



# Audit and prioritisation of physical barriers to fish passage in the Wet Tropics region

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## Abstract

Barriers to fish passage, such as flood mitigation, drainage structures, and extensive road, rail and canal networks, can have a significant impact on native fish assemblages. We identified artificial physical barriers in the Wet Tropics bioregion, Far North Queensland, Australia, through a desktop GIS analysis of the stream/river and transport networks. A total of 5,536 potential artificial, physical barriers to fish passage were identified in a stream network of 19,764 km at a scale of 1:100 000. The Mulgrave (1,076) and Johnstone (1,069) basins contained the highest number of potential barriers, whilst most potential barriers comprised road crossings (66%) and cane rail crossings (18%). Due to the unavailability of consistent datasets at smaller scales, we have not identified artificial physical barriers smaller than 50 m. Hence it is very likely that the total number of potential barriers to fish passage in the region is many times higher. We subsequently prioritised the 5,536 potential barriers, to identify those barriers that will provide the greatest habitat value for native fish species when removed and/or mitigated. A total of 104 potential barriers were identified as high priority for rehabilitation, with the Daintree (32), Mossman (19) and Mulgrave (17) basins having the highest numbers. We recommend that the high priority status and attributes of these 104 barriers be verified on-ground, and that rehabilitation of barriers be experimentally examined as a management strategy to improve native fish movement and reduce invasive fish abundance in the Wet Tropics region.

## Introduction

Modification and alienation of significant aquatic habitat areas, including the construction of barriers to fish passage, can have a significant impact on native fish assemblages. Barriers to fish passage have been well described, and are known to affect migration of fish and invertebrate species (Pollard and Hannan 1994, Halls *et al.* 1998, 1999, Kroon and Ansell 2006). If adults are prevented from moving past a barrier, spawning migrations may be affected, whilst migration to nursery habitats may be affected if juveniles cannot move past a barrier. As a result, the capacity of habitats beyond the barrier to act as spawning or nursery areas may be reduced, with potential effects on population genetics and dynamics, including stock size. Moreover, physical barriers to fish passage may promote growth of growth of invasive macrophytes and fish (Moyle and Light, 1996a, b; Lozon and MacIsaac, 1997) through obstructing natural flow patterns.

In Australia, at least 50% of commercial and recreational target species undertake migrations to and from the sea (Kailola *et al.* 1993), and could be exposed to physical movement barriers. The Wet Tropics bioregion of Far North Queensland, Australia (Figure 1) contains 78 (40%) of Australia's 190 freshwater fish species (Pusey and Kennard 1996), with many of these species undertaking migrations (Pusey *et al.* 2004). The Wet Tropics bioregion also contains six non-native fish species, whilst at least 13 other non-native fish species have been reported from areas adjacent to this region (Poon *et al.* 2006).

Since European settlement, much of the Wet Tropics bioregion, particularly the coastal lowlands, has been cleared and developed for urban and agricultural land uses. This has included the construction of potential barriers to fish passage, such as flood mitigation, drainage structures, and extensive road, rail and canerail networks. Barriers to fish passage have been audited for rehabilitation in several other regions of eastern Australia (NSW: Gordos *et al.* 2007, Williams and Watford 1997; Mackay Whitsunday: Marsden *et al.* 2006; Burdekin Dry Tropics: Carter *et al.* 2007) but not in the Wet Tropics. The absence of such an audit will hamper rehabilitation efforts of aquatic ecosystems and fisheries stocks in the bioregion.

The aim of this study is to identify and prioritise potential artificial barriers to fish passage in the Wet Tropics bioregion.



> Figure 1. Location of the Wet Tropics region, in relation to Australia. The 10 basins considered in our study are labelled.

Here, we focus on artificial, physical barriers, and do not consider hydraulic, chemical or behavioural obstructions. Moreover, we do not consider natural barriers such as waterfalls, rapids and aquatic macrophyte beds. To identify artificial physical barriers, we conducted a desktop GIS analysis of the stream/river and transport networks in the Wet Tropics bioregion. We then prioritised and ranked the identified barriers, using several criteria, based on the value of habitat upstream of individual barriers. This prioritisation will contribute to identifying those barriers that will provide the greatest habitat value for native fish species when removed and/or mitigated.

