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Frederieke J Kroon
Australian Institute of Marine Science

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Short Communication

Identification of human-made physical barriers to fish passage in the Wet Tropics region, Australia

Frederieke J. Kroon[A,C] *and Seonaid Phillips*[B]

[A]CSIRO Ecosystem Sciences, PO Box 780, Atherton, Qld 4883, Australia.
[B]CSIRO Land and Water, PO Box 780, Atherton, Qld 4883, Australia.
[C]Corresponding author. Present address: Australian Institute of Marine Science, PMB 3, Townsville, Qld 4810, Australia. Email: f.kroon@aims.gov.au

Abstract. Human-made physical barriers to fish passage were identified in the Wet Tropics region, Far North Queensland, Australia, through a desktop GIS analysis of the stream and transport networks. A total of 3748 of such potential barriers, comprising bridges, culverts and causeways, were identified in a stream network of 18 363 km at a scale of 1 : 100 000. These records provide a first step for a complete barrier inventory and assessment for this region, which can be used to prioritise potential barriers for removal and remediation to improve native fish movement and fisheries production.

Additional keywords: bridges, causeways, connectivity, culverts, flow regime, migration.

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Introduction

Barriers to fish passage restrict or prevent movement by native species (Katano *et al.* 2006; Lassalle *et al.* 2009; Eberhardt *et al.* 2011), and can result in declines in fisheries production and catches (Sultana and Thompson 1997; Halls *et al.* 1998, 1999). Human-made barriers can comprise physical (e.g. dams (Lovett 2014), floodgates (Kroon and Ansell 2006)), hydraulic (e.g. high velocity flow, Vowles *et al.* (2014)), chemical (e.g. acid sulphate soil discharge, Kroon (2005)), and behavioural (e.g. light availability, Vowles *et al.* (2014)) obstructions. Management of physical barriers to improve fish passage includes their complete removal such as the dismantling of large dams (Lovett 2014), or remediation such as the replacement of undersized culverts with larger ones (Eberhardt *et al.* 2011) or limited opening of tidal barriers (Boys *et al.* 2012; Mouton *et al.* 2014).

The identification of potential fish barriers is an important and logical first step in prioritising barriers regarding their effect on fish passage and subsequent management. Field surveys and small-scale topographic maps have been used to identify potential barriers (Williams and Watford 1997; Gordos *et al.* 2007; Gargan *et al.* 2011). These techniques are generally complemented with geographical information system (GIS) to interrogate available georeferenced data layers such as dam databases as well as drainage and road network data layers, to identify potential barriers in stream networks (Gordos *et al.* 2007; Gargan *et al.* 2011; Januchowski-Hartley *et al.* 2013). GIS is particularly useful for establishing systematic inventories of potential barriers at large scales (Januchowski-Hartley *et al.* 2013), including in remote areas that are difficult to access. The potential barriers identified can subsequently be assessed in more detail in the field to obtain structural and environmental data for inclusion in a prioritisation process (Williams and Watford 1997; Gordos *et al.* 2007; Kemp and O'Hanley 2010).

The Wet Tropics region of Far North Queensland, Australia (Fig. 1) is a hotspot of biodiversity for both plants and animals (Stork and Turton 2008), and contains the greatest fish diversity of any region in Australia (Allen *et al.* 2003; Pusey *et al.* 2004). More than 130 native fish species have been recorded from its freshwater habitats, comprising potamodromous, diadromous, estuarine, and marine species (Pusey *et al.* 2004; Wet Tropics Management Authority 2013). Since European settlement in the late 1800s, much of the Wet Tropics region has been cleared and selectively logged, with development of urban and agricultural land uses particularly on the coastal lowlands (Furnas 2003). This has included the construction of potential barriers to fish passage such as dams, weirs, extensive road and rail networks, as well as flood mitigation and drainage structures. However, the effect of these barriers on fish passage has not been assessed, partly because large areas of the region are remote and difficult to access.

