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# Enhancing whole-of-river conservation

Richard G. Pearson[A,B,*], Aaron M. Davis[B] and R. Alastair Birtles[A]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Richard G. Pearson
College of Science and Engineering, James Cook University, Townsville, Qld 4811, Australia
Email: richard.pearson@jcu.edu.au

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## ABSTRACT

We argue for improved conservation of freshwater ecosystems at catchment or eco-regional scales by explicit assignment of values to all river sections and wetlands, recognising current disturbance, and aiming for 'no further harm' to the commons. The need is indicated by the global deterioration of biodiversity and ecosystem services of rivers and wetlands, increasing demands on water and land resources, and climate change. Regional pressures include multiple jurisdictions, competing demands, piecemeal management, pollution and habitat impacts. Effective resource and conservation management needs to integrate multiple uses via governance of activities of stakeholders, recognising hydrogeomorphic, water quality and ecological properties of ecosystems. Complete ecological protection is impractical amidst water-resource and land-use development, but we suggest that all river reaches and wetlands be given a conservation rating based on habitat, biodiversity and connectivity values. We present a straightforward approach to spatial conservation rating of freshwaters, using hydrogeomorphic typology and assignment of conservation values on the basis of available information and expert elicitation. We illustrate the approach by using the large Burdekin River catchment in north-eastern Australia. This approach is complementary to more spatially focused conservation prioritisation and could greatly improve management for sustainability, reduce further decline in conservation values, and facilitate rehabilitation.

**Keywords:** Burdekin River, catchment scale, development, prioritisation, stream, tropic, typology, water resources, wetland.

## Introduction

Effective management of freshwater resources and ecosystems is regarded as one of humanity's highest priorities because of increasing demands on water resources (Dudgeon *et al.* 2006; Vörösmarty *et al.* 2010; Elliott *et al.* 2019; Albert *et al.* 2021) and the disproportionate loss of biodiversity in these habitats (Williams-Subiza and Epele 2021). These demands impair the ecological status of waterways as a result of changes to natural hydrology, morphology and water quality (Lemm *et al.* 2021). The need for improved stewardship of the common asset is urgent; for example, the 'Brisbane Declaration' calls for action to restore flows and ecosystems for their values and services as an integral component of water resource management and sustainable development (Arthington *et al.* 2018*a*, 2018*b*). The recent 'second warning to humanity' highlighted the need to address 'the loss and degradation of wetlands, the declining availability of freshwater, and the likely consequences of climate change' (Finlayson *et al.* 2019). Although it is generally recognised that freshwaters and estuaries provide vital ecosystem services as a commons (e.g. Capon and Bunn 2015; Maynard *et al.* 2015; Pearson *et al.* 2021), explicit whole-of-river, or even subcatchment, conservation is very rare. Conservation of freshwater ecosystems is challenging because of extensive catchment and instream connectivity. However, environmental management at the catchment scale has advanced greatly in some jurisdictions; for example, in Australia, natural resource management (NRM) organisations partner with government, funding agencies, landowners, scientists and other stakeholders, aiming for positive environmental outcomes (e.g. Bohnet *et al.* 2013; Curtis *et al.* 2014; NRM Regions Australia 2021). Nevertheless, these entities have inconsistent governance mandates among states and their activities are constrained by competing priorities, including agricultural and water resource developments, which frequently prevail over resource and biodiversity conservation (e.g. Beasley 2021). Informed management may also be constrained by limited research on the links among biogeography, climate change, ecosystem processes and biodiversity (Barmuta 2003).

A strong theoretical base for conservation management has developed, mostly focused on areal terrestrial and marine management. In the past decade, interest has grown in rivers and riparian zones as important habitats and, particularly, as agents of instream and catchment connectivity (Kingsford *et al.* 2005; Hermoso *et al.* 2011; Linke *et al.* 2011, 2012). The emphasis has been mainly on prioritising high-value species and ecosystems, but the need to accommodate both biodiversity and human utility in conservation (Barmuta *et al.* 2011) is recognised, for example, via 'multiple protection tiers', which indicate different levels of conservation action to accommodate human use (Linke *et al.* 2019). Modelling approaches for conservation prioritisation require substantial data input (e.g. Kennard 2011; Turak *et al.* 2011) but in data-poor areas more coarse strategies are necessary – for example, classification according to landscape and hydrogeomorphic characteristics for conservation planning (van Deventer *et al.* 2016).

