Resilient Landscapes

National Environmental Science Program

Mapping potential aquatic biodiversity, including threatened species, in the catchments of the south-eastern Gulf of Carpentaria

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1. Australian Rivers Institute, Griffith University.

Disclaimer

Cover photograph

Gulf river and floodplain. Photo: Michael Douglas.

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Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders.

Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

Contents

List of figures

List of tables

1. Executive summary

The south-east Gulf of Carpentaria remains a region of Australia with relatively little impacts from human activity. However, there is pressure to develop the water resources in this region for irrigated agriculture, with potential impacts on aquatic biodiversity and threatened species. One of the challenges in determining the impacts of development on the natural environment is the lack of data on species and habitats in this region. One approach is to use existing Australia-wide habitat-suitability maps for threatened species and biodiversity (Kennard 2010; Pintor et al. 2019). Therefore, this study used a down-scaled model of habitat suitability to identify potential areas of higher aquatic biodiversity and presence of threatened species in 3 catchments earmarked for development across the south-east Gulf of Carpentaria, Queensland – the Flinders, Mitchell and Gilbert catchments (Figure 1-1). This included identification of habitats that may be suitable for threatened species. This information was compared with maps of spatially explicit development pressures from agricultural development, as well as areas where climate change is predicted to have the greatest impact.

The study found that the downstream areas of the Flinders and Gilbert rivers had higher numbers of threatened aquatic species than upstream areas. This is unsurprising, as these rivers typically cease flow in the dry season, with substantial contraction of the aquatic area in the upper reaches. For the Mitchell River, the area with the highest number of threatened species extended further up the catchment, likely due to the more consistent flow in this river system. In all 3 river systems, the coastal and estuarine areas were the primary areas for migratory shorebirds, including threatened species, and marine turtles. In terms of total number of species of freshwater turtles and birds, the upper Flinders River was also an important area.

In a previous study (Eccles et al. 2022), suitable land for new agricultural development was mapped across all 3 catchments. The Flinders catchment was shown to have the most extensive area that may be suitable; however, the scores tended to be relatively low compared with the maximum potential score. In contrast, the Mitchell catchment had the least amount of suitable land; however, within these areas, land suitability was high, especially in the upper catchment. Approximately 60% of the Gilbert catchment was assessed to have moderate to high levels of suitability.

Climate change has the potential to significantly affect biodiversity and threatened species. The threats include increased temperature impacting thermal tolerances of species, sea level rise impacting habitat availability, higher evaporation rates reducing availability of freshwater habitats and increasing estuarine salinities in the dry season, and extreme events causing habitat disruption. Many of these factors can come together to result in compounding climate extremes. The cause-effect relationships of these threats are poorly understood and hence it is difficult to predict the scale of the impacts under different climate-change scenarios. Based on the data that are available, a climate dissimilarity map has been generated and down-scaled for the Gulf catchments, based on Pintor et al. (2018). It showed the integrated relative change in season length, temperature and rainfall across the catchments and highlights where the greatest changes from present-day are likely to occur.

This dissimilarity was highest in the Flinders catchment, suggesting the greatest risk to biodiversity and threatened species, followed by the Gilbert catchment. The Mitchell catchment exhibited the lowest level of dissimilarity.

As mentioned above, the biodiversity and threatened-species maps generated in this study, which were down-scaled from Australia-wide maps, are based on habitat suitability. This approach was used due to the paucity of ground-truthed data. Therefore, ground-truthed data are needed to validate the habitat-suitability maps and provide a more robust approach to planning and decision-making. Additionally, locations with low species richness are not necessarily less important than those with higher biodiversity. There may be species critical to the ecosystem that would not be identified with the biodiversity modelling approach. Further model development is needed that can link development pressures upstream with impacts on biodiversity downstream. These maps are also snapshots in time, and it is clear that, over time, climate change will alter habitats and hence change the distribution of species. Predicting the threats to species from climate change and how this interacts with proposed development (e.g. irrigated agriculture) remains poorly understood and warrants further work.

Figure 1-1. Map showing the Mitchell, Gilbert and Flinders river catchments. Image: Resilient Landscapes Hub.

2. Introduction

Northern Australia is home to a wide range of rivers that flow through diverse landscapes. The region has been identified by state and federal governments as a priority for water-resource development in the coming years, with the south-east Gulf of Carpentaria a particular focus of this interest. Currently, rivers of this region support many existing water users, including First Nations people, commercial and recreational fisheries, and graziers. The region also contains many significant ecological assets, including wetlands of national significance which support a wide array of biodiversity and many threatened species.

The region is home to a high diversity of aquatic species that persists in a wide array of hydrologic, geomorphic and topographic settings. This includes high levels of endemism (i.e. species that occur only in the region) as well as many threatened species (Kennard 2010; Pintor et al. 2019). For example, at least 4 species of sawfish – the most threatened family of all sharks and rays (Dulvy et al. 2014) – are found in the rivers of the Gulf of Carpentaria (Peverell 2005). In terrestrial systems, new endemic species are still being discovered due to the relatively low numbers of surveys being undertaken (Oliver et al. 2017). Despite expanding conservation efforts around the world, biodiversity loss continues, with land use change, overexploitation and pollution being key causes (Isbell et al. 2023).

Pressure from an expanding population and degradation of existing cultivated land in Australia has increased demand for new land suitable for agriculture (Robertson, 2010). The wet–dry tropical climate of the south-east Gulf of Carpentaria with major rainfall events over a few months each year and an extended dry period, makes agricultural expansion a considerable challenge. Therefore, water-resource developments are being considered to capture runoff from wet seasons. Recent water-resource assessments have identified potential locations of dams and other infrastructure, as well as identifying links between development and aquatic ecosystem impacts (e.g. Petheram et al., 2018). Research has shown how these impacts are likely to occur both at the site of the water-resource infrastructure and elsewhere in the catchment and region (e.g. O'Mara et al. 2021; Molinari et al. 2022, Lowe et al. 2022).

Despite the size of the catchments in the region and the wet–dry seasonal hydrology, the rivers, floodplains and estuaries are highly connected in space and time. Large numbers of fish move from coastal and estuarine regions as far upstream as headwaters to find food and refuge habitat (O'Mara et al. 2021; Stewart-Koster et al. 2021, Leahy et al. 2021). The freshwater flows that facilitate these movements also drive coastal, estuarine and floodplain productivity (Burford et al. 2016, 2021a; Ndehedehe et al. 2020a; Molinari et al. 2022). The relative importance of flows delivered from rainfall in the headwaters means water-resource development in one area will likely have impacts downstream as well as locally (Broadley et al. 2020; Ndehedehe et al. 2021; Molinari et al. 2022), potentially affecting traditional harvests and coastal fisheries as well as native biodiversity that is reliant on floodplain productivity. Understanding the distribution of areas of higher biodiversity builds on recent research identifying where primary productivity is highest in the region. This research also examined the implications of water-resource development on the ecosystem processes that depend on this primary productivity.

In this study, we develop maps of probable areas of higher biodiversity for aquatic species in 3 catchments of the south-east Gulf of Carpentaria. These are all rivers earmarked by the Queensland and Australian governments as highly likely to have water-resource development and have been the focus of study in the Flinders and Gilbert Agricultural Resource Assessment and the **Northern Australia Water Resource Assessments** (Mitchell River catchment). Additionally, natural resource studies have been conducted within the Commonwealth Environmental Research Facility's Tropical Rivers and Coastal Knowledge program, the National Environmental Research Program and past National Environmental Science Program projects. As part of the study, we identify areas that are likely to support a high richness of threatened aquatic species, as well as all aquatic species. We then discuss the implications of water-resource development in the catchments.

3. Methodology

3.1 Study region

The Mitchell, Gilbert and Flinders rivers flow into the Gulf of Carpentaria in the Australian wet–dry tropics (Figure 1-1). They all have unpredictable summer flow which is highly intermittent (Class 10 rivers in the classification scheme of Kennard et al. 2010). The catchment areas are 71,670 km^2, 46,406 km^2 and 109,000 km^2, for Mitchell, Gilbert and Flinders rivers respectively. The mean annual rainfall is typically highest in the Mitchell River catchment, with headstreams in the Wet Tropics, followed by the Gilbert then the Flinders (Figure 3-1). The levels of evaporation in each catchment have similar patterns (Burford et al. 2020, Broadley et al. 2020).

The Flinders River starts in the Great Dividing Range, extends westward into Gulf Savanna country towards Julia Creek, then heads north to drain through a delta into the Gulf of Carpentaria. The Gilbert River rises below Conical Hill in the Einasleigh Uplands, draining the eastern slopes of the Gregory Range and the western slopes of the Newcastle Range, north of Hughenden. One-third of the catchment is a vast estuarine delta largely consisting of tidal flats and mangrove swamps. The Mitchell River rises on the Atherton Tableland about 50 km northwest of Cairns and flows about 750 km across Cape York Peninsula from Mareeba to the Gulf of Carpentaria. The Mitchell River has Queensland’s largest annual discharge, with 34 tributaries and, similar to the Gilbert catchment, a vast estuarine delta flowing into the Gulf. It has the most extensive perennial wetland areas. All the catchments are dominated by pastoral activities and, more recently, an increasing number of agricultural irrigation schemes.

The Gilbert and Flinders river estuaries are characterised as having simple meandering river channels with some small tidal creeks, fringed with a relatively narrow line of mangroves, behind which are extensive salt flats which are only inundated during the wet season or at the highest astronomical tides. The Mitchell River estuary has many of the same characteristics but is a deltaic fan with multiple estuary mouths.

