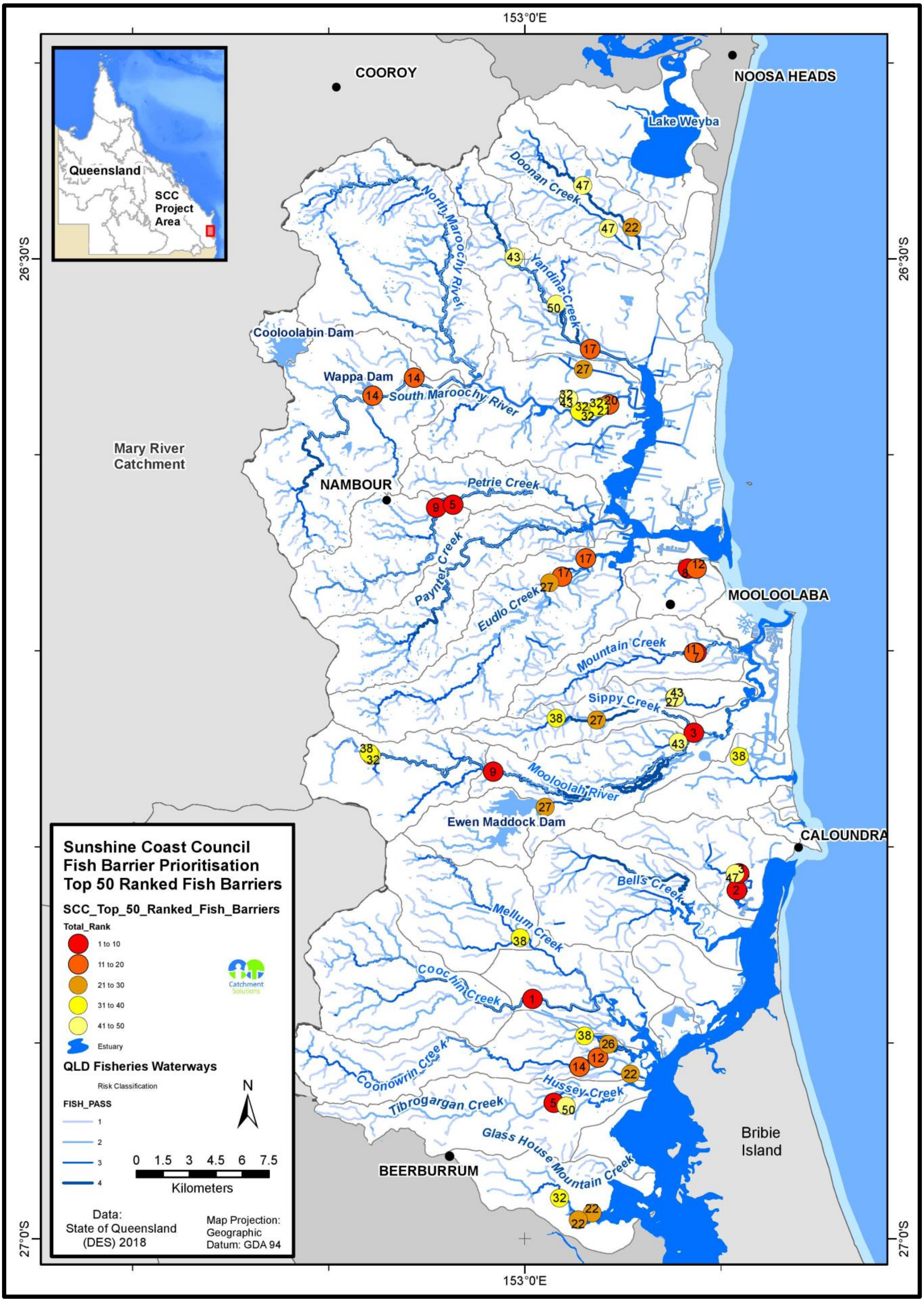

Figure 10. Location and overall priority rank of the top 50 barriers to fish passage in the GB region.