Protected areas provide inadequate conservation of freshwaters globally because they typically do not capture the full range of aquatic habitats (Hermoso *et al.* 2016). For example, in Australia, ~8% of streams are in protected areas (Stein and Nevill 2011), compared with ~15% globally (Bastin *et al.* 2019). Even in the Australian Wet Tropics World Heritage Area, in which nearly 50% of the land is in protected areas (Great Barrier Reef Marine Park Authority 2012), only headwater streams are well represented, and ~80% of freshwater habitat is excluded (Januchowski-Hartley *et al.* 2011). Although there are promising signs of greater acknowledgement of environmental issues in water management (e.g. Productivity Commission 2021) and environmental assessment (e.g. Queensland Government 2017*b*), proactive catchment-wide conservation management is limited. Management of the Murray–Darling system via legislation and planning was promising, but has not been entirely successful (Chen *et al.* 2021).

Given the need for improved conservation management, we advocate whole-of-river conservation categorisation by using a straightforward approach, especially for systems with limited availability of ecological data. Most advanced approaches to conservation relate to prioritisation of the areas of highest value. Although such prioritisation is valuable, a whole-of-river approach is required (Kingsford *et al.* 2005) because limiting explicit protection to river sections of greatest conservation value precludes capture of the entirety of habitat types, biodiversity and vital connectivity. We propose a prior and complementary step based on geomorphological typology and simple conservation value assignment, applied comprehensively across whole systems as a basis for their protection and management, within the context of current and possible future land and water use (cf. Connolly *et al.* 2011). Our approach has the ultimate aim of broad adoption. We illustrate this approach through a case study of the Burdekin River (Fig. 1), a major system draining into the Great Barrier Reef (GBR) lagoon, which reflects many of the management issues that apply to freshwater systems worldwide. Before outlining our methodology, we summarise the ecological values of the Burdekin River, its current and proposed development status, current management regimes and the need for its explicit conservation within the development context.

## Burdekin catchment: landscape, ecology, development

### Background

We focus on the Burdekin system because of its large size, its economic importance and associated environmental pressures (NQ Dry Tropics 2016*a*), its ecosystem values and services, including the diversity of its environments and biota (Brizga *et al.* 2006; NQ Dry Tropics 2016*a*), its Indigenous values (Davis *et al.* 2014), the importance of its discharge and associated contaminants to the GBR (McCloskey *et al.* 2021), the moderate (although patchy) scientific knowledge of the system (Connolly *et al.* 2011), important management activities in the landscape (e.g. Landsberg *et al.* 1998; O'Reagain *et al.* 2005; McIvor 2012; NQ Dry Tropics 2016*b*), and because the region is reportedly uniquely positioned for agricultural expansion (Australian Government 2015). Despite extensive development, important conservation criteria (e.g. naturalness, representativeness, diversity, rarity, linked habitats, migratory species and dispersal of terrestrial species; Dunn 2004) are relevant to the Burdekin River (Brizga *et al.* 2006), and all 47 subcatchments have been rated positively for their aquatic ecosystem and cultural values (Kerr 2013). However, only 6% of the Burdekin catchment area is in protected areas (NQ Dry Tropics 2016*b*), including some perennial streams and many wetlands, and does not capture intermittent streams or the larger rivers. Environmental research on the Burdekin and other rivers of the GBR catchment has focused on delivery of land-based pollutants to the GBR (e.g. Brodie *et al.* 2012, 2017). Although the need for enhanced holistic planning and management of linked land- and seascapes has been recognised (Productivity Commission 2021), particularly in the GBR region, (Brodie and Pearson 2016; Waterhouse *et al.* 2016), publications concerning the ecology and values of rivers themselves are limited (see below).

### Landscape and ecology

Broad biophysical descriptions of the Burdekin River and basin are summarised in Table 1. The flow regime is dominated by the seasonal wet and dry cycle, and while the seasonality is predictable, flow volumes are not (Fig. 2).