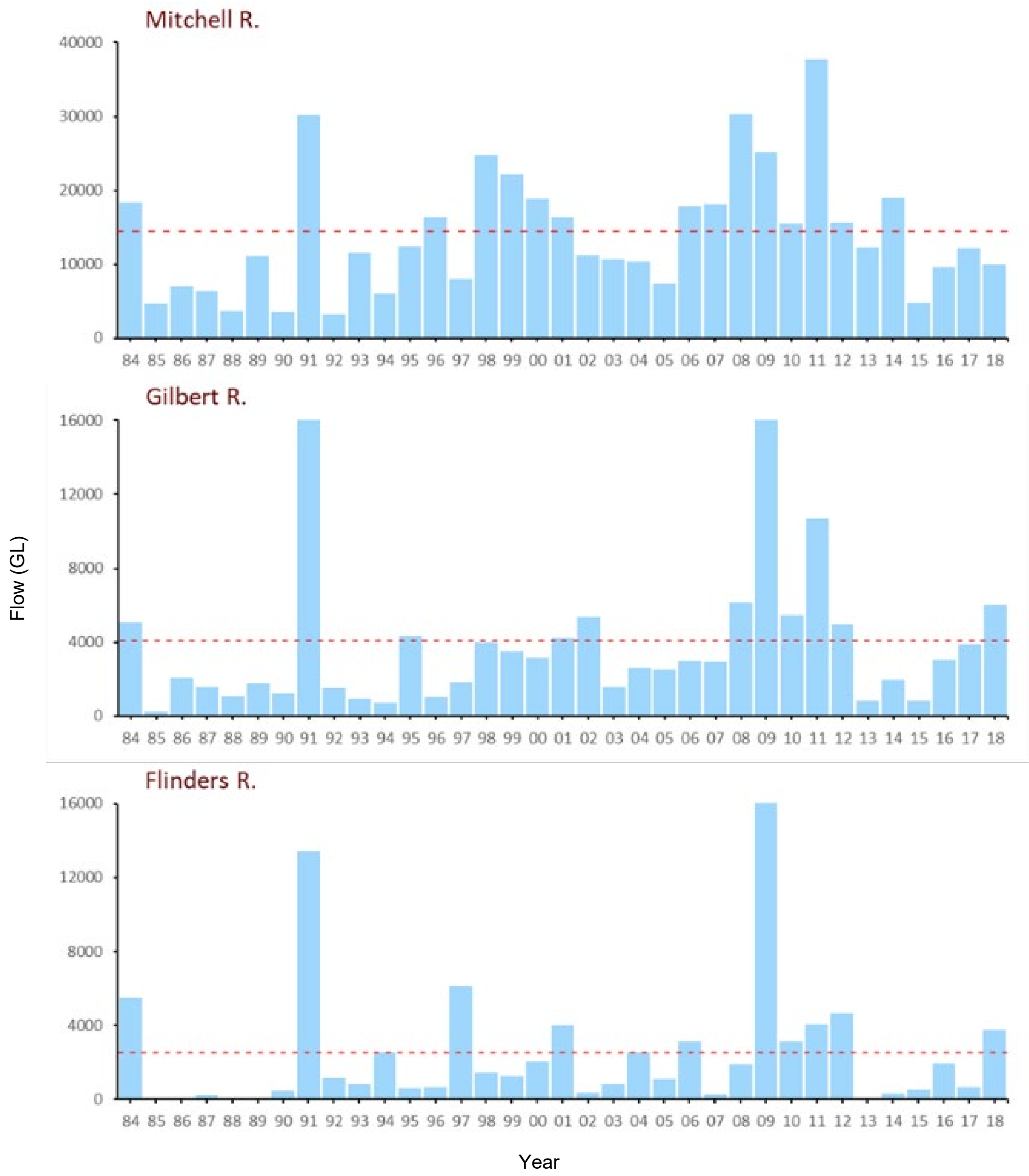

Figure 3-1. Annual gauged flow (GL) from 1985 to 2018 for the Mitchell, Gilbert and Flinders Rivers (adapted from Broadley et al. 2020). Red dashed line represents mean annual flow across the years.

3.2 Mapping approach

3.2.1 Threatened-species biodiversity

Due to the limited availability of species surveys and insufficient data collection across various taxonomic groups in the area, we used previously developed species distribution models (Kennard 2010; Pintor et al. 2018) to generate maps of habitat suitability for freshwater species in the Mitchell, Gilbert and Flinders catchments. It is important to note that these maps do not show estimated species richness but, rather, the number of species that locations could likely support, if those species could colonise them. Consequently, the maps do not provide the exact locations of individual species. Rather, they emphasise catchment areas with the capacity to harbour populations of diverse at-risk species. Threatened-species classifications were based on state, national and international assessments (Appendix Table 7-1).

Pintor et al. (2018) developed a species-distribution modelling approach for threatened aquatic species in northern Australia. The methodology involves several stages.

- Occurrence records were collected from various databases (including museums, Atlas of Living Australia, state collections and others) and cleaned to remove dubious and non-Australian records. Records since 1975 with a 250-m resolution were prioritised; however, criteria were relaxed if fewer than 20 verifiable records were available for a taxon.
- Environmental predictor variables specific to the ecology of the aquatic taxon were selected from a larger dataset.
- Environmental layers were adjusted to the required extent, resolution and coordinate system.
- Species-distribution models were created using the Maxent modelling approach for aquatic species by relating the species occurrence data to the environmental predictor variables.
- Maxent produces a probability that each pixel in the modelling area is suitable habitat for each species, and the modellers used an expert review process to determine the threshold above which to classify the pixel as suitable habitat.

This approach offers a comprehensive methodology for down-scaling species distribution models to specific catchments in order to identify suitable habitat for threatened aquatic species in the Gilbert, Mitchell, and Flinders catchments. We generated maps to show the richness of all threatened aquatic species, and also specific taxonomic groups, i.e. freshwater fish, frogs, shorebirds, strictly aquatic species and water-dependent species.

In addition to the maps for threatened aquatic species, we analysed the outputs from 1,425 individual species distribution models generated by Pintor et al. (2018) to compile species lists representing the potential biodiversity within each focal catchment. This process entailed separately clipping the output of each individual aquatic species-distribution model to the boundary of each catchment and determining if any of the habitat in the catchment was predicted to be suitable for the species (Figure 3-2). We executed this for every aquatic taxonomic group to generate lists of threatened species that could persist within each of the catchments according to the species-distribution models.

Note that the expert vetted species distribution models may use different data and methods to that used by DCCEEW to underpin the Protected Matters Search tool. The user should be aware of the caveats associated with any modelled data before using them. In addition, the time frame of species distribution records used in the species distribution models (generally post-1975) and the grain size of the data (250 m) differs to that used by DCCEEW for their modelling and will therefore generate different results. The intent and purpose may therefore result in different decisions about the data used and the output generated. Also note that any species distribution model is generated at a point in time from available data and can be updated and improved with new and better source data as they become available.

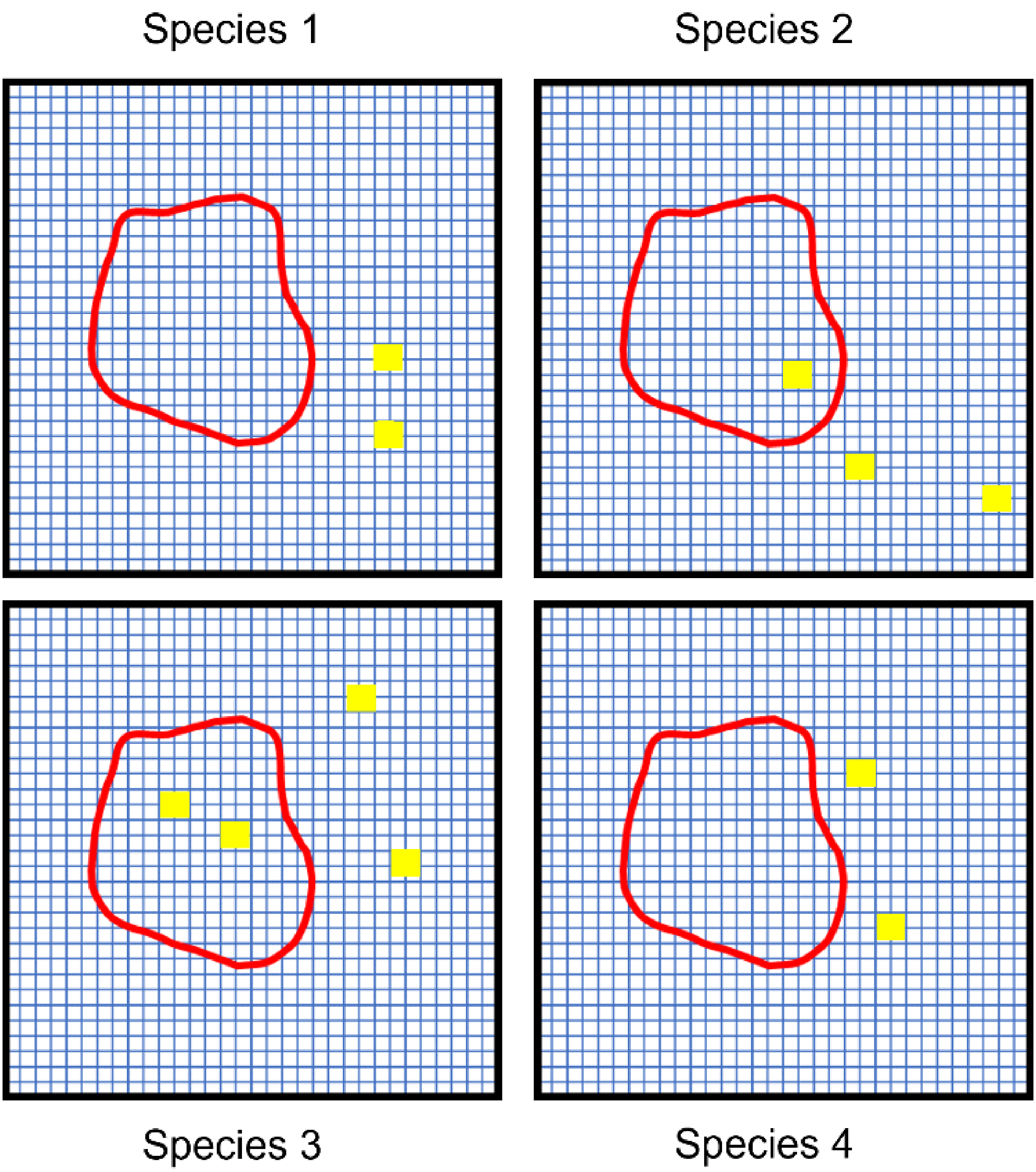

Figure 3-2. Conceptual illustration of the process to identify whether any habitat within a given region is predicted to be suitable for a given aquatic species. Pixels shaded in yellow are predicted to be suitable. Where those fall inside the red polygon, that species is counted as being potentially within the region.

3.2.2 All aquatic biodiversity

We followed a similar approach to mapping all aquatic biodiversity (i.e. including non-threatened species) to that used for threatened aquatic species. Kennard (2010) developed species-distribution models for various aquatic species which identified the number of species for which a given region would provide suitable habitat. These models were developed for nested sub-catchments as the primary spatial unit across northern Australia, as opposed to the pixel-based approach from Pintor et al. (2018). Maps were calibrated using existing data and found to be effective in predicting species distributions in unsurveyed areas. A non-parametric regression modelling method, multivariate adaptive regression splines (MARS), was employed to successfully model the probability of occurrence for different species in the study region. The following methodology was applied.

- Aquatic species records and environmental data were collected, nested within sub-catchments, to form the base spatial unit for predictive models of species distributions. An approximate mean spatial unit area of 72 km^2 was determined for waterbirds due to their mobility and range.
- Sampling records for aquatic macroinvertebrates, fish, turtles and waterbirds were identified and a selection of spatial units containing records for these species was used for model calibration. Extremely rare species were excluded from the modelling.
- Local-scale and catchment-scale environmental variables (e.g. climate, terrain, substrate, vegetation, hydrology, stream network characteristics) were selected as predictors for species distributions. Highly correlated variables were removed.
- MARS models were used because of their accuracy and predictive ability when modelling various taxonomic groups and regions and species with low prevalence.
- For model development, presence-only data for all faunal groups were used and the authors created pseudoabsences for missing absence data.
- Model performance was assessed using measures of deviance and the area under the receiver-operating-characteristic curve (AUC). A k-fold cross-validation procedure was used for AUC assessment, and models with AUC > 0.6 were considered acceptable.
- The predictive probabilities of occurrence were converted to a presence/absence estimate, with the choice of probability threshold based on the dataset's observed prevalence.
- Finally, the predictive models were used to generate species-distribution coverages for the study region, except for areas that lacked necessary environmental data or that were beyond the range of environmental variation of calibration sites.

3.2.3 Pressures on aquatic biodiversity

There are many current and emerging pressures on aquatic biodiversity that may impact the distribution and abundance of aquatic species, including many threatened species. These pressures are generated at local and regional scales and include the alteration of local vegetation, water resources development and climate change. To illustrate the pattern of such pressures in the context of the potential spatial extent of aquatic biodiversity, we obtained maps of current and potential pressures in the 3 focal catchments.