Top 20 Priority Ranked SCC 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	276	
Stream Name	Coochin Creek	
Location	-26.877492°	153.003852°
Barrier Type	DNRM Gauging Weir	
Barrier Name	CoochinCreek	
Fishway Type Needed	Full-width Rock Ramp	
Approx. Cost of Fishway	$40-60 k	

Overall Priority Ranking	**2**	
Barrier ID	3837	
Stream Name	Lamerough Creek	
Location	-26.822305°	153.107843°
Barrier Type	Tidal Causeway	
Barrier Name/Info	Pelican Waters	
Fishway Type Needed	Cone/Partial Width Rock Ramp	
Approx. Cost of Fishway	$70 -$120 k	

Overall Priority Ranking	**3**	
Barrier ID	5	
Stream Name	Sippy Creek	
Location	-26.741825°	153.085985°
Barrier Type	1 x Pipe & Rockfill Causeway	
Barrier Name	Laxton Rd - Tidal Interface	
Fishway Type Needed	New Culverts + Bafffles	
Approx. Cost of Fishway	$80-150 k	

Overall Priority Ranking	**3**	
Barrier ID	428	
Stream Name	Lamerough Creek	
Location	-26.813499°	153.108961°
Barrier Type	Tidal Causeway	
Barrier Name	Pelican Waters Pedestrian Weir	
Fishway Type Needed	Concrete Cone	
Approx. Cost of Fishway	$30-$60 k	

Overall Priority Ranking	**5**	
Barrier ID	1020	
Stream Name	Petrie Creek	
Location	-26.625364°	152.963201°
Barrier Type	Weir	
Barrier Name	Nambour Weir	
Fishway Type Needed	Cone/Rock Ramp	
Approx. Cost of Fishway	$80-150 k	

Overall Priority Ranking	**5**	
Barrier ID	68	
Stream Name	Tibrogargan Creek	
Location	-26.930776°	153.014527°
Barrier Type	Pipe Causeway + Big drop	
Barrier Name	Pipe Causeway off Johnstone Rd	
Fishway Type Needed	Bed Level Crossing/Box Culverts	
Approx. Cost of Fishway	$20-30k/$70-120 k	

Overall Priority Ranking	7	
Barrier ID	631	
Stream Name	Mountain Creek	
Location	-26.701129°	153.087264°
Barrier Type	Tidal Rock & Gabion Basket Weir	
Barrier Name	Wetland Control Weir	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$50-80 k	

Overall Priority Ranking	8	
Barrier ID	1142	
Stream Name	Cormeal Creek	
Location	-26.658391°	153.082537°
Barrier Type	Tidal Weir	
Barrier Name	Sunshine Cove Canal	
Fishway Type Needed	Concrete Cone/Rock Ramp	
Approx. Cost of Fishway	$50-80 k	

Overall Priority Ranking	9	
Barrier ID	529	
Stream Name	Mooloolah River	
Location	-26.761905°	152.983669°
Barrier Type	Relic Gauging Weir	
Barrier Name	Mooloolah Gauging Weir	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5-30k	

Overall Priority Ranking	9	
Barrier ID	1065	
Stream Name	Petrie Creek	
Location	-26.626830°	152.954793°
Barrier Type	Rock and Concrete Weir	
Barrier Name	2nd Nambour Weir (Upstream)	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$70 -$100 k	

Overall Priority Ranking	11	
Barrier ID	633	
Stream Name	Mountain Creek	
Location	-26.700985°	153.086153°
Barrier Type	Concrete Causeway + Culverts	
Barrier Name	Private Wetland	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$40-$70k	

Overall Priority Ranking	12	
Barrier ID	158	
Stream Name	Coonowrin Creek	
Location	-26.907626°	153.037104°
Barrier Type	Small Pipes + 0.5 m drop	
Barrier Name	Forestry Causeway	
Fishway Type Needed	Bed Lvl Xing/Culverts/Rock Ramp	
Approx. Cost of Fishway	$20-30k/ $40-70k/ $30-40k	

Overall Priority Ranking	**12**	
Barrier ID	728	
Stream Name	Cornmeal Creek Tributary	
Location	-26.657994°	153.087298°
Barrier Type	Relic Tidal Interface Weir	
Barrier Name	Sands Tavern Weir	
Fishway Type Needed	Rock Ramp/Removal	
Approx. Cost of Fishway	$30-$50 k	

Overall Priority Ranking	**14**	
Barrier ID	160	
Stream Name	Coonowrin Creek	
Location	-26.912387°	153.027727°
Barrier Type	Box Culverts + 350mm Arpon drop	
Barrier Name	Johnston Rd (Forestry)	
Fishway Type Needed	Rock Ramp + Baffles	
Approx. Cost of Fishway	$25-$40k	