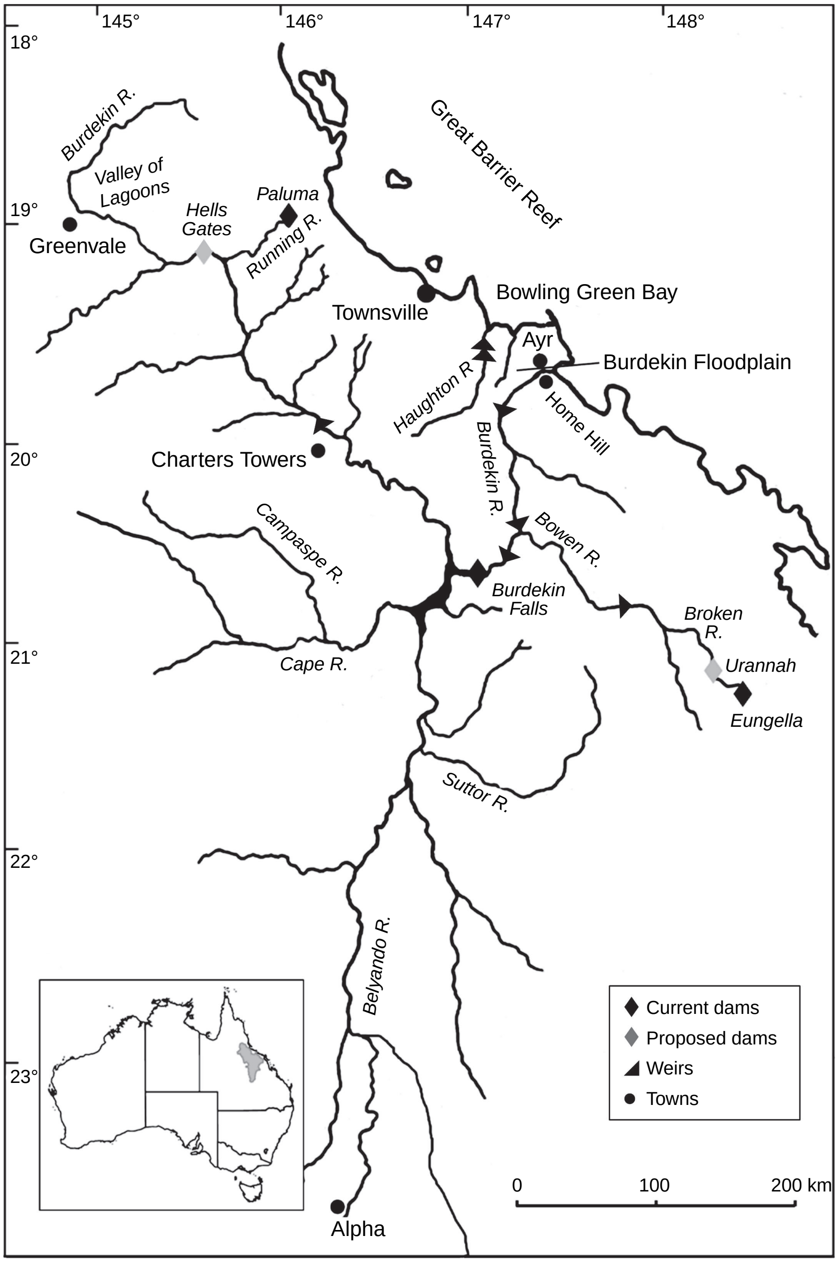


**Fig. 1.** Map of the Burdekin Basin, including the coastal Haughton River, which delineates the western edge of the floodplain. Locations, rivers and dams referred to in the text are indicated; proposed impoundments include Hells Gates Dam (2110 GL) on the Burdekin River, Urannah Dam (970 GL) on the Broken River, raising the current Burdekin Falls Dam (from current 1860 to 2446 GL) and Big Rocks Weir (10 GL) near Charters Towers (SMEC 2018; Queensland Government 2021*a*, 2021*b*, 2021*c*). Inset shows the location of the basin in Australia.

The catchment has received much attention because of its major inputs of freshwater discharge, fine sediments and nutrients into GBR waters (McCloskey *et al.* 2021), but less attention is being given to its freshwater systems. Here we outline the patchy ecological knowledge of the river and wetlands (Table 2).

Headwaters include springs and rocky or sandy streams (orders 1–3), descending to broad plains with low gradient and mostly sandy substrata, eventually converging on the main tributaries. Substantial research has been undertaken on Birthday Creek, a perennial Wet Tropics stream, focusing on drivers of invertebrate diversity and dynamics, and trophic relationships, but this represents only a very small part of the Burdekin catchment. For much of the catchment, headwater streams are intermittent and have received little attention.

Mid-sized streams and rivers (orders 4, 5) may be perennial in basaltic areas but mostly flow seasonally, with disconnected waterholes sustained by the water table. They have moderate invertebrate and fish diversity and food webs are driven by multiple basal sources and omnivory. The larger tributaries and main Burdekin River (orders 6, 7) have high banks, well vegetated flats alongside the main channel, with the wetted area meandering within the channel over a sandy substratum and occasional rocky outcrops. Invertebrates are abundant but appear not to be diverse, whereas fish diversity is comparable with that of other rivers of similar size.