3.2.3.1 Climate change impacts

Pintor et al. (2018) devised a spatially explicit index to forecast the potential impact of climate change on heat and drought in northern Australia by 2050. This was based on spatially explicit bioclimatic variables from 17 global circulation models for current and future conditions under emissions scenario RCP8.5 (the 'business-as-usual' scenario) of the IPCC (Intergovernmental Panel on Climate Change). These variables were converted into a metric that quantified expected changes in heat and drought parameters. The metric quantifies cumulative environmental stress on all ecosystems due to climate change by comparing the current and future values of 10%, 50%, and 90% quantiles for 5 key variables: dry-season length, hot-season length, maximum temperature increase, proportionate change in annual precipitation and proportionate change in hot-season precipitation. This type of mapping approaches provides a mechanism to look at where the greatest change in season length, temperature and rainfall is likely to occur across the landscape. This metric was mapped at the pixel scale at 1 km^2 resolution across northern Australia. It is acknowledged that the predictions for future climate for northern Australia is less certain that other areas of Australia, particularly relating to weather patterns.

3.2.3.2 Development pressures

The opportunities for development of irrigated land in northern Australia has attracted attention from communities, governments, industries and Indigenous groups. Agricultural development can impact downstream water quality via sediment, nutrient, herbicide and pesticide loads, with the severity varying according to the type and intensity of the activities. Previous projects evaluating the development opportunities in the focal catchments include the Flinders and Gilbert Agricultural Resource Assessment and the **Northern Australia Water Resources Assessment** (Mitchell River catchment). More recently, a strategic assessment by Alluvium Consulting identified suitable areas for agricultural development in the Flinders, Gilbert and Mitchell catchments using a multi-weighted criteria analysis (MCA) to identify areas with different levels of development suitability, ranging from 1–5, representing low suitability to high suitability (Eccles et al. 2022). The criteria used were land suitability, economics, salinity risk, environmental, water accessibility, water plan and temperature. Land suitability had the highest rating. We have used the outputs from this MCA to illustrate the potential for agricultural pressures on biodiversity in the focal catchments.

4. Results

4.1 Maps of threatened species and biodiversity – all catchments

Using spatial species distribution models, we have identified potential habitats for threatened species (Figure 4-1) and overall aquatic biodiversity (Figure 4-2). Floodplains of all catchments tend to have habitats that could potentially support a large variety of threatened species (Figure 4-1); however, there are clear differences in the spatial patterns in each catchment. The Mitchell River catchment is predicted to have habitats that may support higher numbers of threatened species than the other 2 catchments. The Gilbert River catchment displays moderate potential for supporting threatened species, while the habitats of the Flinders River catchment are predicted to support the fewest number of threatened species.

Within each catchment there are also some different patterns of where suitable habitat for threatened species is likely to be. The Mitchell River shows a more even distribution of potential habitats, while in the Flinders River there is a notable decrease in potential habitats moving towards its headwaters. The pattern in the Gilbert is broadly similar to the Mitchell, with habitats in both the headwaters and floodplain predicted to be suitable for relatively high numbers of threatened species. These patterns are reflected for most taxonomic groups, including strictly aquatic species (Figure 4-1a) and water-dependent taxa (Figure 4-1b); however, suitable habitat for higher numbers of threatened frogs tended to be found in the headwater regions than the floodplains (Figure 4-1c). A notable difference from these general patterns is in the habitat suitability for all aquatic biodiversity in the Flinders River where a broad region of the upper catchment has habitats that are predicted to be suitable for a relatively high number of aquatic birds and freshwater turtles (Figure 4-2a and Figure 4-2c).

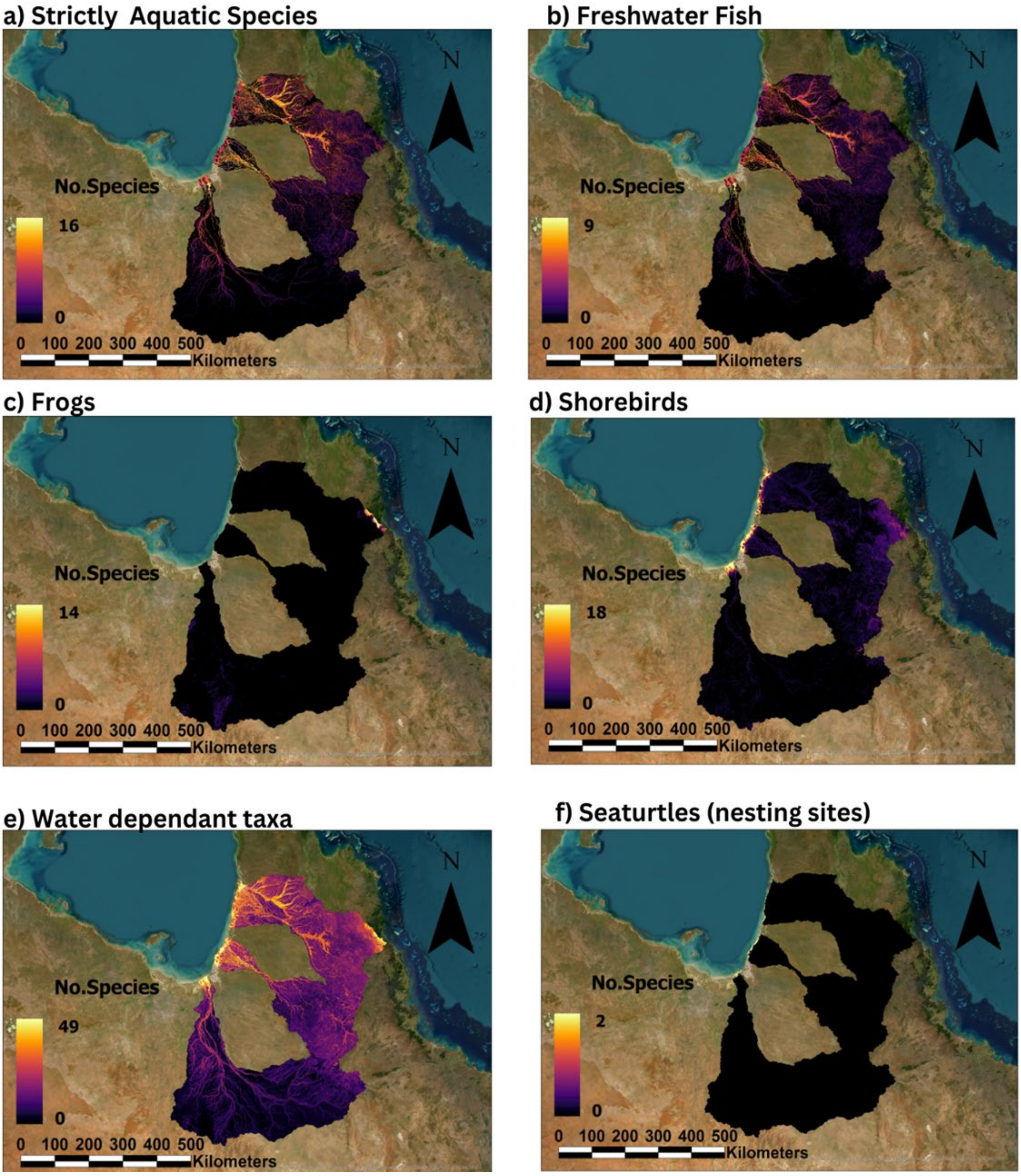

Figure 4-1. Relative importance of habitats suitable for threatened taxa (number of species) across all catchments, down-scaling from Pintor et al. (2019). Warmer colours indicate pixels with suitable habitat for a larger number of species.

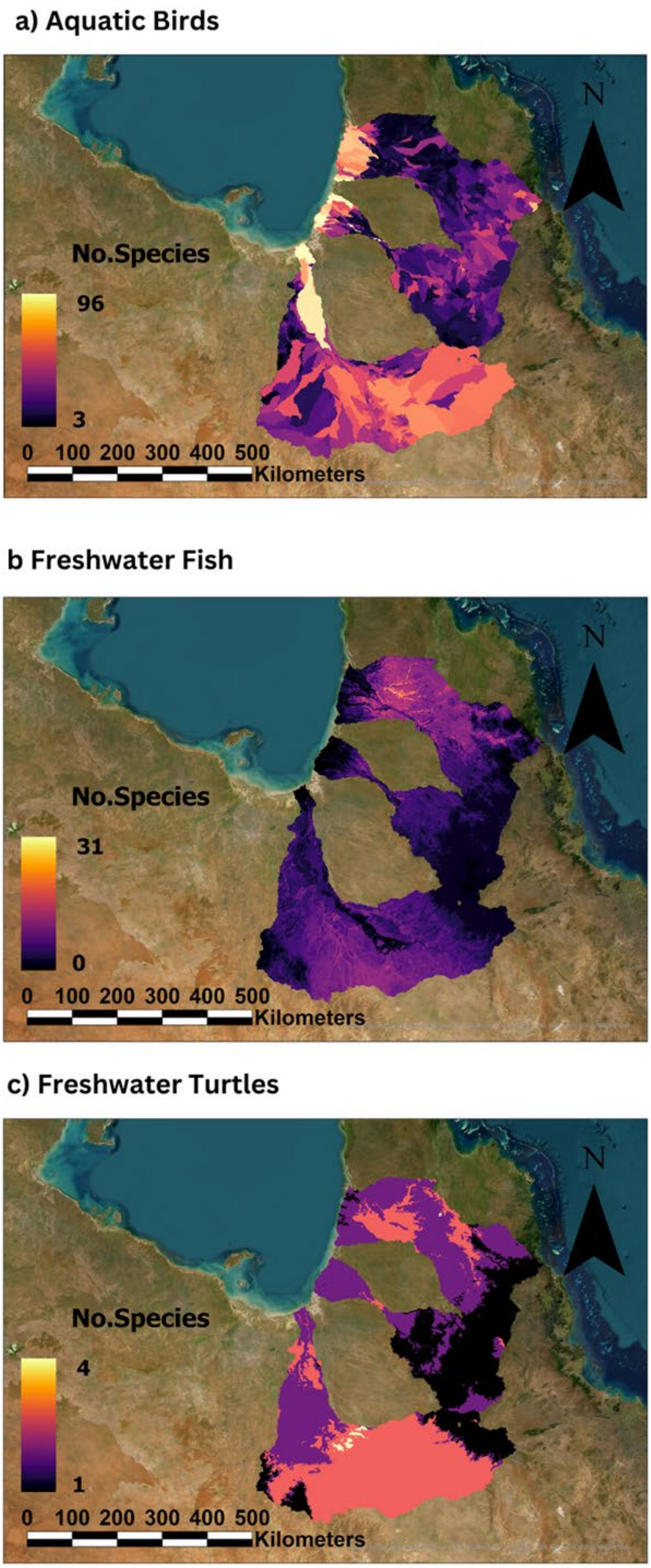

Figure 4-2. Relative importance of habitats suitable for all aquatic taxa from Kennard (2010). Warmer colours indicate sub-catchments with suitable habitat for a larger number of species.

It is important to note that areas predicted to have fewer suitable habitats for threatened species, based on these models, are still very likely to be important to the biodiversity of the region. The areas of higher biodiversity and threatened species provide predictions about **potential** habitats for threatened species, not the identities of the species that may find suitable habitat in the catchments. Additionally, locations with habitats that are expected to support only a small number of species may include highly threatened or culturally significant species. The full list of predicted threatened species for the catchments is listed in Appendix Table 7-2.

