VML:CD
Vicki Lukritz
3810 6221

17 May 2018

Sir/Madam

Notice is hereby given that a Meeting of the **CONSERVATION AND ENVIRONMENT COMMITTEE** is to be held in the **Council Chambers** on the 2nd Floor of the Council Administration Building, 45 Roderick Street, Ipswich commencing at **10.30 am** ***or 10 minutes after the conclusion of the Works, Parks and Sport Committee, whichever is the earlier*** on **Monday, 21 May 2018**.

MEMBERS OF THE CONSERVATION AND ENVIRONMENT COMMITTEE	
Councillor Silver **(Chairperson)** Councillor Bromage **(Deputy Chairperson)**	Councillor Wendt **(Acting Mayor)** Councillor Morrison Councillor Martin

Yours faithfully

ACTING CHIEF EXECUTIVE OFFICER

CONSERVATION AND ENVIRONMENT COMMITTEE AGENDA

10.30 am *or 10 minutes after the conclusion of the Works, Parks and Sport Committee, whichever is the earlier* on **Monday,** 21 May 2018

Council Chambers

Item No.	Item Title	Officer
1	2018 Enviroplan Photographic Competition	PO(EE)
2	EnviroForum 2018 Event	PO
3	Management Options for Yamanto Flying-Fox Colony – Division 7	PO(Biod)
4	Prioritisation and Identification of Further Fish Barrier Works	WHO&PO(Biod)

** Item includes confidential papers

CONSERVATION AND ENVIRONMENT COMMITTEE NO. 2018(05)

21 MAY 2018

AGENDA

1. 2018 ENVIROPLAN PHOTOGRAPHIC COMPETITION

With reference to a report by the Program Officer (Environmental Education) dated 20 April 2018 concerning the annual Enviroplan Photographic Competition.

RECOMMENDATION

That the report be received and the contents noted.

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2. ENVIROFORUM 2018 EVENT

With reference to a report by the Partnerships Officer dated 24 April 2018 concerning the EnviroForum event to be held in 2018.

RECOMMENDATION

That the report be received and the contents noted.

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3. MANAGEMENT OPTIONS FOR YAMANTO FLYING-FOX COLONY – DIVISION 7

With reference to a report by the Planning Officer (Biodiversity) dated 30 April 2018 concerning future management actions for the Yamanto flying-fox colony.

RECOMMENDATION

A. That Council implements Option 1 to undertake one more run of maintenance of the area along Deebing Creek that was subject to the previous vegetation modification works.

B. That Council investigates the feasibility of a subsidy program to support impacted residents, as detailed in Option 5 of the report by the Planning Officer (Biodiversity) dated 30 April 2018.

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4. PRIORITISATION AND IDENTIFICATION OF FURTHER FISH BARRIER WORKS

With reference to a joint report by the Waterway Health Officer and Planning Officer (Biodiversity) dated 2 May 2018 concerning future fish barrier works in the Bremer River Catchment.

RECOMMENDATION

That Council undertakes a design and scope of works for each of the three priority fish barriers as identified in the report by the Waterway Health Officer and Planning Officer (Biodiversity) dated 2 May 2018.

** Item includes confidential papers

and any other items as considered necessary.

Conservation and Environment Committee	
Mtg Date: 21.05.18	OAR: YES
Authorisation: Bryce Hines	

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20 April 2018

M E M O R A N D U M

TO: ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

FROM: PROGRAM OFFICER (ENVIRONMENTAL EDUCATION)

RE: 2018 ENVIROPLAN PHOTOGRAPHIC COMPETITION

INTRODUCTION:

This is a report by the Program Officer (Environmental Education) dated 20 April 2018 concerning the annual Enviroplan Photographic Competition.

BACKGROUND:

The Enviroplan Photographic Competition and Exhibition is now entering its sixteenth year. The competition provides photographers the opportunity to capture nature shots within Ipswich and also provides a tool to promote the natural wonders of Ipswich to the broader community.

The objectives of the competition are as follows:

- Raise public awareness and increase communities use of Ipswich's natural areas;
- Increase visitation to Ipswich's Conservation Estates;
- Raise public awareness of the purpose and function of Enviroplan;
- Promotion and education of Ipswich's natural environment;

Categories within the competition tailor to environmental and conservation messaging to promote a "greener" future with adults and youth categories to attract entries from people of all ages.

The table below shows a breakdown over the last three years of the number of images that were entered and the number of entrants. The number of entrants over the last three years has slightly increased.

YEAR	NUMBER OF IMAGE ENTRIES					NUMBER OF ENTRANTS
	Adult	Secondary	Primary	Instagram	Total	
2015	1006	181	45	N/A	1232	154
2016	881	137	31	N/A	1049	171
2017	633	176	20	262	1091	176

Each year participants in the program are recognised at an Awards Night. The 2017 Awards Night held on 12 September 2017 saw 115 attendees, with twenty-four entrants awarded for their images. The images were displayed in an exhibition at the Queens Park Environmental Education Centre from the 15 September – 2 October 2017. Images from the competition were selected to be printed in the Enviroplan calendar.

Earlier this year a review was undertaken in regard to the objectives and structure of the program. This review is outlined below.

REVIEW OF PHOTO COMPETITON:

As part of the review the objectives of the competition were considered in terms of whether they are being achieved and if sufficient information was being collected to make this determination. Further, the review considered the methods of entering the competition, how entry details are presented to entrants and what they included, evaluation of the set objectives, restructuring the presentation of awards for the youth categories, promotion of the event, and additional competition strategies.

Overall, based on the review it is proposed that small changes be made this year and to evaluate if the competition is achieving the previously mentioned objectives and contributing to Advance Ipswich’s strategic priority of Caring for Our Environment. The outcomes of the review and improvements to the competition for 2018 have been summarised below and the full review can be found in Attachment B.

2018 ENVIROPLAN PHOTO COMPETITION:

The 2018 competition will incorporate the following improvements:

- Incorporate provision for both open age and youth entries (full description in Attachment A). Categories include - Native Wildlife (Open), Native Plants (Open), Natural Landscapes (Open), People in Nature (Open), Kids (12 years & under), and Teen (13 – 18 years).

- Instagram to be included as a method of entry for 2018, along with the standard website entry method.

- Image location to be compulsory for entrants. This will be clear in the terms and conditions and will be required on Instagram through hashtag or location tag.

- Promotion of competition via three targeted environmental education campaigns in Instagram ‘Photo of the Month’ competition.

- Assessing program objectives through evaluations completed by entrants and general public who view photo collage.

- Restructure of the presentation of awards for Teen and Kids categories at school assemblies. Councillors to be invited to present awards to students in front of peers.

It will be launched on Tuesday 5 June 2018 coinciding with World Environment Day. Entries will close on Friday 24 August 2018. Sponsors will be sought, as has occurred in previous years, to support the competition; and total prizes will be valued at over $2,300.

CONCLUSION:

The Enviroplan Photographic Competition and Exhibition is now entering its sixteenth year. The competition provides photographers the opportunity to capture nature shots within Ipswich and also provides a tool to promote the natural wonders of Ipswich to the broader community. Each year participants in the program are recognised at an Awards Night.

Earlier this year a review was undertaken in regard to the objectives and structure of the program. Overall, based on the review it is proposed that small changes be made over the next few years to evaluate if the competition is achieving the objectives and contributing to Advance Ipswich’s strategic priority of Caring for Our Environment.

ATTACHMENTS:

Name of Attachment	Attachment
2018 Competition Categories	Attachment A
Review of Photo Competition	Attachment B

RECOMMENDATION:

That the report be received and the contents noted.

Sienna Harris
PROGRAM OFFICER (ENVIRONMENTAL EDUCATION)

I concur with the recommendation/s contained in this report.

Kaye Cavanagh
ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

I concur with the recommendation/s contained in this report.

Bryce Hines
ACTING CHIEF OPERATING OFFICER (WORKS PARKS AND RECREATION)

2018 ENVIROPLAN PHOTO COMPETITION CATEGORIES

Attachment A:

Age Category	Category Name	Category Description:	How to enter:	Prizes:		Awards Presented at:
Open	Native Wildlife	This category embraces the diversity of native wildlife found within the Ipswich region. The primary subject must be a native species and can include birds, insects, fish, molluscs, crustaceans, reptiles and mammals. Species must be photographed within the City of Ipswich. The preference is for images taken in the wild however images of captive native species will be accepted. Macro photography is welcome in this category.	Via website and Instagram.	Winner: $250 cash, printed and framed photo and certificate Runner-up: Printed and framed photo, and certificate	Overall winner of open section: $750 cash, trophy and certificate Runner-up: certificate	Award's Night
	Native Plants	This category showcases the natural beauty of native plants found within the Ipswich region. The primary subject must be a native species, either plant or fungi, and photographed within the City of Ipswich. The preference is for images taken in the wild however images of potted native species will be accepted. Macro photography is welcome in this category.	Via website and Instagram.	Winner: $250 cash, printed and framed photo and certificate Runner-up: Printed and framed photo, and certificate		Award's Night
	Natural Landscapes	This category embraces photos that showcase Ipswich's wonderful natural areas. The subject of these landscapes photos include waterways, wetlands, mountains, paddocks and anything that captures our cities scenery. All images must be photographed within the City of Ipswich.	Via website and Instagram.	Winner: $250 cash, printed and framed photo and certificate Runner-up: Printed and framed photo, and certificate		Award's Night
	People in Nature	This category is open to photos that show individuals or groups of people embracing the great outdoors and getting out in the natural	Via website and Instagram.	Winner: $250 cash, printed and framed photo and certificate		Award's Night

		environment. Don't forget to make sure you have permission to photograph people within the photo, and all individuals in the photo are aware of entry into the competition category. All images must be photographed within the City of Ipswich.		Runner-up: Printed and framed photo, and certificate	
12 years & under	Kids	This category encourages youth 12 years & under to explore Ipswich's natural environment and capture a photo of their experiences. Kids in this age group may wish to photograph a native animal, native plant, natural landscape, water body or anything that relates to the themes of the open categories. All images must be photographed within the City of Ipswich.	Via website, same as previous years.	Winner: $150 cash or voucher, printed and framed photo, trophy and certificate Runner-up: Printed and framed photo, and certificate	School assembly and acknowledged at Award's Night.
13-18 years	Teens	This category encourages youth 13 - 18 years to explore Ipswich's natural environment and capture a photo of their experiences. Teens in this age group may wish to photograph a native animal, native plant, natural landscape, water body or anything that relates to the themes of the open categories. All images must be photographed within the City of Ipswich.	Via website and Instagram.	Winner: $250 voucher, printed and framed photo, trophy and certificate Runner-up: Printed and framed photo, and certificate	School assembly and acknowledged at Award's Night.
Open (Instagram)	Photo of the Month	Based on three different targeted themes that relate back to the open categories. Each month a theme will be introduced with corresponding environmental education/awareness message.	Via Instagram.	Winner each month: $50 value, local sustainable product or experience	Announced online and sent to winner.

REVIEW OF ENVIROPLAN PHOTO COMPETITION

Attachment B:

Outcome	Improvements for 2018	Further Comments
As Instagram was offered as a category in 2017, which resulted in 262 images from 55 entrants, it was determined that this is an important method of entry. This is alongside the standard website method which has been used as an efficient uploading platform for 2016 and 2017.	Instagram will be included in the 2018 competition as a method of entry, along with the standard website entry method.	The Instagram method will be evaluated at the end of 2018 to see if a transition to this media platform could be possible for 2019's competition. This allows customers greater access to the competition whilst also reinforcing Council's commitment to technology and Smart Cities.
It is unknown if the objectives of the competition are being achieved.	Building in evaluation will be an indication of how to structure next year's competition, based on the effectiveness of the 2018 competition in achieving the objectives. For this to occur we will put in place evaluation with the entrants and the general public that are viewing the photo collage.	On completion of the 2018 photo competition we will use these evaluations to continue the program review and make improvements where needed.
Additional strategies could be implemented to assist in achieving the objectives of the competition.	Additional strategies would benefit the competition through increased interest, entries, and education and awareness on Ipswich's natural areas and Conservation Estates.	These strategies will continued to be reviewed each year based on evaluations and feedback.
The inclusion of the images location have not been consistent when entries are made.	Include in the terms and conditions and entry details that the location of the image is compulsory for image to be included in judging. Include hashtag or location tag on Instagram.	Effective method to evaluate the entrants in relation to the objective of increasing visitation and awareness of Ipswich's natural areas and Conservation Estates.

The category names have not been clear and simple enough for entrants to be able to determine in which category their image should be included. Dividing into age groups allows fairer opportunity for entrants to be judged.	The total number of categories has reduced from 2017. Minor changes will be made in the category names and descriptions to be clearer for entrants. Inclusion of defined age groups, this includes Teen and Kids categories.	Category names and descriptions still align with Council objectives.
There is a need to encourage entrants to regularly post throughout the competition to avoid an influx at the end.	Include 'Photo of the Month' competition on Instagram during competition period. Three individual 'Photo of the Month' campaigns will be run.	The 'Photo of the Month' will provide targeted environmental education messages, along with raising awareness and encouraging participants to visit Conservation Estates and natural areas. These methods will provide a more regular opportunity to achieve the objectives of the competition. This will also raise interest in posting to the Instagram media platform to support the transition to Instagram as mentioned above.
Awareness and promotion of the competition, and Ipswich's natural areas and Conservation Estates to school communities is needed due to decrease in entrants from primary students.	The youth category awards, Kids and Teens, will this year be presented at school assemblies and entrants acknowledged at the Awards Night.	Councillors will be invited to present the award to the student winners in front of peers at the relevant schools.

Conservation and Environment Committee	
Mtg Date: 21.05.18	OAR: YES
Authorisation: Bryce Hines	

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24 April 2018

M E M O R A N D U M

TO: ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

FROM: PARTNERSHIPS OFFICER

RE: ENVIROFORUM 2018 EVENT

INTRODUCTION:

This is a report by the Partnerships Officer dated 24 April 2018 concerning the EnviroForum event to be held in 2018.

BACKGROUND:

The Ipswich EnviroForum has been held annually since 2014 and showcases the initiatives and innovation surrounding sustainable management of our natural resources. The EnviroForum aims to:

- Increase awareness of current and emerging projects and trends;
- Bring like-minded individuals/groups together to exchange information, innovative ideas and experiences;
- To strengthen the environmental network within Ipswich and provide opportunities for the local community to contribute towards natural resource planning in Ipswich.

Participants at the forums gain knowledge from the presentations, network and discuss relevant projects and trends applicable to the region. Industry professionals, government representatives, community environmental groups and the general public from Ipswich and South East Queensland attend the event.

The previous themes for the EnviroForum have been:

2017	Nature Conservation in the Digital Age
2016	Bridging Communication Gaps: How to tailor environmental messages to build communication bridges?
2015	Sharing water wisdom for a sustainable future
2014	Biodiversity

<u>BENEFITS TO COMMUNITY AND CUSTOMERS</u>:

The EnviroForum is the only event of its kind delivered in the Ipswich region and has many benefits to the community including:

- Opportunity for community to network;
- Opportunity for community to share ideas and discuss relevant environmental matters;
- Increased knowledge within the community on sustainable management of natural resources;
- Strengthened environmental network within Ipswich;
- Environmental outcomes through increased education within the community.

<u>2018 PLANNING</u>:

It is proposed to host the 2018 EnviroForum on Friday, 10 August 2018 with the theme based around "from small things, big things grow" and showcasing that people working together can achieve greater conservation outcomes.

A range of expert speakers will present at the EnviroForum providing information on programs which have had a positive conservation impact as a result of many people and groups working together. Dedicated networking opportunities will also be provided to accommodate feedback received in previous years that networking is considered a valuable part of the EnviroForum.

The full list of speakers is currently being finalised. Discussion is also being undertaken with the Health, Security and Regulatory Services Department to collaborate on the event in line with the proposed Youth Sustainability Summit. There has also been discussion with the Sustainability Action Group of incorporating both events in the one week and creating a "Sustainable Ipswich Week" for local businesses and community to also participate in. Costa Georgiadis from ABC's Gardening Australia will be a keynote presenter during the week.

<u>REGISTRATION AND FEES</u>:

The EnviroForum is funded through Ipswich Enviroplan and registration fees. The event provides a significant opportunity for people in the region to attend a high quality, local environmental forum, therefore a small registration fee is charged. In previous years the registration fee has been $20 per person for early bird registrations and $50 per person for general registrations. It is proposed the registration fee for 2018 will be under $50 per person with options for discounted tickets for early bird and multiple purchase tickets.

SPONSORS:

Sponsorship is being sought for the event to provide further opportunities to improve the event and increase partnerships and networking opportunities for attendees. Organisations will be approached for sponsorship for the event itself and also for the "Sustainability and Environment Week".

CONCLUSION:

As a result of continued success hosting the Ipswich EnviroForum, it is proposed to host the 2018 EnviroForum on Friday, 10 August 2018. The event will bring together industry professionals, government representatives, community groups and individuals to network, receive information and education on relevant environmental topics and see new ideas at the event to take away and implement within their home and/or community.

RECOMMENDATION:

That the report be received and the contents noted.

Vada Hoger
PARTNERSHIPS OFFICER

I concur with the recommendation/s contained in this report.

Kaye Cavanagh
ACTING SPORT, RECREATION AND NATURAL RESOURCES MANAGER

I concur with the recommendation/s contained in this report.

Bryce Hines
ACTING CHIEF OPERATING OFFICER (WORKS, PARKS AND RECREATION)

Conservation and Environment Committee	
Mtg Date: 21.05.2018	OAR: YES
Authorisation: Bryce Hines	

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30 April 2018

M E M O R A N D U M

TO: ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

FROM: PLANNING OFFICER (BIODIVERSITY)

RE: MANAGEMENT OPTIONS FOR YAMANTO FLYING-FOX COLONY – DIVISION 7

INTRODUCTION:

This is a report by the Planning Officer (Biodiversity) dated 30 April 2018 concerning future management actions for the Yamanto flying-fox colony.

BACKGROUND:

The Yamanto flying-fox colony extends across Deebing Creek, covering Box Street and Beechwood Drive and is located on private property and Unallocated State Land (being the Deebing Creek corridor). This roost has been raised as a concern by a number of residents previously, and more recently through an email to Mayor dated 18 March 2018.

Under Council's Flying-fox Roost Management Plan the Yamanto roost is classified as medium risk; which specifies - where a medium conflict roosts exists on private property Council may consider a partnership with the Queensland Government and landholders to undertake in-situ management actions on private land. Dispersal actions would only be considered under high risk scenarios.

In 2016, Council undertook works to create a distance buffer between residents and roosting flying-foxes. This was done by altering vegetation on the western and southern sides of Deebing Creek through removal of large woody weeds and selected trimming of native vegetation.

PURPOSE:

This report outlines a process for Council to be able to make an informed decision regarding the on-going management of the Yamanto Flying Fox Roost.

The report lists a suite of management options including the potential advantages, disadvantages and cost to Council for each.

All management options will need to be in accordance with Council's adopted Flying-fox Roost Management Plan (FFRMP), Flying-fox Roost Management Policy, the *Nature Conservation Act 1992 (Qld)* and its associated regulations and codes of practice, and the *Environmental Protection and Biodiversity Conservation Act 1999 (Cwth).*

Council is required to make a decision to either stand by the previous arrangement to do no further work at the Yamanto roost site, or to invest in further works selected from the options outlined below.

MANAGEMENT OPTIONS:

Option 1: Vegetation modification

Description:
Much of the vegetation removed in 2016 to create a physical buffer between roosting flying-foxes has regrown and may recreate the previous flying-fox habitat on the western and southern sides of Deebing Creek. The licence agreements signed by the participating residents in 2016 stated that on-going management of vegetation following completion of the initial works was the responsibility of the landholder. However, Council understands that this has not occurred.

Management option 1 is to undertake another round of vegetation modification to consolidate the buffer created in 2016 through removal of regrowth and woody weeds.

Advantages:
- This action was successful previously at this location;
- Removal of regrowth is relatively easy given the previous clearing of woody weeds;
- Some residents who participated in the initial works may be receptive to follow up actions.

Disadvantages:
- Vegetation modification works are dependent on when and where flying-foxes are located in a colony;
- On-going management of the site was not undertaken following the initial works, as specified in the licence agreement with residents;
- There are many areas within the creek corridor where vegetation management cannot occur under state legislation (ie: Riverine Protection Permits);
- Further action may not appease all residents, particularly where they feel impacts have been compounding over time and cite issues such as mental health impacts

Costs:
Works conducted in 2016 cost $60,000 for vegetation modification and weed removal on 14 properties and one bank of Deebing Creek.

Given the work has previously been done, it is expected that further vegetation management in these areas would cost $40,000-$50,000, depending on the presence and abundance of flying-foxes within the colony, as prices will increase where night works are required.

Option 2: Active dispersal

Description:
Active dispersal involves the continual use of accepted techniques in an attempt to permanently disperse flying-foxes from a colony. The actions that can be undertaken are regulated through the relevant State and Commonwealth legislation and associated guidelines, guiding the timing and type of actions. In addition, the success of the dispersal is highly variable as flying-foxes are extremely mobile and often travel short distances to form a new roost, or make use of another existing roost.

Active dispersal of the Yamanto colony would require Council staff or contractors, in agreement with landholders, to enter private property to conduct dispersal actions. To ensure a successful outcome native vegetation on private property and along Deebing Creek would need to be removed.

Advantages:
- If successful, permanently disperse flying-foxes from the current colony.

Disadvantages:
- High chance of failure;
- High risk and uncertainty of where flying-foxes will settle once dispersed;
- High risk of creating a new roost in close proximity to the current site or joining another existing or previous site such as Lorikeet Street Reserve or Queens Park Nature Centre;
- Effort is high cost and resource intensive in the immediate to short term;
- Dispersal actions will need to be recurring until all animals have left the roost site;
- Loss of native vegetation on private property and along Deebing Creek increasing a risk of bank erosion and regrowth of weed species;
- Noise disturbance to residents whilst undertaking the dispersal actions which may extend over a number of days to weeks. Actions are required to be undertaken before dawn or after dusk;
- Legislative constraints on the time of year when dispersal actions can be undertaken.

Costs:
Cost can be highly variable depending on a number of factors including:
- Size of colony and area requiring dispersal actions;
- Number of personnel required;
- Number of days required to undertake works;
- Whether dispersal actions are successful;
- Where dispersed flying-foxes land;
- Whether vegetation modification is required;
- The time a colony of flying-foxes has occupied a site for;

- Presence and abundance of local food sources.

When considering all of the factors above, upfront dispersals cost could be anywhere between $50,000 and $500,000. Given the large numbers of flying-foxes and area covered by the Yamanto colony, costs are likely to be in the hundreds of thousands. Given that the colony occupies the riparian area of the highly erosive Deebing Creek, complete vegetation removal may not be an option, so flying-foxes would continually be drawn back to the site. As such an ongoing yearly cost of $50,000 to $100,000 would be required.

Case studies:
The Melbourne Botanic Gardens is the best example of the amount of effort required to conduct a flying-fox dispersal where complete vegetation removal is not appropriate. Dispersal efforts were successful at a cost of over $3,000,000 with works ongoing to this day to ensure flying-foxes do not return to the gardens.

Other dispersals, such as in Charters Towers, have cost over $400,000 and are still considered unsuccessful.

Option 3: Extend distance buffer

Description:
Further works conducted within Deebing Creek to extend the buffer between residents on Beechwood Drive and Box Street. Further habitat is available for roosting on the Briggs Road side of Deebing Creek where conflict with landowners is substantially lower.

Works would potentially require additional remediation of Deebing Creek to minimise potential erosion.

Previous correspondence with the Department of Natural Resources and Mines indicates that additional works within the creek corridor (deemed to be Unallocated State Land) would require additional permits before vegetation clearing and potentially written approval from the Minister.

Advantages:
- Increase the effectiveness of previous buffering actions as a method for reducing the impacts;
- Push flying-foxes further from residences where current conflict occurs;
- Avoid the need to remove flying-foxes from the roost while reducing impacts on residents livelihoods;
- Existing Licence Agreements between Council and the majority of landholders in this area.

Disadvantages:
- Significant risk involved with further clearing of vegetation on Deebing Creek and increased erosion risk;

- Increased administration and potential delays to obtain permits required from the Department Natural Resources Mines and Energy with Ministerial approval;
- Pushing flying-foxes further towards Briggs Road and further from the creek corridor (through substantial removal of roosting vegetation) could potentially make the entire roost unsuitable and flying-foxes may begin roosting in different parts of Deebing Creek or more to another nearby site;
- Further works in Deebing Creek will remove a substantial portion of the heat stress refuge habitat within the Yamanto flying-fox colony, increasing risk of mortality at this location;
- Previous works at Yamanto flying-fox colony have shown that on-going maintenance of the site has not been undertaken by landholders;
- Council is unable to maintain the site as it is on private property and Unallocated State Land.

Costs:
- It is expected that costs would increase from the previous works, due to remediation works to reduce erosion risk on Deebing Creek post vegetation clearance;
- Potential expectation for Council to fund on-going maintenance works to ensure vegetation does not become suitable for roosting again.

Option 4: Artificial buffering (e.g. canopy mounted sprinklers)

Description:
Where complete removal of vegetation is not possible or desirable by residents, artificial buffers can be used. Currently, approved artificial buffers are mostly limited to the use of canopy mounted sprinklers. The arc of the sprinklers creates a zone that flying-foxes find non-desirable and are not likely to roost in. Sprinklers can be mounted along a boundary of a property or along the current edge of a colony to push or nudge roosting flying-foxes in the desired direction. This technique was recently trialled in the Queens Park Nature Centre with anecdotal success.

Council can consider giving ownership of the sprinklers to residents, allowing the residents to decide when to turn them on and off. Council may also consider subsidizing water costs to residents.

Advantages:
- Non offensive buffering effect;
- Can retain trees and aesthetic value and other vegetation whilst still making trees undesirable for roosting;
- Can be very selective and target specific trees for buffering;
- Can give residents ownership and sense of power with managing the issues;
- The technique has been used successfully by other local authorities at trail sites.

Disadvantages:
- Requires additional permits under the Nature Conservation Act beyond Council’s current as-of-right provisions;

- Will require a commitment from all landholders to ensure there is no “gap” in the artificial buffer;
- Will not completely remove the impacts of smell and mess from a colony;
- Costs and works are ongoing indefinitely;
- Can be logistic difficulties in installation.

Costs:
Refer to Sunshine Coast case study below.

Case studies:
Sunshine Coast Regional Council has installed an extensive series of canopy mounted sprinklers at one of their most contentious flying-foxes colonies. The council used a line of sprinklers on either side of the colony where houses ran adjacent and pushed the colony towards the middle of the site. Sunshine Coast gave control of the sprinklers to the residents and subsidised water costs. The Council had to hire professional tree climbers to install the sprinklers.

During the first year of the project Sunshine Coast Regional Council spent approx. $60,000, including equipment purchase, installation costs and water costs.

Option 5: Subsidy program (double glazing and other services)

Description:
A subsidy program would provide an option for residents living directly next to an active flying-fox roost to receive a subsidy towards a pre-determined set of products or services. The subsidy would only be available to residents who immediately adjoin an active roost site and can demonstrate a significant financial or health impact. The subsidy would cover products or services that can reduce in-situ impacts of roosting flying-foxes on residents such as noise and smell. These may include:

- Air fresheners;
- Car covers;
- Clotheslines covers;
- High pressure water cleaners;
- Professional solar panel cleaning;
- Double glazing windows.

Advantages:
- Solutions can be tailored to the needs of an individual based on their main grievances;
- Relatively inexpensive;
- Can increase resident satisfaction with Council actions, creating a working relationship.

Disadvantages:
- Different methods may have varying level of effectiveness;
- The set of products or services may not appease residents of the flying-fox colony;
- Determining an appropriate subsidy to be made available to residents;
- Residents may still be restricted for use of their outdoor areas.

Costs:
Costs vary greatly depending on the following:
- ∑ Number of residents to take up the subsidy;
- ∑ The willingness and uptake of residents;
- ∑ Amount of subsidy provided to each applicant.