# Methods

## Study Area

The study area encompassed the Wet Tropics bioregion (the 'region') of Far North Queensland, Australia (Figure 1). This region is a hotspot of biodiversity for both plants and animals (Stork and Turton 2008), and contains 41% (78 of 190) of Australia's freshwater fish species. The Wet Tropics World Heritage Area (WTWHA) protects an area of 2,700 km<sup>2</sup> in the Wet Tropics bioregion, and contains Australia's largest continuous area of rainforest (Tracey 1982). Here, we used the administration extent of the regional Natural Resource Management body (Terrain NRM) as the boundary (Figure 1). The Terrain NRM administration area covers 2 222 094 km<sup>2</sup> and contains 10 basins.

## Audit of potential barriers to fish passage

To conduct the GIS analysis of potential artificial, physical barriers in the Wet Tropics region, we used streams/rivers, transport (roads and rail), documented barrier points, and land use area to identify potential barriers. All GIS work (except for the stream network) was conducted using ArcGIS 9.3. Mathematica was used to convert output text files to comma delimited files that could be read back into ArcGIS 9.3.

### Stream network

Readily available streams/rivers networks for the region did not contain any flow direction or accumulation information. We created a stream layer (scale 1:100 000) with directional flow and accumulation information using the following processes in ArcHydro Tools for ArcGIS 9.3 (Merwade 2009):

- Digital Elevation Model (DEM) Reconditioning – this burns linear features to a DEM. As many raw DEM's lack elevation data, this process was used to burn a stream layer to the raw DEM so as to create a distinct path along the streams that is not present in the raw DEM.
- Fill Sinks – This tool looks for cells where a cell is surrounded by cells of higher elevation; water cannot flow through this lower elevation. This tool rectifies this problem.
- Flow Direction – This tool generates a direction for a cell based on the steepest descent from that cell as this is the direction in which water will flow.
- Flow Accumulation – This tool accumulates the number of cells upstream of a cell that contributes to that cell's water flow. Thus, the number of cells that contributes to the flow of a particular cell increases further downstream.
- Stream Definition – This tool is used to define a stream bed. A threshold value is used to define the catchment area for stream delineation. The larger the threshold the coarser the stream layer. For this project, to get a stream network consistent with a 1:100 000 scale dataset a threshold of 0.01 was used.

- Stream Segmentation – This tool defines the different segments of a stream/river and gives them a unique identifier (ID). For example, this tool identifies parts of the stream length as a head segment or a segment between two segment junctions.
- Drainage Line Processing – This tool converts the newly created stream/river grid from above stream segmentation into a drainage line feature class.

Next, we converted the stream/river feature class into a landscape network (LSN). This allowed us to measure distances along the stream/river route between points, as well as the head of a stream/river and the coast. Building the LSN and subsequent analysis of the LSN was done using the Functional Linkage of Water Basins and Streams (FLoWs) toolbox for ArcGIS 9.3.

To build the stream network, we used the Polyline to LSN tool. To check the topology of the network for errors, we used the Check network topology tool and analysed the resulting topology error file. Errors may occur where a junction between streams is not linked, where the outlet point has been identified incorrectly or where the flow has been digitised incorrectly. Once these processes were completed we had a stream/river network suitable for analysis.

### Transport

To identify potential artificial physical barriers to fish movement, we examined where transport lines crossed a stream/river. To create a transport layer, road, rail and cane rail layers were merged. This transport layer was then intersected with the stream/river network and the resulting layer showed potential barriers in the form of bridges, culverts, causeways, etc.

### Documented artificial, physical barriers

Where available, we included data on documented barrier locations from local councils and other organisations. To ensure compatibility with our own data layers, we only used those locations that were mapped at a scale equal to or larger than 1:100 000. These documented locations were merged with the potential barriers identified from the transport/stream network intersection to produce an overall "barriers" layer.

### Land use

The "barrier" layer was subsequently clipped to the land use area (using Queensland Land Use Mapping Program (Q-Lump)) within the Wet Tropics bioregion. Q-Lump used Landsat TM and ETM+ imagery along with aerial photography to decipher between different land use types. As the extent of the land use area was smaller than the original study area, barriers outside the land use area were removed (mostly in the upper Herbert basin). The resulting layer, renamed "All\_Barriers", was subsequently taken into the LSN.