4.2 Maps of threatened species biodiversity – Mitchell River

There are areas with habitats that are predicted to be suitable for higher numbers of threatened species across the entire Mitchell River catchment (Figure 4-3). For the overall map of strictly aquatic threatened species, aquatic habitat is predicted to be suitable for a higher number of species in the mid-lower catchment (Figure 4-3a), which is consistent with the patterns for threatened freshwater fish (Figure 4-3b). In addition to this, there are areas in the headwaters of the catchment that maybe suitable for relatively high numbers of frogs and shorebirds (Figure 4-3c and Figure 4-3d), while the coastal region of the catchment has habitats that are expected to be suitable for the highest richness of shorebirds (Figure 4-3d). These patterns were reflected in the map of all water-dependent taxa, with habitats that are predicted to be suitable for higher numbers of threatened species that depend on water at some stage of their life cycle found in the headwaters as well as the mid-lower catchment (Figure 4-3e). Additionally, these patterns are broadly consistent with the maps of all aquatic birds and freshwater fish, with the mid-lower catchment expected to have habitats that are suitable for higher freshwater-fish richness (Figure 4-3a) and the habitats of the headwaters and lower catchment expected to be suitable for higher numbers of aquatic birds (Figure 4-4b).

While these maps do not identify the species, the spatial analyses of the individual species models indicate that the Mitchell River catchment is the only catchment in this study that is predicted to have habitats that may be suitable for a several crustacean species, including *Austrothelphusa tigrine* and *A. valentula* (Appendix Table 7-1). The catchment is also the only one that is predicted to have suitable habitat for the tree frog species *Litoria lorica*, *L. nannotis* and *L. longirostris*. These species are not yet known to occur in the catchment; however, they occupy similar nearby habitats of the Wet Tropics and other parts of Cape York. The habitats of the Mitchell are also predicted to be suitable for *Taphozous australis* (common sheath-tailed bat) and the *Xeromys myoides* (false water-rat). Again, it is important to recognise that these results are based on potential habitat suitability and do not confirm the actual presence of these species in the catchment.

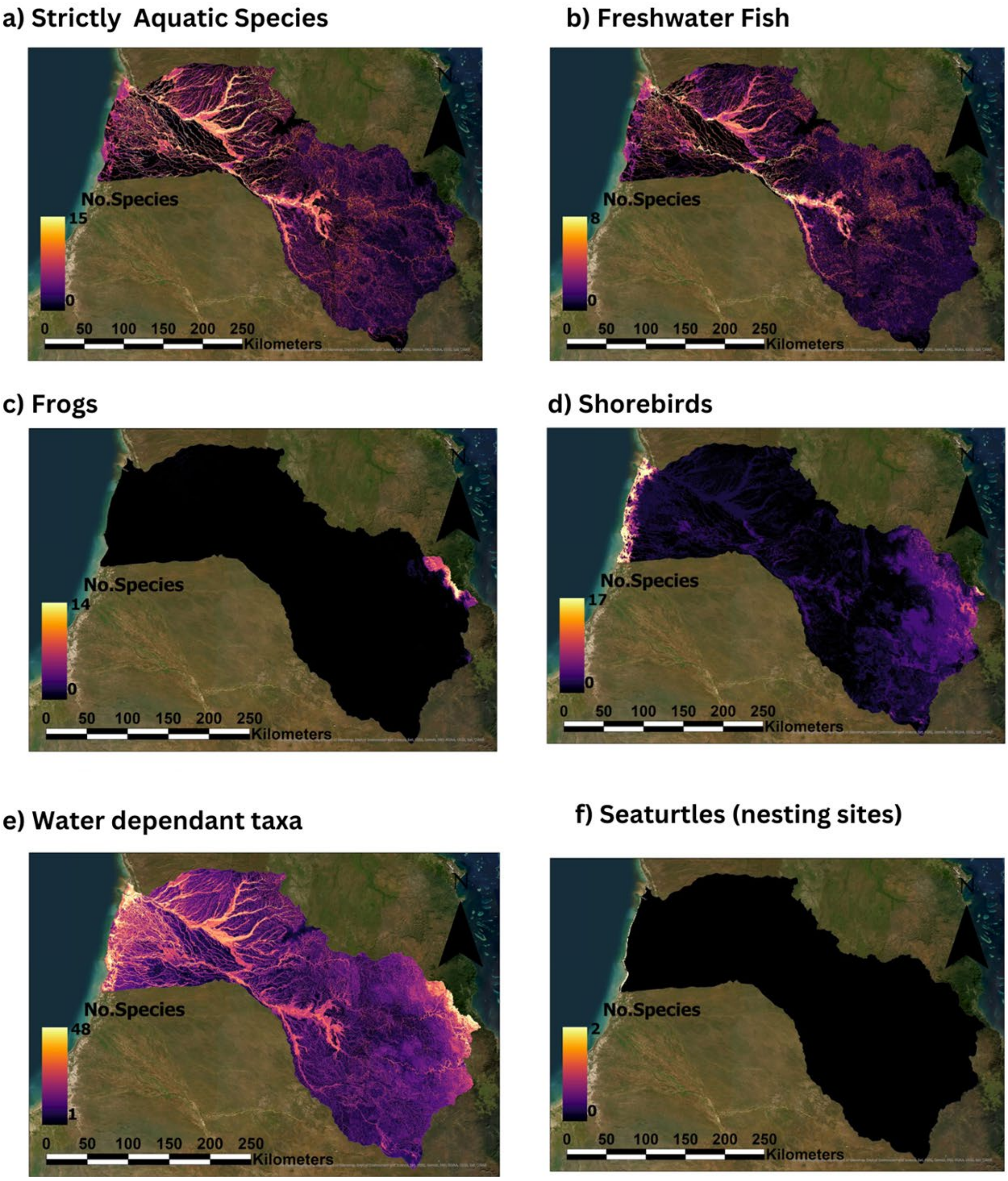

Figure 4-3. Relative importance of habitats suitable for threatened taxa (number of species) in the Mitchell River system from Pintor et al. (2019). Warmer colours indicate pixels with suitable habitat for a larger number of species.

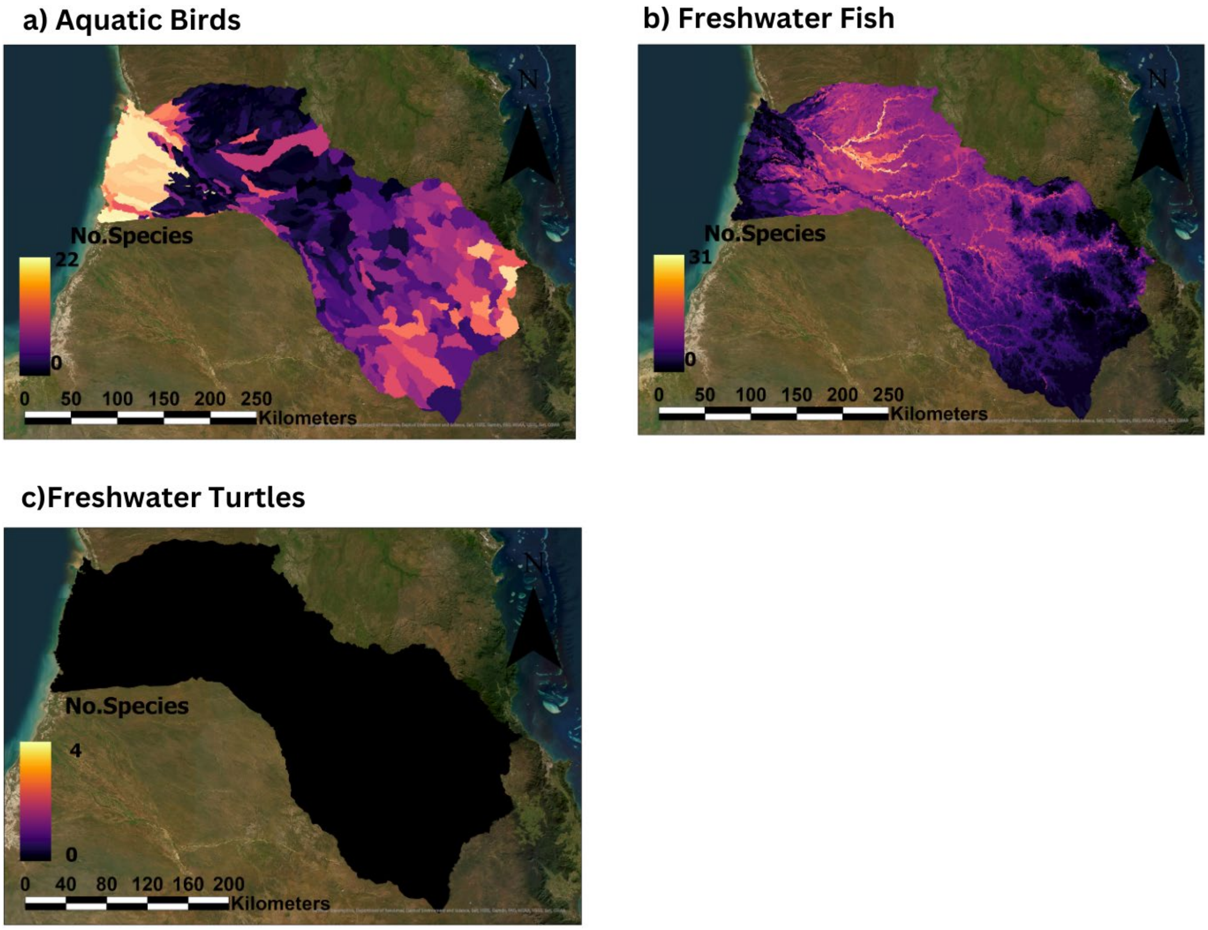

Figure 4-4. Relative importance of habitats suitable for aquatic taxa (number of species) in the Mitchell River system from Kennard (2010). Warmer colours indicate sub-catchments with suitable habitat for a larger number of species.

4.3 Maps of threatened species and biodiversity – Gilbert River

As noted above, areas of habitat that are predicted to be suitable for higher numbers of threatened species in the Gilbert River tend to be in the middle-lower reaches and the floodplain (Figure 4-5). Nonetheless, there are several strictly aquatic threatened species for which suitable habitat is predicted in the middle and upper reaches of the river (Figure 4-5a). The large alluvial floodplain and coastal zone of the Gilbert is predicted to have habitats that may be suitable for higher numbers of threatened freshwater fish and shorebirds (Figure 4-5b and Figure 4-5d). Habitats that may support higher numbers of water-dependent taxa are found throughout the catchment (Figure 4-5e). These patterns were generally consistent for all aquatic biodiversity, with habitats in the middle and lower catchment expected to be suitable for higher species richness (Figure 4-6). This was particularly evident in the floodplain and coastal zone, where habitats may support the highest number of aquatic bird species (Figure 4-6a), while the habitats of the middle reaches of the catchment are likely to be suitable for higher freshwater fish and turtle richness (Figure 4-6b and Figure 4-6c).