Case studies:
Noosa Council subsidy program

Noosa Council trialled a subsidy program for one of its flying-fox colonies that was offered to 55 affected residences within 75m of the colonies extent.

After a three month trial, residents were surveyed to gauge their satisfaction with the services provided. The most important finding was that the program had successfully reduced the majority of residents concerns with regard to living near a flying-fox colony:

Previous impact of FF on their lifestyle = 7.6/10

Current impact of FF on their lifestyle = 3.2/10

CONCLUSION:

A suite of management options are available to Council, each of which has distinct advantages and disadvantages. No one option is likely to be 100% effective at reducing the direct and indirect impacts of roosting flying-foxes on the livelihood of Yamanto residents.

If Council decides to undertake further works, that Option 1 - Vegetation Modification be considered in the first instance, with a proposal for Option 5 - Subsidy Program to be presented with additional cost details at a future Conservation and Environment Committee.

If Council decides to not undertake further works, that advice be provided to the affected residents in Beechwood Drive and Box Street.

RECOMMENDATION

A. That Council implements Option 1 to undertake one more run of maintenance of the area along Deebing Creek that was subject to the previous vegetation modification works.

B. That Council investigates the feasibility of a subsidy program to support impacted residents, as detailed in Option 5 of the report by the Planning Officer (Biodiversity) dated 30 April 2018.

Tim Shields
PLANNING OFFICER (BIODIVERSITY)

I concur with the recommendation/s contained in this report.

Kaye Cavanagh
ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

I concur with the recommendation/s contained in this report.

Bryce Hines
CHIEF OPERATING OFFICER (WORKS, PARKS AND RECREATION)

Conservation and Environment Committee	
Mtg Date: 21.05.18	OAR: YES
Authorisation: Bryce Hines	

DA: DA
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2 May 2018

M E M O R A N D U M

TO: ACTING SPORTS RECREATION AND NATURAL RESOURCES MANAGER

FROM: WATERWAY HEALTH OFFICER AND PLANNING OFFICER (BIODIVERSITY)

RE: PRIORITISATION AND IDENTIFICATION OF FURTHER FISH BARRIER WORKS

INTRODUCTION:

This is a joint report by the Waterway Health Officer and Planning Officer (Biodiversity) dated 2 May 2018 concerning future fish barrier works in the Bremer River Catchment.

BACKGROUND:

A report has been released by consultants Catchment Solutions (Attachment A) dated April 2018 highlighting major barriers to fish passage across greater Brisbane, including Ipswich.

The barriers have been prioritised according to their significance to fish movement, ecological conditions and feasibility of remediation works. Within the Ipswich Local Government Area (LGA) seven priority fish barrier sites have been identified within the top 100 barriers from across south-east Queensland. Three fish barriers from the Bremer River Catchment (Bremer River and Warrill Creek) were identified in the top twenty sites.

BARRIERS IDENTIFIED WITHIN IPSWICH LOCAL GOVERNMENT AREA:

Overall Priority	Stream Name	Barrier Type	Fishway type required
Equal 12th	Warrill Creek	V Notching Gauging Weir	Cone and/or Rock Ramp
Equal 12th	Bremer River	V Notching Gauging	Cone and/or Rock

		Weir	Ramp
Equal 15th	Warrill Creek	Weir – Sheet Pile and Gabian Basket	Removal of barrier or full width rock ramp
Equal 32nd	Bundamba Creek	Rock weir	Rock ramp
Equal 37th	Bundamba Creek	Pipe Causeway	New box culverts and/or rock ramp
Equal 47th	Woogaroo Creek	Rock weir	Rock ramp
Equal 56th	Six Mile Creek	Rock weir	Removal/rock ramp

BASELINE DATA:

The fish barriers that were ranked in the top twenty were analysed in a secondary study undertaken by Catchment Solutions (Attachment B). The three barriers that were analysed in this study occur upstream of the fishway at Berry's Weir. An analysis was undertaken along the Bremer River and Warrill Creek to ascertain the impact of the barriers on fish movements.

A map showing the location of the three sites is provided in Attachment C.

The results can be seen below:

Overall Priority	**Stream Name**	**Results**	**Recommendation**
Equal 12th	Warrill Creek	The impact of the barrier is very high. No fish were captured successfully leaping over the weir crest or climbing the weir wall during camera monitoring.	Undertake a design and scope of works for implementation
Equal 12th	Bremer River (Walloon)	The impact of the barrier is high. 40% of fish species were not able to ascend the barrier, and fish catch rates were a lot higher downstream than upstream.	Undertake a design and scope of works for implementation
Equal 15th	Warrill Creek (near Runymede trotting stable)	The impact of the barrier is very high. 80% of the fish species sampled at the bottom of the weir were not recorded upstream	Undertake a design and scope of works for implementation

FUTURE WORKS:

In the next twelve months, it is recommended that a design and scope of works is undertaken to remediate the three fish barriers. Once this is completed, it is recommended that the works be considered for future budgets.

CONCLUSION:

Ipswich City Council has seven fish barriers that are listed in the top 100 barriers of significance in South-East Queensland in the Catchment Solutions report (Attachment A). Of these seven barriers, there are three barriers that are listed within the top twenty barriers of significance. These barriers were investigated (Attachment B), and it was concluded that the two Warrill Creek barriers are of high importance for remediation, and the barrier at the Bremer River also requires remediation, however is of lesser importance than the two Warrill Creek Barriers.

ATTACHMENT/S:

Name of Attachment	Attachment
Greater Brisbane Fish Barrier Prioritisation	Attachment A
Bremer River and Warrill Creek Fish Barrier Assessment Report	Attachment B
Map of Three Priority Fish Barriers Upstream of Berry's Weir	Attachment C

RECOMMENDATION:

That Council undertakes a design and scope of works for each of the three priority fish barriers as identified in the report by the Waterway Health Officer and Planning Officer (Biodiversity) dated 2 May 2018.

Danielle Andlemac
WATERWAY HEALTH OFFICER

Tim Shields
PLANNING OFFICER (BIODIVERSITY)

I concur with the recommendation/s contained in this report.

Kaye Cavanagh
ACTING SPORT RECREATION AND NATURAL RESOURCES MANAGER

I concur with the recommendation/s contained in this report.

Bryce Hines
CHIEF OPERATING OFFICER (WORKS, PARKS AND RECREATION)

Catchment Solutions

Find your **solution.**

Greater Brisbane Fish Barrier Prioritisation

April 2018

Matt Moore, Jack McCann & Trent Power

For further information contact:

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Project Officer

Catchment Solutions – Fisheries and Aquatic Ecosystems

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Cover Figure: From top, left to right (fish barriers): Luscombe Weir located on the lower Albert River, DNRM V- notch gauging weir located on the lower Warrill Creek upstream from the Cunningham Highway, Pipe culverts located on the Pimpama River downstream from the Pacific Highway, Enoggera Creek tidal interface weir located adjacent to Hulme St, Berrys Weir partial width rock-ramp fishway located in the lower reaches of the Bremer River in Yamanto. Fish images; juvenile freshwater mullet (captured from Leitchs Crossing fishway– South Pine River), juvenile and adult bullrout, (top to bottom) Sea mullet, Duboulay's rainbowfish, unspecked hardyhead, firetail gudgeon Australian smelt, empire gudgeon, and forked- tailed catfish and yellowfin bream all captured successfully ascending Berrys weir rock-ramp fishway on the lower Bremer River.

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Glossary of Terms

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 – Different life stages migrate into different habitats.

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.

Head loss – 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

CS -	Catchment Solutions
NRM -	Natural Resource Management Group
RCL -	Reef Catchments Limited
GBFBP -	Greater Brisbane Fish Barrier Prioritisation
GB -	Greater Brisbane
FBPP -	Fish Barrier Prioritisation Process
GIS -	Geographic Information Systems
GEP -	Google Earth Pro
DDL -	Declared Downstream Limit
DAF -	Department of Agriculture and Fisheries
DNRM -	Department of Natural Resources and Mines
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 freshwater and saltwater habitats are often of the highest socio-economic 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

This report forms part of the overarching project 'Re-Connecting Aquatic Habitats Across the Greater Brisbane Urban Area', which was commissioned by the Federal Government under the 'Targeted Area Grants' program via Reef Catchments Limited (RCL) Natural Resource Management (NRM) group. The objective of the Greater Brisbane Fish Barrier Prioritisation (GBFBP) was to identify and assess the large number of anthropogenic barriers that prevent, delay or obstruct fish migration in the Greater Brisbane (GB) region. 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 GB 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 GB region impact fisheries' productivity and create environmental conditions favourable for invasive pest fish species. Significantly, almost half of the GB 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 remediating fish passage barriers throughout the GB region.

Explicitly, the overall aims of the project were to;

1. Systematically identify all potential barriers to fish passage in the GB 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 50 priority ranked fish barriers in the GB region showing remediation options and indicative costs
6. Facilitate the adoption of fish barrier remediation by Local Governments and Natural Resource Managers
    a. Construction of appropriately designed fishways at several high priority sites in partnership with respective Councils
    b. Evaluation monitoring to assess remediation success
    c. Field day – South-East Queensland fish passage field trip

The fish barrier prioritisation process involved identifying potential barriers using high resolution aerial imagery across the GB region. In total, 13,629 potential barriers were identified in the project area (3,582 km^2) at a rate of 3.8 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 socio-economic flow-on benefits of improving aquatic ecosystem connectivity were considered i.e. the degree to which barrier remediation may increase fisheries productivity and/or conserve vulnerable fish species, e.g. jungle 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 natural resource management 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 groundtruthing the top priority potential barriers in order of importance. The resultant GBFBP report and associated priority ranked fish barrier list will assist natural resource managers and decision makers in determining where best to allocate funding opportunities to ensure the greatest environmental and socio-economic outcomes for the GB region.

The GBFBP was also used to guide the remediation of several priority fish barrier sites as part of the overarching project. Fish barrier sites were chosen based on priority ranking and available resources. Five fishways were designed, constructed and monitored by Catchment Solutions (CS) between 2016 and 2017, and delivery of individual fishway projects were undertaken in partnership with each respective Local Government (LG) (Table A). Rock-ramp fishways (RRF) were chosen as the preferred design option at all sites due to their ability to pass weaker swimming juvenile and small bodied species, their natural appearance, pool roughness (creating micro-eddies) and minimal cost outlay when compared to highly engineered, smooth-sided fishways such as vertical-slot fishways. Rock-ramp fishways were constructed on the:

- Bremer River (Berrys Weir - ranked 7th),
- South Pine River (Leitchs Crossing - ranked 11th),
- Hilliards Creek (Hilliards Weir - ranked equal 36th) and
- Slacks Creek (Paradise Road overpass - ranked equal 36th). Due to site constraints, a horizontal culvert baffle fishway was constructed in addition to the rock-ramp fishway at Paradise Road on Slacks Creek.

Fishway monitoring was undertaken to evaluate the success of each fishway at facilitating fish passage for the entire fish community. Results showed that all expected juvenile diadromous and small bodied species were able to ascend the fishways. The 2.4 m high, 90 m long, 33 ridge Bremer River partial width rock-ramp fishway recorded the highest numbers and diversity of fish, with over 16,000 individuals recorded in just over four days of monitoring at a catch rate of 4,075 fish per day. The median size of all fish captured was just 34 mm, highlighting the success of the fishway at passing weaker swimming juveniles and small bodied species. Notable captures included the migration of key juvenile diadromous species, such as sea mullet, freshwater mullet and bullrout, which represented catch rates of 316, 266, and 27 individuals per day respectively. The success of each fishway project can be directly attributed to the strong working partnerships developed between CS and each LG to remediate priority fish barriers and deliver significant aquatic connectivity remediation outcomes for the benefit of the environment and local communities.

Table A. Showing information relating to the remediation of fish barriers as part of this project.

Waterway	Barrier	Local Gov.	Rank	Barrier Height	Fishway Type/s
Bremer River	Berrys Weir	ICC	7th	2.4 m	33 ridge partial width rock-ramp
South Pine River	Leitchs Crossing	MBRC	11th	0.45 m	7 ridge full width rock-ramp
Hilliards Creek	Relict Weir (Sturgeon St.)	RCC	36th	0.7 m	9 ridge full width rock-ramp
Slacks Creek (x2)	Paradise Road Culverts	LCC	36th	1.8 m	16 ridge full width rock-ramp and 10 ridge horizontal concrete baffle f/way

Introduction

The majority of freshwater fish species of the Greater Brisbane (GB) 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 50 native freshwater fish species found to occur in the GB region (See 'Greater Brisbane Freshwater Fish Communities Overview', pp. 31- 35), almost half (44%) 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 Greater Brisbane Fish Barrier Prioritisation (GBFBP) has been developed to assess and rank fish passage barriers having the greatest impacts on freshwater fish communities of the GB 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 almost half (44%) of the 50 native freshwater fish species recorded in GB freshwater environments (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 GBFBP 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 access to freshwater.

Many Greater Brisbane 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 and that barriers preventing key migratory species potentially contribute towards conditions that favour the establishment and 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 (Figure 1), mangrove jack (*Lutjanus argentimaculatus*), tarpon (*Megalops cyprinoides*) sea mullet 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 500 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 GBFBP 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 large, 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 GB 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 50 priority ranked fish barriers in the GB region showing remediation options and indicative estimated costs
6. Facilitate the adoption of fish barrier remediation by Local Governments and Natural Resource Managers

a. Construction of appropriately designed fishways at several high priority sites in partnership with respective Councils
b. Evaluation monitoring to assess remediation success
c. Field day – South-East Queensland fish passage field trip

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 Ck), b) tidal floodgates (Behm Ck), c) V-notch stream gauging weir (Warrill Ck), d) Sheet pile and gabion basket weir (Warrill Ck), 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 as part of this project. 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 (See 'Case Studies' in the Appendices of report for detailed breakdown of fishway monitoring results).

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 fishes.

Swimming abilities of different fish species play 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 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) are 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 as part of this project showed that juvenile empire gudgeon (*H. compressa)* (34 mm), striped gudgeon (*Gobiomorphus australis)* (44 mm) and sea mullet *(M. 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 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 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. However, the unique climbing abilities of juvenile long-finned eels 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 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 affected greater. 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 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 (dark shadows/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 GBFBP 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 GBFBP, 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 biologists have an understanding of local waterways, barrier types, fish biology and species expected to occur at a site scale within the study region when assessing these criteria.

Fish Passage Remediation Options

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 are able to negotiate faster velocities and higher water turbulence than Australian native fish species, with the added advantage of a leaping ability. Atlantic salmon 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 high 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, concrete cone ramps, vertical-slot, denil and vertical and horizontal culvert baffle fishways.

Rock-ramp fishways

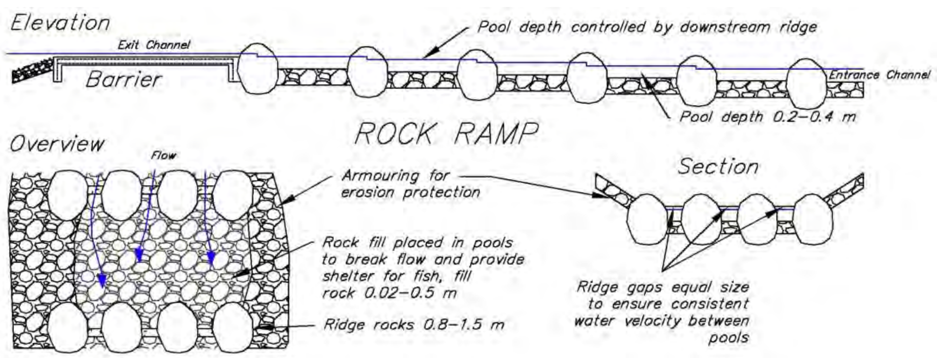
Rock-ramp fishways, or nature-like fishways, are the most common fishway type constructed in Queensland. Over the past decade, rock-ramps have been refined to suit the swimming abilities of native fish species and represent a low cost option to more formal fishway designs (Gebler 1988; Pasche et al 1995;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

Figure 6. 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 6) 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 1 below for a full list of advantages and disadvantages of rock-ramp fishways.

Table 1. 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

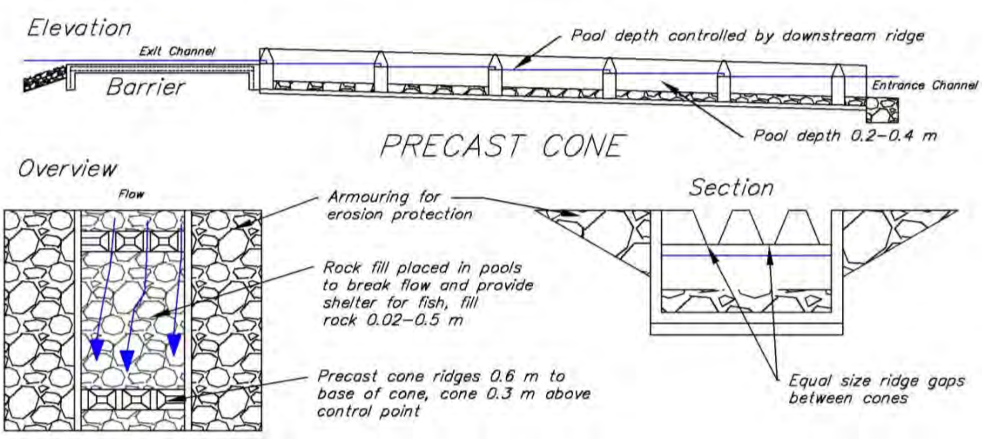
In an operational sense cone fishways are similar to rock-ramps, comprising of a series of pools interspersed at regular intervals by ridges within a channel on a minimum gradient of approximately 1:20. The main differences between the two fishway types, centers around the prefabrication of materials 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 2). The highly engineered structural nature of cone fishways (Figure 7) 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 7. 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 2. Showing advantages, disadvantages and conceptual design cone fishways

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



Vertical-slot Fishways

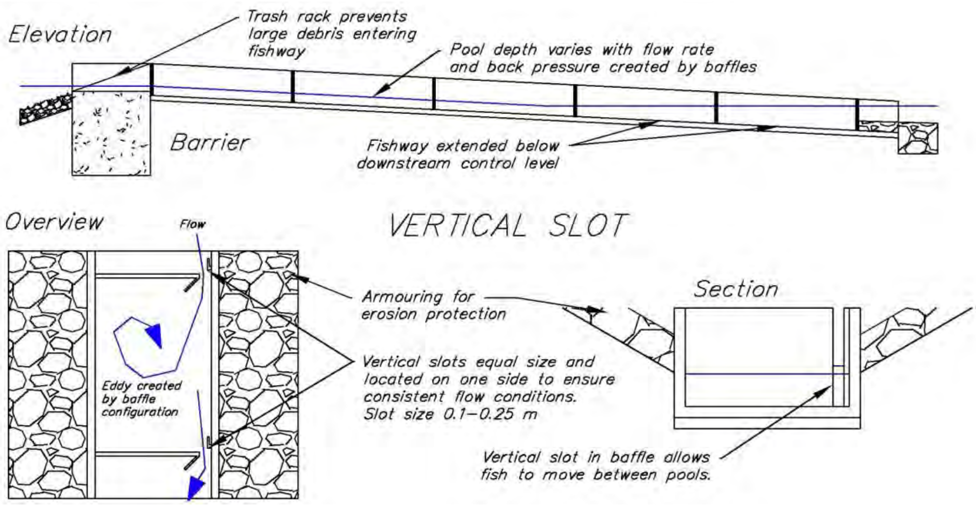
Vertical-slot fishways have been widely used throughout Australia and proven successful at passing a variety of species. Vertical-slot fishways operate by creating a series of pools separated by baffles that have a narrow vertical-slot on one side (Table 3). The baffles are installed into a concrete 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 8. Showing a vertical-slot fishway on Waterpark Creek, Byfield. Note: The partial width nature and small entrance of vertical-slot fishways means it may be difficult for fish to locate the entrance.

Vertical-slot fishways (Figure 8) 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 3. 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

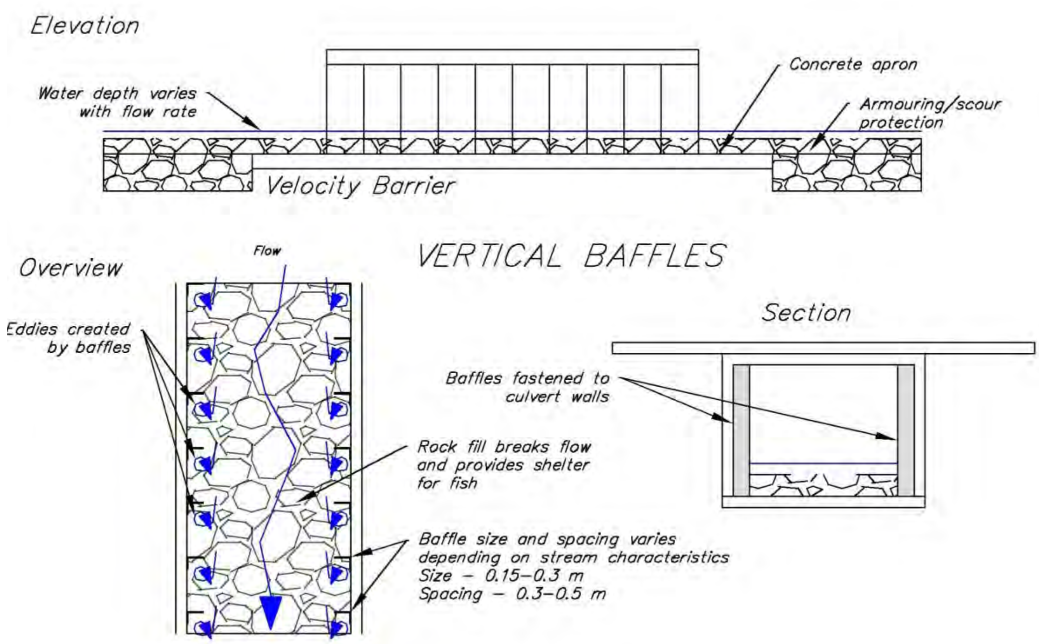
Vertical culvert baffles are an option for improving fish passage through box culverts. The relatively low cost and ability to easily retrofit to existing structures has seen the installation of baffles at many culvert structures throughout Queensland (Table 4). However, unlike horizontal baffles, they 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 9). 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 4.

Figure 9. 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 4. 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 Culvert Baffles

Horizontal culvert baffles (Figure 10) are a recent, innovative option for improving fish passage through box culverts. Monitoring has demonstrated that they are highly effective at passing fish, particularly juvenile species, with the fishway in Figure 10 recording a catch rate of 1,371 individual fish per day. Unlike vertical baffles, they provide resting pools for migrating fish (Table 5). Resting pools are important for native fish attempting to ascend past velocity barriers, particularly when these barriers occur for extended distances, such as through culverts located under road transportation networks. Resting areas are even more imperative for small-bodied species which don't possess the swimming abilities of larger bodied species (Rodgers et al., 2014; Domenici, 2001). This is because larger fish have more muscle to propel them through the water (Tillinger and Stein, 1996). Small bodied fish comprise the most common component of fish communities migrating upstream through coastal waterways in Queensland.

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

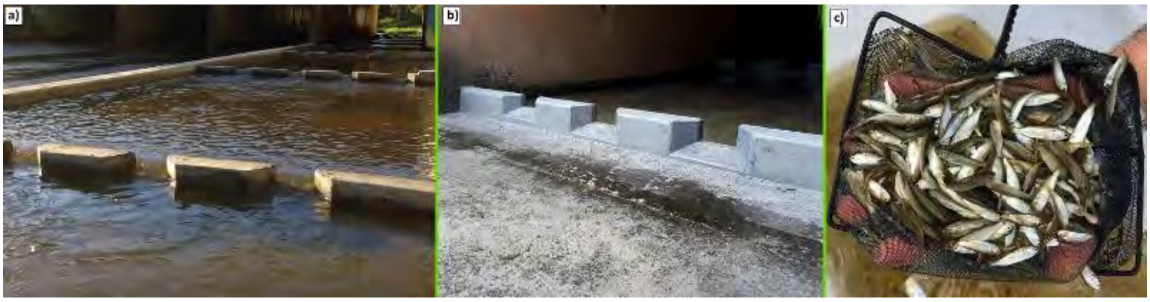
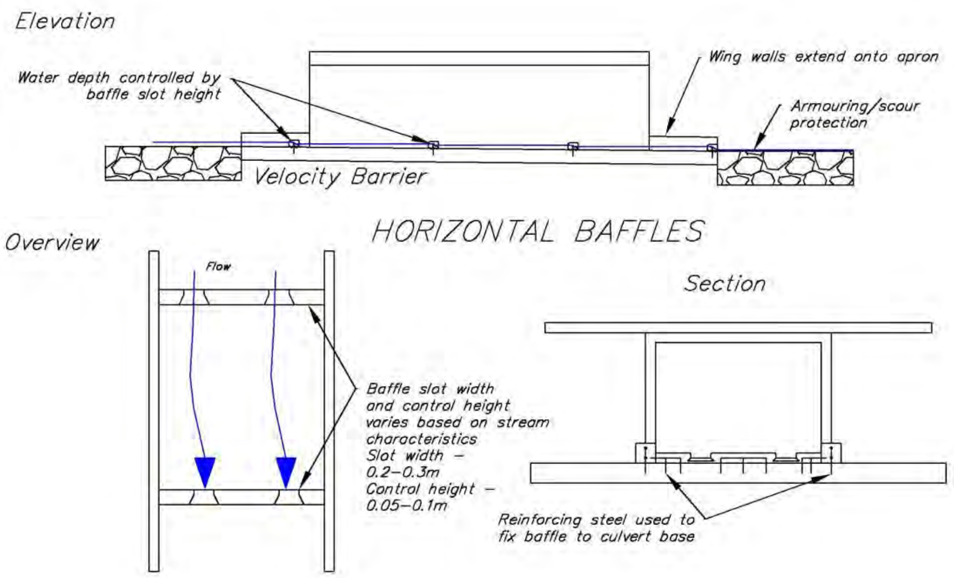


Figure 10. a) Retrofitted horizontal culvert baffles in operation under Paradise Road on Slacks Creek. Note: Nib wall to divert all base attraction flows down the fishway. Prior to remediating this barrier, the flow was spread out across four 2.4 m wide culvert barrels creating a shallow water surface barrier under base flow conditions. b) Horizontal baffles with the boxing recently removed c) Predominantly showing Juvenile sea mullet and striped gudgeon captured successfully ascending through the horizontal culvert baffle fishway at catch rates of 256 and 793 individuals per day respectively.

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

Table 5. 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.



Greater Brisbane Regional Overview

The South-East Queensland region covers an area of approximately 23,000 km^2 incorporating a total of 14 catchments (SEQ Catchments 2018). The region extends from the Noosa, Maroochy and Mooloolah catchments in the north, out to the upper Brisbane and Lockyer catchments in the west, down through to the regions southern boundaries of the Logan-Albert and Gold Coast catchments in the south. For most of the region, headwaters of major rivers originate in the coastal hinterlands, including the Sunshine and Gold Coast hinterlands as well as the Great Dividing Range, and drain east towards the greater Moreton Bay region.

Figure 11 below displays a regional map of South-East Queensland, with the LGA boundaries outlined in bold (MBRC, BCC, ICC, LCC, RCC and GCCC). This map also shows the defined project boundaries, as coloured waterways identified on the map. The spatial stream layer depicted on the map is the Queensland Waterways for Waterway Barrier Works layer.