## Total number of potential barriers

The “All\_Barriers” layer contained all points where a road, rail or cane rail line crosses a stream/river. However, not all these crossings will be barriers. We assumed that crossings over a Strahler stream order of 6 or more, and where a road is part of a highway network, are unlikely to be barriers to fish passage, as these are generally large structures over wide rivers that leave much of the river flow intact. We computed Strahler Stream Order on the network using FLoWs tools, and removed potential barriers being a highway across stream/river with a stream order of 6 from the analysis.

## Prioritising potential barriers

To prioritise the large number of potential artificial, physical barriers identified in the desktop analysis for management, we ranked the identified barriers based on the value of habitat upstream of individual barriers. Our prioritisation was based on Carter *et al.* (2007), and chosen over other methods (e.g. Marsden *et al.* 2006) for the following reasons: (i) access to available datasets, (ii) study area size, (iii) diverse number of barrier types, and (iv) availability of site based information. Carter *et al.* (2007) prioritise barriers according to fish values, habitat values and threats. Due to a lack of spatial information on fish values and threats in the Wet Tropics region, we prioritised potential barriers based on habitat values only.

Based on data availability in the region, we included the following habitat values based on Carter *et al.* (2007):

- Upstream habitat quality (Land use as a surrogate for river condition),
- Stream Order,
- Position of barrier in basin,
- Distance to next barrier upstream,
- Uninterrupted stream length upstream (including tributary drainages), and
- Presence/absence of downstream barrier.
- Due to lack of information, we did not use the following habitat values:
- Upstream habitat quantity (Perennial water in Ha),
- Upstream habitat quantity (Ephemeral water in Ha), and
- Proximity to downstream aquatic refugia (where aquatic habitat above barrier is non-perennial).

Based on Carter *et al.* (2007), all habitat values were weighted using scores in a 0 to 100 system. 0 was given to the most undesirable situation, while 100 was given to the most desirable situation; 1 and 10 were used as low and medium scores, respectively. Please see Carter *et al.* (2007) for more detailed information.

## Upstream habitat quality (Land use as a surrogate for river condition)

Upstream habitat quality was scored using the Q-Lump data. Land use was divided into the categories including: protected areas, state forest, timber reserves, plantations, wetlands, rural residential, residential, and various agricultural uses (Table 1). Potential barriers were subsequently scored according to the Q-Lump score based on upstream land use. Barriers with marsh/wetland, nature conservation or water above them were scored high, whilst those with urban and agricultural land uses were scored low, with forestry scored medium (Table 1).

## Stream order

Stream Order was calculated in the FLoWs tool, which populates each stream/river reach within the feature class in Strahler stream order. In contrast to Carter *et al.* (2007), we did include barriers on 1st order streams in our scoring and prioritisation. Barriers on a 5th order stream were scored high, whilst those on 1st and 2nd order were scored low, with others intermediate (Table 2).

## Position of potential barrier in basin

The position of each potential barrier in a basin was assessed by estimating the proportion of upstream length of the total stream length. Barriers with >80% of stream length above them were scored high, whilst those with 0-25% were scored low, with others intermediate (Table 3).

> Table 1. Scores of QLUMP land uses classes upstream from potential artificial, physical barriers in the Wet Tropics region.

Value	Description	Score
High	Marsh/wetland, Nature Conservation, water	100
Medium	Forestry	10
Low		1
None	Grazing, Irrigated Cropping, Services, Manufacturing and Industrial, Horticulture, Sugar, Aquaculture, Intensive animal production, Residential, Rural residential and other uses	0

> Table 2. Scores of stream orders within which potential artificial, physical barriers are located in the Wet Tropics region.

Value	Description	Score
High	5th Order	100
Medium	4th Order	10
Low	3rd Order	1
None	1st and 2nd Order	0

### Distance to next potential barrier upstream

Distance to next potential barrier upstream was calculated in FLoWs using the 'Upstream Only Distance' tool. This tool produces an asymmetric matrix file showing upstream distances between points. Barriers with >100 kms of stream length to next barrier upstream were scored high, whilst those with <10kms were scored low, with others intermediate (Table 4).

### Un-interrupted stream length upstream

Un-interrupted stream length upstream from potential barriers, including all tributary drainages upstream, was also analysed with the 'Upstream Only Distance'. Barriers with >1,000 kms of stream length above them were scored high, whilst those with <500 kms were scored low, with others intermediate (Table 5).

> Table 3. Scores of position of potential artificial, physical barrier in a catchment's stream network in the Wet Tropics region.