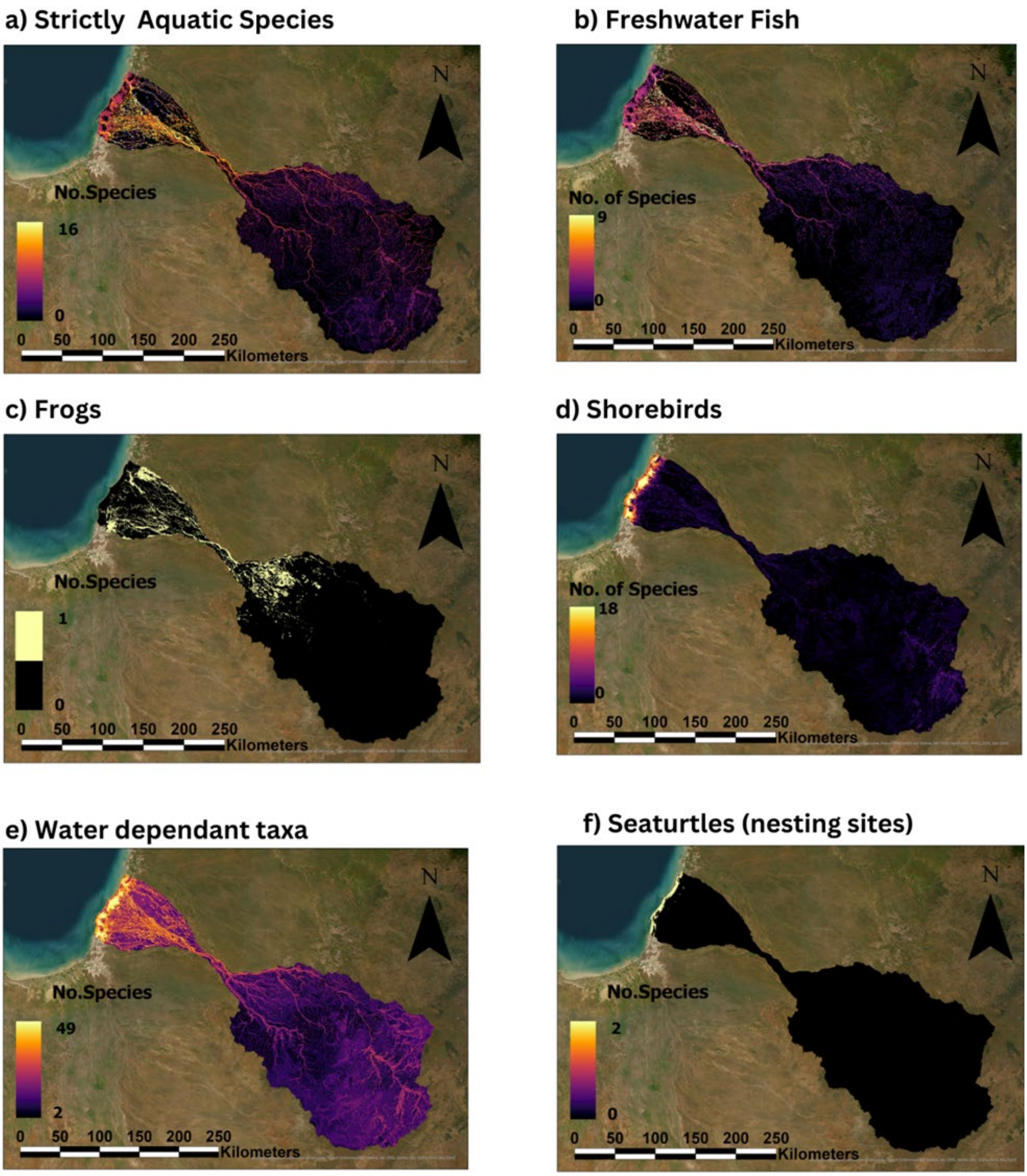

Figure 4-5. Relative importance of habitats suitable for threatened taxa (number of species) in the Gilbert River system from Pintor et al. (2019). Warmer colours indicate pixels with suitable habitat for a larger number of species.

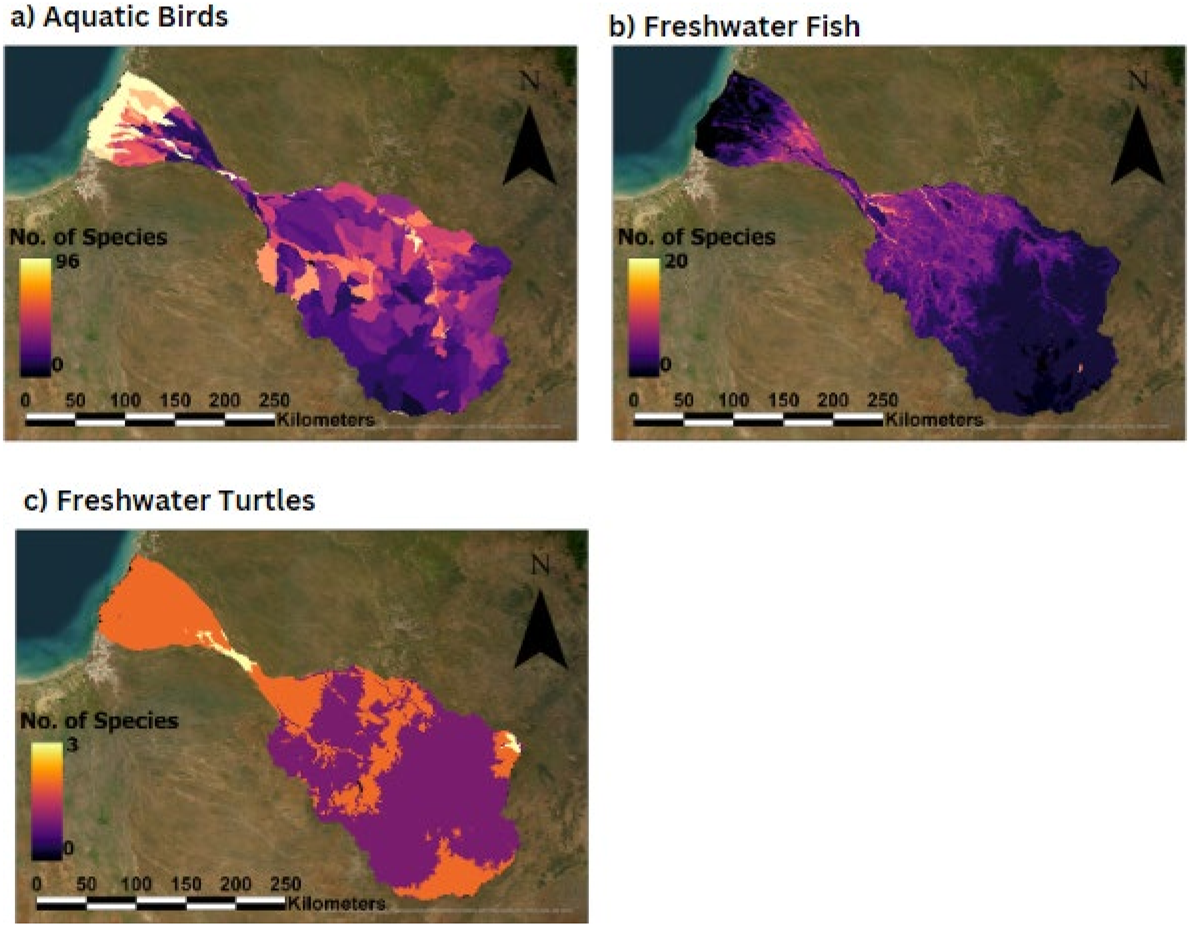

Figure 4-6. Relative importance of habitats suitable for aquatic taxa (number of species) in the Mitchell River system from Kennard (2010). Warmer colours indicate sub-catchments with suitable habitat for a larger number of species.

4.4 Maps of threatened species and biodiversity – Flinders River

As noted above, habitats that are predicted to be suitable for higher numbers of threatened species in the Flinders River tended to be in the lower catchment (Figure 4-7). This pattern is true for the majority of the threatened aquatic taxonomic groups, including water-dependent taxa. This includes habitats for the desert spadefoot toad (*Notaden nichollsi*), a species that is presumed extinct by the Qld Government (Appendix Table 7-1 and Table 7-2). In terms of all aquatic species richness, habitats in the lower catchment are predicted to be suitable for higher aquatic bird richness (Figure 4-8a). In contrast, habitats in the middle and upper catchment are predicted to be suitable for higher numbers of freshwater fish and turtle species (Figure 4-8b and Figure 4-8c).

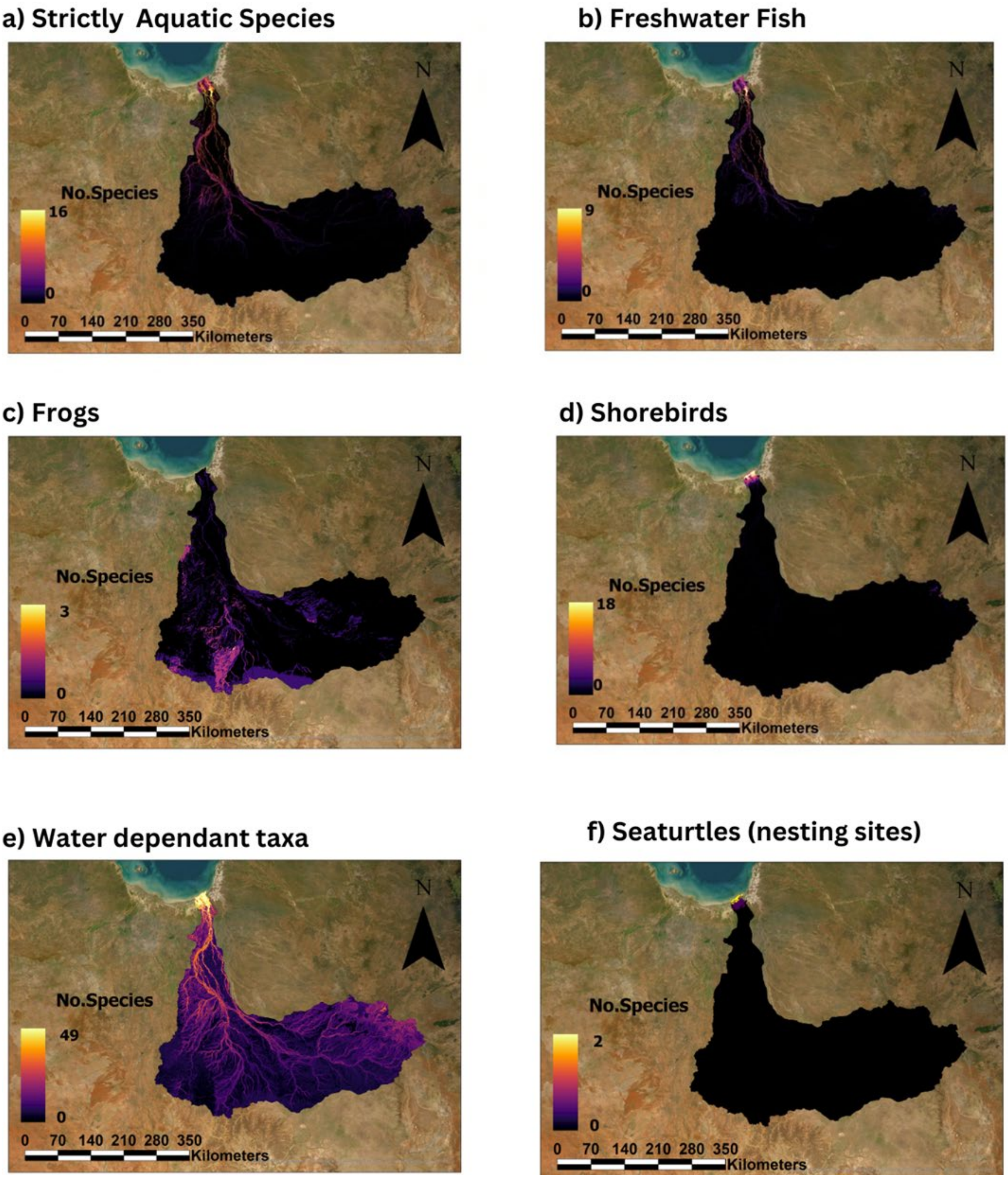

Figure 4-7. Relative importance of habitats suitable for threatened taxa (number of species) in the Flinders River system from Pintor et al. (2019). Warmer colours indicate pixels with suitable habitat for a larger number of species.