Overall Priority Ranking	**14**	
Barrier ID	1096	
Stream Name	South Maroochy River	
Location	-26.569811°	152.922157°
Barrier Type	Dam	
Barrier Name	Wappa Dam	
Fishway Type Needed	Fish Lift	
Approx. Cost of Fishway	$1- $2 mil	


Image courtesy Seqwater

Overall Priority Ranking	**14**	
Barrier ID	1070	
Stream Name	South Maroochy River	
Location	-26.700998°	153.085973°
Barrier Type	Box Culvert Causeway	
Barrier Name	Colemans Road	
Fishway Type Needed	Baffles	
Approx. Cost of Fishway	$10-15k	

Overall Priority Ranking	**17**	
Barrier ID	787	
Stream Name	Eudlo Creek	
Location	-26.662303°	153.018678°
Barrier Type	Culvert Causeway + Apron drop	
Barrier Name	Eudlo Flats Rd	
Fishway Type Needed	Rock Ramp + Baffles	
Approx. Cost of Fishway	$30-$40	

Overall Priority	**15**	
Barrier ID	1737	
Stream Name	Yandina Creek	
Location	-26.545892°	153.033090°
Barrier Type	Box Culverts	
Barrier Name	Yandina-Coolum Rd	
Fishway Type Needed	Baffles	
Approx. Cost of Fishway	$40-80k	

Overall Priority	**17**	
Barrier ID	704	
Stream Name	Eudlo Creek Tributary	
Location	-26.652807°	153.031000°
Barrier Type	Relic Tidal Pipe Causeway	
Barrier Name		
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$5 - 10 k	

Overall Priority	**20**	
Barrier ID	1198	
Stream Name	Boggy Creek	
Location	-26.574336°	153.042804°
Barrier Type	Pipe Causeway	
Barrier Name	River Rd	
Fishway Type Needed	New Culverts	
Approx. Cost of Fishway	$30-$40	

Discussion

The desktop study of coastal catchments of the Sunshine Coast Council region identified a total 3,826 potential barriers at a density of 2.9 potential barriers per km² (total catchment area). Potential barriers located on first ordered waterways that didn't discharge directly into estuarine environments were removed from further assessment in stage 1. These waterways are generally typified as ephemeral headwater streams and are deemed to be low risk in terms of fish passage requirements (Fisheries QLD 2013). Although some fish may intermittently utilise these habitats during periods of elevated stream flow, the expected species possess good swimming and/or unique climbing abilities (eel sp., cox's and striped gudgeon). Some upper catchment specialists have evolved an ability to climb wet surfaces and negotiate faster velocities to enable them to ascend natural barriers such as waterfalls and steep riffle bars which are commonly encountered in upper catchment headwater streams (Pusey, Kennard and Arthington 2004; Allen, Midgley and Allen 2002). Therefore, the small size and ephemeral nature of these waterways combined with the climbing abilities of the fish that commonly occur in these habitats meant that potential barriers in these locations were a low priority. Although these potential barriers were removed prior to stage 1 scoring and assessment, they remain on file for any potential future assessment.

Following the removal of all potential barriers which occurred on first order waterways (and did not discharge directly into estuarine waters), a total of 1,804 potential barriers remained. These barriers were assessed and ranked in accordance with the spatial and temporal habitat characteristic criteria set out in stage 1. This was achieved using the analytical GIS stream network processing tool; RivEX. 156 high ranking potential barriers were visited in the field in line with the prioritisation list. Of the 156 ground-truthed potential barriers, 72 were determined to be barriers that prevent, delay or obstruct fish migration. The remaining 85 potential barriers were assessed as not affecting fish passage (Figure 8). These generally consisted of strangler figs, bridges, log jams and bed level crossings.

All waterway barrier works (culverts, pipes, weirs) in QLD are regulated under the Fisheries Act 1994. Minor works or those deemed low risk due to the waterway type (stream classification), can be completed via self-assessment (Accepted Development). In this situation, works can be completed by adhering to the standards and requirements of Fisheries QLD '*Accepted Development requirements for operational work that is construction or raising waterway barrier work'* without having to gain Development Approval (Figure 11).

Figure 11. Culvert crossing conforming to Accepted Development requirements. Note: Low flow channel and wall roughening.