**Table 1.** Burdekin catchment landscape.

| Category | Characteristics |
|---|---|
| Location | Centrally in GBR catchment; 6° of latitude |
| Size | 134 000 km$^2$; river ~1000 km long (Belyando–Burdekin) |
| Climate | Wet–dry tropical. Rainfall mean: e.g. Charters Towers 642 mm, Paluma (Wet Tropics) 2627 mm |
| Discharge | Highly seasonal; greatest maximum, but not median, in Australia; perennial in parts |
| River characteristics | Some perennial, many intermittent; permanent waterholes |
| Wetland characteristics | Intermittent and permanent wetlands in catchment and on floodplain |
| Vegetation | Woodland and grassland; rainforest on mountains; woodland, open forest and wetlands on floodplain |
| Land use | Mainly grazing, some dryland cropping; irrigated cropping on floodplain; some mining; infrastructure |
| Protected areas | ~6% of the catchment, plus Defence Department land (~4%) |
| | 25 sites listed in Directory of Important Wetlands including Ramsar-listed Bowling Green Bay wetlands |
| Human population | 33 600; density 0.25 km$^{-2}$ |
| Water resource development | Dams: Burdekin Falls, 1860 GL; Eungella, 131 GL; Paluma, 12 GL; several large weirs |

Based on Brizga et al. (2006), NQ Dry Tropics (2016a), Australian Government (2019) and Pearson et al. (2022).

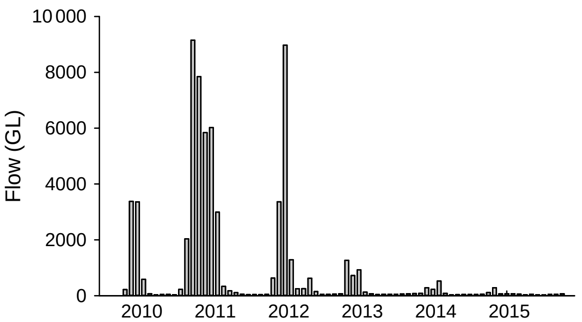


**Fig. 2.** Typical patterns of monthly and annual flow variability in the lower Burdekin River, 2010–2015, showing years of moderate and low flow. Over the period 1975–2020, mean discharge = 696 GL and median = 66 GL per month. Queensland Government data (https://water-monitoring.information.qld.gov.au/).

The Burdekin Falls (site of the major dam site) delineates middle- and lower-river sections. Many invertebrates and fish occur in the lower river, including many opportunistic marine or estuarine species and some that depend on connectivity between freshwater and marine environments for spawning (Pearson et al. 2021). However, there is very limited ecological information. The Burdekin estuary comprises the 1.0-km-wide main river channel and ancillary distributaries, within Australia's largest delta. There is little published information on the estuary but it is expected to be productive and provide extensive habitat, like other estuaries in the region.

Lentic waters comprise lakes and swamps, both perennial and intermittent, as well as the riverine waterholes. In the upper catchment, groundwater sustains perennial wetlands, especially in basaltic parts of the north. The floodplain has a great expanse of freshwater and brackish wetlands that are of international importance and Ramsar-listed. They are fed by local rainfall, occasional flooding of the Burdekin River and high groundwater levels, as well as by irrigation supply and tailwater.

Groundwater sustains the river and wetlands through most of the year, in the absence of surface run-off and irrigation tailwater (e.g. Davis et al. 2017). It is used for irrigation on the delta, requiring control of recharge and use (Great Barrier Reef Marine Park Authority 2013). There is very little ecological information on groundwater in the catchment.

## Development impacts

Little of the Burdekin system has escaped the impact of development over the past 150 years, including changes in land use, water quality and habitat, water flow, and climate, many of which co-occur and probably interact (Pearson et al. 2021). The major land use in the catchment by areal extent is cattle grazing across the wooded and cleared rangelands. Resultant impacts have been weed invasion, erosion, salinity and elevated sediment and nutrient loads in the river (Table 3). Cropping is dominated by irrigated sugarcane (~80 000 ha) on the delta and coastal floodplain. Irrigation has caused issues of water management (greatly raising some water tables and lowering others), loss of riparian vegetation, weed invasion and water quality for the extensive wetlands (Great Barrier Reef Marine Park Authority 2013; NQ Dry Tropics 2016b). The huge Burdekin Falls Dam has reduced floods and coarse sediment transport, while supplementing dry-season flow in the river and across the floodplain, with impact on invasive weeds and water quality. Climate change is predicted to affect various attributes of coastal wetlands and to reduce biodiversity. The catchment is not subject to concentrated