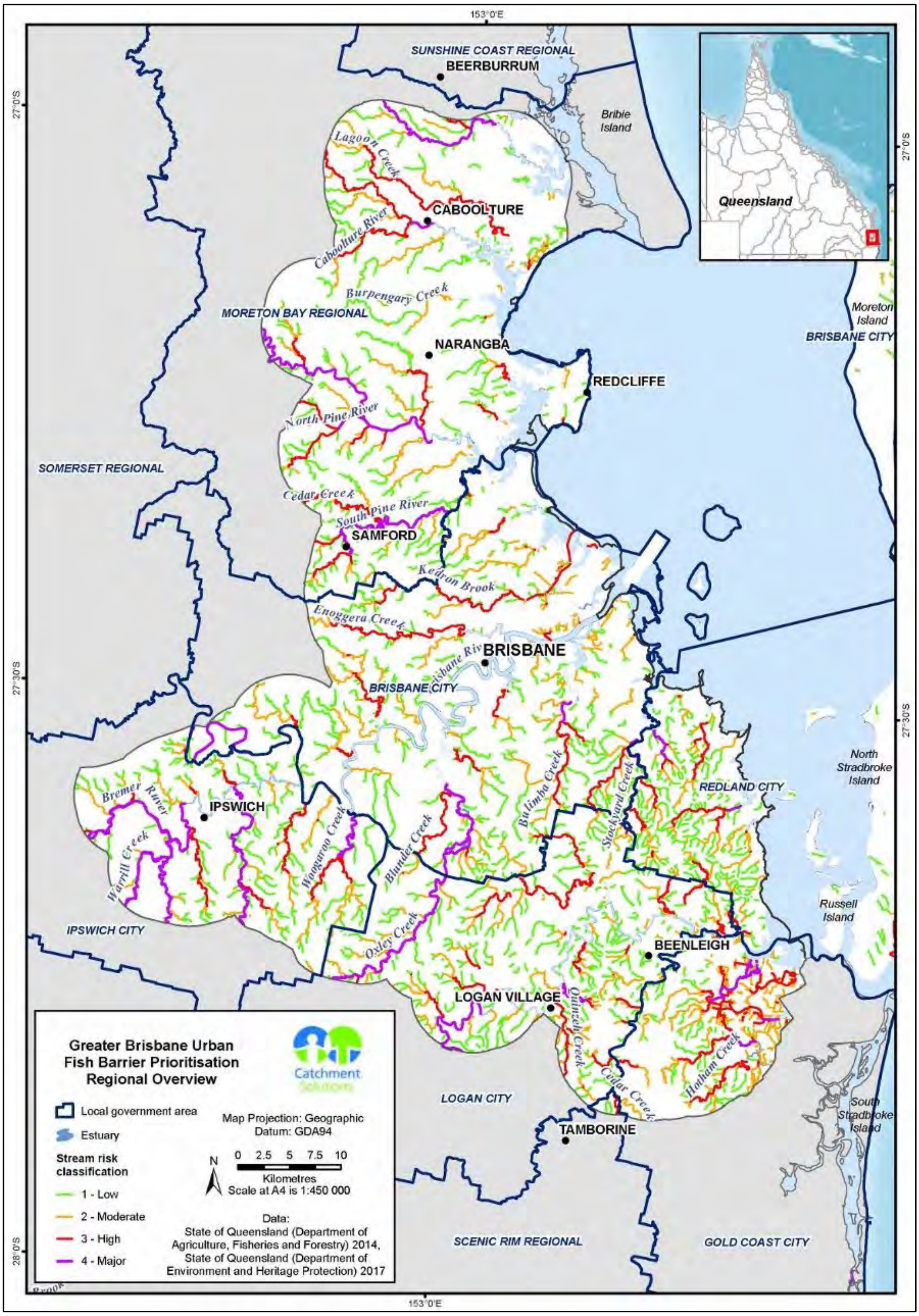


Figure 11. South-East Queensland regional overview, with local government area boundaries shown

South-East Queensland is one of the most highly urbanised and populated regions in Australia, accommodating 3.3 million of Queensland's 4.7 million residents (Queensland Government Statisticians Office 2018). Despite the many areas of exceptional biodiversity in the upper reaches and associated national parks of the regions catchments, 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 in South-East Queensland 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, with many localised population decreases of native species observed.

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 instream 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. Figure 12 maps the intensity of land usage in South-East Queensland, in which catchment condition was used as important criteria throughout the barrier scoring process. The image clearly illustrates the intensity of land usage in South-East Queensland, with over half of the total project area ranking as the most intensive land use.

Water storage infrastructure throughout the region for domestic, industrial and agricultural supply usage is extensive, with Seqwater owning and operating 26 major dams and 51 weirs which supply up to 90% of the regions drinking water (Seqwater 2016). Whilst undoubtedly serving a purpose for societal welfare, these large, significant head loss barriers cause many issues for 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 total list of 77 owned and operated water storage facilities are only a snapshot of the total number of fish passage barriers in South-East Queensland, with many other gauging stations, weirs, causeways and culvert crossings known to significantly obstruct fish passage within the region (Kennard and Balcombe 2014).

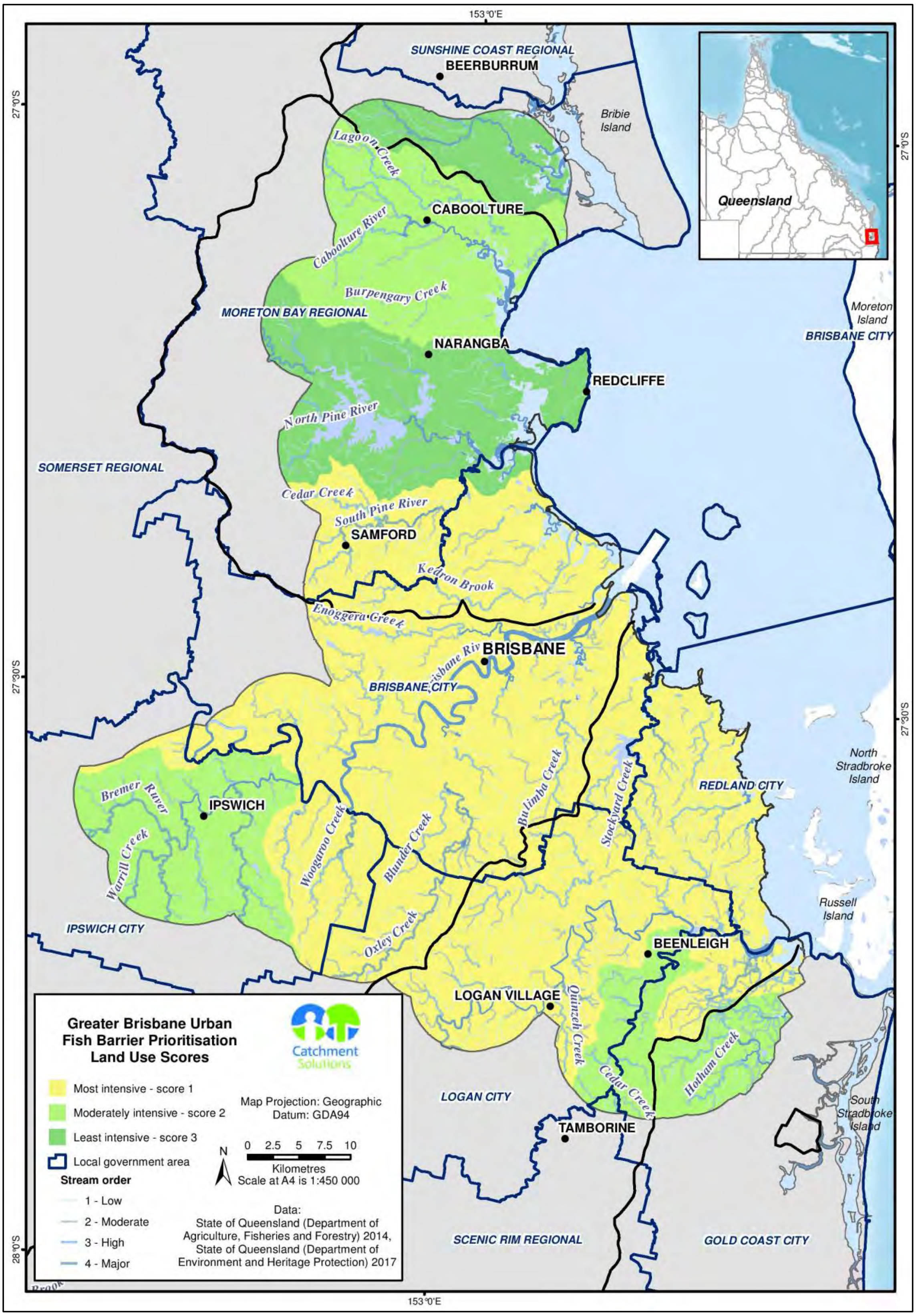


Figure 12. Map of South-East Queensland with regional land usage highlighted

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

Greater Brisbane Freshwater Fish Communities Overview

In undertaking a fish passage barrier prioritisation in the Greater Brisbane 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 present within waterways, as these migratory species require unimpeded passage from saltwater riverine reaches of the system right up to the upstream freshwater stream reaches (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 all 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. To this dataset, all of Catchment Solutions own recorded fish surveys over the last five years within freshwaters of South-East Queensland were added, which provided several additional species to the overall species list.

The finalised list comprised of a total of 59 fish species being identified within freshwaters of South-East Queensland since 2003. This can be broken down into five species categories based on migration classifications (Table 6);

- 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.
- 18 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.
- 27 Potamodromous species - Species which migrate wholly within freshwater habitats, and can complete their entire life-cycle within these environments.
- 1 Insufficient knowledge species - The snub-nosed garfish (*A. sclerolepis*) was unable to be categorised into a distinguished migration classification, as this species is known to complete its entire life-cycle in freshwater habitats, and in riverine saltwater habitats.
- 9 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 South-East Queensland streams, with almost half (44%) of the native fish population found within freshwaters of the region requiring unimpeded access to estuarine habitats to maintain sustainable populations. 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. On occasions, 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 possess swimming abilities sufficient to ascend past the barrier. The likelihood of the 'right' conditions prevailing at the next upstream barrier, and 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 Greater Brisbane fish communities.

It was determined that 66% of the native species found in the regions streams are deemed to be of socio-economic importance through conservation status, commercial, recreational, indigenous and aquarium trade fisheries. Species including Australian bass (*P. novemaculeata*), jungle perch (*K. rupestris*), sea mullet (*M. cephalus*) and freshwater mullet (*T. petardi*) are all key diadromous species with significant economic value. Further to this, four species present in the region are listed as threatened species on the EPBC Act (1999), including the endangered Mary River cod (*M. mariensis*) and Oxleyan pygmy perch (*N. oxleyana*), the vulnerable Queensland lungfish (*N. forsteri*) and Honey blue-eye (*P. mellis*). In-addition to these four species, the status of freshwater mullet (*T. petardi*) and the potential listing of this species under the EPBC Act (1999) is currently under review. This is due to significant declines in population abundance across its known range.

Note, this species list is an overall species list for South-East Queensland and all of these species were considered in the barrier prioritisation process. Some of these species have been surveyed within the defined project catchments, however not within defined project boundaries. For example, headwaters of the Brisbane River catchment were outside the defined project boundary, whereas the lower reaches of the Brisbane River catchment were within the project boundary, however, all fish species recorded in the Brisbane River catchment have been included. Additionally, some of these species in the table have been surveyed within South-East Queensland, however not within the defined project catchments, for example, catchments between and including Burpengary and Doonan Creeks were outside project boundary, yet fish species recorded in these catchments have been included. These species have been identified throughout the species list table.

Figure 13. Showing fish species occurring in SEQ waterways. See Table 6 for common and species name.

Table 6. Freshwater fish species recorded in SEQ waterways, including migration class, common name, species name and importance to commercial, recreational, indigenous or aquarium trade fisheries. Note: Letter e.g. (A) after common name refers to species with a fish image in Figure 13 above.

Migration Classification	Common name	Species	Importance
Marine Vagrant	Bull shark	*Carcharhinus leucas*	C, R
(n= 4)	Dusky flathead	*Platycephalus fuscus*	C, R, I
	Estuary glassfish (R)	*Ambassis marianus*	-
	Yellowfin bream (S)	*Acanthopagrus australis*	C, R, I
Diadromous	Australian bass (N)	*Percalates novemaculeata*	R, I, A
(n= 18)	Bullrout (W)	*Notesthes robusta*	A
	Common silverbiddy	*Gerres subfasciatus*	-
	Cox's gudgeon	*Gobiomorphus coxii*	-
	Empire gudgeon (D)	*Hypseleotris compressa*	A
	Freshwater mullet (V)	*Trachystoma petardi*	R, I
	Fork- tailed catfish (M)	*Arius graeffei*	I, A
	Jungle perch (H)	*Kuhlia rupestris*	R, I, A
	Lamprey species[2]	*Mordacia sp.*	-
	Large- mouth goby	*Redigobius macrostoma*	-
	Long- finned eel (B)	*Anguilla reinhardtii*	C, R, I
	Pacific shortfin eel	*Anguilla australis*	C, R, I
	Roman- nosed goby	*Awaous acritosus*	-
	Sea mullet (Q)	*Mugil cephalus*	C, R, I
	Speckled goby (F)	*Redigobius bikolanus*	-
	Striped gudgeon (G)	*Gobiomorphus australis*	A
	Tamar goby[2]	*Afurcagobius tamarensis*	-
	Tarpon (X)	*Megalops cyprinoides*	R, A
Potamodromous	Agassizi's glassfish (A)	*Ambassis agassizii*	A
(n= 27)	Australian smelt (J)	*Retropinna semoni*	A
	Banded grunter (K)	*Amniataba percoides*	A
	Bony bream (O)	*Nematalosa erebi*	-
	Common galaxias[2]	*Galaxias maculatus*	-
	Crimson- spotted rainbowfish (L)	*Melanotaenia duboulayi*	A
	Dwarf flathead gudgeon (T,b)	*Philypnodon macrostomus*	-
	Eel- tailed catfish	*Tandanus tandanus*	R, I, A
	Firetail gudgeon (E)	*Hypseleotris galii*	A
	Flathead gudgeon (T,a)	*Philypnodon grandiceps*	I
	Unspecked hardyhead	*Craterocephalus fulvus (I)*	A
	Honey blue- eye[2]	*Pseudomugil mellis*	S, A
	Marjorie's hardyhead	*Craterocephalus marjoriae*	-

	Mary River cod (P)	*Maccullochella mariensis*	S
	Mouth almighty	*Glossamia aprion*	A
	Ornate rainbowfish	*Rhadinocentrus ornatus*	A
	Oxleyan pygmy perch[2]	*Nannoperca oxleyana*	S, A
	Pacific blue- eye (C)	*Pseudomugil signifer*	A
	Purple- spotted gudgeon	*Mogurnda adspersa*	A
	Queensland lungfish	*Neoceratodus forsteri*	S
	Rendahl's catfish[1]	*Porochilus rendahli*	I
	Sleepy cod[1]	*Oxyeleotris lineolatus*	A
	Spangled perch (U)	*Leiopotherapon unicolor*	I
	Swamp eel	*Ophisternon sp.*	-
	Unspecked hardyhead	*Craterocephalus fulvus*	A
	Western carp gudgeon	*Hypseleotris klunzingeri*	-
	Yellowbelly	*Macquaria ambigua*	R, I, A
Insufficient Knowledge (n= 1)	Snub- nosed garfish	*Arrhamphus sclerolepis*	R, I
Pest Fish (n= 9)	Carp	*Cyprinus carpio*	-
	Goldfish	*Carassius auratus*	-
	Guppy	*Poecilia reticulata*	-
	Mosquitofish	*Gambusia holbrooki*	-
	Oriental weatherloach	*Misgurnus anguillicaudatus*	-
	Pearl cichlid	*Geophagus brasiliensis*	-
	Platy	*Xiphophorus maculatus*	-
	Swordtail	*Xiphophorus helleri*	-
	Tilapia	*Oreochromis mossambicus*	-

[1] **Species surveyed within project catchments, however not within project boundaries**

[2] **Species surveyed within South-East Queensland, however not within project catchments**

Importance: S= Status, C= Commercial, R= Recreational, I= Indigenous and A= Aquarium

Methods

Greater Brisbane Region

The GB region boundary used for the current study was determined by the Federal Government to align with the Targeted Area funding theme 'Restoring and Maintaining Urban Waterways and Coastal Environments'. The project boundary encompasses all urban and peri-urban catchments surrounding the Brisbane region, from Pimpama River catchment in the south, northwards along the coast to and including Elimbah Creek catchment and west to Ipswich. Headwater reaches of the Brisbane, Caboolture, Bremer and Logan-Albert River systems were outside the project boundary, with the vast majority of the lower and middle reaches of these systems within the project boundary. Smaller coastal rivers and creeks wholly within the project boundary include; South Pine River, Kedron Brook, Oxley, Enoggera, Bulimba, Cedar, Norman, Moggill, Burpengary and King John Creeks to name a few.

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 free 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 spatial and 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 to look out for in these scenarios include dead trees, which have potentially drowned and died due to the ponding of water caused by a downstream barrier, and 'lake like' large bodies of water that are out of character with the rest of the waterway. On occasions when river reaches comprised dense canopy cover, potential barrier waypoints were assigned when 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 telltale 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 individual potential barrier. Identified 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. sugar cane) 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 Waterway Barrier ordered drainage 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 - 10) 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 Greater Brisbane 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 7). 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 7: 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 8).

Table 8. Showing proportion (%) of intensive land use and associated scores for each category.

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

Question 3. Number of Potential Barriers Downstream

Number of potential barriers downstream along the stream network until the declared downstream limit (DDL) e.g. estuary. *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 9)

Table 9. 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 10).

Table 10. 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 11). Barriers close to the tidal interface that prevent connectivity to the rest of the catchment score high.

Table 11. 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 (~500) 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.

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 12. 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 12. 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 13.

Table 13. 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 14.

Table 14. 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 15.

Table 15. 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 16.

Table 16. 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 GB region. The end result of the third stage is a priority ranked list of the top 50 barriers to fish migration in the GB 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 17. Fishway monitoring *not* included in cost estimates.

Table 17. 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 18.

Table 18. 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 19.

Table 19. 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 20.

Table 20. 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 (barrier transparency) – How often are fish potentially able to ascend past the barrier?

Table 21. 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 13,629 potential in-stream barriers were identified (Figure 16). Ipswich City Council (ICC) recorded the highest rate of potential barriers per km² at a rate of 4.84 potential barriers per km², followed by Logan City Council (LCC), Redland City Council (RCC), Moreton Bay Regional Council (MBRC), Gold Coast Council (GCCC) and Brisbane City Council (BCC) with 4.38, 4.20, 4.18, 3.76 and 2.48 PB's per km² respectively. Following the identification of potential barriers, those that were not located on Fisheries QLD fish passage stream risk classification waterway layer were removed from further assessment, leaving 4,916 potential barriers that were assessed against stage 1 criteria. Three potential barriers received the equal highest stage 1 score of 29 out of a possible 32 points; Elimbah Creek Tidal Causeway, Mt Crosby Weir on the Brisbane River and Kerkin Road Tidal Floodgates on the Pimpama River. The Caboolture River Barrage and Behm Creek Tidal Floodgates each recorded the second highest score in stage 1 with 28 points.

Stage 2 - Fine Scale Site Specific Ecological Assessment

A total of 522 potential barriers were assessed in the field during the second stage of the prioritisation. Actual barriers to fish passage accounted for 264 (51%) of the field validated potential barriers (Figure 17), the remaining 258 non-barriers predominantly consisted of bridges, logs (Figure 14), bed control structures and full-width culvert configurations constructed within the stream bed and/ or with a low flow channel and roughening. A further 217 potentials barriers were removed via desktop that were identified on local government structure inventories and confirmed by respective council officers as total span bridges. The 264 fish barriers were assessed against site specific ecological criteria set out for stage 2, before advancing to stage 3 of the prioritisation process. The tidal causeway barrier on Elimbah Creek (barrier ID 3728) was the highest scoring barrier in stage 2, scoring 23 out of a maximum 25 points, to bring its combined stage 1 and 2 score to 52 points and an overall rank of 1. Four fish barriers recorded the equal second highest score (22) in stage 2; Luscombe Weir on the Albert River (ID 10352), Caboolture River Barrage (ID 13941), and Pimpama River (ID 13801) and Behm Creek (ID 13800) Tidal Floodgates.

Figure 14. Showing example potential barriers identified via aerial imagery & assessed in the field as not affecting fish passage

Stage 3 – Social, Economic and Fisheries Productivity Prioritisation

The third and final stage involved assessing the top 264 ranked barriers after stage 2. The end product was a priority ranked list of the top 50 barriers to fish passage in the Greater Brisbane (GB) region. The top-ranking barrier in stage 3 was the DNRM gauging weir on Warrill Creek (ID 8231) with a score of 20 out of a possible 25 points. Scores for the three stages were totalled to acquire the final priority rank. The Caboolture River Barrage acquired the highest score after 3 stages (70 points) becoming the number one ranked priority fish barrier in the GB region, followed by Elimbah Creek Tidal Causeway with 69 points and an overall rank of two (Table 22). Luscombe Weir on the Albert River and Mt Crosby Weir (ID 12850) on the Brisbane River each scored 68 points and an overall rank of three, followed by the Pimpama River Tidal Floodgates and Stanmore Road Causeway on the Albert River equal with a score of 67 points and a rank of five. The location and priority rank of the top 50 barriers is shown in Figure 18. Details of the top 50 priority ranked barriers including remediation options and indicative estimated costs are provided in Appendix 1.

Remediated Barriers

Four high priority ranked barriers were remediated as part of this project: Berrys Weir on the Bremer River (overall rank 7th), Leitchs Crossing on the South Pine River (11th), Paradise Road Causeway on Slacks Creek (36th)(Figure 15) and Hilliards Creek Weir (36th). These remediated barriers have been removed from the three-stage scoring assessment found within this report. The location of these remediated barriers and their associated fishways can be seen in Figure 16. Case studies with information regarding fishway type and monitoring results can be found in Appendix 2.

Figure 15. Showing one of the four priority ranked barriers remediated as part of this project; Slacks Creek, (Paradise Road) 17 ridge rock-ramp and horizontal culvert baffle fishway (photo courtesy of Leo Lee).

Table 22. Top 36 priority ranked fish barriers, including: total score after each assessment stage, overall final rank, barrier ID, barrier name and configuration and name of waterway each barrier is located on.

Barrier ID	Waterway	Barrier Configuration/Name	Stage 1 Score	Stage 2 Score	Stage 3 Score	Final Rank
13941	Caboolture River	Tidal Weir- ~3 m head loss (Redundant structure)	28	22	20	**1**
3728	Elimbah Creek	Tidal Causeway- ~1 m head loss and small pipe culvert	29	23	17	**2**
10352	Albert River	Weir– Luscombe weir (Redundant structure)	27	22	19	**3**
12850	Brisbane River	Weir- Mt Crosby Weir	29	20	19	**3**
13801	Pimpama River	Tidal Flood Gates- Kerkin Rd	29	22	13	**5**
10351	Albert River	Tidal Pipe Causeway- Stanmore Rd	27	21	16	**5**
4374	Tingalpa Creek	Dam- Leslie Harrison Dam	27	21	15	**7**
13800	Behm Creek	Tidal Gates- Jacobs Well Rd	28	22	13	**7**
218	South Pine River	Culvert Causeway & Apron Drop- Bunya Crossing	27	16	19	**9**
12199	Enoggera Creek	Tidal Weir- Hulme St, 1.2 m head loss	25	21	15	**10**
2279	North Pine River	Dam- North Pine Dam	26	18	15	**11**
2252	North Pine River	Culvert Causeway & Apron Drop- Young's Crossing	26	18	14	**12**
8231	Warrill Creek	DNRM V-Notch Gauging Weir- ~800 mm head loss	22	15	21	**12**
8933	Bremer River	DNRM V- Notch Gauging Weir- ~300 mm head loss	25	14	19	**12**
4876	Hilliards Creek	Causeway & Buried Pipe- Fellmonger Pk	20	19	18	**15**
4170	Scrubby Creek	Causeway & Apron Drop– Queens Rd	20	19	18	**15**
13807	Warrill Creek	Gabion Basket and Sheet Pile Weir- ~ 1 m head loss	23	15	19	**15**
13911	Hotham Creek	Tidal Bund – Private Property	24	18	14	**18**
10719	King John Creek	1 x Small pipe + 300 mm drop - Private Property	26	17	13	**18**
5810	Sandy Creek	Tidal Floodgates - Loves Rd - Main West Arm	23	17	15	**20**
11864	Norman Creek	Apron Drop- ~300 mm drop into Estuary – Hanlon Pk	23	16	16	**20**
2107	Freshwater Creek	Tidal Bund - Further investigation required during flow	26	18	10	**22**
5807	Sandy Creek Trib.	Tidal Gates (East)- School Rd	23	16	15	**22**
2278	North Pine River	Weir - 3 m high @ Petrie Town- Seqwater	22	16	16	**22**
13992	King John Creek	1 x small pipe + 500 mm drop into Estuary	26	15	13	**22**
12433	Moggill Creek	Old pipes & concrete - 750 mm head loss - Moggill Rd	19	19	15	**26**
2277	North Pine River	Causeway + 2 small pipes - next to sporting fields	23	16	14	**26**
4890	Hilliards Creek	1.5 m high Weir + culverts @ DPI Research St.	17	17	19	**26**
7083	Quinzeh Creek	1.5 m large rock weir on estuarine interface	19	20	14	**26**
13942	Waraba Creek	Weir- Waraba Weir ~1.5 m head loss	17	16	20	**26**
13996	Cabbage Tree Creek	Weir- ~500 mm rock weir- Est interface @ AFL oval	20	20	13	**26**
2106	Freshwater Creek	Bund - Further investigation during flow	24	18	10	**32**
9649	Bundamba Creek	Weir- Rock/Bed Control	26	12	14	**32**
12435	Moggill Creek	2 x Small pipes + 300 mm apron drop @ Kilkivan Ave	18	18	16	**32**
6388	Scrubby Creek	Relic Causeway/weir - 0.8 m high - D/S Logan Motorway	17	17	18	**32**
6387	Scrubby Creek	Weir, Small Pipe & Apron Drop- ~1.5 m, Gilmore Rd	17	17	18	**32**

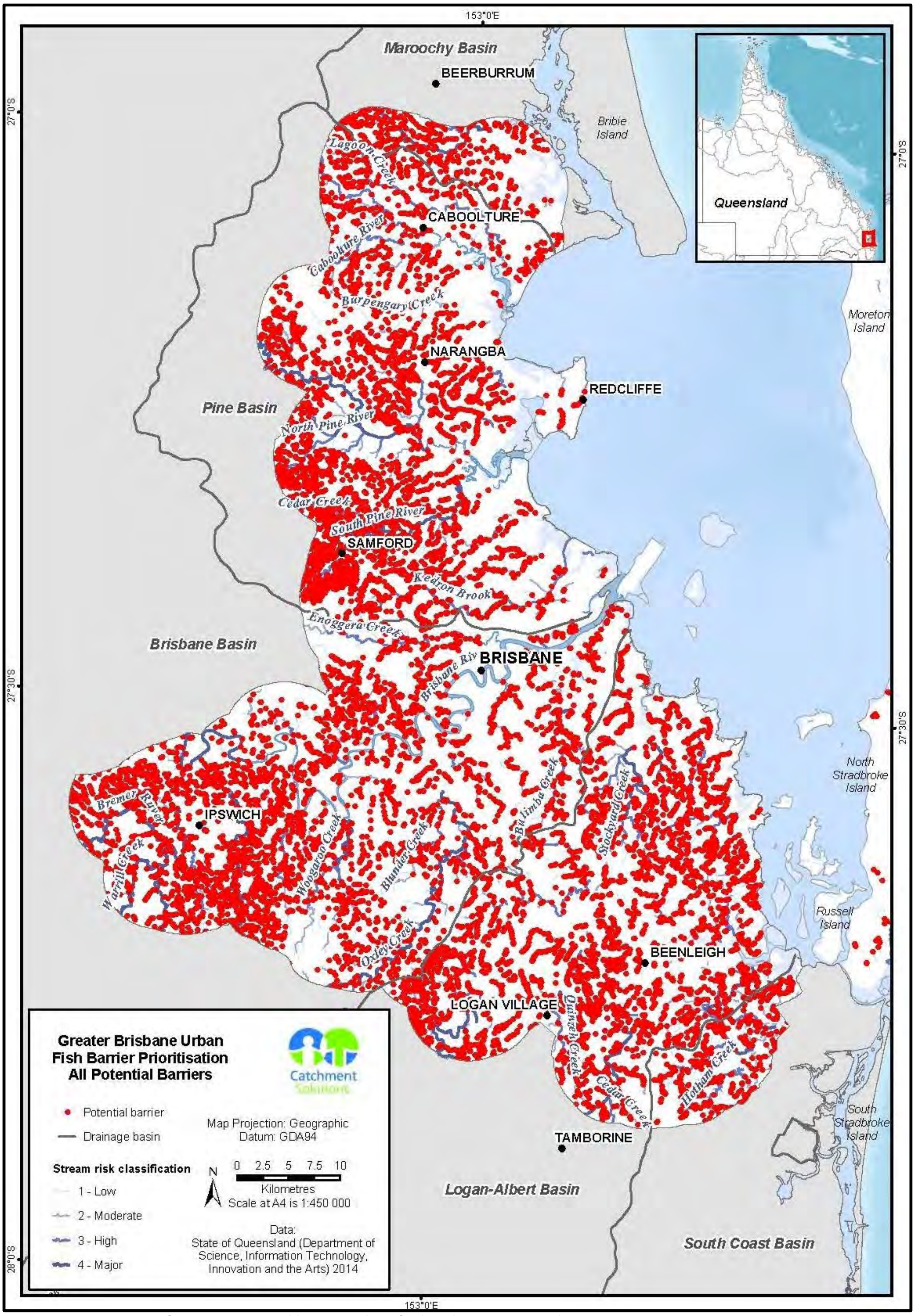


Figure 16. Locations of 13,629 potential barriers identified in the current study.