Through the prioritisation process, barriers were ranked according to the impact they have on Sunshine Coast fish communities and the cost and technical feasibility of rehabilitation of fish passage at the site. From this process a list of top priority barriers has been developed. This list (See Appendix 1) provides a prioritised guide to the most important places that targeted rehabilitation of fish passage will have the greatest benefit to fish communities of the region.

Overall, the top three highest priority ranked barriers in the SCC region were (1) Coochin Creek DNRME stream gauging weir, (2) Lamerough Creek canal weir lock, and equal third, Lamerough Creek weir (at Tweddell Dr.) and the Sippy Creek rock and concrete causeway. The reason these barriers scored so highly in the prioritisation process, along with many other barriers ranked in the top 50, was due to a combination of critical criteria these barriers met in terms of potential for fish community impacts. Generally, these barriers were located on high ordered streams, situated on, or in close proximity to the estuary, had minimal to no barriers downstream and blocked access to large areas of available habitat upstream. This combination of factors meant that these barriers, and barriers with similar traits, present the biggest overall impacts to fish community condition and overall aquatic ecosystem health within SCC catchments, and thus, ranked highest in priority for remediation works.

With the prioritisation now completed and a list of potential sites for rehabilitation of fish passage recommended, investment and funding is required to remediate the various options outlined for each structure in the priority list (Top 20 Priority Ranked SCC Fish Barriers). It should be recognised that the list is a guide only and some unforeseeable scenarios may make some sites more or less practical. In all cases, rehabilitation of a site should be further investigated to ensure circumstances have not changed and investment expenditure is being spent at the most beneficial site.

Conclusion

3,826 potential barriers within the SCC region were identified and refined to a list of the highest priority sites within the region. The priority ranked sites represent the greatest return in terms of ecological restoration with the least financial expenditure. By remediating fish passage at these sites, extensive areas of fish habitat will become accessible to many socio-economically important migratory fish species. This will ensure the sustainability of fish populations and improve aquatic ecosystem health in many of the region’s waterways, while investing rehabilitation funds in the most efficient manner.

“Access to habitat is just as important as habitat itself”

Recommendations

- Development of investment strategies for a fish barrier remediation program targeting high priority barriers identified within this report. This program would include:
  - Preparation of an investment strategy for the highest priority sites
  - Undertake a Fish Passage Options Assessment to determine the most appropriate remediation design at each site
  - Conduct detailed surveys of the sites and production of design documents for suitable fishways
  - Construction of suitable fishway designs
  - Pre and post barrier remediation fishway and fish community sampling to determine the effectiveness of providing fish passage past the barrier
- Fish monitoring of potential and/or actual barriers to determine the degree of impact the structure is having on fish communities i.e. if you're unsure of the extent of the barrier to fish passage, then undertake fish barrier monitoring to quantify number, type and size classes of species able to ascend past during different flow conditions (if at all).
- Further fishway monitoring into the future to determine long term benefits of the fishway on fish communities and fish migration requirements of local species.
- Continue to ground truth and validate priority barriers in the field that were not visited during the rapid assessment of fish barriers completed for this report.
- Update SCC Fish Barrier Priorisation list with new barrier information as it becomes available.

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Appendix 1- Top 50 Barriers and Associated Information

Table 17. Top 50 priority ranked barriers in SCC region with associated barrier description and total score following prioritisation scoring process