**Table 2.** Examples of published information on aquatic ecology in the Burdekin system.

| River section | Information available | Example references |
|---|---|---|
| Whole system | Outline of vegetation, fish, invertebrates, etc. | Brizga *et al.* (2006); Pearson *et al.* (2022) |
| Perennial headwater stream | Invertebrate dynamics | Benson and Pearson (2020) |
| | High diversity of riparian vegetation | Bastian *et al.* (2007) |
| | High diversity of invertebrates | Pearson *et al.* (2015) |
| | Assemblage drivers | Pearson *et al.* (2017) |
| | Mobile fauna | Connolly and Pearson (2018) |
| | Resilient fauna | Connolly and Pearson (2007); Rosser and Pearson (2018) |
| | Disturbance refugia | Wulf and Pearson (2017) |
| | Waterfall fauna | Clayton and Pearson (2016) |
| | Food webs | Cheshire *et al.* (2005); Coughlan *et al.* (2010); Schmidt *et al.* (2017) |
| | Litter dynamics | Wootton *et al.* (2019); Benson and Pearson (2020); Boyero *et al.* (2021) |
| Intermittent headwater streams | Diversity and dynamics (nearby catchments only) | Orr and Milward (1984); Smith and Pearson (1987); Dell *et al.* (2014); Stitz *et al.* (2017*a*, 2017*b*) |
| | Riparian vegetation refugia | Williams (1994); Bengsen and Pearson (2006) |
| Mid-sized streams – permanent waterholes | Water quality, phytoplankton dynamics | Preite and Pearson (2017, 2021) |
| | Invertebrate diversity dynamics | Blanchette and Pearson (2012, 2013) |
| | Fish dynamics; food webs – multiple basal resources | Pusey *et al.* (2010); Davis *et al.* (2011, 2012, 2018); Blanchette *et al.* (2014) |
| Main river and tributaries | Invertebrate diversity and dynamics | Davis *et al.* (2015) |
| | Fish dynamics, translocations etc. | Pusey *et al.* (2006); Burrows *et al.* (2009); Davis *et al.* (2012, 2015, 2018) |
| Lower river | Limited information | Brizga *et al.* (2006); Davis *et al.* (2015) |
| Estuary | Little information; regional estuaries described | Sheaves (2009, 2015); Sheaves and Johnston (2009) |
| Swamps and lakes | In upper catchment, permanent wetlands support fish and birds | Brizga *et al.* (2006); Maughan *et al.* (2006); Pusey *et al.* (2006) |
| | Coastal floodplain has extensive vegetated wetlands | Sheaves and Johnston (2008); Connolly *et al.* (2012); Great Barrier Reef Marine Park Authority (2013); Davis *et al.* (2014); Waltham *et al.* (2019) |
| | Bowling Green Bay Ramsar wetlands | Lankester *et al.* (2007); Commonwealth of Australia (2020, 2021); Weller *et al.* (2020); Tarte and Yorkston (2020) |
| Groundwater | Sustains rivers and wetlands, but little ecological information | Brizga *et al.* (2006) |

heavy industry or intense urbanisation. Mining occurs to a limited extent.

## Future development

The Australian Government's (2015) White Paper on developing the north highlighted the unique ecological values of the rangelands ('the largest intact tropical savanna in the world') and identified the key threats as fire, climate change, coastal development, feral animals, overgrazing, fishing, weeds, land clearing and water quality. An additional threat is loss of Indigenous values and cultural heritage. All are relevant to proposed impoundments in the Burdekin catchment (Fig. 1). These proposals, associated with agricultural expansion and within the framework of the Burdekin Basin Water Plan (Queensland Government 2007), have long been mooted, with substantial public funding to investigate proposals. Raising of the Burdekin Falls Dam is the most cost-effective development in the whole of northern Australia (Petheram *et al.* 2018), although it may exacerbate current environmental issues (Brizga *et al.* 2006). Nevertheless, the other proposals are being strongly promoted. All proposals present high risk of substantial degradation of habitats, connectivity and ecological processes, including migrations by freshwater fish (Burrows 1999; Brizga *et al.* 2006), coastal fishery production,

**Table 3.** Major development impacts in the Burdekin system.

| Major pressure | Deleterious effects | Example references |
|---|---|---|
| Grazing in the rangelands | Riparian weeds and fire | Valentine 2006; Valentine *et al.* (2007) |
| | Erosion and salinity | Williams *et al.* (1997); Wilkinson *et al.* (2018) |
| | Increased suspended sediments and nutrients | Lewis *et al.* (2021); Bartley *et al.* (2014) |
| | Perpetually turbid water in lower river | Burrows (1999); Burrows and Butler (2007) |
| Sugarcane growing and irrigation | Altered water regime and quality, loss of riparian vegetation, weed invasions | Burrows (2004); Burrows and Butler (2007); Great Barrier Reef Marine Park Authority (2013); Davis *et al.* (2014, 2017); Petheram *et al.* (2014); NQ Dry Tropics (2016*b*) |
| | Weed invasion and fish diversity | Perna *et al.* (2012); Davis *et al.* (2014); Waltham *et al.* (2020*a*, 2020*b*) |
| Impoundments and flow management | Reduced flooding, increased dry-season flow; disconnection of river sections; flooding of turtle nesting habitat | Burrows (1999); Brizga *et al.* (2006) |
| | Perpetually turbid water in lower river | Burrows (1999); Burrows and Butler (2007) |
| | Changing water regimes on floodplain | Connolly *et al.* (2012); Waltham *et al.* (2019, 2020*a*); Tait (2021) |
| Proposed impoundments | Alterations to flow and connectivity | Burrows (1999); Brizga *et al.* (2006); SMEC (2018); Queensland Government (2021*a*, 2021*b*, 2021*c*) |
| Climate change | Predicted extirpation of crayfish, fish and turtles | James *et al.* (2017); Barbarossa *et al.* (2021) |
| | Predicted sea-level, temperature and hydrology changes in coastal wetlands | Grieger *et al.* (2020) |