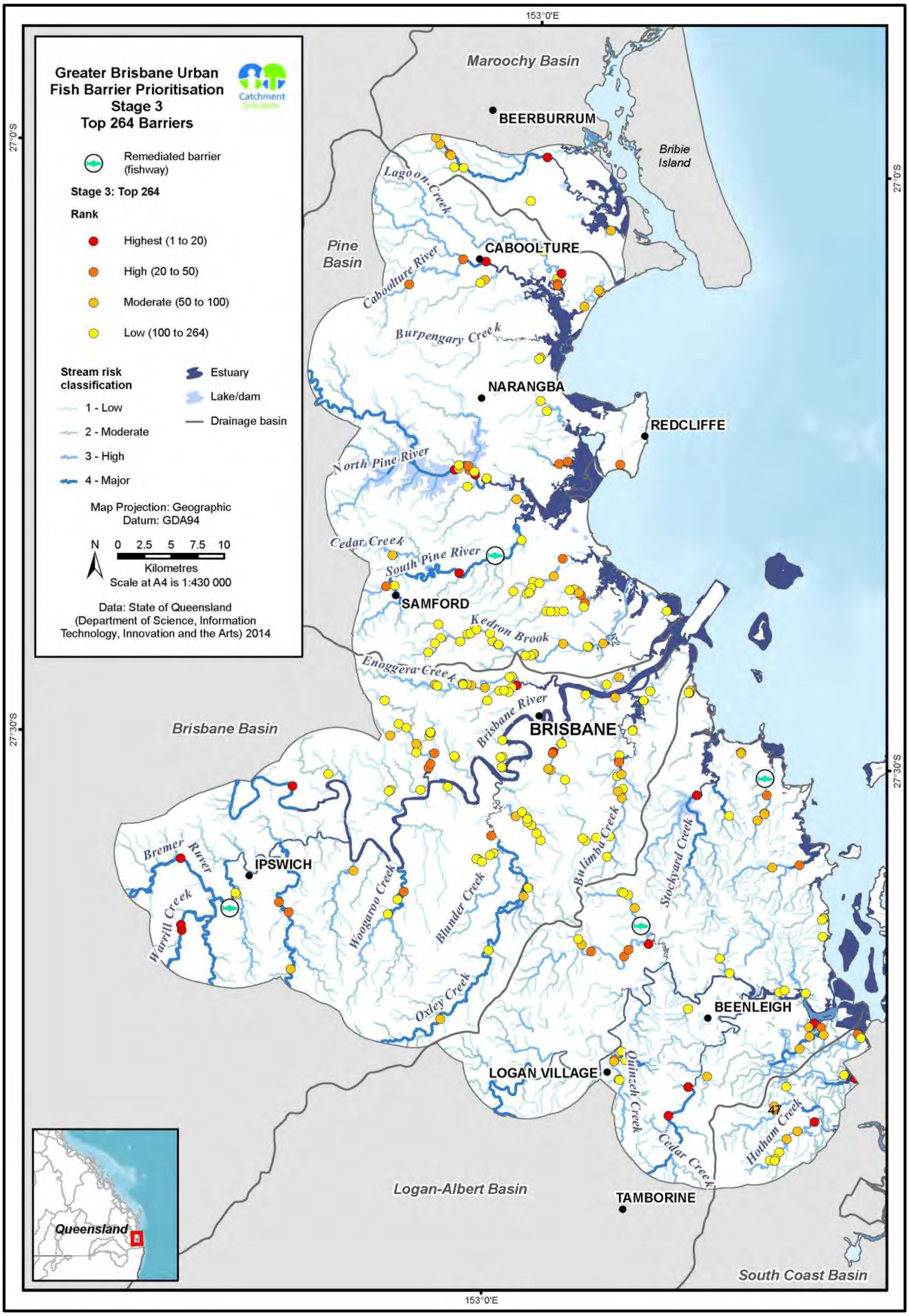


Figure 17. Showing the location of the top 264 barriers after stage 2 of the prioritisation

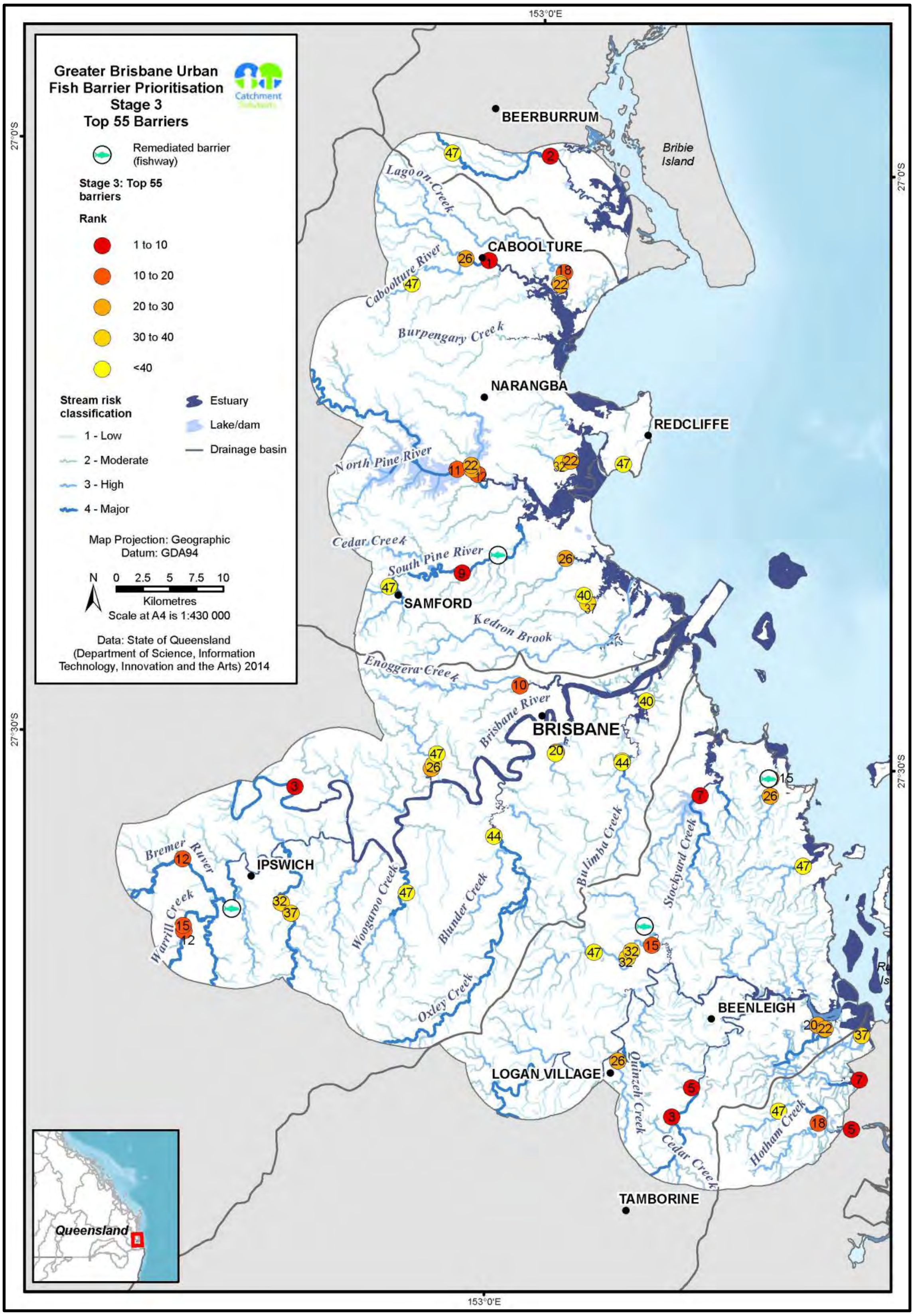


Figure 18. Location and overall priority rank of the top 50 barriers to fish passage in the GB region.

Discussion

The desktop study of the Greater Brisbane region identified a total 13,629 potential barriers at a density of 3.8 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 rock riffles 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 4,916 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. 522 high ranking potential barriers were visited in the field in line with the prioritisation list. Of the 522 ground-truthed potential barriers, 264 were determined to be barriers that prevent, delay or obstruct fish migration. The remaining 258 potential barriers were assessed as not affecting fish passage (Figure 16). These generally consisted of bridges, logs and full width culverts installed below bed level and/or with a low flow channel and wall baffles (Figure 19). All waterway barrier works (culverts, pipes, weirs, causeways) 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. A high number of potential barriers visited in the field comprised culvert crossings which appeared to conform to the Accepted Development requirements and therefore deemed not to be barriers (Figure 19).

Figure 19. 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 Greater Brisbane 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. The list also contains a number of structures that have fishways installed on them, however it should be recognised that some of these are older 'salmon' fishways, and due to their poor design, block fish passage.

Overall, the top three highest priority ranked barriers in the GB region were (1) Caboolture River Barrage, (2) Elimbah Creek Tidal Causeway, and equal third, Luscombe Weir on the Albert River and Mt. Crosby Weir on the Brisbane River. 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 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, 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 (Appendix 1). 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

13,629 potential barriers within the GB 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 individual council and relevant state government agency investment strategies for a fish migration barrier remediation program targeting the top 5-10 barriers identified in each LGA area within this report. This program would include:
    - Preparation of an investment strategy for the highest priority sites based on information in this report
    - Undertake Fish Passage Options Assessment to determine most appropriate remediation option at each site
    - Detailed survey of the sites and production of design documents for suitable fishways
    - Construction of agreed fishway designs
    - Monitoring of the rehabilitated sites to ensure proper operation of the fishway
    - Pre and post barrier remediation fishway and fish community sampling to determine the effectiveness of providing fish passage past the barrier.
- A SEQ wide fish barrier remediation project targeting the top 5-10 barriers identified in this report.
- 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 if it's a barrier to fish passage, then quantify through barrier monitoring the number, type and size of species able to ascend past (See Slacks Creek Case Study 1 in Appendix 2).
- Further fishway monitoring to better understand fish communities and their migration requirements.

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Appendix 1- Top 50 Barriers and Associated Information

Overall Priority	**1**	
LGA/LGA Priority	MBRC	1
Barrier ID	13941	
Stream Name	Caboolture River	
Location	-27.086745°	152.957708°
Barrier Type	Redundant Tidal Barrage	
Barrier Name	Caboolture Weir	
Fishway Type Needed	Bypass R.Ramp/Retrofit Cone	
Approx. Cost of Fishway	$180 - $250k	

Overall Priority	**2**	
LGA/LGA Priority	MBRC	2
Barrier ID	3728	
Stream Name	Elimbah Creek	
Location	-26.996403°	153.010241°
Barrier Type	Tidal Causeway	
Barrier Name/Info	Within Forestry Area	
Fishway Type Needed	Removal/Bed Lvl Xing/R.Ramp	
Approx. Cost of Fishway	$60 -$100k	

Overall Priority	**3**	
LGA/LGA Priority	GCCC & LCC	1* & 1*
Barrier ID	10352	
Stream Name	Albert River	
Location	-27.800196°	153.169262°
Barrier Type	Redundant Weir	
Barrier Name	Luscombe Weir	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$1.3 million	

Overall Priority	**3**	
LGA/LGA Priority	BCC	1
Barrier ID	12850	
Stream Name	Brisbane River	
Location	-27.537293°	152.797935°
Barrier Type	Weir	
Barrier Name	Mt Crosby Weir	
Fishway Type Needed	Concrete Cone	
Approx. Cost of Fishway	$800 k - $1 .1 million	

Overall Priority	**5**	
LGA/LGA Priority	GCCC	2
Barrier ID	13801	
Stream Name	Pimpama River	
Location	-27.802888°	153.339623°
Barrier Type	Tidal Floodgate	
Barrier Name	Kerkin Road North	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	*$25 - $150k	

Overall Priority	**5**	
LGA/LGA Priority	GCCC & LCC	3 & 2
Barrier ID	10351	
Stream Name	Albert River	
Location	-27.775037°	153.186256°
Barrier Type	Tidal Pipe Causeway	
Barrier Name	Stanmore Road	
Fishway Type Needed	Bridge/Culverts	R.Ramp/Cone
Approx. Cost of Fishway	$100-$300 k	$50-$90 k

Overall Priority	**7**	
LGA/LGA Priority	RCC	1
Barrier ID	4374	
Stream Name	Tingalpa Creek	
Location	-27.528354°	153.180559°
Barrier Type	Dam	
Barrier Name	Leslie Harrison Dam	
Fishway Type Needed	Fish Lift/Cone	
Approx. Cost of Fishway	$1-2 million	

Overall Priority	**7**	
LGA/LGA Priority	GCCC	4
Barrier ID	13800	
Stream Name	Behm Creek	
Location	-27.760848°	153.344678°
Barrier Type	Tidal Floodgate	
Barrier Name	Stapylton-Jacobs Well Rd	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 - $75 k	

Overall Priority	**9**	
LGA/LGA Priority	MBRC	3
Barrier ID	218	
Stream Name	South Pine River	
Location	-27.350244°	152.946384°
Barrier Type	Culvert Causeway	
Barrier Name	Bunya Crossing	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$25 -$40 k	

Overall Priority	**10**	
LGA/LGA Priority	BCC	2
Barrier ID	12199	
Stream Name	Enoggera Creek	
Location	-27.443336°	153.005675°
Barrier Type	Tidal Weir	
Barrier Name	Bancroft Park (Hulme St)	
Fishway Type Needed	Full-width or partial Rock Ramp	
Approx. Cost of Fishway	$80 -$100 k	

Overall Priority	**11**	
LGA/LGA Priority	MBRC	4
Barrier ID	2279	
Stream Name	North Pine River	
Location	-27.263543°	152.937002°
Barrier Type	Dam	
Barrier Name	North Pine Dam	
Fishway Type Needed	Fish Lift	
Approx. Cost of Fishway	$1 - 2 million	

Overall Priority	**12**	
LGA/LGA Priority	ICC	1
Barrier ID	8231	
Stream Name	Warrill Creek	
Location	-27.659011°	152.698957°
Barrier Type	DNRM V-notch Gauging Weir	
Barrier Name	DNRM Weir	
Fishway Type Needed	Cone (1st ridge) &/or R.Ramp	
Approx. Cost of Fishway	$70 - $100 k	

Overall Priority	**12**	
LGA/LGA Priority	ICC	1
Barrier ID	8933	
Stream Name	Bremer River	
Location	-27.602753°	152.695117°
Barrier Type	DNRM V-notch Gauging Weir	
Barrier Name	DNRM Weir	
Fishway Type Needed	Cone (1st ridge) &/or R.Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	**12**	
LGA/LGA Priority	MBRC	5
Barrier ID	2252	
Stream Name	North Pine River	
Location	-27.266964°	152.956523°
Barrier Type	Culvert Causeway	
Barrier Name	Youngs Crossing	
Fishway Type Needed	Rock Ramp + Vertical Baffles	
Approx. Cost of Fishway	$25 - $40 k	

Overall Priority	**15**	
LGA/LGA Priority	RCC	2
Barrier ID	4876	
Stream Name	Hilliards Creek	
Location	-27.511266°	153.246640°
Barrier Type	Causeway (pedestrian)	
Barrier Name	Fellmonger Park	
Fishway Type Needed	New Culverts + Rock Ramp	
Approx. Cost of Fishway	$60 - $100 k	

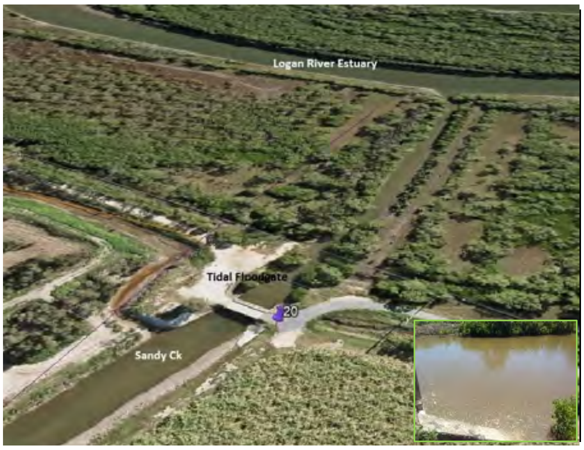
Overall Priority	**15**	
LGA/LGA Priority	ICC	3
Barrier ID	13807	
Stream Name	Warrill Creek	
Location	-27.602485°	152.695277°
Barrier Type	Weir - Sheet Pile & Gab. Bask.	
Barrier Name	200 m U/S Cunningham Hwy	
Fishway Type Needed	Removal/Full-width R.Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	**15**	
LGA/LGA Priority	LCC	3
Barrier ID	4170	
Stream Name	Scrubby Creek	
Location	-27.656718°	153.142060°
Barrier Type	Culvert Causeway + Ap. Drop	
Barrier Name	Queens Rd	
Fishway Type Needed	Removal + Bridge	
Approx. Cost of Fishway	$70 - $90 k	

Overall Priority	**18**	
LGA/LGA Priority	GCCC	5
Barrier ID	13911	
Stream Name	Hotham Creek	
Location	-27.799051°	153.307883°
Barrier Type	Tidal Causeway	
Barrier Name	Sugar Cane Crossing	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$30 - $40 k	

Overall Priority	**18**	
LGA/LGA Priority	MBRC	6
Barrier ID	10719	
Stream Name	King John Creek	
Location	-27.093888°	153.028851°
Barrier Type	Pipe Causeway	
Barrier Name	Estuary diverted	
Fishway Type Needed	Bed Level Xing &/or R.Ramp	
Approx. Cost of Fishway	$15 - $25 k	

Overall Priority	**20**	
LGA/LGA Priority	GCCC	6
Barrier ID	5810	
Stream Name	Sandy Creek	
Location	-27.716465°	153.302614°
Barrier Type	New Tidal Floodgate	
Barrier Name	Loves Rd (main west arm)	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 - $75 k	



Overall Priority	**20**	
LGA/LGA Priority	BCC	3
Barrier ID	11864	
Stream Name	Norman Creek	
Location	-27.497907°	153.043011°
Barrier Type	Tidal Culvert Apron Drop ~300mm	
Barrier Name	Logan Road - Hanlon Park	
Fishway Type Needed	R.Ramp/Cone + horizontal baffles	
Approx. Cost of Fishway	$20 - $40 k	

Overall Priority	22	
LGA/LGA Priority	MBRC	7
Barrier ID	2107	
Stream Name	Freshwater Creek	
Location	-27.252072°	153.043054°
Barrier Type	Tidal Bund	
Barrier Name	Hays Inlet FHA	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $30 k	

Overall Priority	22	
LGA/LGA Priority	MBRC	7
Barrier ID	13992	
Stream Name	King John Creek	
Location	-27.104366°	153.025763°
Barrier Type	Tidal Pipe Causeway	
Barrier Name	Tidal causeway adj FHA	
Fishway Type Needed	Removal/Bed level Crossing	
Approx. Cost of Fishway	$5 - $25 k	

Overall Priority	22	
LGA/LGA Priority	MBRC	7
Barrier ID	2278	
Stream Name	North Pine River	
Location	-27.259740°	152.950767°
Barrier Type	Weir ~2.5 m high	
Barrier Name	Seqwater @ Petrie Town	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$60 - $90 k	

Overall Priority	**22**	
LGA/LGA Priority	GCCC	7
Barrier ID	5807	
Stream Name	Sandy Creek East	
Location	-27.719208°	153.309700°
Barrier Type	Tidal Floodgate	
Barrier Name	School Rd	
Fishway Type Needed	Fish Friendly Auto Tidal Gate	
Approx. Cost of Fishway	*$25 -$75 k	

Overall Priority	**26**	
LGA/LGA Priority	BCC	4
Barrier ID	12433	
Stream Name	Moggill Creek	
Location	-27.516509°	152.925948°
Barrier Type	Concrete & Pipe Weir ~1m high	
Barrier Name	Under Moggill Rd	
Fishway Type Needed	Removal and/or Rock Ramp	
Approx. Cost of Fishway	$40 - $70 k	

Overall Priority	**26**	
LGA/LGA Priority	RCC	3
Barrier ID	4890	
Stream Name	Hilliards Creek	
Location	-27.525889°	153.246758°
Barrier Type	Box Culvert Causeway	
Barrier Name	QLD Gov.(DAF) Research Stn.	
Fishway Type Needed	Rock Ramp + Culverts	
Approx. Cost of Fishway	$60 - $90 k	

Overall Priority	26	
LGA/LGA Priority	BCC	4
Barrier ID	13996	
Stream Name	Cabbage Tree Creek	
Location	-27.334655°	153.043116°
Barrier Type	Rock Weir	
Barrier Name	Lemke Rd - adj AFL Club	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $10 k	

Overall Priority	26	
LGA/LGA Priority	LCC	4
Barrier ID	7083	
Stream Name	Quinzeh Creek	
Location	-27.755147°	153.115479°
Barrier Type	Causeway	
Barrier Name	D/S Waterford-Tamborine Rd	
Fishway Type Needed	Removal + Bd Level Xing/R.Ramp	
Approx. Cost of Fishway	$25 - $60 k	

Overall Priority	26	
LGA/LGA Priority	MBRC	10
Barrier ID	13992	
Stream Name	North Pine River	
Location	-27.263190°	152.951383°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Opposite Old Petrie Town	
Fishway Type Needed	Bed Level Xing/New Culverts	
Approx. Cost of Fishway	$20 - $50 k	

Overall Priority	26	
LGA/LGA Priority	MBRC	10
Barrier ID	13942	
Stream Name	Waraba Creek	
Location	-27.086080°	152.935456°
Barrier Type	Weir	
Barrier Name	Waraba Weir - Caboolture	
Fishway Type Needed	Cone/V-Slot/Bypass R.Ramp	
Approx. Cost of Fishway	$80 - $200 k	

Overall Priority	32	
LGA/LGA Priority	BCC	6
Barrier ID	12435	
Stream Name	Moggill Creek	
Location	-27.513516°	152.927873°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Kilkivan Avenue	
Fishway Type Needed	Low Flow & High Flow Rock Ramp	
Approx. Cost of Fishway	$20 - $80 k	

Overall Priority	32	
LGA/LGA Priority	LCC	5
Barrier ID	6387	
Stream Name	Scrubby Creek	
Location	-27.662613°	153.123738°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	Gould Adams Prk - Kingston Rd	
Fishway Type Needed	Full-width Rock Ramp	
Approx. Cost of Fishway	$60- $100 k	

Overall Priority	**32**	
LGA/LGA Priority	MBRC	12
Barrier ID	2106	
Stream Name	Freshwater Creek	
Location	-27.668090°	153.119794°
Barrier Type	Earthern Bund	
Barrier Name	Upstream Hays Inlet FHA	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$5 - $30 k	

Image courtesy MBRC

Overall Priority	**32**	
LGA/LGA Priority	LCC	5
Barrier ID	6388	
Stream Name	Scrubby Creek	
Location	-27.668090°	153.119794°
Barrier Type	Pipe Culvert Causeway	
Barrier Name	D/S Logan Motorway	
Fishway Type Needed	Removal/Bed Level Xing + R.Ramp	
Approx. Cost of Fishway	$30 k - $60 k	

Overall Priority	**32**	
LGA/LGA Priority	ICC	4
Barrier ID	9649	
Stream Name	Bundamba Creek	
Location	-27.635605°	152.790513°
Barrier Type	Rock Weir	
Barrier Name	Worley Park	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$5 - $8 k	

Overall Priority	**37**	
LGA/LGA Priority	BCC	7
Barrier ID	665	
Stream Name	Downfall Creek	
Location	-27.371446°	153.065862°
Barrier Type	Weir	
Barrier Name	Virginia Golf Course	
Fishway Type Needed	Removal & or RRamp/Cone	
Approx. Cost of Fishway	$30 k - $80 k	


Image courtesy BCC

Overall Priority	**37**	
LGA/LGA Priority	ICC	8
Barrier ID	9748	
Stream Name	Bundamba Creek	
Location	-27.644044°	152.800083°
Barrier Type	Pipe Causeway	
Barrier Name	East Owen Street	
Fishway Type Needed	New Box Culverts &/or Rock Ramp	
Approx. Cost of Fishway	$20 - $90 k	

Overall Priority	**37**	
LGA/LGA Priority	GCCC	8
Barrier ID	5525	
Stream Name	Cabbage Tree Point Creek	
Location	-27.722999°	153.344490°
Barrier Type	Tidal Floodgate - Pipe	
Barrier Name	Cabbage Tree Point	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	$10 - $15 k	

Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	343	
Stream Name	Zillmere Waterholes	
Location	-27.364832°	153.061926°
Barrier Type	Culvert Causeway	
Barrier Name	Sandgate Road	
Fishway Type Needed	Rock Ramp + Nib wall & Baffles	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	13828	
Stream Name	Hemmant Creek	
Location	-27.451713°	153.125205°
Barrier Type	Tidal Floodgate	
Barrier Name	Hemmant Tingalpa Rd	
Fishway Type Needed	Fish Friendly Auto-tidal Gates	
Approx. Cost of Fishway	$25 - $35	

Overall Priority	**40**	
LGA/LGA Priority	MBRC	13
Barrier ID	13940	
Stream Name	King John Creek	
Location	-27.102760°	153.025381°
Barrier Type	Earthern Bund	
Barrier Name	Deception Bay FHA	
Fishway Type Needed	Removal/Bed Level Crossing	
Approx. Cost of Fishway	$5 - $15 k	

Overall Priority	**40**	
LGA/LGA Priority	BCC	8
Barrier ID	11865	
Stream Name	Norman Creek	
Location	-27.499142°	153.042516°
Barrier Type	Concrete lined drain	
Barrier Name	Hanlon Park	
Fishway Type Needed	Horizontal Culvert Baffles	
Approx. Cost of Fishway	$40 - $90 k	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	11647	
Stream Name	Bulimba Creek	
Location	-27.502643°	153.105451°
Barrier Type	Culvert Causeway	
Barrier Name	Opposite Carindale Shop. Cntr	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$15 - $25	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	13943	
Stream Name	Blunder Creek	
Location	-27.571258°	152.987956°
Barrier Type	Causeway	
Barrier Name	Oxley Creek Junction	
Fishway Type Needed	Removal/Bed Level Xing	
Approx. Cost of Fishway	$3 -$5 k	