Structure Number	Waterway Name	Barrier Description	Total Score	Rank
276	Coochin Creek	DNRME gauging weir- 400 mm headloss	62	**1**
3837	Lamerough Creek	Canal weir- 500 mm headloss at low tide	60	**2**
428	Lamerough Creek	Weir at Tweddell Dr.- 200 mm headloss	58	**3**
5	Sippy Creek	Concrete and rock causeway + 1 x 900 mm pipe	58	**3**
68	Tibrogargan Creek	Causeway + small pipe + substantial water surface drop	56	**5**
1020	Petrie Creek	Concrete weir- 2 m high at Nambour	56	**5**
631	Mountain Creek	1.6 m high rock weir on tidal interface	55	**7**
1142	Cornmeal Creek	Tidal concrete weir- 500 mm headloss at low tide	54	**8**
529	Mooloolah River	SCC Relic gauging weir	53	**9**
1065	Petrie Creek	Rock weir- approx. 2-2.5 m high at Nambour	53	**9**
633	Mountain Creek	1.2 m concrete and rock weir + 7 x large box culverts	51	**11**
158	Coonowrin Creek	2 x small 400 mm pipe culverts + 500 mm headloss	50	**12**
728	Cornmeal Creek Trib.	1 m high relic concrete tidal weir (behind '*Sands Tavern*')	50	**12**
160	Coonowrin Creek	Johnson Rd.- 2 x box culverts + 350 mm apron drop	49	**14**
1070	South Maroochy River	Colemans Rd.- 5 x full width box culverts	49	**14**
1096	South Maroochy River	Wappa Dam	49	**14**
704	Eudlo Creek Trib.	Relic tidal causeway with 2 x 600 mm pipe culverts	48	**17**
787	Eudlo Creek	4 x large box culvert causeway + 300 mm headloss	48	**17**
1737	Yandina Creek	Full width large box culvert (below bed-level)	48	**17**
1199	Boggy Creek	1 x 900 mm pipe- River Rd. 7	47	**20**
1198	Boggy Creek	1 x 1.2 m pipe- River Rd. 6	46	**21**
97	Glass Mountain Creek Trib.	Box culverts	45	**22**
88	Glass Mountain Creek Trib.	Dirt road causeway	45	**22**
108	Hussey Creek Trib.	3 x 350 mm pipe culverts	45	**22**
1616	Doonan Creek	Doonan Bridge Rd.- 2 x 1.2 m pipes	45	**22**
203	Saltwater Creek	Causeway with 1 x small 300 mm pipe	44	**26**
468	University Creek	1.5 m high weir on wetland 1	43	**27**
574	Mooloolah River Trib.	Ewen Maddock Dam	43	**27**
20	Sippy Creek	Rock & fill causeway- 2 x 300 mm pipes	43	**27**
1170	Yandina Creek Trib.	Yandina-Coolum Rd.- Full width box culverts	43	**27**
788	Eudlo Creek	Full channel width box culverts below bed-level	43	**27**
530	Mooloolah River	Shady Lane Causeway - 4 x 400 mm pipes + 1.2 m headloss	42	**32**
86	Glass Mountain Creek	Murphys Rd. causeway- 3 x large box culverts	42	**32**
1193	Boggy Creek	2 x 600 mm pipes- River Rd. 1	42	**32**
1196	Boggy Creek	1 x 600 mm pipe- River Rd. 4	42	**32**
1195	Boggy Creek	2 x 600 mm pipes- River Rd. 3 and Store Rd.	42	**32**
1197	Boggy Creek	1 x 600 mm pipe- River Rd. 5	42	**32**
207	Saltwater Creek	Causeway- 3 x 600 mm x 400 mm box culverts	41	**38**
532	Mooloolah River	Harris Rd. Causeway- 6 x small 350 mm pipes	41	**38**

Structure Number	Waterway Name	Barrier Description	Total Score	Rank
56	Sippy Creek	2 x 300 mm pipes + 300 mm headloss	41	**38**
233	Bluegum Creek	Low causeway- 1 x 900 mm box culvert + 2 x 600 mm pipes	41	**38**
2445	Currimundi Creek North	Wetland control- 1 x 250 mm pipe + approx. 1.5 m drop	41	**38**
597	Mooloolah River Trib.	Laxton Rd- 1 x 900 mm pipe	40	**43**
1194	Boggy Creek	2 x 600 mm pipes- River Rd. 2	40	**43**
1836	Yandina Creek	1 x 4.5 m box culvert	40	**43**
469	University Creek	Claymore Rd.- 11 x large 1.2 m box culverts	40	**43**
1628	Doonan Creek	Doonan Bridge Rd. causeway- 3 x 800 mm pipes	39	**47**
1696	Doonan Creek	Road causeway- 3 x 2.5 m culverts	39	**47**
427	Lamerough Creek	Pedestrian causeway- 4 x 1.2 m full width culverts	38	**47**
121	Hussey Creek Trib.	Forestry Rd. crossing- box culvert causeway	37	**50**
1811	Yandina Creek	Toolborough Rd.- 2 x 2.5 m culvert	37	**50**