sediment transport and possibly floodplain wetlands (Burrows 1999; Wolanski and Hopper 2022).

## Management and research for mitigation and conservation

Typically, governance and management of a catchment is within the auspices of several government departments and agencies, the goals of which may differ and compete. For example, for the Burdekin River, there is a complex of regulations and plans relevant to water management, environmental protection and native title (Queensland Government 2007, 2017*a*, 2021*c*; NQ Dry Tropics 2016*b*). Improvements in land management are promoted and facilitated by the NRM board, which has a whole-of-system approach to land and water management, in partnership with funding bodies, stakeholders and researchers, in keeping with the Reef Water Quality Protection Plan and Reef 2050 Plan targets (NQ Dry Tropics 2016*a*, 2016*b*, 2021). However, adoption by industry of best-practice guidelines has been slow (Great Barrier Reef Marine Park Authority 2019), with mixed success in restoration of wetlands (Waltham *et al.* 2019).

The current environmental impact statement (EIS) process in Queensland, required for new projects, is illustrated by the terms of reference for the Urannah Dam proposal (Queensland Government 2021*a*). The objectives include assessment of environmental, social and economic impacts of the project, within the regional and local infrastructure context, and refer specifically to environmental-flow objectives, terrestrial impacts, crops to be irrigated and resultant water quality, and long-term protection of aquatic biodiversity and connectivity. The context includes possible cumulative impacts and the need for holistic appraisal, which were not addressed in the development of the Burdekin Falls Dam (Day 1989; Moon 1998); however, anecdotal information suggests that holistic assessment may not be achieved because of the involvement of different practitioners on the various projects.

### Current conservation status

Conservation approaches and associated legislation vary among jurisdictions. In Queensland, the government increasingly recognises the importance of freshwaters (Queensland Government 2017*b*), but protected-area management is mainly focused on terrestrial systems, with limited explicit conservation of river sections, as elsewhere (Stein and Nevill 2011; Nogueira *et al.* 2021). Incidental protection may occur in land-based reserves, such as in the Wet Tropics, a large proportion of which is in the Wet Tropics World Heritage Area; however, even there, protection of the bioregion's freshwater habitats is limited (Januchowski-Hartley *et al.* 2011). Although the Wet Tropics World Heritage Area, the Bowling Green Bay Ramsar wetlands and declared fish habitat afford some protection in the Burdekin catchment (Connolly *et al.* 2011), these areas fail to capture the full diversity of freshwater/estuarine environments. Implicit protection may apply through regulations on water quality or species protection, but may be ineffective, for example, for nesting turtles downstream of the Burdekin Falls Dam (Brizga *et al.* 2006). More explicit conservation, especially of rivers, is warranted (Pearson *et al.* 2021) and, recognising the current development status, could be applied to different extents to specified sections (Linke *et al.* 2019). For example, the upper-middle Burdekin River is largely in good condition and warrants special protection, whereas downstream of the Burdekin Falls Dam, which has been greatly modified, urgent protection of remaining habitat, connectivity and biodiversity values is warranted. A conservation management plan for the whole river and floodplain is required (Great Barrier Reef Marine Park Authority 2013) to provide stewardship, protecting against further damage (Reside *et al.* 2017), mitigating predicted species losses (James *et al.* 2017) and rehabilitating damaged systems (Burrows and Butler 2007) from catchment to coast (Waterhouse *et al.* 2016).