Value	Description	Score
High	>80% of stream length above the barrier in relation to the total stream length	100
Medium	50 – 80% of stream length above the barrier in relation to the total stream length	10
Low	25 – 50% of stream length above the barrier in relation to the total stream length	1
None	0 – 25% of stream length above the barrier in relation to the total stream length	0

> Table 4. Scores of distance to next potential artificial, physical barrier upstream in the Wet Tropics region.

Value	Description	Score
High	>100 kms	100
Medium	50-100 kms	10
Low	10-50 kms	1
None	<10 kms	0

> Table 5. Scores for un-interrupted stream distance upstream from potential artificial, physical barriers in the Wet Tropics region.

Value	Description	Score
High	>1 000 kms	100
Medium	500-1 000 kms	10
Low		1
None	<500 kms	0

### Presence/absence of downstream barrier

The presence/absence of a downstream barrier criterion was modified from Carter *et al.* (2007), since we could not differentiate between partial or complete barriers and did not analyse natural barriers. Therefore, we only measured presence and absence of barriers regardless of structural attributes of the barrier. We used the 'Downstream Only Distance' tool in FLoWs to identify the presence of a downstream barrier. Barriers with no barriers downstream were scored high, whilst those with a barrier downstream were scored low (Table 6).

### Ranking of all potential, artificial barriers based on habitat value scores

Once all the habitat values were scored, a new field was added to the barrier attribute table 'total\_score'. This field was populated with the sum of all the scored values. This total score gave each barrier a score out of a potential 600. Another new field 'Priority' was then added to the attribute table and barriers were ranked from highest to lowest score. This ranked the barriers from those with the highest habitat value upstream (i.e. the highest 'total\_score') to those with the lowest habitat value upstream (i.e. the lowest 'total\_score'), with others intermediate (Table 7).

> Table 6. Scores for presence/absence of barrier downstream from potential artificial, physical barrier in the Wet Tropics region.

Value	Description	Score
High	Absence of downstream barrier	100
Medium		10
Low		1
None	Presence of downstream barrier	0

> Table 7. Ranking scheme for potential artificial, physical barriers in the Wet Tropics region.

Total Score	Rank	Priority
501 – 600	1	High
401 – 500	2	High
301 – 400	3	Medium
201 – 300	4	Medium
101 – 200	5	Low
0 – 100	6	Low

# Results

## Audit of potential barriers to fish passage

### Stream network

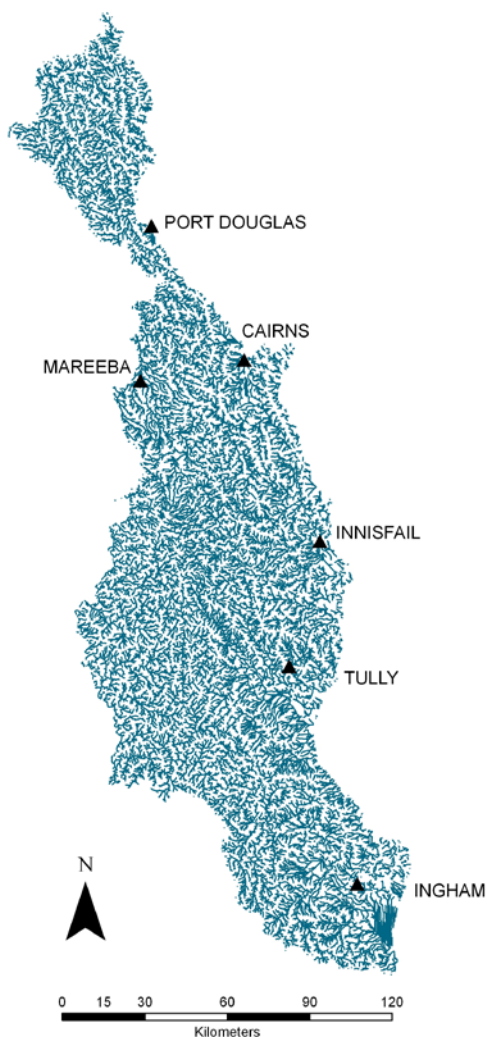
In the Wet Tropics region, we estimated a total stream network length of 19,764 km at a scale of 1:100 000 (Table 8, Figure 2). The Herbert basin contains by far the most of this stream network (7,245 km), followed by the Johnstone (2,384 km), Barron (2,332 km) and Mulgrave-Russell (2,041 km). The Endeavour is the basin with the shortest stream network (81 km).