Appendix 2- Fish Passage Remediation Options

Rock-ramp Fishways

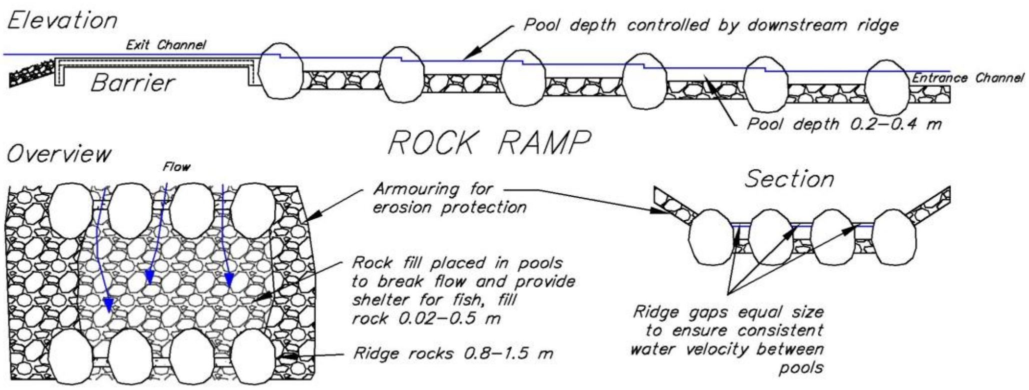
Rock-ramp fishways, or nature-like fishways, are the most common fishway type constructed in Queensland. Over the past decade, rock- ramps have been refined to suit the swimming abilities of native fish species and represent a low cost option to more formal fishway designs (Gebler 1988; Pasche et al 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. 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 12. 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 12) 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 18 below for a full list of advantages and disadvantages of rock-ramp fishways.

Table 18. 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

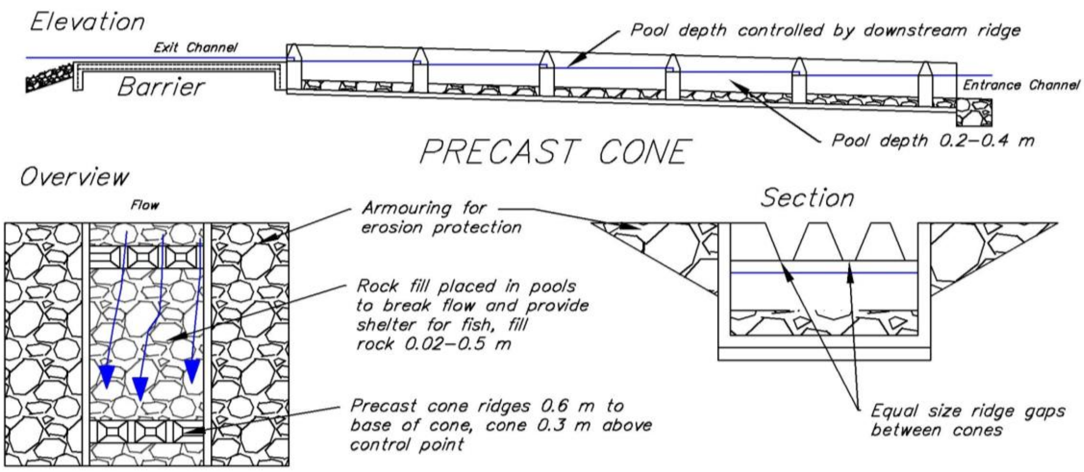
In an operational sense cone fishways are similar to rock-ramps, comprising of a series of pools interspersed at regular intervals by ridges within a channel on a minimum gradient of approximately 1:20. The main differences between the two fishway types, centers around the prefabrication of materials 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 19). The highly engineered structural nature of cone fishways (Figure 13) 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 13. 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 19. Showing advantages, disadvantages and conceptual design of pre-cast concrete 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