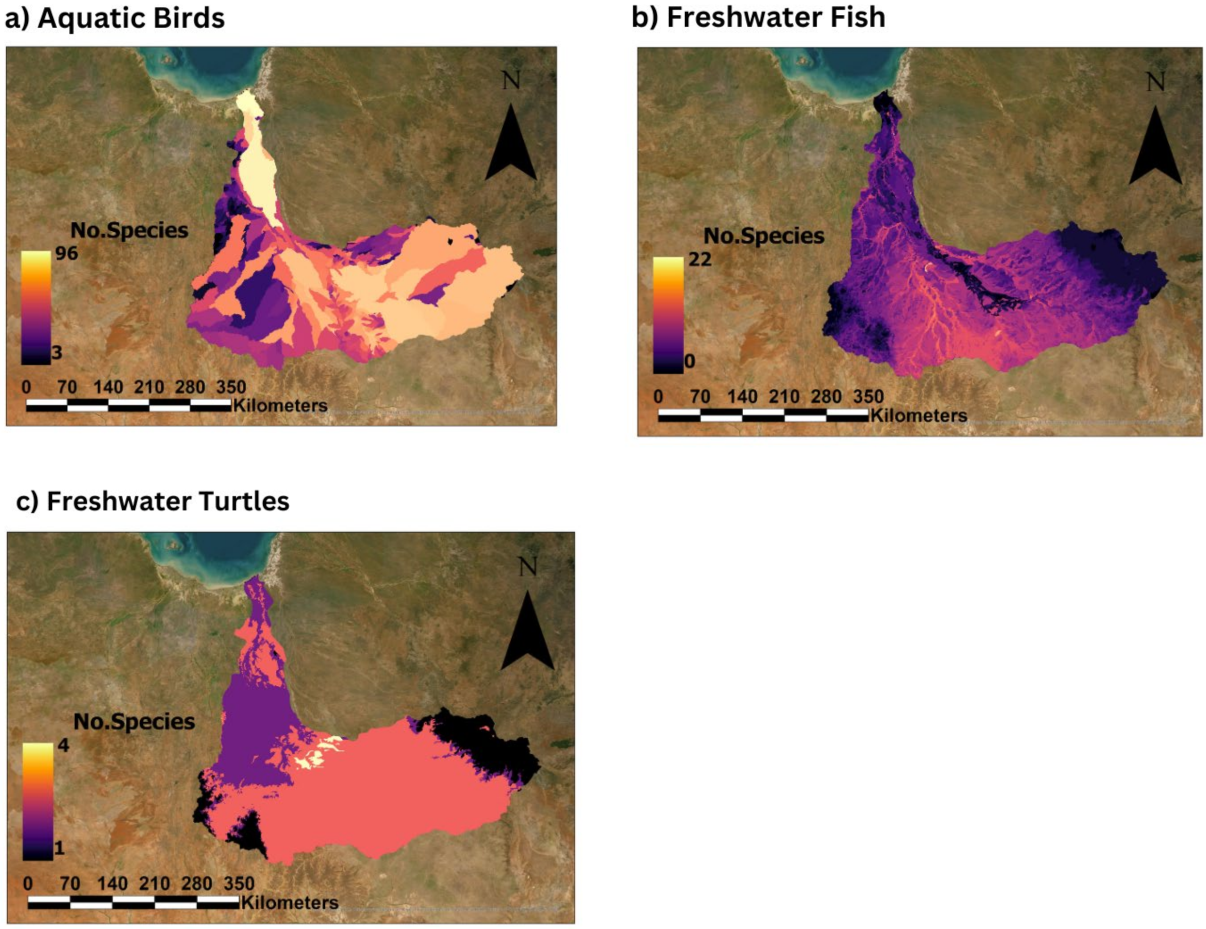

Figure 4-8. Relative importance of habitats suitable for aquatic taxa (number of species) in the Flinders River system from Kennard et al. (2010). Warmer colours indicate sub-catchments with suitable habitat for a larger number of species.

4.5 Anthropogenic pressures on the region

4.5.1 Agricultural development

According to the recent MCA, there may be suitable land for additional agricultural development across all three catchments (Figure 11, Eccles et al. 2022). The Flinders catchment has the most extensive area that may be suitable; however, the scores tend to be relatively low compared with the maximum potential score. Unsurprisingly, the areas of the Flinders with higher suitability tend to be very close to the major river channels (indicated by the darker colours that follow the major drainage channels of the catchment). In contrast, the Mitchell catchment has the least amount of suitable land; however, the likely suitability for agriculture is relatively high, especially towards the headwaters of the catchment. Approximately 60% of the Gilbert catchment was assessed as potentially suitable with moderate to high levels of suitability throughout the catchment.

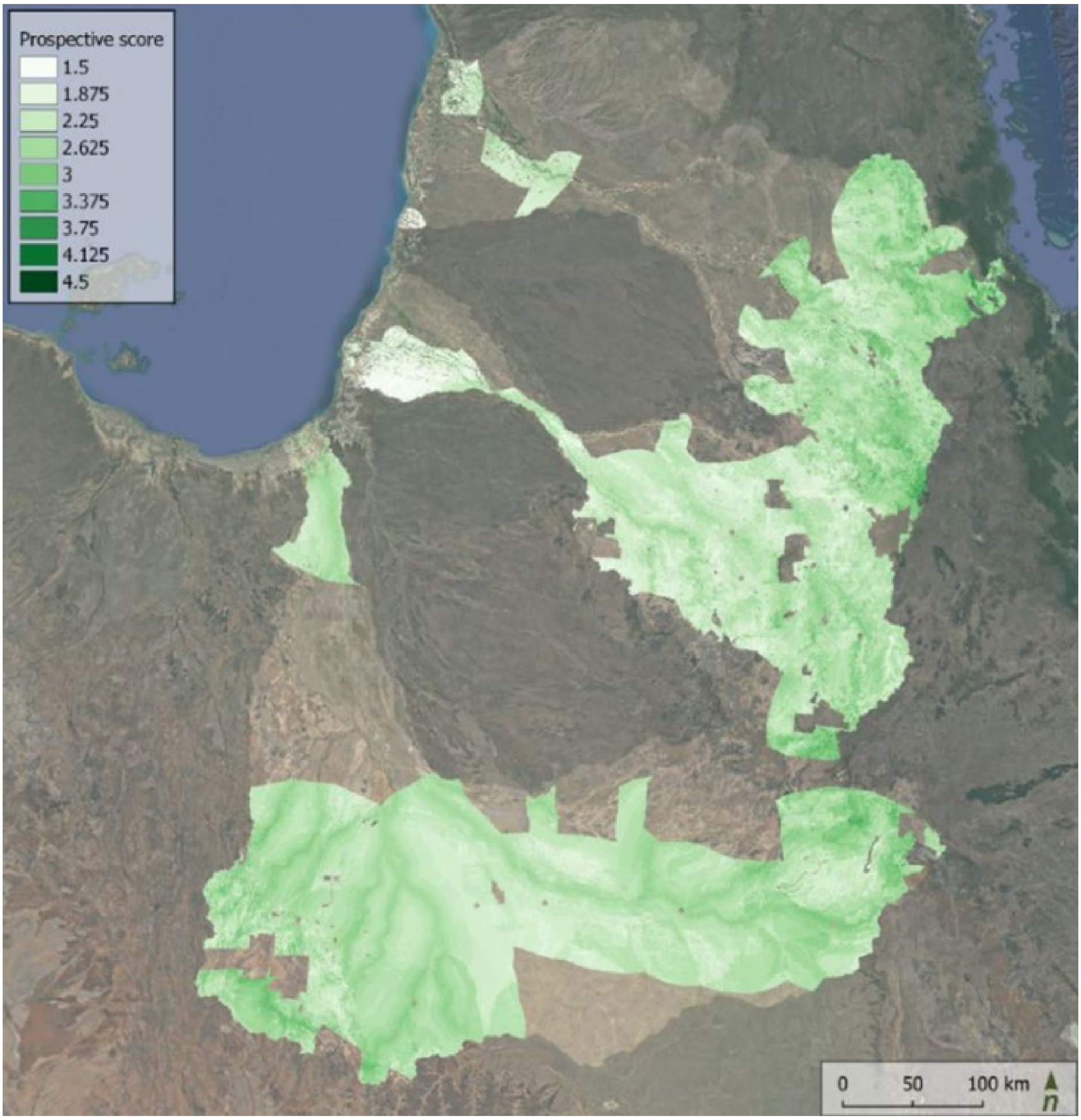

Figure 4-9. Suitability of land identified following the multicriteria analysis (MCA; score of 5 being most suitable and 1 being least suitable) as feasible in a recent agricultural suitability assessment (reproduced from Eccles et al. 2022).

4.5.2 Climate change

A climate dissimilarity map (Pintor et al. 2018) was generated, based on dry-season length, hot-season length, maximum temperature increase, proportionate change in annual precipitation and proportionate change in hot-season precipitation. This type of mapping approach provides a mechanism to look at where the greatest change in season length, temperature and rainfall is likely to occur across the landscape. This map demonstrates highest dissimilarity close to the floodplains that feed into the Gulf of Carpentaria across all catchments (Figure 4-10). In other words, this is where there is the greatest deviation from the current climate in a projection through to 2050 under IPCC emissions scenario RCP8.5 (the 'business-as-usual' scenario). This pattern is most pronounced in the Flinders catchment, followed by the Gilbert catchment, while the Mitchell catchment exhibits the lowest level of dissimilarity. Climate dissimilarity seems to diminish away from the Gulf of Carpentaria, with lower dissimilarity around the Atherton Tablelands and Wet Tropics of the Mitchell catchment and the southern headwaters of the Flinders catchment.