Overall Priority	**44**	
LGA/LGA Priority	BCC	11
Barrier ID	11648	
Stream Name	Bulimba Creek	
Location	-27.504079°	153.105604°
Barrier Type	Culvert Causeway	
Barrier Name	Opposite Carindale Shop. Cntr	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$3 - $5 k	

Overall Priority	**47**	
LGA/LGA Priority	ICC	9
Barrier ID	12970	
Stream Name	Woogaroo Creek	
Location	-27.622268°	152.908130°
Barrier Type	Rock Weir	
Barrier Name	Newman St Easement	
Fishway Type Needed	Rock Ramp	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	1523	
Stream Name	South Pine River	
Location	-27.365176°	152.877745°
Barrier Type	Culvert Causeway	
Barrier Name	Cannington Crt - Samford	
Fishway Type Needed	Rock Ramp + Baffles/Culverts	
Approx. Cost of Fishway	$40 k - $80 k	

Overall Priority	**47**	
LGA/LGA Priority	BCC	14
Barrier ID	12461	
Stream Name	Moggill Creek	
Location	-27.504555°	152.930528°
Barrier Type	Pipe Causeway	
Barrier Name	Branton Street	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$20 k - $80 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	15
Barrier ID	11071	
Stream Name	Caboolture River	
Location	-27.109714°	152.885927°
Barrier Type	Culvert Causeway	
Barrier Name	Litherland Road	
Fishway Type Needed	Rock Ramp + Baffles	
Approx. Cost of Fishway	$30 - $50 k	

Overall Priority	**47**	
LGA/LGA Priority	LCC	14
Barrier ID	13407	
Stream Name	Scrubby Creek	
Location	-27.664953°	153.087981°
Barrier Type	Weir	
Barrier Name	Demeio Park	
Fishway Type Needed	Full-width Rock Ramp	
Approx. Cost of Fishway	$50 k - $80 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	3953	
Stream Name	Six Mile (Elimbah) Creek	
Location	-26.997845°	152.918202°
Barrier Type	Relic Causeway	
Barrier Name	Beerburrum West State Forest	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$4 - 8 k	

Overall Priority	**47**	
LGA/LGA Priority	GCCC	9
Barrier ID	7749	
Stream Name	Pimpama River	
Location	-27.790614°	153.269688°
Barrier Type	Pipe Causeway	
Barrier Name	Relic barrier in GC train corridor	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$5 - $15 k	

Overall Priority	**47**	
LGA/LGA Priority	MBRC	14
Barrier ID	2417	
Stream Name	Bells Creek	
Location	-27.252733°	153.092914°
Barrier Type	Culverts + Concrete lined drain	
Barrier Name	Bells Paddock Reserve	
Fishway Type Needed	Horizontal & Vertical Baffles	
Approx. Cost of Fishway	$15 - $50 k	

Overall Priority	**47**	
LGA/LGA Priority	RCC	4
Barrier ID	5071	
Stream Name	Eprapah Creek	
Location	-27.583315°	153.281349°
Barrier Type	Culvert Causeway	
Barrier Name	Redland Bay Road	
Fishway Type Needed	Culvert Baffles	
Approx. Cost of Fishway	$15 - $40 k	

Overall Priority	**56**	
LGA/LGA Priority	ICC	10
Barrier ID	3953	
Stream Name	Six Mile Creek	
Location	-27.606753°	152.859900°
Barrier Type	Rock Weir	
Barrier Name	Urban Utilities Pipeline barrier	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$10 - $40 k	

Overall Priority	**56**	
LGA/LGA Priority	MBRC	18
Barrier ID	1264	
Stream Name	Cedar Creek	
Location	-27.338880°	152.882218°
Barrier Type	Perched Culvert Causeway	
Barrier Name	Hanson Road	
Fishway Type Needed	New culverts/ Rock Ramp	
Approx. Cost of Fishway	$40 - $80 k	

Overall Priority	56	
LGA/LGA Priority	LCC	15
Barrier ID	10540	
Stream Name	Oxley Creek	
Location	-27.728289°	152.948461°
Barrier Type	Perched Culvert Causeway	
Barrier Name	Roberts Road	
Fishway Type Needed	New culverts/Rock Ramp	
Approx. Cost of Fishway	$40 - $80 k	

Overall Priority	56	
LGA/LGA Priority	RCC	5
Barrier ID	4850	
Stream Name	Tarradarrapin Creek	
Location	-27.490879°	153.220676°
Barrier Type	Culvert Apron Drop	
Barrier Name	Dorsal Drive	
Fishway Type Needed	Retro-fit Cone/Rock Ramp	
Approx. Cost of Fishway	$50 - $80 k	

Overall Priority	56	
LGA/LGA Priority	BCC	15
Barrier ID	4256	
Stream Name	Wynnum Creek	
Location	-27.440850°	153.169327°
Barrier Type	Tidal Weir	
Barrier Name	Adjacent Tingal Rd	
Fishway Type Needed	Removal/Rock Ramp	
Approx. Cost of Fishway	$4 - $30 k	


Image courtesy BCC

Overall Priority	56	
LGA/LGA Priority	BCC	15
Barrier ID	13995	
Stream Name	Bulimba Creek	
Location	-27.514289°	153.108399°
Barrier Type	Rock Weir	
Barrier Name	Pacific Golf Course	
Fishway Type Needed	Removal	
Approx. Cost of Fishway	$2 - $5 k	

Overall Priority	56	
LGA/LGA Priority	GCCC	10
Barrier ID	7811	
Stream Name	Pimpama River	
Location	-27.787995°	153.268460°
Barrier Type	Culvert Causeway	
Barrier Name	Stewarts Road	
Fishway Type Needed	Rock Ramp + Baffles/Box Culverts	
Approx. Cost of Fishway	$30 - $70 k	

Appendix 2 - Greater Brisbane Fish Barrier Remediation Case Studies

Case Study 1 - Paradise Road Overpass, Slacks Creek

Introduction

The remediation of the Paradise Road overpass barrier in Slacks Creek was undertaken in partnership between Logan City Council and Catchment Solutions. The Paradise Road overpass was ranked the 36th highest priority barrier in the GB region. A fish passage options assessment was undertaken to determine the most appropriate fish passage solution at this site. The investigation determined that a combination of two fishway designs would provide suitable fish passage; rock-ramp fishway to assist fish ascending the concrete culvert apron drop, and a series of horizontal concrete baffles retrofitted to the base of the culverts to assist fish passage through the 50 m long culverts (500 mm head loss).

Barrier Ranking	36th in the Greater Brisbane region
Barrier Type(s)	Surface drop, water depth and flow velocity
Total Surface Drop (head loss)	1.8 m, consisting of 0.5 m through culverts and 1.3 m off culvert apron
Best Remediation Method	Combination of nature-like partial-width rock-ramp and horizontal culvert baffle fishways
Length of Fishway	91 m
Number of Ridges	17 ridges in rock-ramp, 10 horizontal culvert baffle ridges
Drops Between Pools	80 mm for rock-ramp & 50 mm for the horizontal baffles
Slots (number & type)	4 slots, consisting 2 x high flow and 2 x low flow
Total Construction Time	3 weeks
Total Rock Used	783 t – predominantly consisting of large rock: 1.2 - 3 m (up to 11 t)
Total Overall Cost	$ 124 000

Figure 20. Left; showing the 1.3 m surface drop barrier off the downstream face of the culvert apron. Right; showing stream flow spread out across all four box culverts creating a shallow water surface barrier along the entire 50 m length of the structure. During stream flow events the culverts also created a flow velocity barrier.

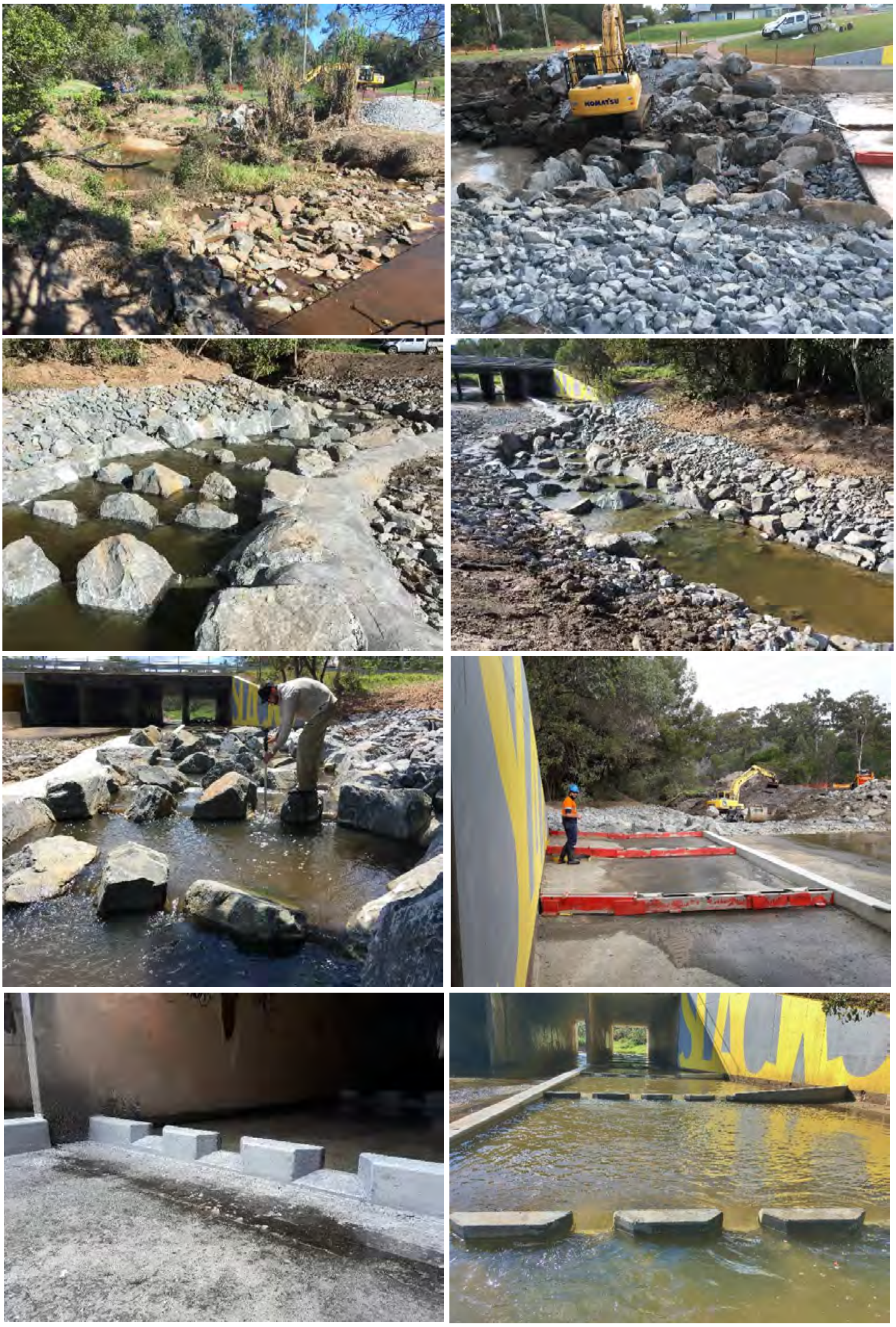


Figure 21. Showing during and post construction of the rock-ramp and horizontal culvert baffle fishways

Pre Fishway Construction Monitoring

Prior to fishway construction works, the barrier was monitored for one week to evaluate the overall impacts to the fish communities of Slacks Creek and determine how many, and what species, were making it past the barrier. Over almost five days of monitoring, six species were surveyed ascending the barrier, at an overall catch rate of 4.12 individual fish per day. Two of the fish species recorded in the trap; striped gudgeon and long-finned eel, possess an ability to climb vertical wet surfaces (barriers).

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	21- 64	0.62
	Long-finned eel	*Anguilla reinhardtii*	19- 56	0.82
	Striped gudgeon	*Gobiomorphus australis*	19- 69	0.82
Potamodromous	Hypseleotris sp.	*Hypseleotris species*	17	0.21
	Firetail gudgeon	*Hypseleotris galii*	31- 46	0.62
	Western carp gudgeon	*Hypseleotris klunzingeri*	16- 20	1.03
		Total Species and Overall CPUE	**6**	**4.12**

Post Remediation Works

Following the construction of the rock-ramp and horizontal baffle fishway, monitoring was again carried out to assess the success of the fishways at passing the full suite of fish species and size classes expected to occur within Slacks Creek. Over almost five days of monitoring, 6,546 fish representing 11 species were surveyed successfully ascending the fishways, at an overall catch rate of 1,384.18 fish per day. This is a substantial increase from pre-construction monitoring results of only 4.12 fish per day able to ascend the barrier, and highlights the numbers of fish which were previously trying to move past the Paradise Road overpass barrier, however were unable to do so. Significantly, juvenile diadromous fish species were recorded at the highest catch rates, with striped gudgeon captured at a rate of 812 fish per day, followed by empire gudgeon and sea mullet with 272 and 258 fish per day respectively. Native fish comprised 98.9% of the total catch (individuals), which again emphasises the importance of this remediated fish barrier.

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	16- 72	272.14
	Long-finned eel	*Anguilla reinhardtii*	40- 300	4.65
	Sea mullet	*Mugil cephalus*	24- 51	257.76
	Striped gudgeon	*Gobiomorphus australis*	14- 112	812.62
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	31- 36	0.85
	Flathead gudgeon	*Philypnodon grandiceps*	19- 62	12.69
	Western carp gudgeon	*Hypseleotris klunzingeri*	18- 34	8.88
Pest Fish	Mosquito fish	*Gambusia holbrooki*	12- 44	12.26
	Platy	*Xiphophorus maculatus*	31- 33	0.85
	Swordtail	*Xiphophorus helleri*	38	0.42
	Tilapia	*Oreochromis mossambicus*	125- 390	1.06
		Total Species and Overall CPUE	**11**	**1384.18**

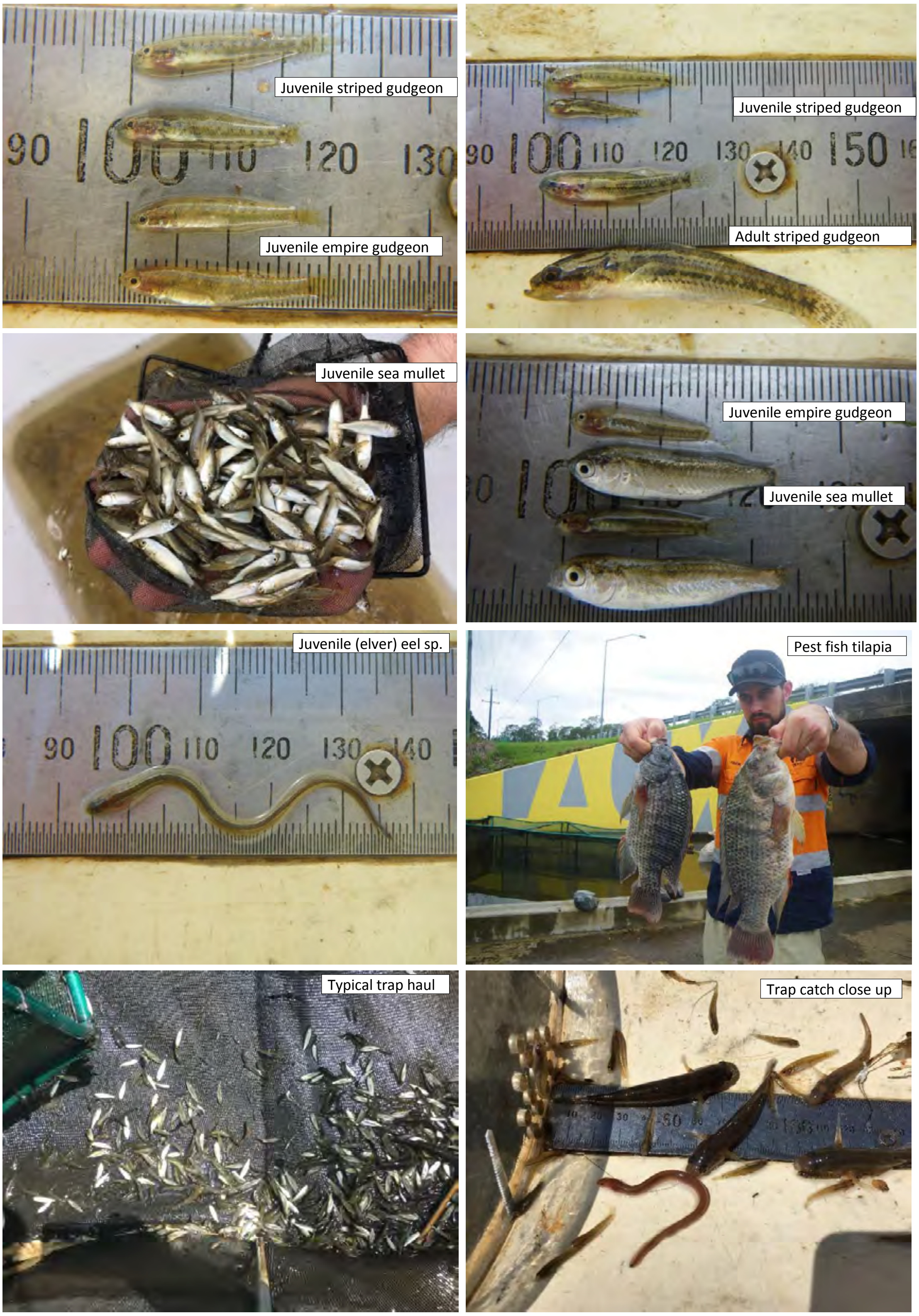


Figure 22. Fish captured successfully ascending the Slacks Creek fishways during assessment monitoring

Case Study 2- Berrys Weir, Bremer River

Introduction

The remediation of Berrys Weir with rock-ramp fishway on the Bremer River was undertaken in partnership between Ipswich City Council and Catchment Solutions in 2016. Berrys Weir was the 7th highest priority ranked fish barrier in the Greater Brisbane region. The 2.4 m high weir was constructed in the 1960's to impound water for power generation (Stanwell). A fish passage options assessment determined that a partial width rock-ramp fishway would be the best remediation option at this site.

Barrier Ranking	7th in Greater Brisbane region
Barrier Type(s)	Surface drop
Total Surface Drop	2.4 m
Best Remediation Method	1:33 Partial- width rock-ramp fishway + 1:15 full width
Length of Fishway	90 m
Number of Ridges	33
Drops Between Pools	75 mm
Total Construction Time	3 weeks
Total Rock Used	480 t
Total Overall Cost	$ 96 000

Figure 23. Berrys Weir fish barrier before remediation works, with relict north- American style fish ladder visible down left side of weir

Fishway Construction Works

Figure 24. Berrys Weir fishway construction images

Fishway Monitoring

Following fishway construction, two separate rounds of monitoring were carried out in December 2016 and December 2017 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur within Bremer River. On both occasions, the fishway trap was set at the exit of the fishway on the upstream side of the weir, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. In 2016, a total of 19 different species were captured at a rate of 690.4 fish per trapping day, whilst in 2017, 16 species were captured at a rate of 4,075.5 fish per day. Significantly, four 'new' native species were captured successfully ascending the fishway that had not been recorded in over 14 years of EHMP fish surveys within the Bremer River, including freshwater mullet, speckled goby, yellowfin bream and fork-tailed catfish. These results highlight the impact that barriers close to the estuarine interface have on the health of freshwater fish communities. Other notable fishway monitoring results (2017) include the capture of 1,073 juvenile freshwater mullet at a catch rate of 267 fish per day, and 1,273 sea mullet at a catch rate of 316 fish per day.

Migration Classification	Common Name	Species Name	**Size Range** (mm)		**CPUE** (Fish/day)	
			2016	**2017**	**2016**	**2017**
Marine Vagrant	Yellowfin bream	*Acanthopagrus australis*	254	-	0.2	-
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 52	21- 64	114.1	2020.5
	Long-finned eel	*Anguilla reinhardtii*	70- 550	400- 1200	2.8	1.5
	Bullrout	*Notesthes robusta*	35- 58	28- 165	1.6	27.8
	Eel sp.	*Anguilla species*	-	50- 65	-	1
	Freshwater mullet	*Trachystoma petardi*	-	51- 79	-	266.6
	Sea mullet	*Mugil cephalus*	38 72	34- 234	38.9	316.3
	Striped gudgeon	*Gobiomorphus australis*	21- 52	21- 83	80	1283.7
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	31- 33	28- 42	1	12.7
	Flathead gudgeon	*Philypnodon grandiceps*	20- 51	19- 25	10.2	0.5
	Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	18- 74	36- 41	177.4	0.5
	Hypseleotris sp.	*Hypseleotris species*	15- 41	-	248.1	-
	Bony bream	*Nematalosa erebi*	110- 254	39- 204	1.2	21.1
	Speckled goby	*Redigobius bikolanus*	25- 33	-	2.4	-
	Australian smelt	*Retropinna semoni*	24- 40	22- 54	2	121
	Fork-tailed catfish	*Arius graeffei*	230- 350	-	1.2	-
	Pacific blue-eye	*Pseudomugil signifer*	32	-	0.2	-
	Eel-tailed catfish	*Tandanus tandanus*	34	-	0.2	-
	Agassiz's glassfish	*Ambassis agassizii*	40- 53	-	0.4	-
	Banded grunter	*Amniataba percoides*	-	110	-	0.2
	Spangled perch	*Leiopotherapon unicolor*	-	165- 195	-	0.5
	Unspecked hardyhead	*Craterocephalus fulvus*	-	35- 56	-	1.2
Pest Fish	Platy	*Xiphophorus maculatus*	25	-	0.2	-
	Tilapia	*Oreochromis mossambicus*	72	385	0.2	0.2
		Total Species and Overall CPUE	**19**	**16**	**690.4**	**4075.5**

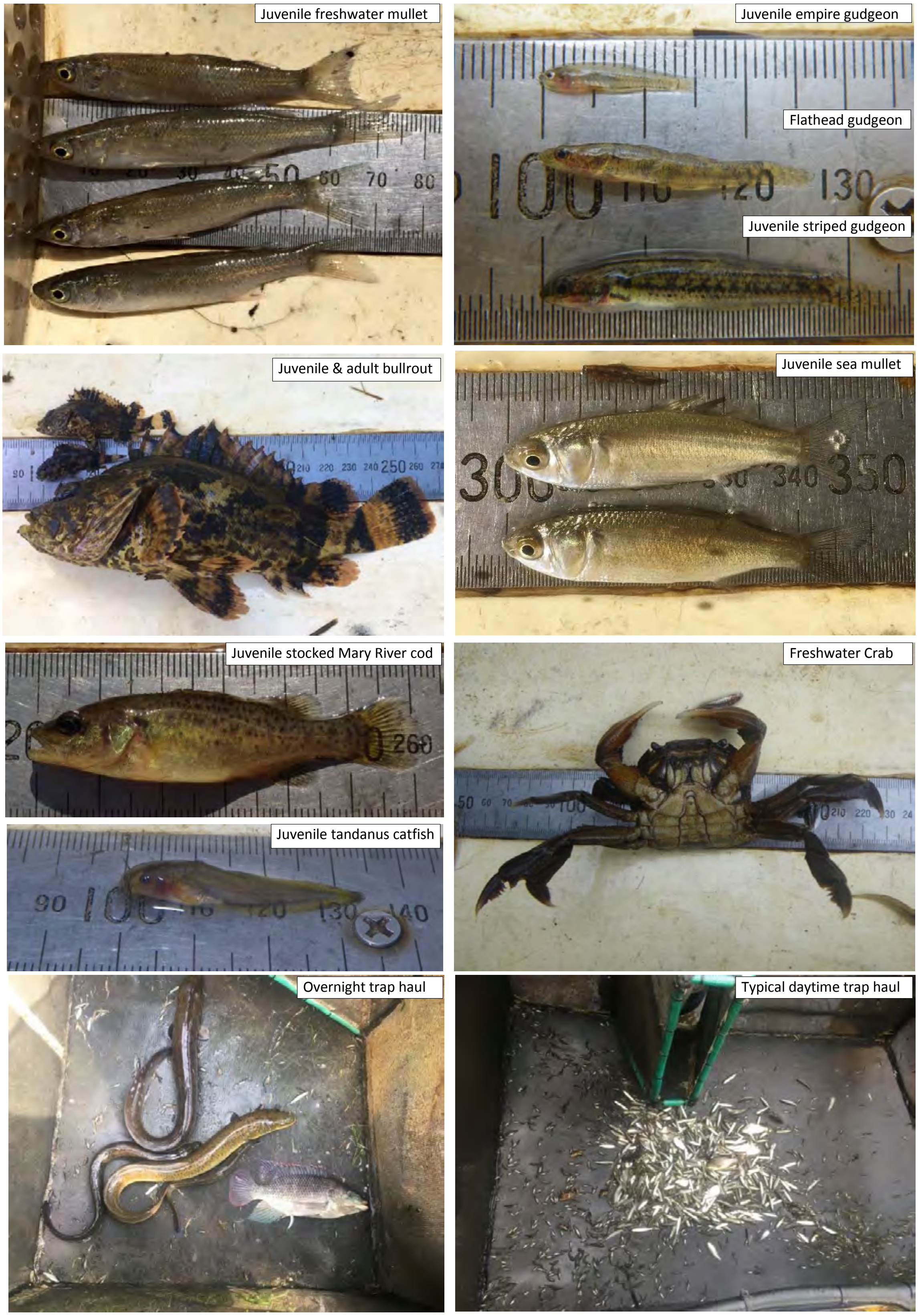


Figure 25. Fish captured ascending Berrys Weir fishway during monitoring

Case Study 3 - Leitchs Crossing, South Pine River

Introduction

The remediation of Leitchs Crossing with a nature-like rock-ramp fishway was undertaken in partnership between Moreton Bay Regional Council and Catchment Solutions. Leitchs Crossing is located in the lower reaches of the South Pine River and was ranked the 11th highest priority fish barrier in the Greater Brisbane region. A fish passage options assessment determined that a full width rock-ramp fishway was the best fish passage remediation option for this barrier type in assisting fish to ascend past the barrier.

Barrier Ranking	11th in Greater Brisbane region
Barrier Type(s)	Surface drop barrier, water depth barrier and flow velocity barrier
Total Surface Drop (head loss)	0.5 m
Best Remediation Method	Full width rock-ramp fishway
Length of Fishway	15
Number of Ridges	7
Drops Between Pools	75 mm
Total Construction Time	4 days
Total Rock Used	192 t
Total Overall Cost	$60 000

Figure 26. Showing Leitchs Crossing fish barrier prior to fishway construction

Fishway Construction Works

Figure 27. Showing during and post construction of Leitchs Crossing fishway

Post Remediation Works

Following the construction of the rock-ramp fishway at Leitchs Crossing, fishway monitoring was carried out in October 2017 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur in South Pine River. The fishway trap was set at the exit of the fishway on the upstream side of the crossing, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. Across five days of monitoring, a total of 19 species were surveyed ascending the fishway, at an overall rate of 1,195.9 fish per day. Notable captures include juvenile freshwater mullet and speckled goby, both diadromous fish species that had not previously been recorded during annual EHMP fish surveys in the South Pine River (survey site located upstream of the barrier/fishway site). It's anticipated that improved connectivity as result of the fishway will assist in the recovery of freshwater mullet and speckled goby populations in the South Pine River. Also significant was the high numbers of juvenile sea mullet; SEQ most important inshore net commercial species, recorded at a catch rate of 209 fish per day. Similar to all fishway monitoring sites, no wild Australian bass were recorded, potentially suggesting poor and/or failed recruitment of this species. Australian bass populations in SEQ waterways appear to be masked by escaped stocked fish from impoundments during overtopping events.