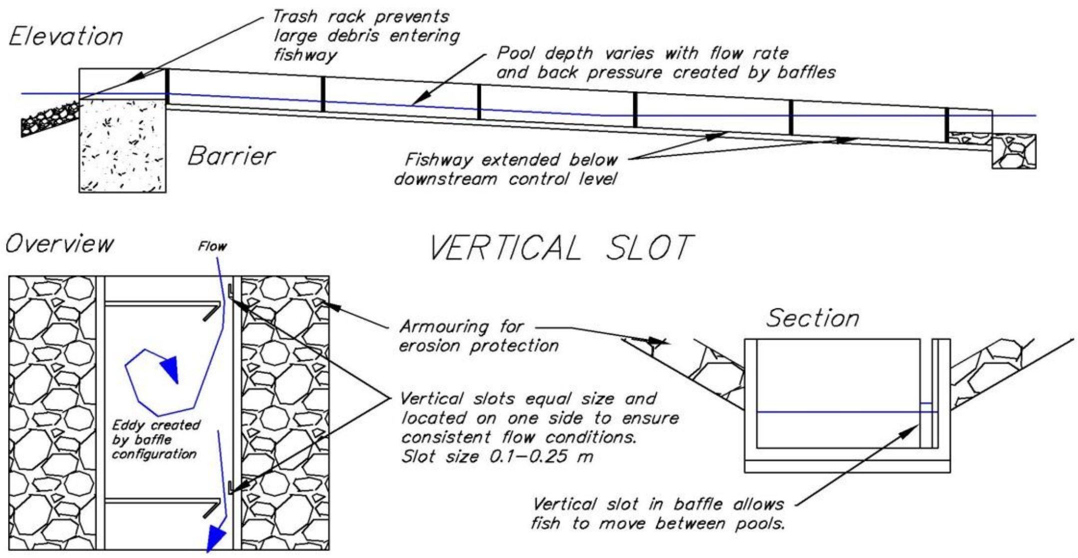
Vertical-slot fishways have been widely used throughout Australia and proven successful at passing a variety of species. Vertical-slot fishways operate by creating a series of pools separated by baffles that have a narrow vertical-slot on one side (Table 20). The baffles are installed into a concrete 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 14. Showing a vertical-slot fishway on Waterpark Creek, Byfield. Note: The partial-width nature and small entrance of vertical-slot fishways makes it difficult for fish to locate the entrance.

Vertical-slot fishways (Figure 14) 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 20. 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

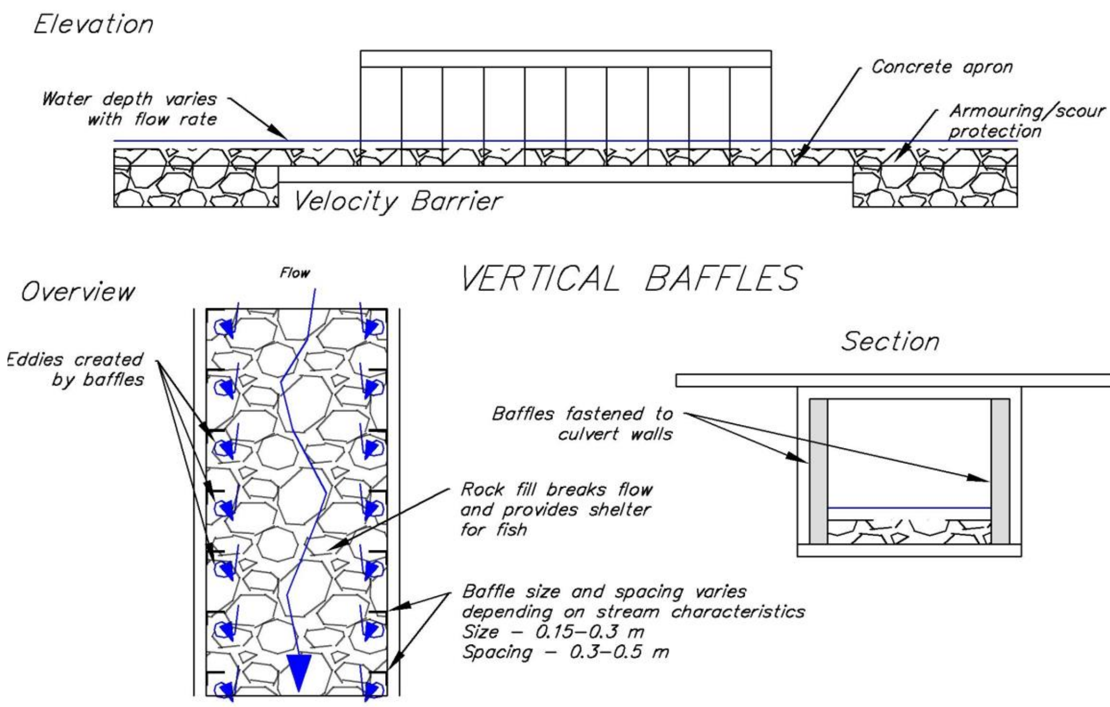
Vertical culvert baffles are an option for improving fish passage through box culverts. The relatively low cost and ability to easily retrofit to existing structures has seen the installation of baffles at many culvert structures throughout Queensland (Table 21). However, unlike horizontal baffles, they 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 15). 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 21.