In this study, we identified human-made, physical barriers to fish passage in the Wet Tropics region, specifically bridges, culverts and causeways, by intersecting the region's drainage and transport networks using a desktop GIS analysis. We focussed on interrogating available georeferenced drainage, road, and rail network data layers to identify potential barriers in the region's stream networks. Our interrogation did not include databases or data layers for dams, weirs, and flood mitigation and drainage structures, as these are currently not readily available for the whole Wet Tropics region. Our study thus provides an important and logical first step in completing a

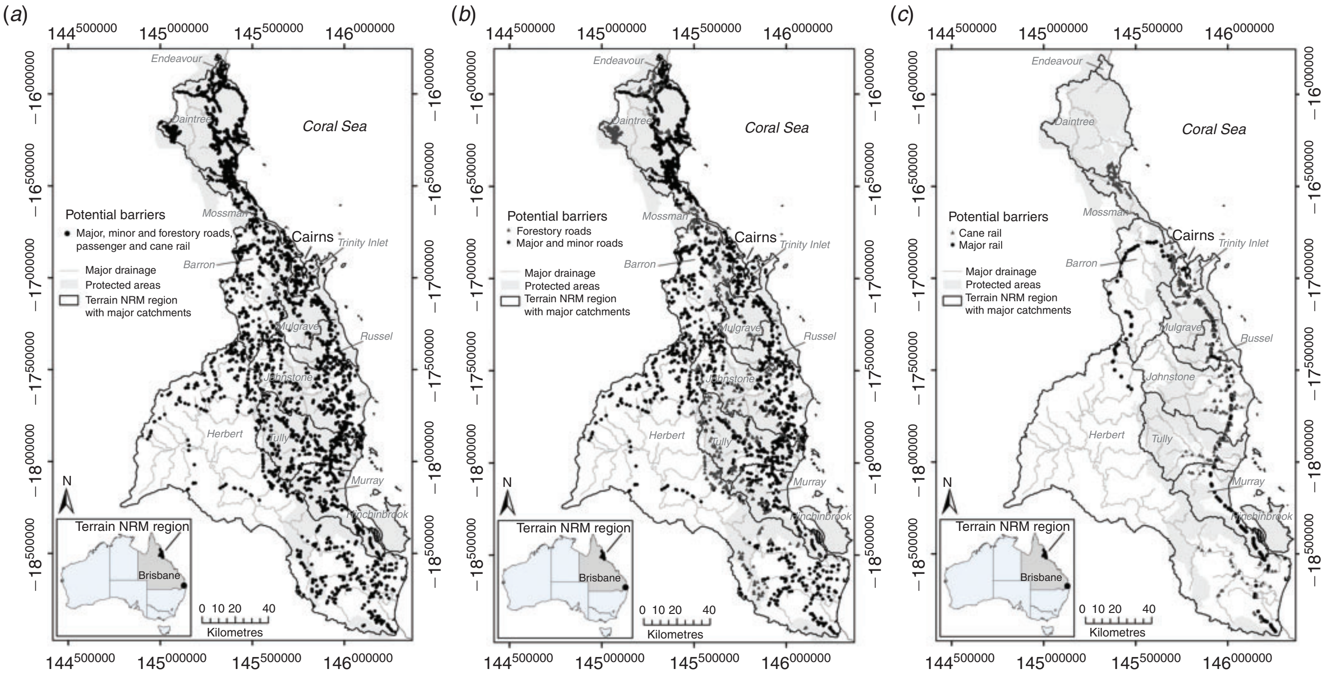

Fig. 1. Locations of potential physical barriers to fish passage in the Terrain Natural Resource Management region, Far North Queensland, Australia, at a scale of 1 : 100.000, namely (*a*) all barriers identified, (*b*) barriers comprising road crossings, and (*c*) barriers comprising rail crossings.