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 72	19.87
	Long-finned eel	*Anguilla reinhardtii*	70- 800	1.42
	Sea mullet	*Mugil cephalus*	23- 308	209.36
	Striped gudgeon	*Gobiomorphus australis*	19- 41	17.74
	Bullrout	*Notesthes robusta*	45- 150	2.60
	Freshwater mullet	*Trachystoma petardi*	50- 65	6.86
Potamodromous	Firetail gudgeon	*Hypseleotris galii*	19- 38	812.62
	Flathead gudgeon	*Philypnodon grandiceps*	19- 56	62.69
	Western carp gudgeon	*Hypseleotris klunzingeri*	19- 34	0.95
	Agassiz's glassfish	*Ambassis agassizii*	25- 54	15.38
	Unspecked hardyhead	*Craterocephalus fulvus*	25- 63	15.61
	Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	54	0.24
	Dwarf flathead gudgeon	*Philypnodon maculatus*	16- 28	15.38
	Philypnodon sp.	*Philypnodon species*	21- 45	1.42
	Speckled goby	Redigobius bikolanus	21- 26	0.95
	Australian smelt	Retropinna semoni	21- 42	8.75
Pest Fish	Mosquito fish	*Gambusia holbrooki*	19- 29	1.18
	Platy	*Xiphophorus maculatus*	28- 32	0.95
	Tilapia	*Oreochromis mossambicus*	15- 330	1.89
		Total Species and Overall CPUE	**19**	**1195.86**

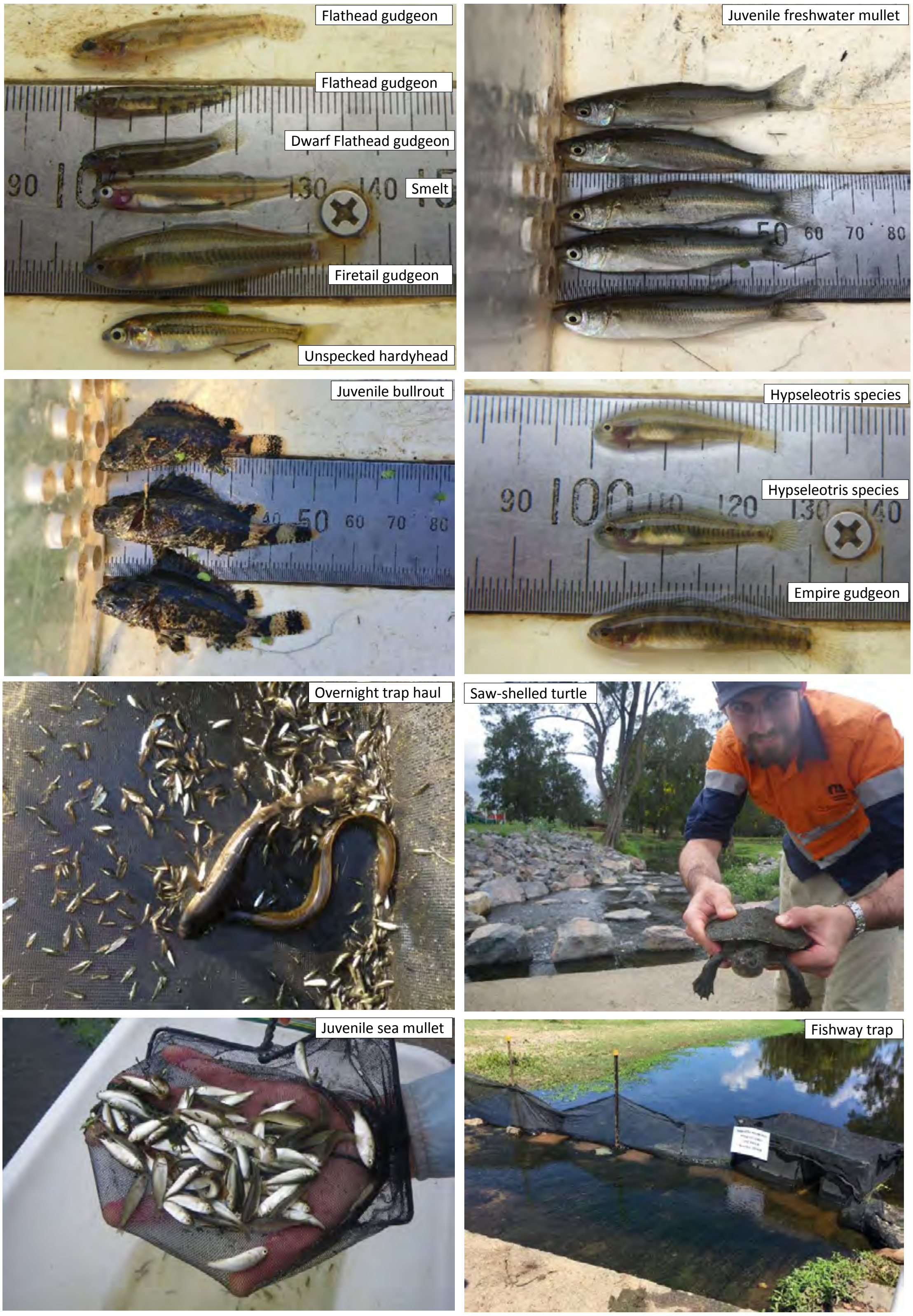


Figure 28. Fish captured successfully ascending Leitchs Crossing fishway during monitoring

Case Study 4 - Hilliards Weir, Hilliards Creek

The remediation of Hilliards Creek Weir with a rock-ramp fishway was undertaken in partnership between Redland City Council and Catchment Solutions. The relic weir on Hilliards Creek was ranked the 36th highest priority fish barrier in Greater Brisbane region. A fish passage options assessment determined that a full width rock-ramp fishway was the best fish passage remediation option for this barrier type in assisting fish to ascend past the barrier.

Barrier Ranking	36th in Greater Brisbane region
Barrier Type(s)	Surface drop barrier
Total Surface Drop	0.75 m
Best Remediation Method	Full width rock-ramp fishway
Length of Fishway	18 m
Number of Ridges	9
Drops Between Pools	80 mm
Total Construction Time	4 days
Total Rock Used	205 t
Total Overall Cost	$ 42 000

Figure 29. Showing the Hilliards Creek weir prior to fishway construction.

Fishway Construction Works

Figure 30. Showing construction images of Hilliards Creek fishway

Post Remediation Works

Following the construction of the rock-ramp fishway, monitoring was carried out in December 2016 to assess the capabilities of the fishway at passing the full suite of fish species and size classes expected to occur in Hilliards Creek. The fishway trap was set at the exit of the fishway on the upstream side of the crossing, to show the numbers and species of fish that were able to ascend the rock-ramp fishway. Across five days of monitoring, a total of 9 species were surveyed ascending the fishway, at an overall catch rate of 177.66 fish per day. The small size of fish (≥15 mm) that were successful at ascending the fishway indicates the fishway is operating as intended (small size fish are generally weaker swimmers than adults, as they don't possess the same muscle to propel them through the water). However, due to a low passability fish barrier located downstream in Fellmonger Park (Figure 31), the numbers of fish migrating through the fishway were reduced when compared to other fishways constructed as part of this project.

The Fellmonger Park barrier consists of a raised pedestrian causeway with two small partially blocked pipe culverts buried underneath. This causeway is a major barrier to fish passage during all base, low and medium flow events. Only during very in-frequent 'drown out' events is fish passage potentially available past this barrier, but only if migrating fish are located below the weir at the time of 'drown out' and possess swimming abilities in-excess of the velocities experienced at the barrier site.

Boat electrofishing surveys were undertaken upstream and downstream of this barrier to detect any differences in fish community condition. The survey results demonstrated the barrier was significantly impacting upstream fish communities, with the catch rate (56.97 fish/min) of diadromous fish species downstream of the barrier more than four times higher than upstream of the barrier (12.37 fish/min) (Moore, 2017).

Table 1. Showing fish species, size range and catch per unit effort of fish (fish/day) successful at ascending the fishway

Migration Classification	Common Name	Species Name	Size Range (mm)	CPUE (Fish/day)
Diadromous	Empire gudgeon	*Hypseleotris compressa*	19- 81	18.22
	Long-finned eel	*Anguilla reinhardtii*	60- 800	1.08
	Sea mullet	*Mugil cephalus*	38- 51	15.62
	Striped gudgeon	*Gobiomorphus australis*	38- 51	1.3
Potamodromous	Hypseleotris species	*Hypseleotris sp.*	20- 43	77.44
	Unspecked hardyhead	*Craterocephalus fulvus*	20- 71	54.66
Pest Fish	Mosquito fish	*Gambusia holbrooki*	15- 35	8.68
	Platy	*Xiphophorus maculatus*	64	0.22
	Tilapia	*Oreochromis mossambicus*	329	0.22
Total Species and Overall CPUE			**9**	**177.66**

Figure 30. Showing Hilliards Creek fishway monitoring catch results.

Figure 31. Left; showing an adult tarpon captured immediately upstream of the barrier site post fishway construction. tarpon are a highly prized recreational fishing species, which breed in estuarine waters before migrating upstream into freshwater as juveniles. Barriers significantly impact the distribution and population of this species. Right; Fellmonger Park pedestrian causeway fish barrier. A Hilliards Creek fish community study found this barrier to be significantly impacting fish populations within Hilliards Creek , particular diadromous species.

Appendix 3 - Barriers of Each LGA

Brisbane City Council LGA

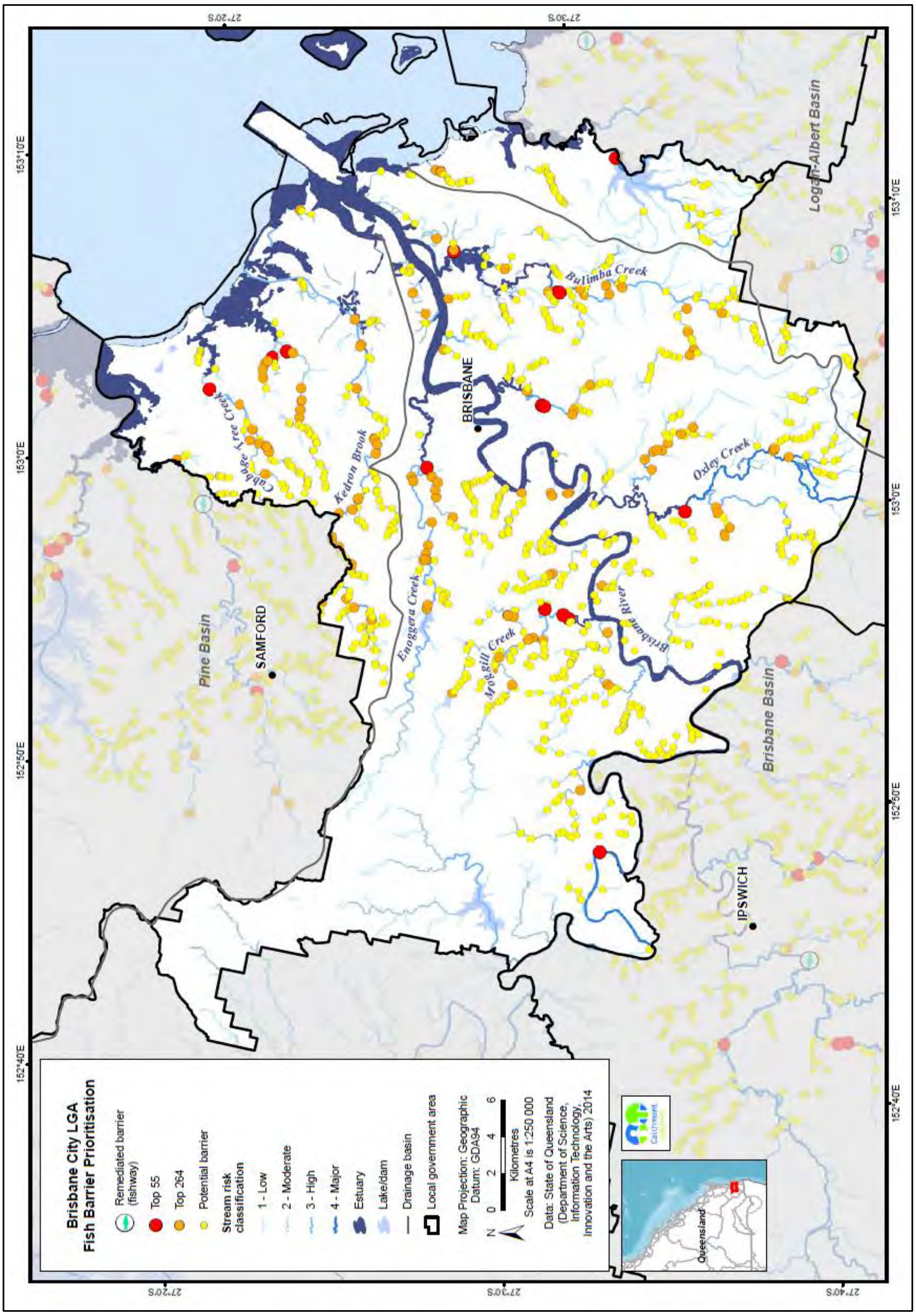


Figure 32. Brisbane City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Gold Coast City Council LGA

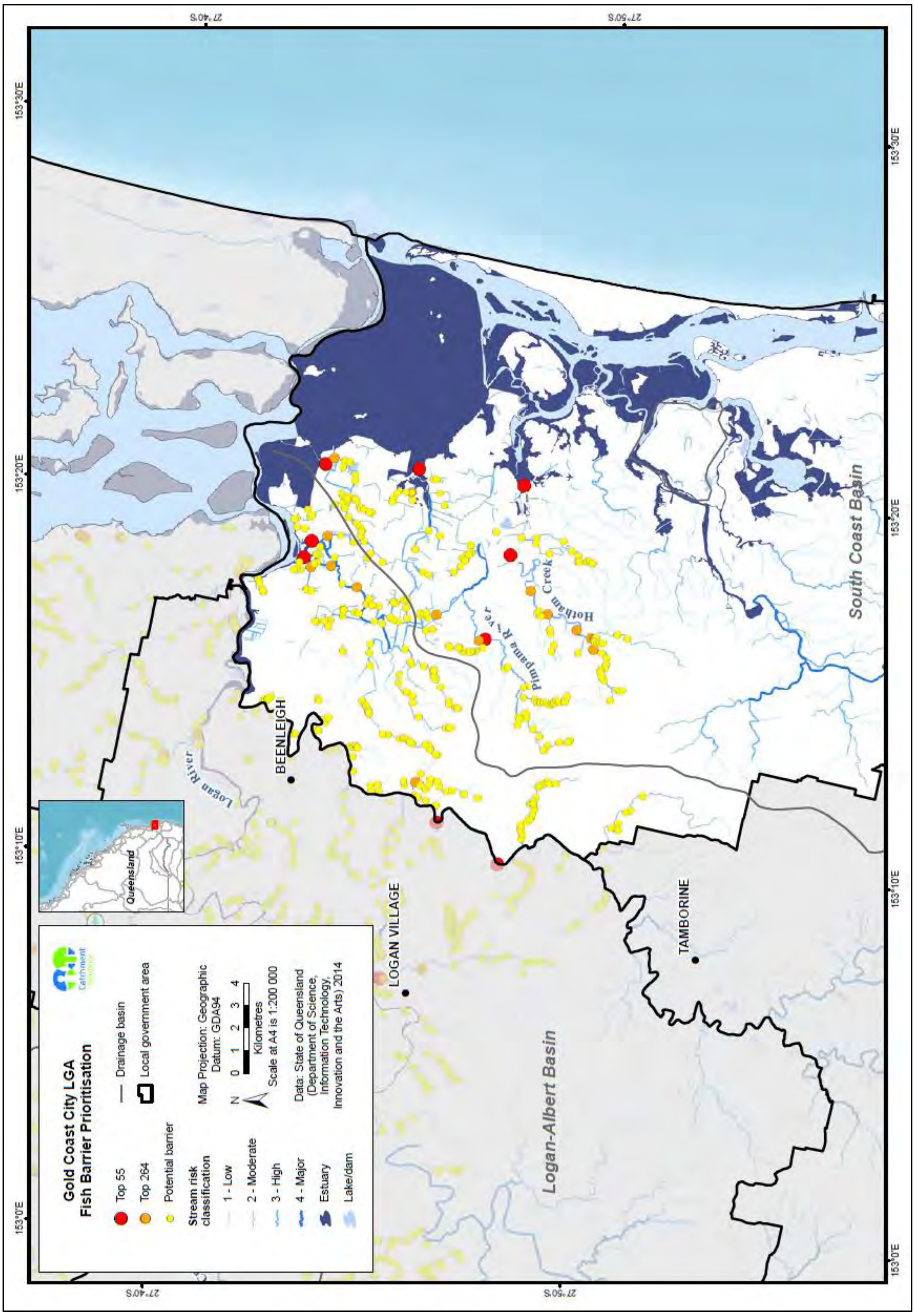


Figure 33. Gold Coast City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Ipswich City Council LGA

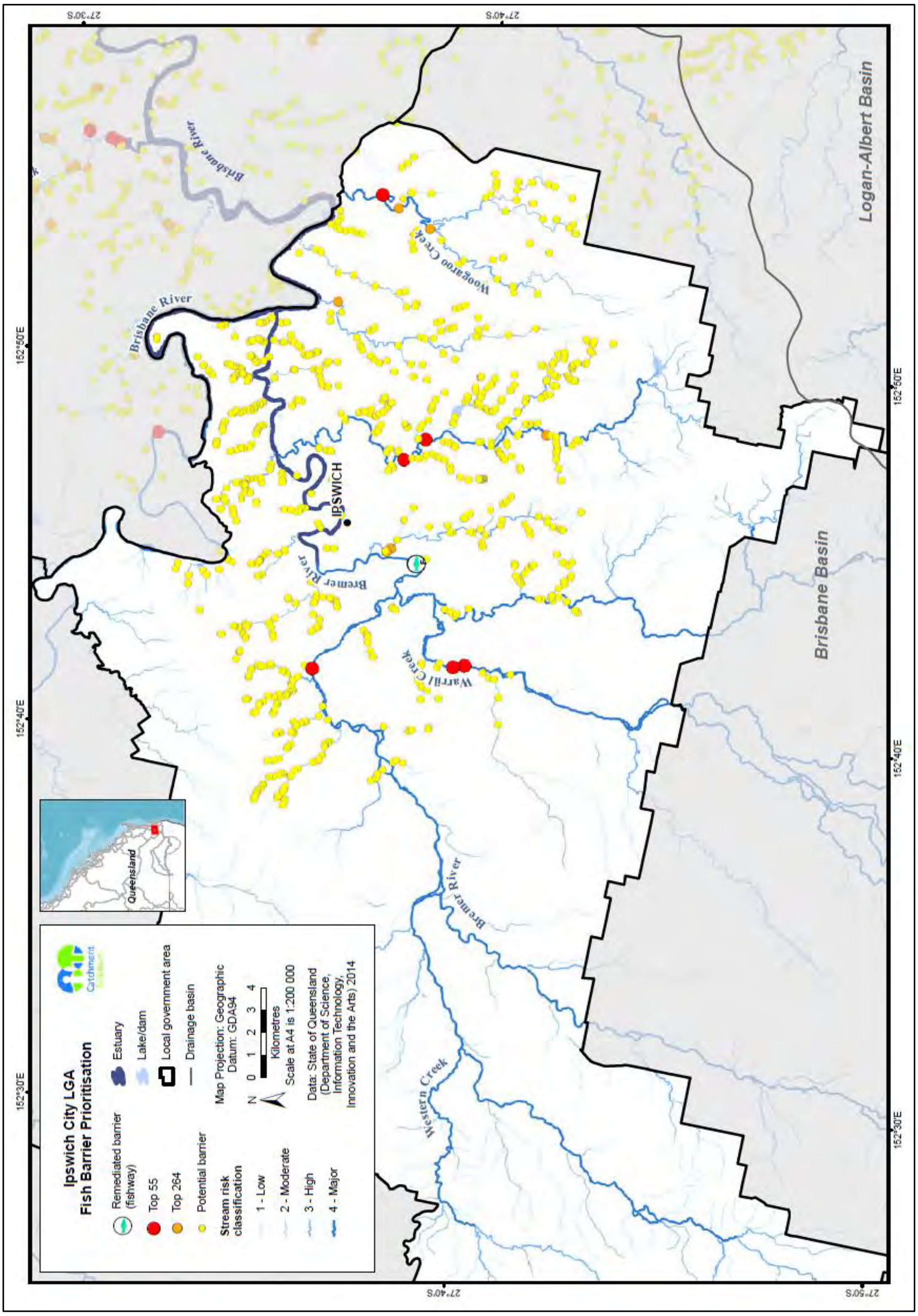


Figure 34. Ipswich City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Logan City Council LGA

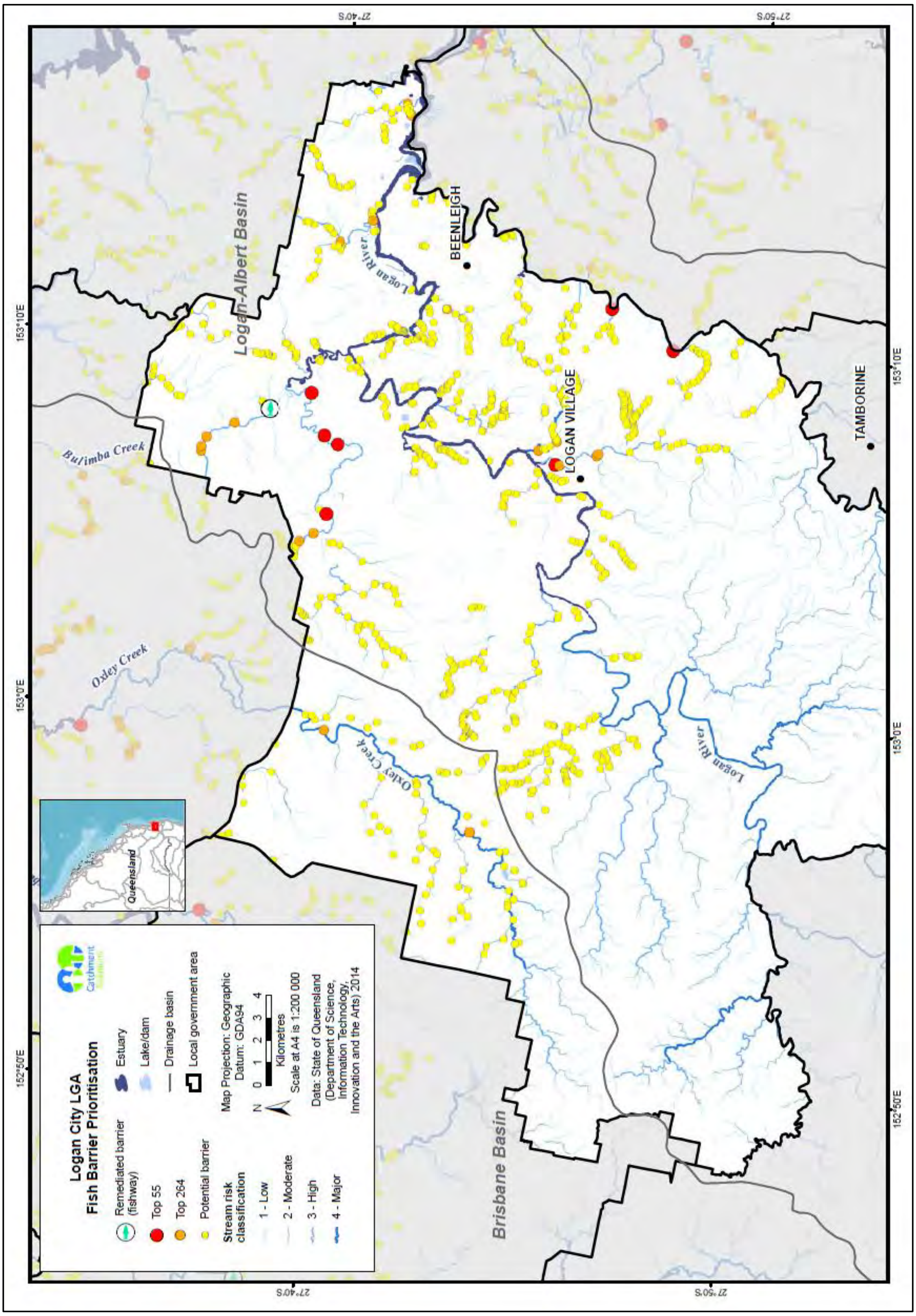


Figure 35. Logan City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Moreton Bay Regional Council LGA

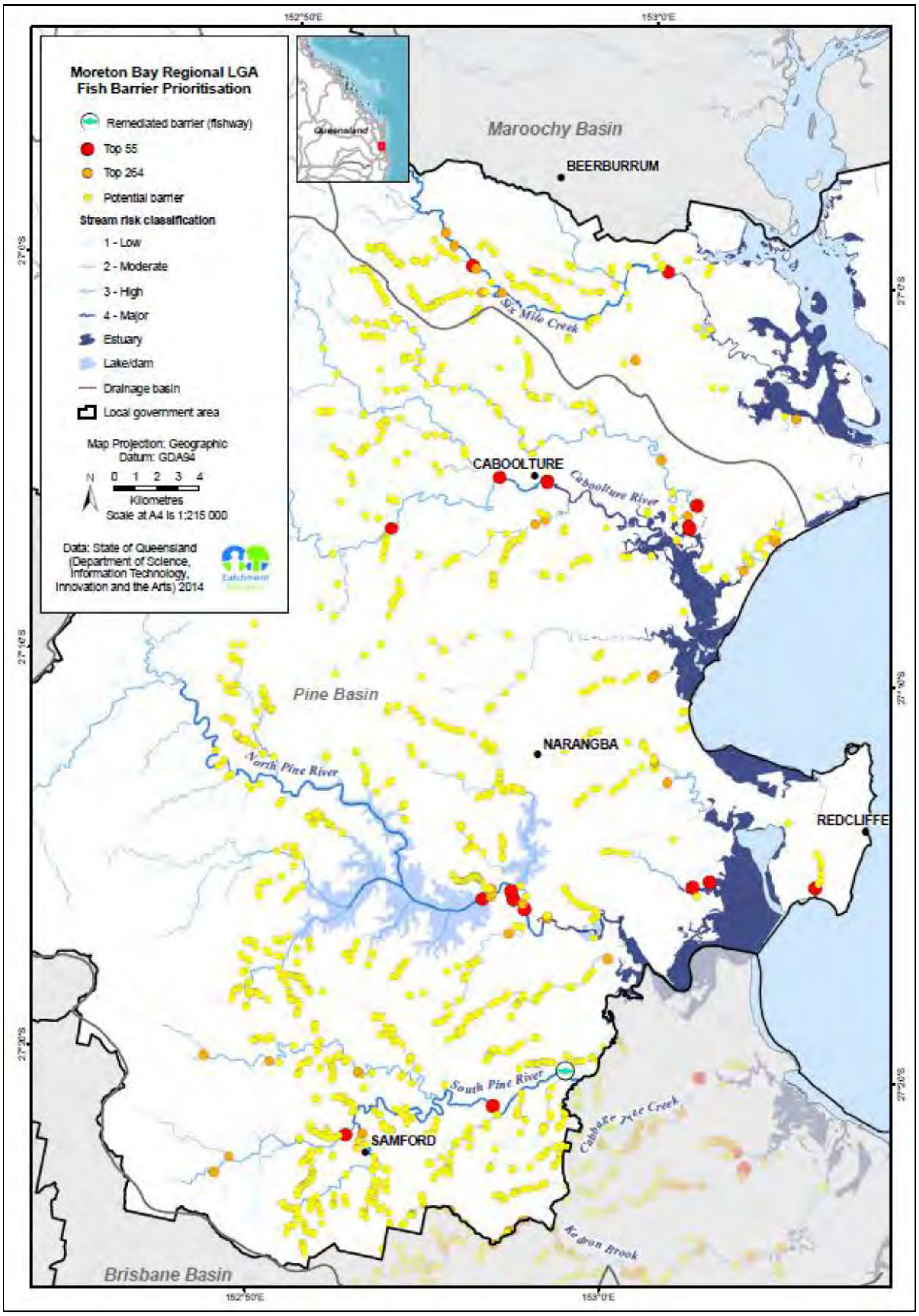


Figure 36. Moreton Bay Regional Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Redland City Council LGA