Figure 15. 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 21. 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. Minimises 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 Baffles

Horizontal culvert baffles (Figure 16) 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 16 recording a catch rate of 1,371 individual fish per day. Unlike vertical baffles, they provide resting pools for migrating fish (Table 22). 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). 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.

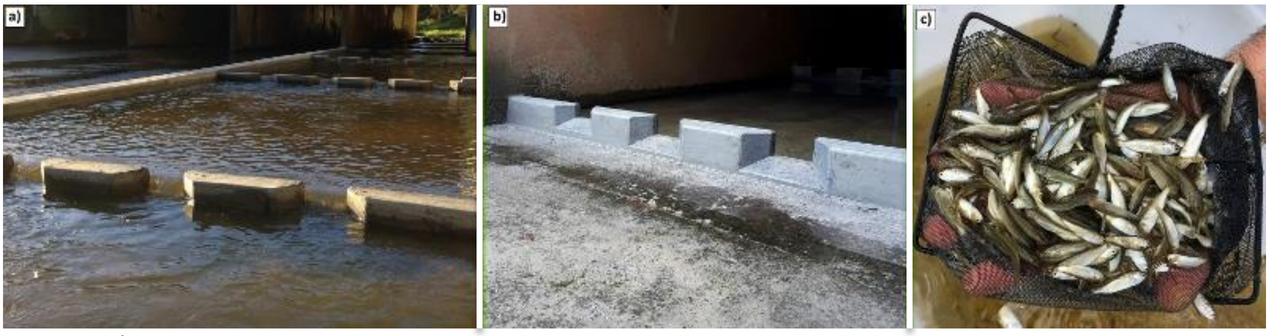
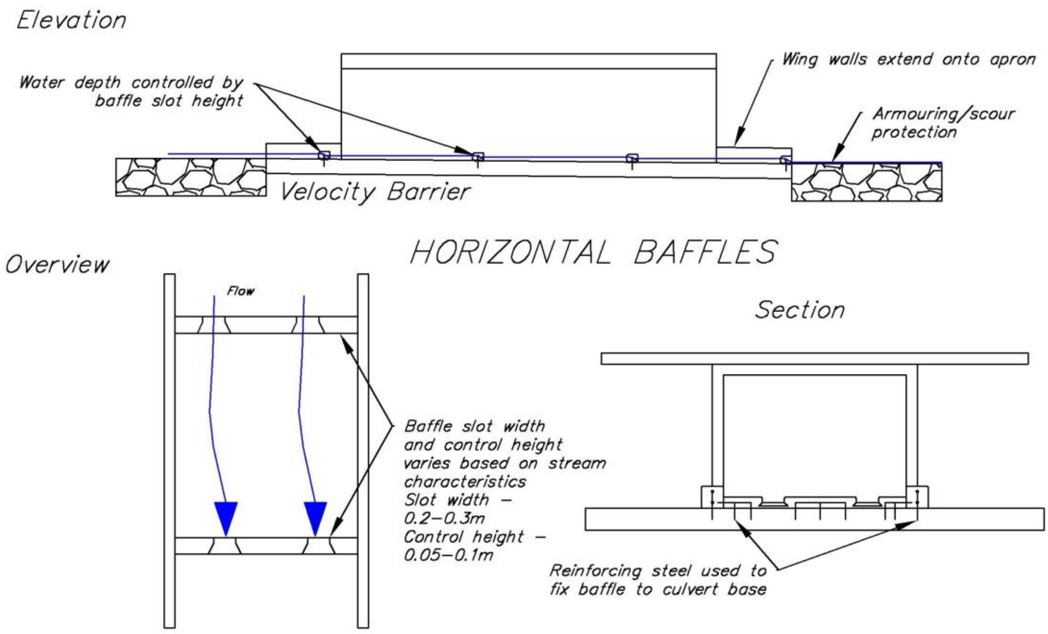


Figure 16. a) Retrofitted horizontal culvert baffles in operation under Paradise Road on Slacks Creek in South-east Queensland. Note: Nib wall on left hand side to divert all base attraction flows down the fishway. Prior to remediating this barrier, the flow was spread out across four 2.4 m wide culvert 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 22. 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.



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