Table 1. Presence of potential physical barriers to fish passage in the 11 river basins considered across conservation and non-conservation land uses in the Terrain Natural Resource Management region

Only the section of the Endeavour River basin within the Terrain NRM region has been considered here. Density of barriers presented as mean length of stream network (km) that contains one barrier

River basins	Stream length assessed (km)	Land use		Roads		Rail		Total	Density of barriers (km)
		Conservation	Agricultural and urban	Forestry roads	Major and minor roads	Major rail	Sugarcane rail		
Endeavour	121	55	12	2	65	0	0	67	1.8
Daintree	5516	472	449	215	683	0	23	921	6.0
Mossman	657	118	119	14	170	0	53	237	2.8
Barron	1570	174	289	95	312	39	17	463	3.4
Trinity Inlet	180	42	75	6	73	10	28	117	1.5
Mulgrave	522	64	90	31	78	12	33	154	3.4
Russell	379	49	101	13	82	19	36	150	2.5
Johnstone	1480	163	258	88	251	16	66	421	3.5
Tully	1014	195	164	98	217	5	39	359	2.8
Murray	724	161	89	35	165	41	9	250	2.9
Herbert	6200	241	368	164	371	35	39	609	10.2
Total	18 363	1734	2014	761	2467	177	343	3748	4.9

systematic barrier inventory for this region, essential for prioritising barriers regarding their effect on fish passage and subsequent management (Kemp and O'Hanley 2010).

Materials and methods

The administration extent of the Terrain Natural Resource Management (NRM) region was used as the project boundary, covering an area of 22 221 km^2 and encompassing most of the 8940 km^2 Wet Tropics World Heritage Area (WHA) (Fig. 1). In Australia, NRM regions are managed by regional NRM bodies which are responsible for protecting and managing Australia's natural resources. To identify river basins that contain potential barriers to fish passage, the Division I Drainage Basins of the Queensland Government (https://data.qld.gov.au/dataset/drainage-basins-queensland, accessed April 2014) was adjusted to the management units used by the Terrain NRM body, resulting in a total of 12 river basins (Fig. 1, Table 1). The Qld Government ordered drainage 100K (https://data.qld.gov.au/dataset/ordered-drainage-100k-queensland, accessed April 2014) was used for drainage network; all streams and rivers with Strahler stream orders ≥2 were included. This network did not cover the Hinchinbrook Island basin which was subsequently excluded from the analyses. Note, however, that barriers to fish passage have been identified in this basin using different methods (Lawrence *et al.* 2009). The transport network data was created by merging datasets comprising the infrastructure of road and rail. Road data came from (i) the Qld Government physical road network (https://data.qld.gov.au/dataset/physical-road-network-queensland, accessed April 2014), including all categories except 'proposed roads', and (ii) a forestry road dataset from Lawson *et al.* (2010). Rail data comprised passenger and sugarcane rail networks, and were (i) extracted from the Geoscience Australia 250K digital topographic data (http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_63999, accessed April 2014), and (ii) provided by the respective sugar mills in the region. The drainage and transport networks were intersected using GIS analyses to identify locations of bridges, culverts, and causeways that could act as potential barriers to fish passage. All identified road and rail crossings were considered potential barriers to fish passage, acknowledging that field visits are required to confirm whether the waterway crossing is in fact a barrier to migrating fish. To identify the land uses surrounding barriers to fish passage, the most recent data (2009) of the Queensland Land use Mapping Program (QLUMP, http://www.qld.gov.au/environment/land/vegetation/mapping/qlump/, accessed April 2014) was used. The primary land use categories of QLUMP 2009 were divided into (i) conservation (Conservation and natural environment), and (ii) agricultural and urban (All other primary categories). ArcMap version 10.1 GIS tools and functionality were used for all processing and analytical GIS work.