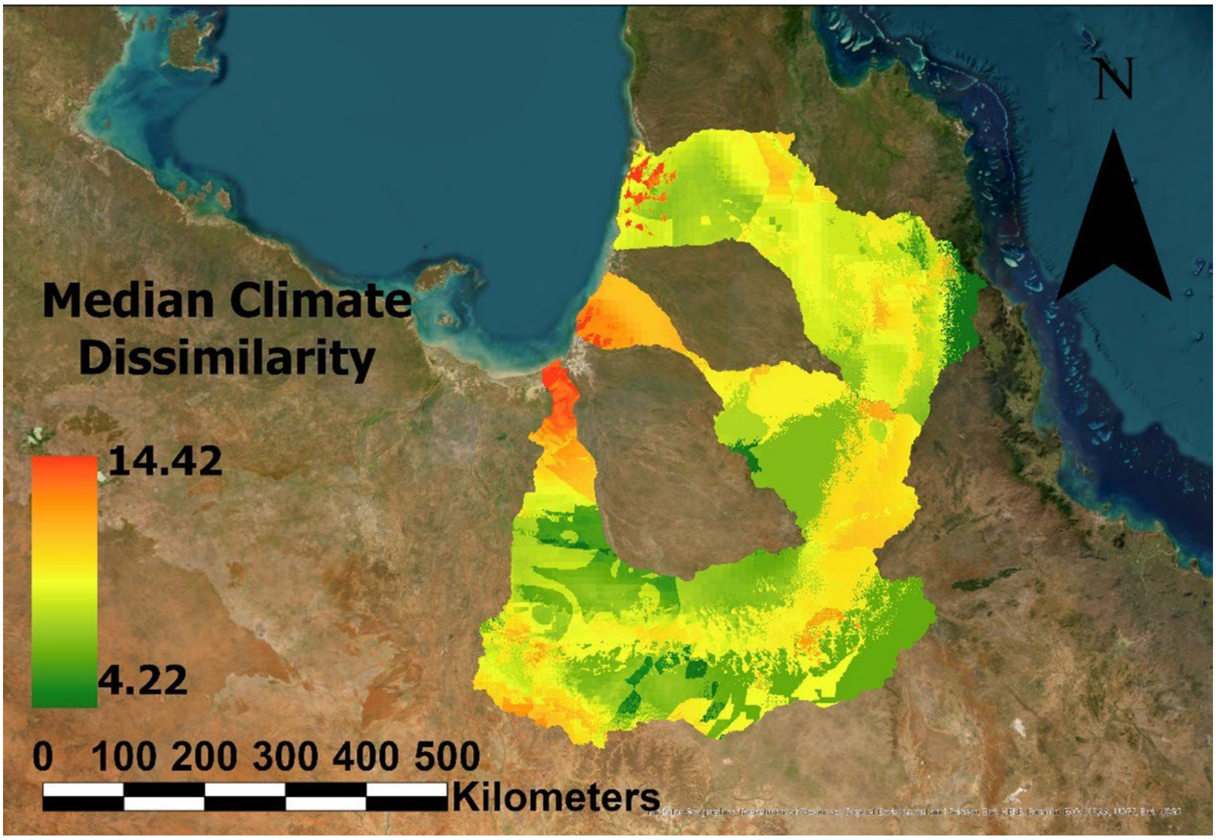

Figure 4-10. Median climate dissimilarity across all catchments in the study from Pintor et al. (2019) showing the relative difference between today's climate and 2050 under RCP8.5. Warmer colours indicate higher dissimilarity and cooler colours indicate lower dissimilarity.

5. Discussion

We have predicted areas with higher potential numbers of threatened aquatic species, as well as all species, based on habitat-suitability mapping for 3 major rivers of the south-east Gulf of Carpentaria – the Flinders, Gilbert and Mitchell rivers. These 3 river systems have been earmarked for water-resource development (DNMRE 2018a,b). We combined the mapping approach with future potential pressures due to agricultural development and climate change.

The study found that habitats predicted to be suitable for relatively high numbers of species occurred throughout the Mitchell River, while such habitats tended to be primarily in the downstream reaches of the Flinders and Gilbert rivers. This is likely due to the rainfall and runoff patterns in these 3 systems. The Mitchell River originates in the Wet Tropics, and headwater streams are likely to be flowing for more of the year. On the other extreme, the headwaters of the Flinders River are dry for much of the year so there is limited habitat for aquatic systems (Faggotter et al. 2010, Kennard et al. 2010, Burford et al. 2021a).

The maps of habitat suitability showed that the 3 catchments have the potential to support a diverse range of species. However, these species lists are only modelled predictions with little ground-truthing. Additionally, it is important to recognise that the number of species for which a location may be predicted to be suitable is only part of the story. Locations with low species richness are not necessarily less important than those with higher biodiversity. There may be species that play a key role in an ecosystem that are not identified via these approaches. The maps themselves do not identify individual species, and habitats that support fewer species may include keystone or endemic species that are highly important for biodiversity and species that hold significant cultural values.

There has been limited research on the habitats and their species in these 3 river systems. To date, much of the focus has been on the estuaries and particularly commercial species, such as banana prawns (*Penaeus merguiensis*) and barramundi (*Lates calcarifer*) (e.g. Broadley et al. 2020, Burford et al. 2020, Leahy and Robins 2021). The effects of future water-resource development on these species have been predicted. Additionally, coastal environments and estuaries are key habitats for migratory shorebirds, including a number of endangered and critically endangered species (Driscoll 1997, 2001, 2014). This includes the mouths of the Flinders, Gilbert and Mitchell rivers, with the Flinders River mouth having the highest numbers and diversity of birds (Burford et al. 2021b). Freshwaters are poorly studied, with only a few studies characterising species and their flow requirements (e.g. Faggotter 2010, Waltham et al. 2013, McJannet, et al. 2014, O'Mara et al. 2021). However, these studies identify a number of species that use perennial waterholes in the rivers and off-channel as refugia during the dry season, and access floodplains for feeding and breeding during the wet season. Connectivity up and down rivers is also important to ensure that the entire river system is accessible, including for threatened species such as freshwater sawfish (*Pristis pristis*) and giant freshwater whipray (*Himantura dalyensis*). A recent modelling study showed that the freshwater sawfish had a high sensitivity to water-resource development in Gulf of Carpentaria rivers (Plaganyi-Lloyd et al. in press).

The interplay of intra-annual and inter-annual variation in flows is an important aspect of aquatic habitats, providing suitable conditions and access to resources for a range of species at different times of the year (Venarsky et al. 2020; O'Mara et al. 2021, Lowe et al. 2022). Flow also provides critical nutrients that fuel food resources (Burford and Faggotter, 2021). It facilitates a strong connection between river flows originating in the headwaters and the ecological needs of coastal shorebirds and freshwater fish on the floodplains (Burford et al. 2020, 2021a, 2021b; Ndehedehe et al. 2021). Consequently, changes to flows in the headwaters from water-resource development could significantly impact habitats on the floodplain, not just in the headwaters or the location of any infrastructure, with subsequent impacts to threatened biodiversity (e.g. Molinari et al. 2022). The areas flagged as suitable for development tend to be in the middle to upper parts of the catchments. Therefore, it is important to consider not just the local effects of water-resource development on species living in the middle to upper parts of the catchment but also those in downstream reaches, including the estuaries and nearshore (Plaganyi et al. in press).

The threat of climate change and development pressures present challenging management implications for the 3 catchments in this study. The climate dissimilarity map showed increased dissimilarity near the floodplains that feed water into the Gulf of Carpentaria across all catchments. The Flinders catchment displayed the most marked pattern, suggesting that climate change may more significantly impact species distribution here. Changing climatic patterns, including increasing temperatures, variations in rainfall patterns and rising sea levels, may significantly affect the local habitats. This includes perennial waterholes, which in the Flinders and Gilbert river catchments have been predicted to be vulnerable to changes in rainfall and runoff (McJannet et al. 2014). Changes in rainfall are likely to impact the freshwater flows which will affect ecosystems from headwaters to the coastal zone. This region is notable for its high inter-annual variability in flow and long cease-to-flow periods in many sub-catchments, while the floodplains of the 3 rivers hold water for varying lengths depending on annual flows (Ndehedehe et al. 2020b and 2021).

Equally, increased temperatures may lead to heightened thermal stress for native fauna. This is exemplified by increased water temperatures surpassing the physiological thresholds of local fish species and potentially reduced levels of dissolved oxygen (Wallace et al. 2015). However, a study of genetic variability in rainbow fish (*Melanotaenia* spp.) across Queensland's Wet Tropics showed the importance of hybrids in sustaining populations under climate change (Brauer et al. 2023). As such, ensuring protection of sufficient habitat to ensure hybrid populations is critical to managing biodiversity and threatened species into the future.

Habitats, such as mangrove forests, are also likely to be affected. A recent study by Chung et al. (2023) used climate projections from climate change models to indicate an increased occurrence of anomalously low and high sea level events in the Gulf of Carpentaria in the coming century, with scenarios of increased carbon dioxide emissions having greater effects. This, alongside enhanced temperature stress, is likely to significantly increase risk to mangrove health in this region.

A study of streamflow projections for the Murray–Darling river system, based on down-scaled climate change models, found a large range in future projections of hydrological metrics, mainly because of the uncertainty in rainfall projections (Chiew et al. 2022). The same issues are likely to be the same or worse for the Gulf region, given the paucity of down-scaled model projections for this region of Australia.

Compounding climate extremes (CCEs) are an aspect of climate change that is poorly studied. Multiple extreme climate conditions can provide the ‘perfect storm’ to have unpredictable and synergistic effects on species. This is of likely to be of particular concern in the Gulf region, which already has climate extremes testing the tolerances of many species and habitats, as seen in the mangrove dieback event in 2015–16 and the 2020 inland native forest dieback events across northern Australia (Allen et al. 2021). While many ecological communities may have experienced CCEs in past centuries, the addition of new environmental stressors associated with varying aspects of global change may exceed their thresholds of resilience.

5.1 Limitations and future research

It is important to acknowledge the data limitations of this study. The lack of publicly available biodiversity data across the region necessitated the use of the habitat-suitability maps for estimating the potential for areas of higher biodiversity. With the increasing development pressures in the region and the potential for widespread impact from potential developments, protecting the region’s biodiversity relies on effective knowledge of the distribution of threatened species. While currently lacking, the maps of habitat suitability provide a framework for biodiversity surveys to improve such knowledge. Therefore, future studies should undertake species surveys to ground-truth the presence of species across the catchments.

Development-pressure maps were based on multicriteria analysis using land suitability, economics, salinity risk, environmental, water accessibility, water plan and temperature (Eccles et al. 2022). This study had to draw on available data that was relatively limited. Therefore, it is a relatively coarse-scale study and only focuses on water development. There are likely to be other pressures (e.g. mining) that are not currently covered by this study.

The impact of climate change on the region is likely to be multifaceted, with sea level rise combining with changes to rainfall patterns and, subsequently, river flows. The available data showing median climate dissimilarity values does not necessarily capture the full range of possible outcomes, particularly under extreme climate change scenarios that may eventuate. It is also important to consider the potential interactions between climate change and other anthropogenic pressures, such as changes in land use, which could exacerbate the impacts on ecosystems and species (Oliver and Morecroft 2014). Future research on species-specific responses to climate change, including multiple emissions scenarios, to investigate the potential combined effects of climate change and other anthropogenic pressures on these catchments will help protect the region’s biodiversity and threatened species.

6. References

Allen KJ, Verdon-Kidd DC, Sippo JZ and Baker PJ (2021) 'Compound climate extremes driving recent sub-continental tree mortality in northern Australia have no precedent in recent centuries', *Scientific Reports*, 11:18337.

Brauer CJ, Sandoval-Castillo J, Gates K, Hammer MP, Unmack PJ, Bernatchez L and Beheregaray LB (2023) 'Natural hybridization reduces vulnerability to climate change', *Nature Climate Change*, 13:282–289.

Broadley A, Stewart-Koster B, Kenyon RA, Burford MA and Brown CJ (2020) 'Impact of water development on river flows and the catch of a commercial marine fishery', *Ecosphere,* 11:e03194.