### Intersecting transport and stream network

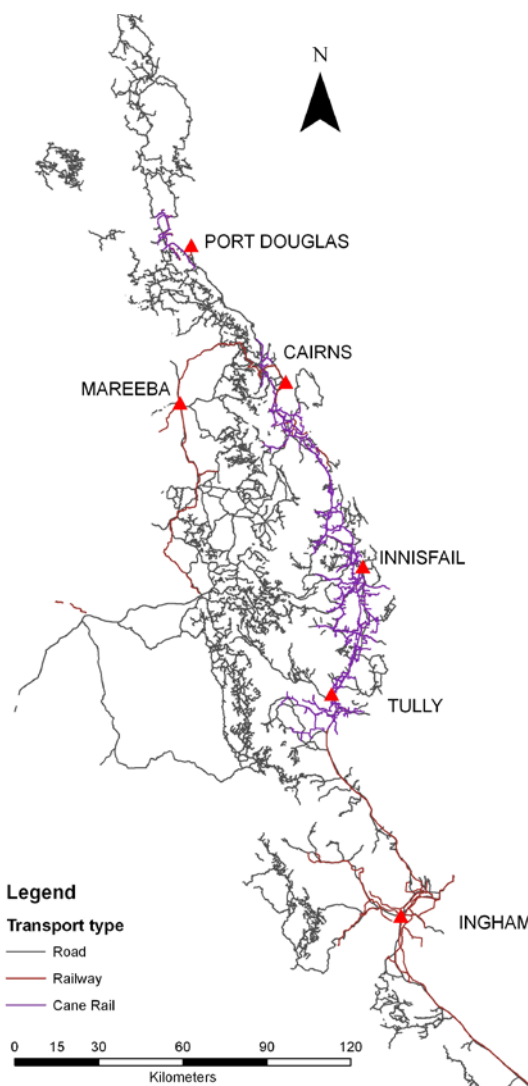
When intersecting our stream network (Figure 2) with the transport (road, rail and cane rail) network (Figure 3), we identified 5,591 potential artificial, physical barriers to fish passage.

> Table 8. Total number of potential artificial, physical barriers and total stream length in each of the Wet Tropics basins, and in the Wet Tropics region as a whole.

Basin	Number of barriers	Total stream length (km)
Barron	837	2,332
Daintree	377	2,198
Endeavour	34	81
Herbert	867	7,245
Johnstone	1,069	2,384
Mossman	233	470
Mulgrave-Russell	1,076	2,041
Murray	309	1,218
Tully	734	1,795
<b>TOTAL</b>	<b>5,536</b>	<b>19,764</b>



> Figure 2. Wet Tropics stream network at a scale of 1:100,000. Note that the upper Herbert has been removed from our analyses due to un-availability of land use maps.



> Figure 3. Wet Tropics transport network at 1:100,000. Road, rail and canerail each with different lines (either differently dashed, or different colours).

### Documented artificial, physical barriers

An additional 2,422 documented barrier points were supplied by other organisations, including Cairns City Council and the Herbert Resource Information Centre. When clipped to our study area, 74 of these points were removed as they were outside of the boundary extent. Of the remaining 2,348 known barriers, 1,645 were mapped at a scale smaller than used in our study, and/or did not map onto any stream/ rivers in our stream network, and were excluded. Of the remaining 703 known barriers, 243 did not fall within 200m of the stream/river network, and were also removed from our analysis. This left a total of 460 documented barriers (Figure 4).