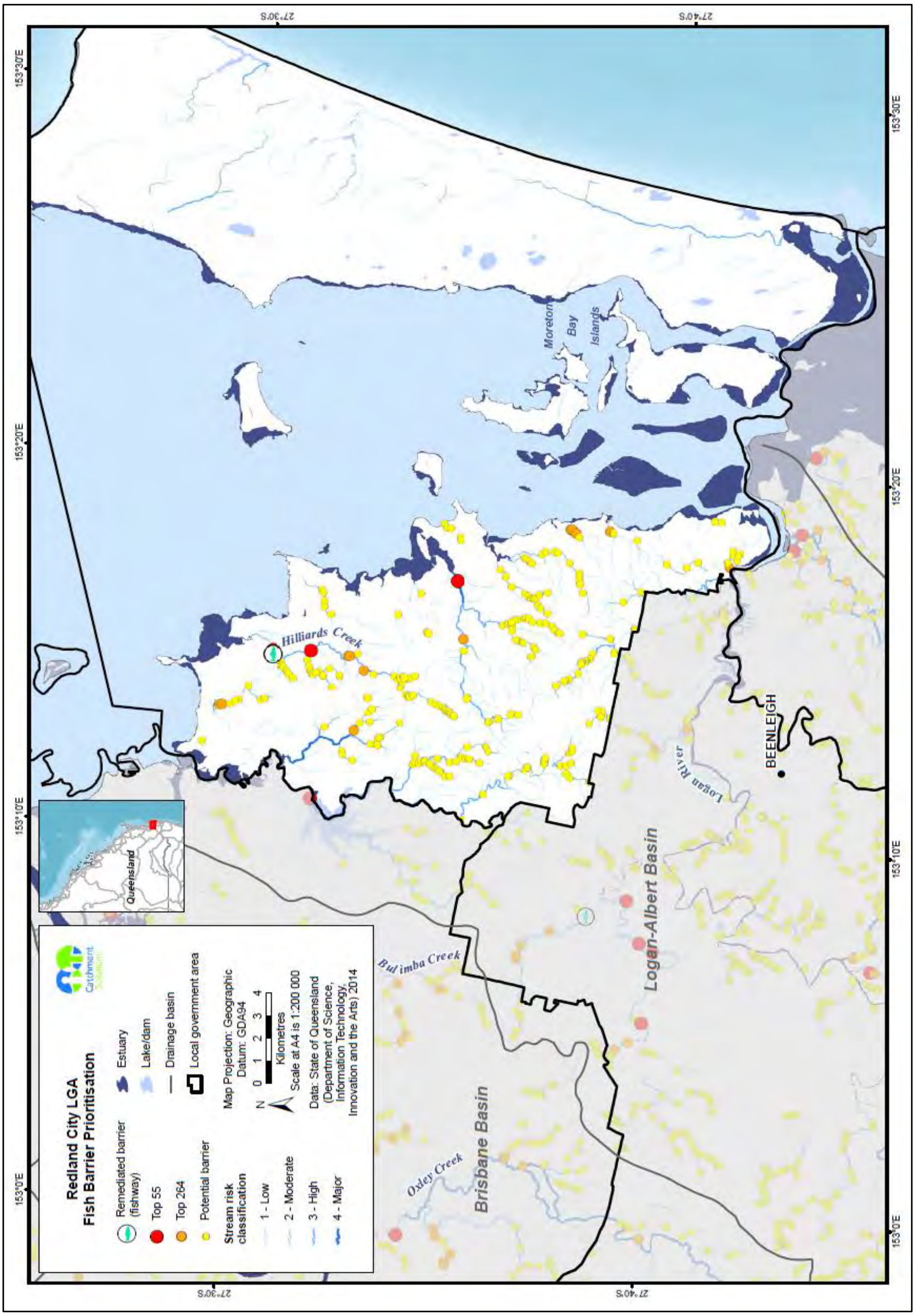


Figure 37. Redland City Council LGA barriers, broken down into top 55 (red), top 264 (orange), potential barriers (yellow) and remediated barriers (green)

Appendix 4. Example Informative Fishway Sign

Hilliards Creek Fishway, Redland City Council

Figure 38. Example informative fishway sign which could be installed at a fish passage remediation site to inform the local community regarding the many benefits of improved aquatic connectivity and describe how fishways operate. ***Fishway Sign designed and installed by Redland City Council.***

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Bremer River and Warrill Creek Fish Barrier Assessment Report

April 2018
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Cover Image: Top, left to right: Bremer River DNRM v-notch gauging weir and Warrill Creek sheet pile weir. Bottom, left to right: Warrill Creek DNRM v-notch gauging weir, fish captured during Bremer River fish community monitoring, clockwise from top; sea mullet (top) freshwater mullet (bottom), Queensland lungfish, Yellow-fin bream and Australian bass.

Contents

Background

Construction of Berry's Weir partial width rock-ramp fishway on the Bremer River in Ipswich was completed in October 2016. The fishway was constructed on a 2.4 m weir (Berrys Weir) that was built in the 1960's to impound water for power generation (Swanbank Power Station). Berrys Weir was identified as the 7th highest priority fish barrier in the Greater Brisbane region, and the highest located wholly within the Ipswich City Council (ICC) region (Moore *et al.,* 2018). The weir is located in the lower reaches of the Bremer River catchment approximately 5 km's upstream from the estuarine interface. Prior to the construction of the fishway, Berrys Weir blocked upstream fish passage to approximately 97.5% of the catchment. This led to significant reductions in upstream fish diversity, fish species distribution and the proliferation of pest fish species such as tilapia and carp. Overall, Bremer River aquatic ecosystem health was significantly impacted by the weir.

To evaluate the effectiveness of the fishway, monitoring was undertaken in December 2016 and again in December 2017. Monitoring demonstrated the fishway was successful at passing the full suite of fish species and size classes expected to occur within the Bremer River catchment. Over 4000 fish per day were recorded successfully ascending the fishway. Notably, fishway monitoring recorded four new fish species (speckled goby, fork-tailed catfish, Yellow-fin bream and freshwater mullet) that have not been recorded within the Bremer River in over 14 years of Environmental Health Monitoring Programme (EHMP) fish surveys. With fish passage past Berrys Weir now restored, assessment of the next fish barriers upstream is required.

As further commitment to improving fish passage within the Bremer River catchment, ICC engaged Catchment Solutions to undertake assessments of the next barriers upstream of Berrys Weir. The assessment aimed to determine the level of impact these barriers have on fish communities of the Bremer River. This report details the barriers which were assessed, findings of the assessments and provides recommendations on the best ways to further improve fish passage in the Bremer River catchment.

Introduction

In coastal Queensland catchments migratory (diadromous) fish species which move between saltwater and freshwater environments in order to complete their life-cycle are most affected by barriers, particularly the first barrier located upstream from the estuary (e.g. Berrys Weir). Within the Bremer River catchment this includes key commercial, recreational and indigenous fishery species such as: Australian bass, sea mullet, freshwater mullet, Yellow-fin bream, long-fin eel, short-fin eel and potentially jungle perch. All these species were impacted by Berrys Weir. Many other non-economic migratory fish were also impacted by Berrys Weir, these include empire gudgeon, striped gudgeon, Redigobius sp., fork-tailed catfish and bullrout. These species play important roles in aquatic food webs (predator-prey relationships) and the transfer of carbon between estuarine and freshwater habitats.

Although low passability barriers located in the lower reaches of coastal catchments have the greatest impact on migratory fish species, potamodromous (wholly freshwater species) are also affected. This is particularly important for the Bremer River catchment which comprises a small population of endangered Mary River Cod (MRC). MRC (Figure 1) have been restocked into the Brisbane-Stanley catchment, including the Bremer River catchment for conservation purposes. The MRC Recovery Plan undertaken by Simpson and Jackson (1996) list the remediation of fish barriers as a key management action required to ensure the long-term maintenance of cod populations. MRC have been known to migrate up to 30 km in both upstream and downstream directions in response to elevated stream flow events, with a tendency to move upstream in spring and summer and downstream in winter (Simpson and Jackson, 1996). This movement may be undertaken to find breeding partners or food resources, before moving back to their home river reach area (100 m – 1000 m), where they reside for the majority of time. Simpson and Jackson (1996) suggest that individual fish may return to a previous home range after an absence of at least 8 months and a return journey up to 70 km. Prior to the construction of Berrys Weir rock ramp fishway, MRC that moved downstream past the weir were most likely blocked from undertaking a return migration. However, now that fish passage has been restored, it's possible for MRC to move freely within the lower reaches of the Bremer catchment.

To test whether MRC are able to negotiate Berrys Weir fishway, a small number (n=20) of juvenile MRC were released at the bottom of the fishway during the first round of fishway monitoring in December 2016. During the subsequent 4 days of fishway monitoring, one 62 mm long MRC was recorded successfully ascending the fishway (Figure 1). While this capture only represents 5% of the fish that were released, the result did provide an indication that juveniles of this species can pass the fishway.

Figure 1. Left; Juvenile MRC released downstream of Berrys Weir fishway as part of a research trial and captured during monitoring having successfully ascended the fishway. Right; Showing an adult MRC captured in the Mary River catchment during research monitoring.

Monitoring of the Berrys Weir fishway occurred across 5 days in December 2016 and again for 5 days in December 2017. Monitoring was undertaken to evaluate the success of the fishway. Monitoring demonstrated the fishway was successful at passing the full suite of fish species and size classes expected to occur within the Bremer River catchment. Fishway monitoring results in December 2016 recorded a total of 3514 individual fish representing 21 species at a catch rate of 690 fish per day, while monitoring in December 2017 recorded 16,401 individuals representing 16 species at a catch rate of 4075 fish per day. With fish passage past Berrys Weir now restored, assessment of the next fish barriers upstream was required. This assessment forms the current report, and was undertaken to determine the impact of the next three barriers upstream within the Bremer River catchment.

Bremer River Catchment Barriers

The Bremer River catchment comprises two major tributaries; the larger Warrill Creek with its headwaters originating in the south of the catchment and the Bremer River with its headwaters originating to the west (Figure 2). These tributaries meet at a junction approximately 2 km upstream from Berrys Weir.

- The first fish barrier along the Bremer River arm is located at Walloon approximately 9 km upstream from Berrys Weir (Figure 2). This barrier structure comprises a v-notch gauging weir operated by the Queensland Department of Natural Resources Mines & Energy. The weir was ranked the 12th highest priority barrier out of 13, 629 potential barriers in a recent fish barrier priorisation project (Moore *et al*., 2018) and the equal 1st in ICC LGA.

- The first fish barrier upstream along Warrill Creek is located approximately 10 km upstream from Berrys Weir adjacent 'Runnymede' trotting stable (Figure 2). The barrier was ranked 15th highest priority in the Greater Brisbane region and consists of a sheet pile weir with gabion basket scour protection.

- Approximately 600 m further upstream along Warrill Creek is the location of the 3rd barrier assessed as part of this project. This barrier comprises a v-notch gauging weir owned and operated by the Queensland Department of Natural Resources and Mines & Energy. This barrier was ranked the equal 12th highest priority fish barrier in the Greater Brisbane region (Moore *et al.,* 2018) and equal 1st in the ICC LGA.

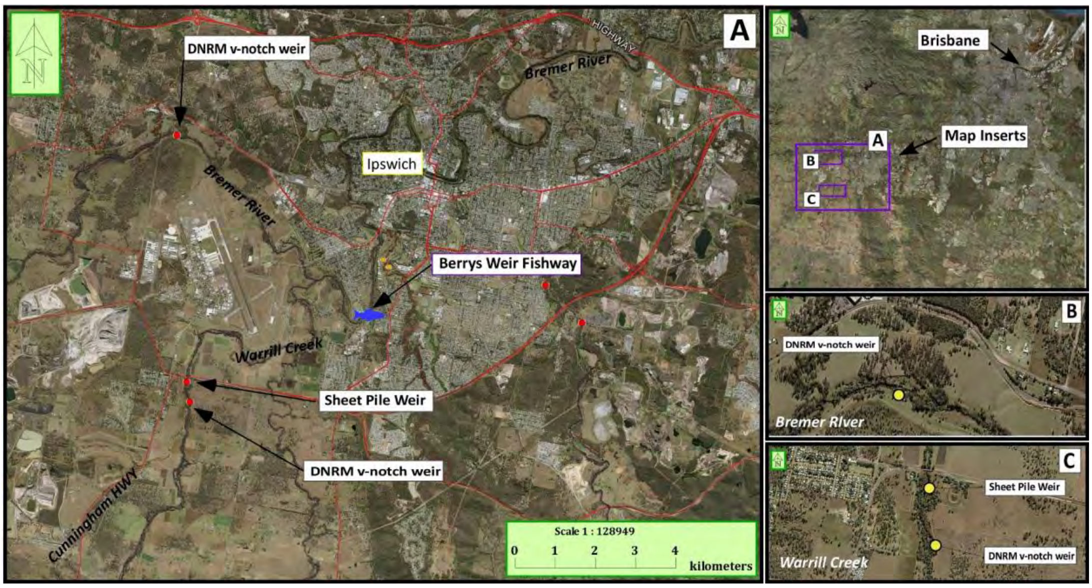

Figure 2. Maps showing the location of the Bremer River, Warrill Creek, Berrys Weir fishway and the three fish barriers assessed as part of this project. Images courtesy of Google Earth.

Assessment of the Bremer River v-notch weir and the Warrill Creek sheet pile weir was undertaken using purpose built fishway traps. The traps were deployed immediately upstream of each barrier and included wing walls to guide fish into the entrance and prevent fish from swimming around or under the traps. Water depth immediately upstream from the v-notch gauging weir on Warrill Creek was too deep (~1.5 m) to successfully set a trap. Instead, a video camera was positioned on the downstream side of the barrier to record any potential fish that were able to ascend. Furthermore, fish community monitoring was undertaken using backpack and boat electrofishing techniques to better understand fish species present in the catchment. Boat electrofishing was undertaken to effectively monitor all habitat types upstream and downstream of Berrys Weir fishway. Due to site constraints, a backpack electrofisher was used to effectively monitor immediately downstream from the sheet pile weir. This was undertaken to compare fish species immediately under the weir (within 10 m) to those potentially captured in the fish trap deployed upstream of the weir.

Fish Barrier Assessments

Walloon V-Notch Gauging Weir, Bremer River

Location

A concrete V-notch gauging station weir had been previously identified in the upper reaches of the Bremer River. The barrier is situated approximately 9km upstream of the Berry's Weir fishway, approximately 7 km upstream of the junction of the Bremer River and Warrill Creek (Figure 3).

Figure 3. Location of upper Bremer River V-notch gauging barrier (Imagery: Google Earth).

The barrier consists of a vertical concrete wall intersecting the full width of the stream, with a deep V-notch groove formed within the concrete to create a channel of flow for stream height gauging (Figure 4). In total, the estimated head loss from upstream to downstream of the barrier was 300 mm, whilst the estimated drop from the lowest point of the notch to the water surface downstream was 80 mm.

Figure 4. Measuring the velocity through the concrete v-notch gauging station barrier at Walloon in the lower reaches of the Bremer River.

Methods

Fish trapping surveys were undertaken upstream and downstream of the Walloon v-notch gauging weir (Figure 5). Sampling was undertaken to identify differences in fish communities successful at ascending the barrier compared to those that were accumulated below the weir (attempting to ascend past).

The trap configuration included a single cone entrance. The frame was covered with shade cloth (4.0 mm mesh size. The trap dimensions were 1400 mm x 1000 mm x 1100 mm. Shade cloth wing walls were used to prevent fish from swimming around and underneath the trap, whilst sand bags were used to secure the trap and wing walls in place. The fish trap positioned immediately above the barrier was set for 24.25 hours (Figure 5). Following trapping above the barrier, the trap was set up below the v-notch to sample fish attempting to migrate past the barrier. The entrance to the fish trap was positioned directly in-line with the prevailing stream flow exiting through the v-notch. Fish possess an inherent behavioural response to swim upstream during stream flow events (rheoreation), attracting fish attempting to migrate upstream into the trap (Wang, 2008). The fish trap was left in place below the barrier for a total of 21.75 hours (Figure 5)

All individual fish captured in the trap were identified to species level, counted and measured to the nearest millimetre (fork length for forked-tailed species, total length for all other species). When more than 25 individuals of a single species were captured in any single trapping event, a randomised subset of 25 fish were measured and the remainder only counted to contribute to abundance data. All native fish were then released back to the site of capture, whilst pest fish species were euthanised as per Biosecurity Queensland legislation and ANZCCART procedures and disposed of in an appropriate manner. In order to evaluate the flow velocities through the v-notch (weir crest) flow velocity measurements were taken using a Global Water flow meter (GWFP111). Flow velocity measurements were taken at the downstream extent of the v-notch (weir crest), at the centre of the v-notch and at the upstream extent of the v-notch at 15:00 on 22/12/2017.

Figure 5. Fish trap set above the V-notch gauging barrier (left), and below the barrier (right)

Results

Upstream Barrier

After 24.25 hours of trapping above the Bremer River v-notch gauging weir, a total of eight native species were captured, comprising three diadromous and five potamodromous fish (Table 1). In total, 105 individual fish were caught ascending the barrier at a rate of 4.33 fish per hour, with the most abundant being firetail gudgeon (*H. galii*) at a catch rate of 1.57 fish per hour, followed by crimson-spotted rainbowfish (*M. duboulayi*), empire gudgeon (*H. compressa*) and unspecked hardyhead (*C. fulvus*) at catch rates of 0.95, 0.78 and 0.33 fish per hour respectively (Figure 6).

Figure 6. Showing fish that were successful at ascending the barrier. Left: fish captured in trap, Right: Close up of some of the captured species: (top to bottom) juvenile sea mullet crimson- spotted rainbowfish, unspecked hardyhead, firetail gudgeon, smelt and empire gudgeon.

Downstream Barrier

After 21.75 hours of trapping below the Bremer River v-notch gauging weir, a total of 12 species were captured, comprising 11 native species and 1 pest fish (mosquitofish) (Table 1). Native fish included four diadromous species and seven potamodromous species. In total, 770 individual fish were caught at a rate of 35.4 fish per hour, with the most abundant species being firetail gudgeon (*H. galii*) at a rate of 27.77 per hour, followed by Australian smelt (*R. semoni*), Bullrout (*N. robusta*) and mosquitofish at catch rates of 3.72, 0.74 and 0.64 fish per hour respectively. Photos of some fish captured below the weir are provided in Figures 6 & 7.

Figure 7. Fish captured whilst trapping below barrier (left), and showing fish captured on measuring board, including bullrout (*N. robusta*), long-finned eel (*A. reinhardtii*) and firetail gudgeon (*H. galii*) (right).

Figure 8. Showing juvenile bullrout, eel sp. smelt, unspecked hardyhead, dwarf flathead gudgeon and firetail gudgeon captured downstream of the Walloon v-notch gauging weir. Note: bullrout, eel sp. and dwarf flathead gudgeon were not captured upstream of the weir, indicating that the weir is potentially blocking upstream passage for these species.

Table 1. Fish catch results of trapping above and below Bremer River v-notch gauging weir barrier

Migration Class	Common Name	Species Name	Total Individuals		CPUE (Fish/hour)	
			Downstream	Upstream	Downstream	Upstream
Diadromous	Empire gudgeon	*Hypseleotris compressa*	6	19	0.28	0.78
	Striped gudgeon	*Gobiomorphus australis*	8	7	0.37	0.29
	Sea Mullet	*Mugil cephalus*		2		0.08
	Bullrout	*Notesthes robusta*	16		0.74	
	Long-finned eel	*Anguilla reinhardtii*	8		0.37	
Potamodromous	Crimson- spotted rainbowfish	*Melanotaenia duboulayi*	11	23	0.51	0.95
	Unspecked hardyhead	*Craterocephalus fulvus*	11	8	0.51	0.33
	Firetail gudgeon	*Hypseleotris galii*	604	38	27.77	1.57
	Flathead gudgeon	*Philypnodon grandiceps*	8	1	0.37	0.04
	Australian smelt	*Retropinna semoni*	81	7	3.72	0.29
	Dwarf flathead gudgeon	*Philypnodon maculatus*	1		0.05	
	Agassiz's glassfish	*Ambassis agassizii*	2		0.09	
Pest Fish	Mosquito fish	*Gambusia holbrooki*	14		0.64	
Total Species, Individuals & Overall CPUE		**13**	**770**	**105**	**35.4**	**4.33**
Total species by fish trapping location			**12**	**8**		

V-notch Flow Velocity

Table 2. Stream flow velocity results taken at the Walloon v-notch (weir crest) gauging weir

V-notch flow measurement location	Distance from the downstream edge of the v-notch (mm)	Flow Velocity (m/sec)
Downstream extent	0	2.2
Center	150	1.7
Upstream extent	300	0.8

Discussion

The results obtained show a substantial difference between upstream and downstream trapping, eluding to the fact that the barrier is severely impacting fish passage to upstream reaches of Bremer River. Although 105 individuals representing eight species were able to ascend the barrier during low flows at a rate of 4.33 fish per hour, downstream results showed 12 species at rate of 35.4 fish per hour were captured attempting to ascend the barrier (Figures 7 and 8). Significantly, five species were captured downstream of the barrier and not upstream, including Agassiz's glassfish (*A. agassizii*), bullrout (*N. robusta*), long- finned eel (*A. reinhardtii*), dwarf flathead gudgeon (*P.maculatus*) and mosquitofish (*G. holbrooki*). It's possible that these species do not possess the swimming ability to ascend the Warrill Creek v-notch gauging weir under the stream flow conditions experienced during monitoring (low flow).

The capture of eight juvenile eel sp. downstream and none upstream potentially indicates that they are unable to 'climb' past this weir. Eels require wet surfaces away from the main flow to climb obstacles such as man-made barriers and natural waterfalls. The downstream concrete face of the weir comprised wet surfaces, which appear to be suitable for eels to climb. However, to ascend up and over v-notch gauging weirs (Walloon and Warrill Creek DNRM weirs) eels have to first climb the vertical downstream face of the weir, then negotiate fast velocities encountered at the downstream lip of the weir crest (v-notch), and finally swim past or climb over the longitudinal distance of the crest (v-notch). The longitudinal distance of the Walloon v-notch crest is 310 mm. Stream velocity measurements were recorded across the crest to determine velocities fish have to negotiate to ascend past. Stream flow velocity measurements recorded at downstream extent of the crest (lip) were very high, measuring 2.2 m/sec, velocities in the middle of the crest (150 mm in from the downstream edge) were still high (1.7 m/sec), while velocity at the upstream edge of the crest were lower at 0.8 m/sec (Table 2). It's not known if 'climbing' species such as eels are unable to negotiate the 2.2 m/sec experienced at the lip of the v-notch crest or they are unable to negotiate the fast velocities experienced across the longitudinal distance (310 mm) of the v-notch crest or a combination of both. However, it is clear that the Walloon gauging weir is a significant barrier to upstream passage of eels. Interestingly, some eel sp. were able to negotiate the significantly shorter longitudinal crest (~10 mm) of the Warrill Creek sheet pile weir, indicating that the distance of the weir crest (Bremer River and Warrill Creek v-notch weirs) may be the limiting factor in the successful passage of eel sp. past v-notch weirs.

A total of 16 juvenile bullrout (Figure 8) were captured downstream of the weir and none upstream. Bullrout are a sedentary bottom dwelling diadromous fish species, which undertake upstream migrations as juveniles from estuarine environments (Pusey *et al*., 2004). Barriers that block upstream passage, such as the Walloon v-notch gauging weir have the potential to significantly reduce upstream populations of bullrout. The configuration of the v-notch weir crest combined with tailwater pool water level being approximately 80 mm lower than the control of the crest, results in the creation of an air pocket or void as stream flow passes over the crest prior to entering the tailwater pool. It's likely that for fish to successfully ascend they would either need to climb the vertical surface (e.g. eels) or leap over the void (e.g. rainbow fish). Sedentary species such as bullrout may not be able to leap over the air pocket. The impact and extent of the Walloon v-notch barrier on the upstream passage of bullrout is further highlighted by EHMP fish surveys, which have not recorded bullrout upstream of this barrier in over 14 years (25 occasions) of fish monitoring.

Warrill Creek Sheet Pile Weir ('Runnymede')

Location

A sheet pile and rock gabion weir had been previously identified in the lower reaches of Warrill Creek (Figure 9). The barrier is situated approximately 10 km upstream of the Berry's Weir fishway, approximately 8 km upstream of the junction of the Bremer River and Warrill Creek.

Figure 9. Location of Warrill Creek rock gabion and sheet pile weir fish barrier (Imagery: Google Earth)

The barrier consists of a shallow rock gabion basket with a step-up of approximately 400 mm where the rock gabion basket continued for approximately 2 m before reaching the base of the sheet pile. The sheet pile, which extended across the full width of the stream, then rises approximately 350 mm to the head of the upstream water body (Figure 10). In total, the combined sheet pile and rock gabion basket barrier poses a 750 mm (approx.) surface drop barrier.

Figure 10. Close up image of the Warrill Creek sheet pile fish barrier (left), and close up of sheet pile surface showing roughness and algae used by striped gudgeon and eel sp. to climb this barrier (right).

Methods

In order to investigate and determine the extent of impact the barrier has on fish movement, surveys were conducted both above and below the structure to determine any differences in fish communities.

Above the barrier, a fishway trap (Figure 11) was used for sampling. The trap configuration included a single cone entrance. The frame was covered with shade cloth (4.0 mm mesh size. The trap dimensions were 1400 mm x 1000 mm x 1100 mm. Shade cloth wing walls were used to prevent fish from swimming around and underneath the trap, whilst sand bags were used to secure the trap and wing walls in place. The fishway trap was positioned immediately above the barrier was set for a total of 45.25 hours.

Figure 11. Image of fishway trap and wing wall assembly set above the Warrill Creek sheet pile weir

Below the barrier, sampling was performed using a backpack electrofisher unit. The backpack unit utilised was a Smith-Root Model-LR24 backpack electrofisher operating a 300-500 volt pulsed-DC current and a standard pulse setting (1ms). An operator and single dip-netter were employed during all backpacking operations. Sampling protocol involved a series of 'shots' that consisted of altering power-on and power-off periods encompassing all instream habitat types present within the site. Power-on time was recorded to standardize results by Catch Per Unit Effort (CPUE). An operator used a sweeping motion as they moved through the pool and riffle below the barrier while a netter followed behind collecting stunned fish (Figure 12). During electrofishing operations, the observation of uncaptured, positively identified fish were also recorded and included in abundance records.

All fish captured by trapping or electrofishing were identified to species level, counted and measured to the nearest millimetre (fork length for forked-tailed species, total length for all other species). When more than 25 individuals of a single species were captured in any single trapping event, a randomised subset of 25 fish were measured and the remainder only counted to contribute to abundance data. All native fish were then released back to the site of capture, whilst pest fish species were euthanised as per Biosecurity Queensland legislation and ANZCCART procedures and disposed of in an appropriate manner.

Figure 12. Image of backpack electrofisher operator conducting fish community surveys below barrier

Results

After 45.25 hours of trapping above the Warrill Creek sheet pile barrier, only two species were captured including striped gudgeon (*G. australis*) and eel sp. (*Anguilla species*) at an overall catch rate of 2.8 fish per hour (Figure 13). In total, 116 Striped gudgeon and 3 eel sp. were captured at catch rates of 2.7 and 0.07 fish per hour respectively (Table 3).

Table 3. Fish catch results of trapping above Warrill Creek rock gabion basket and sheet pile barrier

Migration Classification	Common Name	Species Name	Total Individuals	CPUE (Fish/hr)
Diadromous	Eel sp.	*Anguilla species*	3	0.07
	Striped gudgeon	*Gobiomorphus australis*	116	2.7
Total Species, Individuals and Overall CPUE		**2**	**119**	**2.8**

Figure 13. Showing juvenile striped gudgeon and eel sp. successful at 'climbing' the sheet pile weir.