## Towards more explicit conservation in holistic management

A first step towards broad-scale conservation management is an understanding of the characteristics and values of the 'riverscape' (Fausch *et al.* 2002), including consideration of scale, patchiness and connectivity (Poole 2002), and holistic flow management (Tonkin *et al.* 2021). A hydrogeomorphic typology of waterways is a useful starting point (Rinaldi *et al.* 2016), because it can be a good predictor of the biota (Lathouri *et al.* 2021) and could define management requirements of a practicable number of management units. In Australia, methodologies have been proposed for New South Wales (Brierley *et al.* 2011; Fryirs *et al.* 2021) and tropical rivers (Erskine *et al.* 2005). Butler *et al.* (2009) introduced a bottom-up typology for assessment of site-based water quality and ecological processes in the Burdekin River. However, in the absence of comprehensive data, a top-down approach is more tractable for broad conservation zoning. This can involve statistical classification of management units (e.g. Olden *et al.* 2021) but, again, this approach requires substantial data input. Alternatively, generic typologies (e.g. Parsons *et al.* 2004; The Aquatic Ecosystems Task Group 2012) can be adapted as required. In the Burdekin system, a typology would include riverine, estuarine and floodplain habitats, enhanced by land-use and ecological information (Table 4; see also example in Supplementary material online).

Parallel to developing this biophysical framework, identification of environmental values is required. The Queensland Government (2019) assesses environmental values of wetlands and river sections by equating conservation value with the level of disturbance, with the following four categories: High Conservation Value, Slightly and Moderately Disturbed (sometimes used collectively), and Highly Disturbed, which include implicit targets for improvement (e.g. Connolly *et al.* 2011; Godfrey and Pearson 2012). We propose to use the same system for consistency. A separate process identifies water-quality objectives and guidelines (NQ Dry Tropics 2016*b*; Newham *et al.* 2017). Both approaches recognise that even with the lowest rating, systems may retain some ecological values; that is, disturbance and conservation value are not mutually exclusive. We suggest that ascribing conservation value by means of expert elicitation (e.g. Hemming *et al.* 2018), especially when ecological information is patchy, is the simplest way forward. It should be strongly guided by the precautionary principle, to avoid further deterioration of any river section or wetland or the vital connectivity between them. Combination of this with the typology to delineate conservation zones (Fig. 3) would provide clarity on the needs for river and wetland conservation and would facilitate the subsequent stage, which is developing enhanced conservation targets and rehabilitation programs (Linke *et al.* 2012, 2019; Cattarino *et al.* 2015; Reis *et al.* 2019). It would involve such criteria as distinctiveness and representativeness of hydrological, geomorphological and ecological assets and services (biodiversity and processes; see example in Supplementary material). It would highlight potential constraints on land-use change and water management, and would inform catchment planning processes.

## Conclusions

We advocate holistic conservation categorisation of systems to protect remaining values while balancing competing demands (Pusey *et al.* 2020), with the major goal of ecological sustainability. This process is set in the context of current and future infrastructure and land-use development, and requires an appropriate plan adopted before further development (Productivity Commission 2021). We suggest that all river sections or wetland sites should be given protection levels commensurate with their explicit values, coordinated appropriately to alleviate future negative change (Finlayson *et al.* 2019). We argue, therefore, not via special pleading for our case study catchment, but to present it as a model for river stewardship generally.

In Australia, there is opportunity to protect against further impact on rivers and wetlands and avoid the mistakes of the past, which have caused loss of ecological values and continuing expensive mitigation. We support the principles of integrated catchment management, adopted in Queensland in 1990, including explicit policy for ecosystem sustainability (Thoms and Sheldon 2000; Davis *et al.* 2014). To be effective, such a framework requires whole-of-catchment consideration of development, as evident in contemporary EIS requirements (e.g. Queensland Government 2021*a*). It also needs more systematic information gathering and adaptive management to enhance our suggested

**Table 4.** Simple typology for delineating management zones and associated biota in the Burdekin River.

| Biotope | Major characteristics and modifiers | Conservation management zones | Further modifiers and responders |
|---|---|---|---|
| Riverine | Stream size: headwater, upper river, middle river, lower river, estuary | 1. Headwater steep perennial | Modifiers |
| | | 2. Headwater steep intermittent | • Catchment use: natural, grazing, agriculture etc. |
| | | 3. Headwater low gradient | • Erosion/sedimentation |
| | | Perennial | • Water quality: suspended sediment, N, P, dissolved oxygen, pesticides; point-source pollution |
| | | 4. Headwater low gradient | • Riparian integrity |
| | | Intermittent | • Protection status (national parks, etc.) |
| | | 5. Upper river perennial | • Invasive species: weeds; exotic/translocated animals |
| | Gradient: steep or low gradient | 6. Upper river intermittent | Responders |
| | Lithology: basalt, granite or alluvium | 7. Middle river perennial | • Ecological processes: productivity, food webs, dispersal/migration |
| | Substrate: rock, cobble, sand or silt | 8. Middle river intermittent | • Representativeness |
| | Flow regime: perennial, intermittent or interrupted; supplemented or impounded; connectivity/barriers | 9. Lower river | • Phytoplankton |
| | Fresh or brackish: conductivity/salinity | 10. Estuary | • Macrophytes |
| | Vegetation: catchment, riparian & aquatic | | • Invertebrates |
| Lentic | Water regime: permanent or intermittent | 1. Fresh small permanent | • Vertebrates, especially fish |
| | | 2. Fresh small intermittent | • Endemic species |
| | | 3. Fresh large permanent | |
| | | 4. Fresh large intermittent | |
| | Area | 5. Brackish small permanent | |
| | Depth | 6. Brackish small intermittent | |
| | Connectivity: occasional or permanent | 7. Brackish large permanent | |
| | Conductivity/salinity | 8. Brackish large intermittent | |
| | Vegetation: floating, emergent, submerged | | |