### Land use

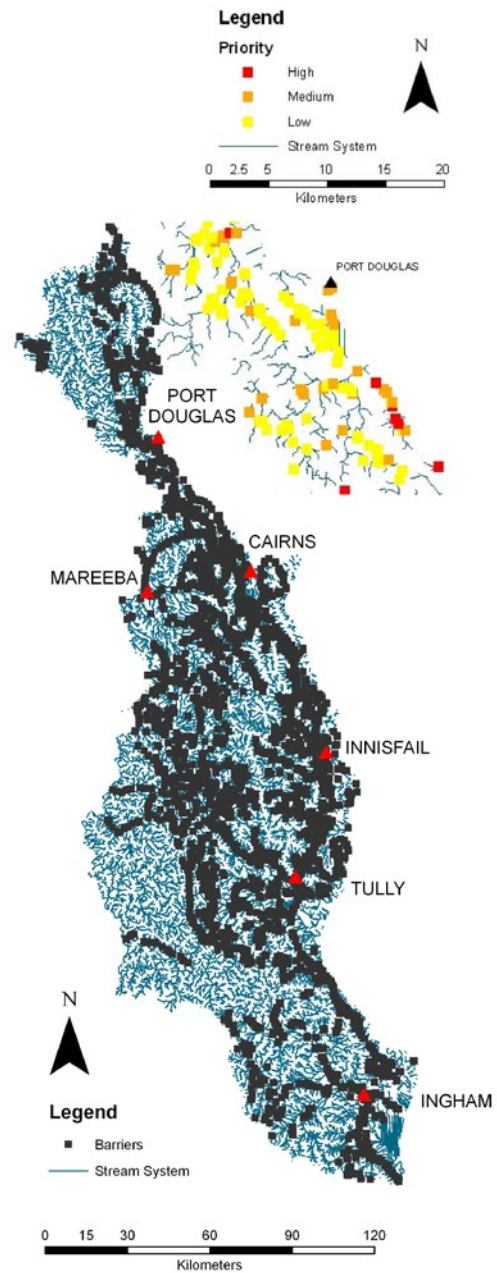
We removed another 515 potential barriers as they fell outside the extent of the land use data for the Wet Tropics region.

### Total number of potential artificial, physical barriers

We conducted our analysis on a total of 5,536 potential barriers. The Mulgrave basin has the highest number of potential fish barriers (1,076), closely followed by the Johnstone basin (1,069), whilst the Endeavour basin has the lowest number (34) (Table 8). The largest basin in the Wet Tropics, the Herbert, has 867 potential barriers within its extents. By far the most of these potential barriers consisted of road crossings (3,629), followed by cane rail crossings (1,016), whilst only two weirs were identified (Table 9).

> Table 9. Total number of potential artificial, physical barrier within each feature type in the Wet Tropics region.

Feature Type	Number
Dam	60
Road	3,622
Railway	826
Weir	2
Cane Rail	1,016
Culvert	10
<b>TOTAL</b>	<b>5,536</b>



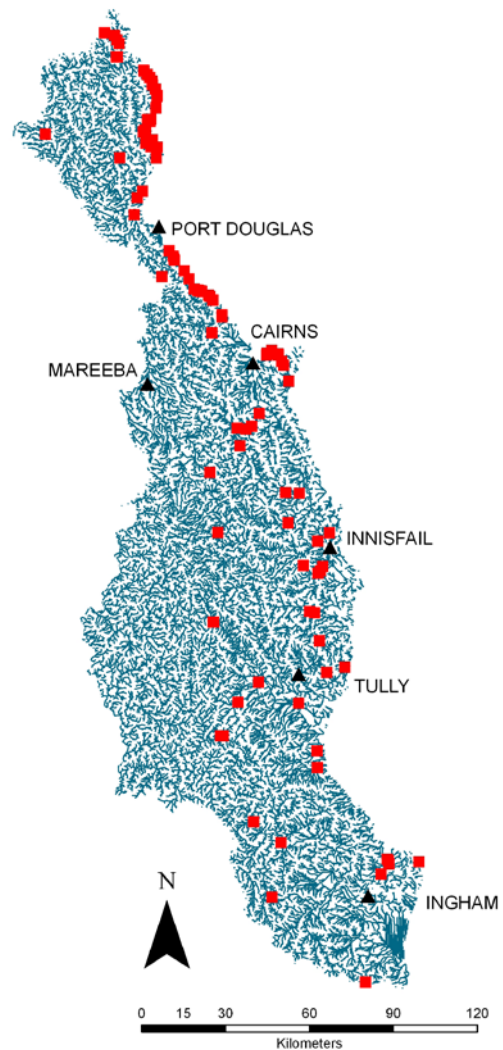
> Figure 4. All potential artificial, physical barriers identified in the Wet Tropics region, with a zoom-in showing an area with three different barrier priorities (high, medium and low).