Fish monitoring below the sheet pile barrier consisted of 245 seconds of 'power on' backpack electrofishing. A total of nine species were captured (Table 4). The nine species were comprised of four native diadromous (migratory) species, four native potamodromous species and one introduced pest species.

Table 4. Fish catch results of electrofishing below Warrill Creek rock gabion basket and sheet pile barrier.

Migration Classification	Common Name	Species Name	Total Individuals	CPUE (Fish/min)
Diadromous	Sea mullet	*Mugil cephalus*	3	0.52
	Empire gudgeon	*Hypseleotris compressa*	138	24
	Striped gudgeon	*Gobiomorphus australis*	328	57
	Eel sp.	*Anguilla species*	9	1.57
Potamodromous	Unspecked hardyhead	*Craterocephalus fulvus*	1	0.17
	Firetail gudgeon	*Hypseleotris galii*	14	2.43
	Gudgeon sp.	*Hypseleotris species*	1	0.17
	Crimson- spotted rainbowfish	*Melanotaenia duboulayi*	2	0.35
Pest Fish	Mosquito fish	*Gambusia holbrooki*	5	0.87
Total Species, individuals and Overall CPUE		**9**	**501**	**87.13**

Striped gudgeon (*G. australis*) were caught in the highest abundance comprising 328 individuals at a catch rate of 57 fish per minute, followed by 138 empire gudgeon (*H. compressa*), 14 firetail gudgeon (*H. galii*) and 9 eel sp. at catch rates of 24, 2.43 and 1.57 fish per minute respectively. Overall, the combined total catch per unit of all species was 87.13 fish per minute. Diadromous migratory species dominated the catch comprising 95% of the total catch below the barrier (Figure 8).

Figure 14. Showing fish captured below the sheet pile weir, Left: juvenile sea mullet (*M. cephalus*), striped gudgeon (*G. australis*) and empire gudgeon (*H. compressa*). Right:, firetail gudgeon (*H. galii*).

Discussion

Only two (22%) of the nine species monitored directly under the sheet pile weir were captured upstream (striped gudgeon and eel sp.), clearly demonstrating that the headloss (750 mm) of the sheet pile weir is significantly impacting fish passage. Two diadromous species were successful at ascending the sheet pile weir, with striped gudgeon dominating the catch representing 97%. All fish captured were juveniles and sub-adults. Both striped gudgeon and eel sp. undertake migrations as juveniles from downstream estuarine environments to upstream freshwater habitats, with eel sp. in-particular known to penetrate to the very upper headwater reaches of waterways. Furthermore, both of these species are noted 'climbers', and have the ability to crawl up rough, wet surfaces to ascend small barriers such as waterfalls. It is postulated that all individual eels and striped gudgeon captured upstream of the barrier had climbed the wet, algae-coated surface of the sheet pile weir to ascend the barrier and move upstream (Figure 10).

Although striped gudgeon were able to 'climb' the sheet pile weir, it's hypothesised that many more striped gudgeon would be attempting to ascend this barrier and are unsuccessful. This is highlighted when the catch rate of striped gudgeon successfully 'climbing' the sheet pile weir is compared to the catch rate of striped gudgeon successfully ascending Berrys Weir fishway, located approximately 10 km downstream (monitoring of both structures occurred concurrently). Striped gudgeon were captured successfully migrating through the fishway at a rate of 1284 fish per day, compared to just 65 per day at the sheet pile weir, equivalent to 22 fold decrease in numbers at the sheet pile barrier. It must be noted that potentially not all striped gudgeon that migrated through the fishway would endeavour to migrate upstream to the sheet pile weir.

Although striped gudgeon and eel sp. are noted 'climbers', the remaining seven fish species monitored downstream of the sheet pile weir and not upstream, are not known to 'climb'. This potentially explains why these species were not captured upstream. Although only a snapshot, these numbers elude to this barrier posing substantial impacts to the fish communities of Warrill Creek and warrant further investigation and remediation works.

Warrill Creek DNRM Gauging Weir

Location

A DNRM v-notch gauging weir had been previously identified in the lower reaches of Warrill Creek (Figure 15). The barrier is situated approximately 10 km upstream of Berry's Weir fishway, approximately 8 km upstream of the junction of the Bremer River and Warrill Creek and 600 m upstream from the 'Runnymede' sheet pile weir.

Figure 15. Showing the location of the DNRM v-notch gauging weir (Imagery: Google earth)

Methods

Site constraints (water depth) prevented the fish trap from effectively being deployed at this site. In lieu of this, waterproof cameras (Go Pro) were set up at the weir across two consecutive days for a total of three hours. Waterproof cameras were set up parallel with the weir wall facing towards the stream flow exiting through the v-notch, so that any fish successful at either 'leaping' over the weir crest or 'climbing' up the weir wall would be captured on footage.

Results

No fish were captured successfully leaping over the weir crest or climbing the weir wall during camera monitoring. At least two (potentially more) Duboulay's rainbowfish were sighted in the footage unsuccessfully attempting to leap past the weir (Figure 17).

Discussion

A second barrier was identified in Warrill Creek only 600 m upstream of the sheet pile barrier (Figure 16). This concrete v-notch gauging station weir poses similar threats to the sheet pile barrier downstream, restricting upstream passage of juvenile and adult native fish. Surveying was intended to take place on this barrier, however site constraints made surveys difficult. The substantial water depth (≥1.5m) on the upstream side of the weir meant that a fish trap could not be set up successfully i.e. a trap could not be set up to prevent fish from going under or around the trap. In lieu of this, waterproof cameras were set up at the barrier across two consecutive days for a total of three hours.

Figure 16. V-notch gauging station weir identified approximately 600 m upstream of sheet pile barrier

Although the monitoring duration was short, no fish were captured in the footage ascending the barrier. Duboulay's rainbowfish were captured attempting to ascend by 'leaping' towards the water flowing through the v-notch (Figure 16). It is possible that some striped gudgeon and eel sp. are able to ascend this weir. However, unlike the sheet pile weir, where potential 'climbing' fish only have to negotiate a short distance of ~10 mm (sheet pile width) with extremely high velocity (as water shoots past the barrier) the width of the gauging weir is approximately 20 times greater. This distance fish has to travel while negotiating high velocities potentially reduces the likelihood of 'climbing' fish ascending this barrier. Along with the sheet pile barrier, the impacts of this gauging station weir warrant further investigation and remediation works to restore connectivity along Warrill Creek

Figure 17. Showing video footage of Duboulay's rainbowfish attempting to 'leap' past the Warrill Creek gauging weir

While the sampling only provided a brief snapshot of current fish passage at these weirs, the results give valuable insight into the impacts these types of smaller head loss barriers (when compared to dams and large weirs) can have on fish passage and aquatic ecosystem health.

Electrofishing Surveys

Location

Boat-based electrofishing surveys were conducted in order to gain a better understanding of the fish species living within the lower reaches of the Bremer catchment, within accessible reaches upstream and downstream of the Berry's weir fishway surveyed.

Upstream of the fishway, the electrofishing boat was launched into a small off-stream pool where good access was available to launch the boat into the river. Electrofishing surveys were then conducted from the reaches immediately upstream of the fishway, to the survey completion point, where log jams prevented further access upstream. In total, approximately 750 m of river was surveyed The habitat at the upstream site was characteristic of weir pool environments, dominated by deep reaches of stream with relatively low flow. In-stream habitat comprised of fallen trees and log jams, with large sections of open water (weir pool) devoid of habitat complexity (Figure 18)

Figure 18.Stretch of river upstream of the Berry's weir fishway that electrofishing surveys were conducted (Imagery: Google Earth)

Downstream of the fishway, a suitable stretch of river was identified in the lower reaches of the Bremer River close to the city of Ipswich, approximately five kilometres downstream of the fishway. This reach was accessed through a small boat ramp at Shapcott Park in Ipswich, where an approximate 650 m stretch of river was electrofished (Figure 19). The upper extent of the site was characterised by deeper water with a large number of trees on the streambanks providing cover, and also a large number of log jams within the stream. The lower reaches of the site were dominated by in-stream rock bars and shallower, faster moving water. Overall, habitat condition at this site was excellent.

Figure 19. Stretch of river approximately five kilometres downstream of the Berry's weir fishway that electrofishing surveys were conducted, accessed through Shapcott Park (Imagery: Google Earth)

Methods

Electrofishing surveys were conducted using a small boat electrofishing unit (Electrolyte). Electrolyte is a 3.7 m vessel which operates a Smith-Root 2.5 GPP electrofisher unit, equipped with a single boom arm, six dropper anode array and hull cathode. An operator and single dip-netter was utilised during electrofishing operations (Figure 20).

Throughout electrofishing operations settings were adjusted based on electrical conductivity of the water on site to maximise the efficacy of electrofishing operations. Sampling was conducted at various depths and encompassed a variety of in-steam habitats as well as cross-sections of the open water. The electrofishing methodology used was a combination of power on, power off for the duration of the sampling effort. Power-on time was recorded to standardise results by Catch Per Unit Effort (CPUE) if necessary. During the sampling, the boat was manoeuvred in and out from the shoreline as well as parallel to the shore in deeper water. The effective electric field of the unit was approximately between a three and five metre radius (centred on the anode) to a depth of between three and five metres below the water surface.

As the surveying was primarily to assess community assemblages, if fish could be positively identified to species level without being removed from the water, their presence was recorded and they were not brought on board. Any fish brought on board for identification were identified to species level and fork length measurements recorded. All native fish were released immediately after processing back to the site of capture, whilst pest fish species were euthanised as per Biosecurity Queensland legislation and ANZCCART procedures and disposed of in an appropriate manner.

Figure 20. Electrofishing dip- netter extracting stunned fish from the water (left) and an aerated tub of fish on board the vessel after being electrofished (right)

Results & Discussion

Upstream of Fishway

Upstream of the fishway, a total of eight species were surveyed at a catch rate of 5.65 fish per minute, with the catch being comprised of seven native species and one pest fish species (Table 4). Of the eight species, five were diadromous migratory species including Australian bass (*M. novemaculeata*), freshwater mullet (*T. petardi*), long finned eel (*A. reinhardtii*), sea mullet (*M. cephalus*) and striped gudgeon (*G. australis*) (Figure 21).

Of the species surveyed, sea mullet were encountered in the highest abundance at a rate of 4.35 fish per minute. Interestingly, only one individual pest fish, carp (*C. carpio*) was surveyed upstream during electrofishing efforts.

Table 5. Electrofishing catch results upstream of Berry's Weir

Migration Classification	Common Name	Species Name	Total Individuals	CPUE (Fish/min)
Diadromous	Australian bass	*Macquaria novemaculaeata*	1	0.48
	Freshwater mullet	*Trachystoma petardi*	14	0.67
	Long-finned eel	*Anguilla reinhardtii*	3	0.14
	Sea mullet	*Mugil cephalus*	91	4.35
	Striped gudgeon	*Gobiomorphus australis*	1	0.48
Potamodromous	Bony bream	*Nematalosa erebi*	1	0.48
	Crimson-spotted rainbowfish	*Melanotaenia duboulayi*	6	0.29
Pest Fish	Carp	*Cyprinus carpio*	1	0.48
		Total Species and Overall CPUE	**8**	**5.65**

Figure 20. Images from upstream Berry's weir electrofishing (top to bottom, left to right) site images of upstream habitat type, bony bream (*N. erebi*), Australian bass (*M. novemaculeata*), sea mullet (*M. cephalus*), carp (*C. carpio*) and freshwater mullet (*T. petardi*) adult and juvenile.

Downstream of Fishway

Downstream of the fishway, a total of 16 species were surveyed at a rate of 12.34 fish per minute, with the catch comprised of 15 native species and one pest fish species (Table 5). Of the 16 species, six were diadromous migratory species including Australian bass (*M. novemaculeata*), empire gudgeon (*H. compressa*), freshwater mullet (*T. petardi*), long finned eel (*A. reinhardtii*), sea mullet (*M. cephalus*) and striped gudgeon (*G. australis*) (Figure 21). Of the species surveyed, sea mullet were encountered in the highest abundance at a catch rate of 3.08 fish per minute. Only one individual pest fish, tilapia (*O. mossambicus*) was surveyed upstream during electrofishing efforts. Notably, 5 Queensland lungfish (*N. forsteri*) were captured as part of the survey (Figure 22).

Table 5. Electrofishing catch results downstream of Berry's Weir

Migration Classification	Common Name	Species Name	Total Individuals	CPUE (Fish/min)
Potamodromous	Bony bream	*Nematalosa erebi*	39	1.51
	Pacific blue-eye	*Pseudomugil signifer*	2	0.08
	Flathead gudgeon	*Philypnodon grandiceps*	7	0.27
	Queensland lungfish	*Neoceratodus forsteri*	5	0.19
Diadromous	Australian bass	*Macquaria novemaculaeata*	22	0.86
	Empire gudgeon	*Hypseleotris compressa*	44	1.71
	Freshwater mullet	*Trachystoma petardi*	39	1.51
	Long-finned eel	*Anguilla reinhardtii*	17	0.66
	Sea mullet	*Mugil cephalus*	79	3.08
	Striped gudgeon	*Gobiomorphus australis*	11	0.42
Marine Vagrant	Bull shark	*Carcharhinus leucas*	1	0.04
	Dusky flathead	*Platycephalus fuscus*	1	0.04
	Estuary glassfish	*Ambassis marianus*	2	0.08
	Fork-tailed catfish	*Arius graeffei*	4	0.16
	Yellowfin bream	*Acanthopagrus australis*	41	1.60
Pest Fish	Tilapia	*Oreochromis mossambicus*	3	0.12
		Total Species and Overall CPUE	**16**	**12.34**

Figure 21. Showing fish species electrofished during fish surveys downstream of Berrys Weir, Bremer River. Left to right, top to bottom: estuary perchlett, dusky flathead, Yellow-fin bream and Australian bass

Discussion

Results of electrofishing surveys show that twice as many species were surveyed downstream of Berry's weir than upstream of Berry's weir. It is postulated that this is due to the good quality in-stream and riparian habitat features located at the lower site, including; pool, run and riffle sections, snags, rock bars and shade. Whereas habitat at the upstream site above Berrys Weir is dominated by deep open water lentic habitat. Australian native fish communities, including coastal Queensland fish communities contain few species that specialise in living in lentic habitats such as weir pools (Koehn and Kennard, 2013). These habitats tend to favour pest fish such as tilapia and carp and a few native demersal species such as bony bream and fork-tailed catfish and can potentially lead to declines in local riverine fish abundance (Koehn and Kennard, 2013).

Following the river continuum theory, lower reach sites such as Shapcott Park usually contain a greater diversity of habitat types and larger stream size and therefore a greater diversity of fish species. This is evident in the sampling, whereby a high number fish species were recorded at Shapcott Park, including bull shark (*C. leucas*), dusky flathead (*P. fuscus*), estuary glassfish (*A. marinus*), fork tailed catfish (*A. graeffei*) and yellowfin bream (*A. australis*). Although at least two of these species have been recorded successfully ascending Berrys Weir fishway and entering the weir pool site; yellowfin bream and fork tailed catfish, they were not captured at the weir pool site during the current electrofishing surveys. The monitoring results here are consistent with Koehn and Kennard (2013), suggesting a preference of Queensland coastal native fish species for river reaches with pool, run and riffle reaches over open weir pool waterbodies, characterised by a lack of structural habitat complexity and stream flow.

Of particular interest, was the capture of five Queensland lungfish (*N. forsteri*) (Figure 22) which are listed under the EPBC Act (1999) as a vulnerable species, with population declines observed throughout south- east Queensland. Their presence in the Bremer River highlights the diversity of this system and ecological importance of this increasingly urbanised catchment. Other significant captures include the high diversity and abundance of key commercial, recreational and indigenous fishery species including sea mullet, freshwater mullet, Australian bass, Yellow-fin bream , dusky flathead and bull shark. The presence and high numbers of some of these species recorded at Shapcott Park highlights the importance of maintaining free connectivity between saltwater and freshwater habitats.

Figure 22. Showing Queensland lungfish (left) and good quality in-stream habitat located Shapcott Park.

Conclusion

The findings of the current study demonstrate that the 'Runnymede' sheet pile weir on Warrill Creek is significantly impacting fish passage. Approximately 80% of the fish species sampled directly under the weir were not recorded in the fish trap upstream. Additionally, the two species that were recorded in the upstream trap, striped gudgeon and eel sp., possess a unique ability to climb wet vertical surfaces, allowing them to ascend some barriers. The number of these species captured upstream of the weir was relatively low compared to the number observed downstream. If the fish observed below the weir were attempting to move upstream, this may be an indication that the weir is still impeding passage of striped gudgeon and eel sp. This is supported by concurrent fish trap monitoring at Berrys weir fishway, where striped gudgeon was recorded successfully ascending the fishway at a catch rate 1284 fish per day, compared to just 64 striped gudgeon per day successful at ascending the sheet pile weir, which is located only 10 km further upstream.

Site constraints (≥1.5 m water depth) at the DNRM v-notch gauging weir located approximately 600 m upstream from the sheet pile weir prevented fish trap barrier monitoring. Instead a waterproof video camera was set up to record any potential fish that were successful at ascending this barrier. Although the camera was deployed only for a short duration (across 2 days for a total of 3 hours), no fish were recorded successfully ascending the Warrill Creek v-notch gauging weir. Duboulay's rainbowfish were recorded attempting to leap past the barrier, however, the ~750 mm headloss at this site prevented their attempts. Coastal Queensland native fish do not possess the leaping ability of their famous Northern Hemisphere cousins; Atlantic salmon, and it's highly unlikely that fish communities of the Bremer River catchment are able to leap over this barrier.

Although a small number of striped gudgeon and eel sp. were able to 'climb' the downstream sheet pile weir, the different configuration of the upstream v-notch gauging weir potentially prevents these species from successfully ascending (climbing). The longitudinal crest distance (thickness) of the sheet pile weir was approximately 10 mm, whereby fish that are able to climb the vertical face only have to negotiate a small distance (10 mm) of extremely high velocity to reach the upstream pool. The longitudinal crest distance (thickness) of the upstream v-notch gauging weir is approximately 15-20 times greater, potentially reducing the chance of fish that are successful in climbing the vertical face of negotiating this distance and associated high velocities. Although striped gudgeon and eel sp. are proficient 'climbers' they are extremely susceptible to high velocities, particularly juveniles, which comprised 100% of those fish captured upstream of sheet pile weir. Furthermore, site conditions at the Bremer River v-notch gauging weir allowed for the fish trap to be set upstream and downstream of this barrier, providing valuable information that can be used to evaluate certain aspects of the Warrill Creek v-notch weir, particularly fish climbing ability.

Upstream and downstream fish trap monitoring results at the Bremer River v-notch gauging weir showed that eight eel sp. were captured below the weir, and no eel sp. were captured in the fish trap above the weir. This provides an indication that the configuration of this v-notch weir, and potentially other v-notch weirs with a similar configuration (e.g. Warrill Creek v-notch weir), contain adverse conditions which may prevent or restrict 'climbing' species, such as eels, from successfully ascending. It is likely, that the longitudinal weir crest distance and associated high velocity encountered over this distance (2.2 m/sec on the downstream lip, 1.7 m/sec in the centre and 0.8 m/sec on the upstream edge) is the limiting factor for successful fish passage of 'climbing' species.

The findings of the current study demonstrate that the Bremer River v-notch gauging weir at Walloon is severely impacting fish passage within the Bremer River catchment. Although eight species were able to ascend the barrier in low abundance (during low flow conditions), five species were not, including economically important eel sp., and bullrout, agassiz's perchlett, dwarf flathead gudgeon and mosquitofish. Furthermore, the catch rate of fish downstream of the weir (35.4 fish/hour) was more than eight times higher than upstream (4.33 fish/hour), further highlighting the impact of this weir on fish passage.

The high number of fish species recorded during fish community boat electrofishing at Shapcott Park in the lower reaches of the Bremer River highlight the importance of well-connected river reaches with good in-stream and riparian habitat. A number of notable captures occurred at this site. Of particular interest, was the capture of 5 Queensland lungfish (*N. forsteri*) (Figure 22) which are listed under the EPBC Act (1999) as a vulnerable species, with population declines observed throughout south- east Queensland. Their presence in the Bremer River highlights the diversity of this system and necessity to continue improving connectivity, in-stream habitat and water quality. Other significant findings include the capture of 39 freshwater mullet, which are currently under consideration to be included as a listed fish species under the EPBC Act (1999). Freshwater mullet populations have undergone significant declines in abundance and distribution along the entire east coast Australian seaboard. The presence and number of freshwater mullet encountered in the Bremer River indicates that this population may be extremely important to the sustainability of this species in south-east Queensland (SEQ).

The presence and relatively high numbers of key recreational species; Australian bass, Yellow-fin bream, sea mullet, freshwater mullet, dusky flathead and bull shark recorded at Shapcott Park potentially indicates that habitat and water quality at this location is in good condition. The presence of these species is a great result for local recreational anglers. Notably, many of the Yellow-fin bream captured at this site were juveniles, indicating that they are potentially using this habitat as a nursery area. Although high numbers of Australian bass were captured (22) at Shapcott Park, they were all mature fish. The absence of juvenile Australian bass at this site, at Berrys Weir fishway and upstream of Berrys Weir indicates that recruitment of wild Australian bass is poor or not occurring at all. These findings align with fishway and boat electrofishing monitoring that has occurred at several other south-east Queensland waterways over the last few years (Catchment Solutions unpublished. Data), which have all failed to record a single juvenile wild Australian bass. It potentially appears the occurrence of Australian bass in SEQ waterways is a direct result of stocked fish that have escaped over dams such as Moogerah, Wivenhoe, Somerset, North Pine and Hinze. The instinct to breed and the necessity to reach estuarine waters for this to occur means that thousands of Australian bass escape over dams during overtopping events, and due to barriers, are unable to access these dams after spawning, and therefore remain in lower river reaches such as the Bremer River at Shapcott Park.

Recommendations

1. Undertake a combined fish passage options assessment at:
    - Warrill Creek sheet pile weir (Runnymede) barrier
    - Warrill Creek DNRM v-notch gauging weir barrier

Fish passage options assessment to include identifying the owner/s of both structures, appetite to remove and/or retro-fit fish passage structures at these sites, most suitable fishway design including a cost/benefit analysis and LiDAR analysis to determine extent of sheet pile weir pool. It is recommended that the fish passage options assessment at these two sites occurs at the same time. Any remediation works that occur at the first barrier upstream (sheet pile weir) such as removal and/or construction of rock ramp fishway, may impact the DNRM v-notch gauging weir located only 600 m upstream.

2. Undertake a fish passage options assessment at the Bremer River DNRM v-notch gauging weir barrier.

Fish passage options assessment to include identifying structure owner, appetite to remove and/or retro-fit fish passage structures at this site, and most suitable fishway design including a cost/benefit analysis.

Combined fish passage options assessment at the two Warrill Creek fish barriers should be prioritised over the Bremer River v-notch weir. Results from the current study suggest that these barriers are having a greater impact on Bremer River fish communities. Warrill Creek also appears to contain a greater amount of fish habitat, and may be more important for the conservation of endangered Mary River Cod.

3. Investigate the health of endangered Mary River Cod populations throughout the Bremer River catchment, including signs of recruitment.

Surveys to be undertaken using boat electrofishing methods in order to effectively monitor deep pool snag habitats where Mary River Cod reside. Surveys to encompass all fish communities to investigate any changes in Bremer River catchment fish community health since the inception of Berrys Weir fishway. Project to include local community component to raise awareness of endangered Mary River Cod populations within the Bremer.

4. Raise local community awareness regarding the impact of fish barriers on aquatic ecosystem health, and the benefits of improving aquatic connectivity (This recommendation could be undertaken in-conjunction with recommendation 3. above)

Focus on endangered Mary River Cod and other key recreational fish species such Australian bass, sea mullet, freshwater mullet, Yellow-fin bream and jungle perch. Promote linkages with improving water quality and habitat with increased fish populations. Encourage the local community to become more involved with local waterways to grow and foster ownership within the community.

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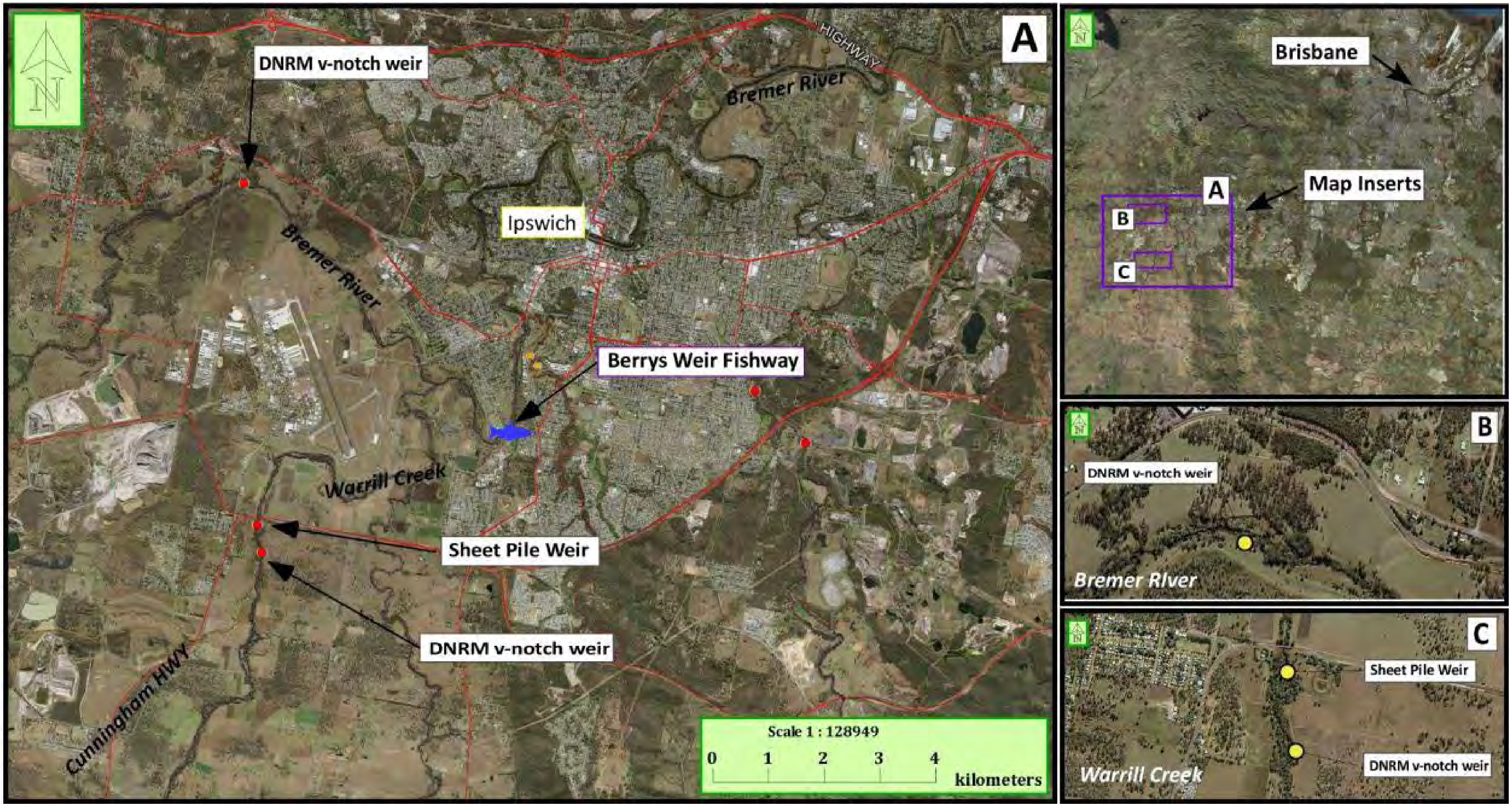
A
DNRM v-notch weir
HIGHWAY
Bremer River
Ipswich
Bremer River
Berrys Weir Fishway
Warrill Creek
Sheet Pile Weir
DNRM v-notch weir
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Scale 1 : 128949
0 1 2 3 4
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Bremer River
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Warrill Creek