Results and discussion

Within the Terrain NRM region, a total stream network length 18 363 km at a scale of 1 : 100 000 was assessed (Table 1). The Herbert (6200 km) and Daintree (5516 km) river basins contain 64% of this network length, with the remaining 36% encompassed by nine basins ranging from 121 km (Endeavour) to 1570 km (Barron). Intersecting this stream network with the transport network identified a total of 3748 potential barriers to fish passage, comprising 3228 road and 520 rail intersections (Fig. 1a–c, Table 1). The Daintree (921) and Herbert (609) contain 41% of all potential barriers identified, reflecting in part the longer stream networks assessed in these river basins. Trinity Inlet and the Endeavour river basins contain the highest density of potential barriers, with one barrier per 1.5 and 1.8 km of stream network, respectively (Table 1). Only a slightly higher proportion of potential barriers was surrounded by agricultural and urban land uses compared to conservation land uses (Table 1), reflecting the legacy of forestry transport infrastructure in areas that are now protected (Lawrence and Goosem 2008). The total number of human-made barriers to fish passage in the region is likely to be many times higher, given that neither physical barriers such as dams, weirs, and flood mitigation and drainage structures, nor hydraulic, chemical or behavioural barriers were considered in this study.

Barrier inventories are essential for prioritising barriers regarding their effect on fish passage and subsequent management (Kemp and O'Hanley 2010). Our study provides an important and logical first step in completing a systematic inventory of potential fish barriers for the Wet Tropics region. Furthermore, it documents the large number of road and rail crossings that are likely to be potential barriers, corroborating the importance of including these crossings in barrier inventories (Januchowski-Hartley *et al.* 2013). To complete a systematic inventory for the region, additional databases and data layers will need to be accessed from relevant authorities, such as State and Local Governments (dams, weirs) and sugar mills (flood mitigation and drainage structures). This inventory then forms the basis for the development of a managed database of identified barriers and non-barriers (Kemp and O'Hanley 2010; Januchowski-Hartley *et al.* 2013). All our spatial records have been submitted to the relevant NRM body and Queensland Government agencies for inclusion in state wide maps and inventories.

Generally, identified potential barriers are assessed in more detail in the field to obtain structural and environmental data for inclusion in a prioritisation process for management (Williams and Watford 1997; Gordos *et al.* 2007; Kemp and O'Hanley 2010). Given that large areas of the Wet Tropics region are remote and difficult to access, an initial prioritisation process will aid in reducing the number of potential barriers to assess in the field. Such a prioritisation process could include information on fish and habitat value criteria such as (i) distribution and abundance of native and non-native fish species (Meixler *et al.* 2009; Kroon *et al.* 2015), (ii) stream order, (iii) location within the catchment, (iv) upstream habitat quantity and quality, and (v) distance downstream and upstream to the next identified barrier (Sheer and Steel 2006; Branco *et al.* 2014; Brevé *et al.* 2014). The barriers prioritised can subsequently be visited to confirm their presence, and to collect structural and environmental information relevant to barrier passability (Poplar-Jeffers *et al.* 2009; Kemp and O'Hanley 2010; Bourne *et al.* 2011). Combining this information on the attributes of each barrier with fish and habitat value criteria in barrier inventories will enable an iterative prioritisation process for barrier removal and remediation to improve connectivity (O'Hanley *et al.* 2013; Januchowski-Hartley *et al.* 2014).

In summary, our GIS desktop study identified a total of 3748 potential barriers to fish passage in the Wet Tropics region, comprising 3228 road and 520 rail intersections in a total stream network length of 18 363 km at a scale of 1 : 100 000. This inventory of potential physical barriers will need to be completed through the inclusion of dams, weirs, as well as flood mitigation and drainage structures. An iterative process of barrier prioritisation will aid in targeted field visit in this large and remote area, and identify barriers for removal and remediation. Ultimately, this will contribute to protecting the high fish diversity in the region (Allen *et al.* 2003; Pusey *et al.* 2004), including in areas that are now protected but have legacy transport infrastructure that is likely to affect native fish movement and migration.

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