## Prioritising potential barriers

Based on our ranking and prioritisation of barriers using habitat values, we identified a total of 104 potential barriers as high priority for rehabilitation (Appendix 1, Figure 5), 1 476 as medium, and 3,957 as low priority (Table 10). The Daintree basin has the highest number of high priority potential barriers (32), followed by the Mossman basin (19) and the Mulgrave-Russell (17), whilst the Barron has the lowest number (2). The largest basin in the Wet Tropics, the Herbert, has 10 high priority potential barriers within its extents.

> Table 10. Total number of high, medium and low priority artificial, physical barriers in each of the Wet Tropics basins, and in the Wet Tropics region as a whole.

Basin	High	Medium	Low
Barron	2	181	654
Daintree	32	123	222
Endeavour	4	11	19
Herbert	10	256	601
Johnstone	10	298	761
Mossman	19	51	163
Mulgrave-Russell	17	224	835
Murray	3	105	201
Tully	6	227	501
<b>TOTAL</b>	<b>103</b>	<b>1,476</b>	<b>3,957</b>



> Figure 5. All high-priority, potential artificial, physical barriers identified in the Wet Tropics region at a scale of 1:100,000.

## Discussion

Our desktop study identified a total of 5,536 potential barriers to fish passage in the Wet Tropics region. These barriers included artificial, physical barriers and do not include natural barriers, such as waterfalls, or other artificial barriers, such as hydraulic, chemical or behavioural barriers to fish passage. Moreover, as we identified potential barriers at a scale of 1:100,000 we would have missed any potential barrier smaller than 50 m. For example, we removed 1,645 documented barriers from the Cairns City Council data, as these were mapped at scales smaller than used in our study (i.e. 1:50,000 or 1:25,000). Hence, it is very likely that the total number of potential barriers to fish passage in the Wet Tropics region is many times higher than those identified in this study.

Our audit of potential barriers to fish passage was influenced by (i) the spatial scale of datasets required, (ii) the availability of relevant datasets, and (iii) temporal inconsistencies amongst datasets. First, due to the limited availability of required datasets at a scale of 1:50,000 or 1:25,000 across the Wet Tropics region, our audit focussed on identifying larger potential barriers. Secondly, relevant datasets were not always available in consistent format across the Wet Tropics region. In particular, datasets on known barriers, such as dams, weirs, floodgates, etc, were non-existent, not available or not consistent across councils and other organisations. This most likely has resulted in a bias in our audit towards those basins where information was (made) readily available. Thirdly, temporal inconsistencies amongst datasets most likely resulted in the mis-match of 243 known barrier points with a stream/river. Given the significant impact even small artificial physical barriers can have on fish passage (e.g. tidal floodgates; Pollard and Hannan 1994; Kroon and Ansell 2006), we recommend that our audit be completed by identifying these smaller physical barriers *and* the accurate location of mis-matched larger barriers, using detailed air photography or satellite imagery combined with extensive field surveys.

We identified a total of 104 potential barriers as high priority for rehabilitation, based on upstream habitat values for native fish species. About 50% of these were located in the northern basins of the Wet Tropics region, including the Daintree and Mossman basins. It is likely that the priority ranking of these barriers will change with the inclusion of more detailed information on fish values, habitat values and threats (Carter *et al.* 2007), or other prioritisation systems (Marsden *et al.* 2006). Until such spatial information is readily available, we recommend that (i) the high priority status and attributes of these 104 barriers is verified on-ground, and (ii) rehabilitation efforts are focussed on confirmed high priority barriers.

Barriers to fish passage restrict or prevent movement by native species (e.g. Katano *et al.* 2006, Lasalle *et al.* 2009), and can result in declines in fisheries production and catches (e.g. Sultana and Thompson 1997; Halls *et al.* 1998, 1999). In Australia, at least 50% of commercial and recreational target species undertake migrations to and from the sea (Kailola *et al.* 1993), and could be exposed to movement barriers. In addition, barriers generally provide a low flow environment that can be conducive to invasion by exotic fish species (Moyle and Light, 1996a, b; Lozon and Maclsaac, 1997). On the other hand, rehabilitation of barriers, such as frequent opening of tidal floodgates, improves passage of juveniles of native fish and prawn species, whilst significantly reducing the abundance of the invasive *Gambusia holbrooki* (Kroon *et al.* 2004, Boyds *et al.* 2009). Hence, we propose that rehabilitation of barriers be experimentally examined as a management strategy to improve native fish movement and reduce invasive fish abundance in the Wet Tropics region.

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