'Lentic' division includes floodplain wetlands. Modifiers and responders may apply to conservation categories (see text).

approach, ideally under the auspices of a governing body. We agree with the Productivity Commission (2021) that water planning processes need to be upgraded to best practice and involve trade-offs between environmental, economic and social outcomes, recognising the needs of Indigenous peoples, and including a specific focus on climate change. Additionally, river conservation policies need to be made more explicit, as is the case in some jurisdictions (Perry *et al.* 2021). Management by a body with jurisdictional authority is required, especially because of the wide range of relevant regulations and stakeholders (Queensland Government 2007, 2017*a*; NQ Dry Tropics 2016*b*). This might be achieved by providing NRM bodies with stronger legislative and regulatory frameworks for sustainable management or creation of independent management authorities with appropriate powers. Such an approach was embodied in the establishment of the Murray–Darling Management Authority and associated legislation, but its progress has been beset by substantial failures, partly owing to interstate disagreement and vested interests (Beasley 2021; Chen *et al.* 2021; Ryan *et al.* 2021). Catchments within states should not have transboundary problems. Australia, as a developed country, is in a position to take a lead in this issue by providing a robust model for sustainable conservation and management of rivers and wetlands. To ensure 'wise use' (following the Ramsar Convention; Kumar *et al.* 2021), it is important that sustaining environmental values, including ecosystem services of direct value to communities, provides the basis for sustainable development.

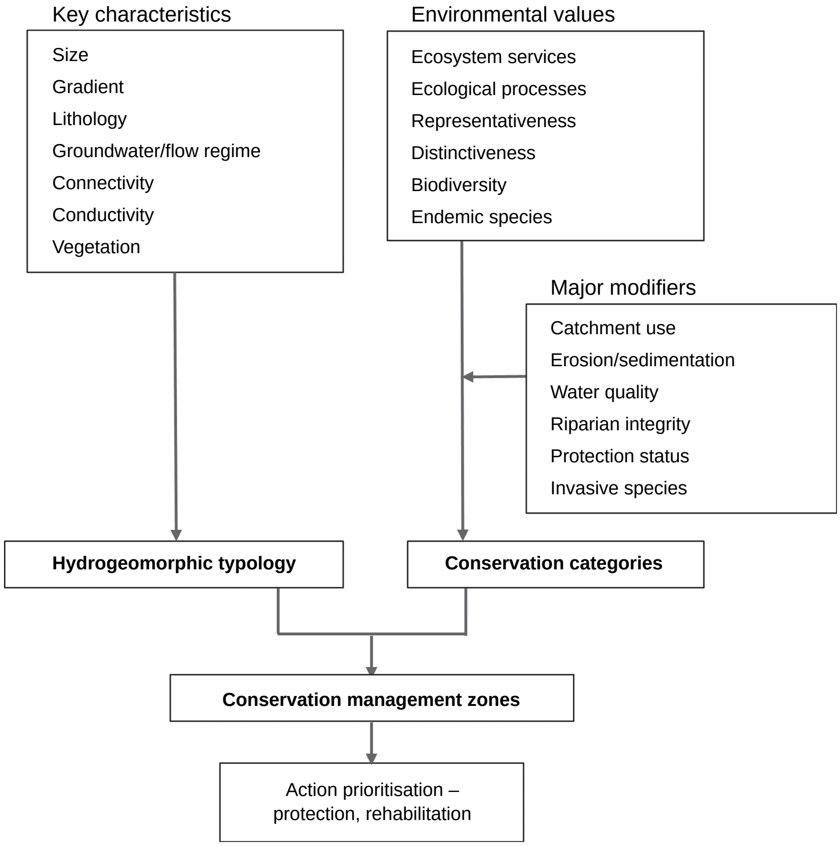


**Fig. 3.** Framework for conservation zoning of rivers and wetlands. Details of categories are shown in Table 4.

## Supplementaty material

Supplementary material is available online.

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**Author affiliations**
[A]College of Science and Engineering, James Cook University, Townsville, Qld 4811, Australia.
[B]TropWater, James Cook University, Townsville, Qld 4811, Australia.