Burford MA, Valdez D, Curwen G, Faggotter SJ, Ward DP and O'Brien KR (2016) 'Inundation of saline supratidal mudflats provides an important source of carbon and nutrients in an aquatic system', *Marine Ecology Progress Series,* 545:29–33.

Burford MA, Faggotter SJ and Kenyon R (2020) *Project 1.4: contribution of rivers to the productivity of floodplains and coastal areas of the southern Gulf of Carpentaria – Component 1*. NESP Northern Australia Environmental Resources Hub final report. Griffith University, Brisbane.

Burford MA and Faggotter SJ (2021a) 'Comparing the importance of freshwater flows driving primary production in three tropical estuaries', *Marine Pollution Bulletin,* 169:112565.

Burford MA, Faggotter SJ, Lowe V, Venarsky M, Frid C, Ronan M, Bush R and Edwards D (2021b) *Project 3.6: the vulnerability of food supplies for migratory shorebirds to altered flow in the southern Gulf of Carpentaria.* NESP Northern Australia Environmental Resources Hub final report. Griffith University, Brisbane.

Chiew FHS, Zheng H, Potter NJ, Charles SP, Thatcher M, Ji F, Syktus J, Robertson DE and Post DA (2022) 'Different hydroclimate modelling approaches can lead to a large range of streamflow projections under climate change: implications for water resources management', *Water*, 14:2730.

Chung CT, Hope P, Hutley LB, Brown J and Duke NC (2023) 'Future climate change will increase risk to mangrove health in northern Australia', *Communications Earth and Environment*, 4:192.

DNRME (Department of Natural Resources, Mines and Energy) (2018a) *Minister's Performance Assessment Report, Water Plan (Gulf) 2007*, DNRME, Qld Government, Brisbane.

DNRME (Department of Natural Resources, Mines and Energy) (2018b) *Minister's Performance Assessment Report, Water Plan (Mitchell) 2007*, Griffith University and DNRME, Qld Government, Brisbane.

Driscoll PV (1997) 'The distribution of shorebirds along the Queensland coastline', in Straw P (ed) *Shorebird conservation in the Asia-Pacific region*, Australasian Shorebirds Studies Group of Birds Australia, Melbourne.

Driscoll PV (2001) *Gulf of Carpentaria Wader Surveys 1998–99, prepared on behalf of QWSG with assistance from AWSG for the Queensland Environmental Protection Agency*.

Driscoll PV (2014) *Shorebird surveys in the southeast Gulf of Carpentaria*, unpublished report.

Dulvy NK, Fowler SL, Musick JA, Cavanagh RD, Kyne PM, Harrison LR, Carlson JK, Davidson LNK, Fordham SV, Francis MP, Pollock CM, Simpfendorfer CA, Burgess GH, Carpenter KE, Compagno LJV, Ebert DA, Gibson C, Heupel MR, Livingstone SR, Sanciangco JC, Stevens JD, Valenti S and White WT (2014) 'Extinction risk and conservation of the world's sharks and rays', *eLife*, 3:e00590.

Eccles R, Thomas N, Binney J and Weber T (2022) *Strategic assessment of sustainable agricultural development potential for Mitchell, Flinders, and Gilbert catchments*, Alluvium.

Faggotter SJ (2010) *Assessing the top-down control of primary productivity in a dryland-tropical river.* Honours thesis, Griffith University.

Isbell F, Balvanera P, Mori AS, He J, Bullock JM, Regmi GR, Seabloom EW, Ferrier S, Sala OE, Guerrero-Ramírez NR, et al. (2023) 'Expert perspectives on global biodiversity loss and its drivers and impacts on people', *Frontiers in Ecology and the Environment*, 21:94–103.

Kennard MJ (ed) (2010) *Identifying high conservation value aquatic ecosystems in northern Australia*, final report for the Australian Department of Environment, Water, Heritage and the Arts and the National Water Commission, Charles Darwin University, Darwin.

Kennard MJ, Pusey BJ, Olden JD, Mackay SJ, Stein JL and Marsh N (2010) 'Classification of natural flow regimes in Australia to support environmental flow management', *Freshwater Biology*, 55:171–193.

Leahy SM and Robins JB (2021) 'River flows affect the growth of a tropical finfish in the wet-dry rivers of northern Australia, with implications for water resource development', *Hydrobiologia*, 848:4311–4333.

Lowe V, Frid CLJ, Venarsky M and Burford MA (2022) 'Responses of a macrobenthic community to seasonal freshwater flow in a wet-dry tropical estuary', *Estuarine, Coastal and Shelf Science,* 265:107736.

McJannet D, Marvanek S, Kinsey-Henderson A, Petheram C and Wallace J (2014) 'Persistence of in-stream waterholes in ephemeral rivers of tropical northern Australia and potential impacts of climate change', *Marine and Freshwater Research*, 65:1131–1144.

Molinari B, Stewart-Koster B, Malthus TJ and Bunn SE (2022) 'Impact of water resource development on connectivity and primary productivity across a tropical river floodplain', *Journal of Applied Ecology*, 59:1013–1025.

Ndehedehe, C, Burford MA, Stewart-Koster, B, and Bunn, S.E. 2020a. Satellite-derived changes in floodplain productivity and freshwater habitats in northern Australia (1991-2019), *Ecological Indicators*, **114**, 106320.

Ndehedehe, C.E, Stewart-Koster, B, Burford MA and Bunn SE (2020b) 'Predicting hot spots of aquatic plant biomass in a large floodplain river catchment in the Australian wet-dry tropics', *Ecological Indicators*, 117:106616.

Ndehedehe CE, Onojeghuo O, Stewart-Koster B, Bunn SE and Ferreira VG (2021) 'Upstream flows drive the productivity of floodplain ecosystems in tropical Queensland', *Ecological Indicators*, 125:107546.

Oliver PM, Laver RJ, Martins FD, Pratt RC, Hunjan S and Moritz CC (2017) 'A novel hotspot of vertebrate endemism and an evolutionary refugium in tropical Australia', *Diversity and Distributions*, 23:53–66.

Oliver TH and Morecroft MD (2014) 'Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities', *Wiley Interdisciplinary Reviews: Climate Change*, 5:317–335.

O'Mara K, Venarsky M, Stewart-Koster B, McGregor GB, Schulz C, Kainz M, Marshall J and Bunn SE (2021) 'Connectivity of fish communities in a tropical floodplain river system and predicted impacts of potential new dams', *Science of The Total Environment*, 788:147785.

Peverell SC (2005) 'Distribution of sawfishes (Pristidae) in the Queensland Gulf of Carpentaria, Australia, with notes on sawfish ecology', *Environmental Biology of Fishes*, 73:391–402.

Petheram C, Watson I, Bruce C and Chilcott C (2018) *Water resource assessment for the Mitchell catchment*, a report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments, CSIRO.

Plaganyi E et al. (in press) 'Quantifying catchment-to-coast ecological drivers to predict impacts of river development on marine fisheries and ecosystems', *Nature Sustainability*.

Pintor A and Graham E (2018) *Expert vetted distribution models and biodiversity hotspot maps of terrestrial and freshwater taxa of conservation concern in northern Australia* [data set], **https://doi.org/10.4225/28/5a9f31e23e80b**.

Pintor A, Kennard M, Álvarez-Romero J and Hernandez S (2019) *Prioritising threatened species and threatening processes across northern Australia: user guide for data*, report to National Environmental Science Program (NESP), Northern Australia Environmental Resources Hub.

Robertson M (2010) 'Agricultural productivity in Australia and New Zealand: trends constraints and opportunities', in Dove H and Culvenor RA (eds) *Proceedings for the 15th Australian Society of Agronomy Conference*, Australian Society of Agronomy, Lincoln, New Zealand.

Stewart-Koster B, O'Mara K, Molinari BS, Venarsky M, McGregor GB, Schulz C, Marshall J, Robins JB, Leahy SM, Crook DA and Bunn S (2021) *Critical water needs to sustain freshwater ecosystems and aquatic biodiversity in Queensland's Mitchell River*, Griffith University.

Venarsky MP, Lowe V, Frid CLJ and Burford MA (2022) 'Flow regime influences benthic biota biodiversity, but not abundance or biomass, in intertidal mudflats and sandflats in wet-dry tropical estuaries', *Estuarine, Coastal and Shelf Science,* 271:107858.

Wallace J, Waltham N, Burrows D and McJannet D (2015) 'The temperature regimes of dry-season waterholes in tropical northern Australia: potential effects on fish refugia', *Freshwater Science*, 34:663–678.

Waltham N, Burrows D, Butler B, Wallace J, Thomas C, James C and Brodie J (2013) *Waterhole ecology in the Flinders and Gilbert catchments. A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy,* CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.

7. Appendix

Table 7-1. A comparative overview of the threatened-species status codes of the 5 classification systems in Pintor et al. (2018). For each system, the statuses range from 'Near Threatened' to 'Critically Endangered', along with some additional system-specific categories.

Classification system	Code	Description
The International Union for Conservation of Nature Red List of Threatened Species	NT	Near Threatened
	EN	Endangered
	VU	Vulnerable
	DD	Data Deficient
	CE	Critically Endangered
EPBC (Environment Protection and Biodiversity Conservation Act 1999)	EN	Endangered
	CE	Critically Endangered
	VU	Vulnerable
Qld (Nature Conservation Act 1992)	VU	Vulnerable
	NT	Near Threatened
	EN	Endangered
	P	Presumed Extinct
WA (Wildlife Conservation Act 1950)	P1	Priority One (Poorly Known)
	P2	Priority Two (Poorly Known)
	IA	Inadequate Information
	VU	Vulnerable
	EN	Endangered
	OS	Outside Scope (does not fit other categories)
	NT(P4)	Near Threatened (Priority Four)
NT (Territory Parks and Wildlife Conservation Act 2000)	NT	Near Threatened
	VU/RR	Vulnerable/Restricted Range
	VU	Vulnerable
	EN/RR	Endangered/Restricted Range
	LC/RR	Least Concern/Restricted Range
	CE	Critically Endangered
	DD	Data Deficient
	EN	Endangered
	DD/RR	Data Deficient/Restricted Range
	NT/RR	Near Threatened/Restricted Range
	CE/RR	Critically Endangered/Restricted Range

Table 7-2. The full list of predicted threatened species across 8 taxonomic groups that were included in the mapping by Pintor et al. (2018). Each species is listed with its conservation status according to the 5 different classifications in Table 7-1. Each species also has an estimate of the likely presence of suitable habitat being found in at least one pixel of each catchment. Estimates of 0–1 = unsuitable-to-suitable habitat but expected to be unoccupied. Estimates of 1–2 = unsuitable-to-suitable in known occupied regions. Each catchment is listed by letter: M = Mitchell, G = Gilbert and F = Flinders. IUCN = International Union for Conservation of Nature; EPBC = Australian *Environment Protection and Biodiversity Conservation Act 1999*.

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Birds	*Acrocephalus australis*	1.9	1.9	1.9				NT	
Birds	*Amaurornis moluccana*	1.4	1.2	1.2				NT	
Birds	*Arenaria interpres*	1.6	1.7	1.7			P	NT	
Birds	*Calidris acuminata*	1.9	1.9	1.9			P		IA
Birds	*Calidris canutus*	1.8	1.8	1.9	NT	EN		VU	
Birds	*Calidris canutus rogersi*	1.8	1.8	1.9					
Birds	*Calidris ferruginea*	1.9	1.9	1.9	NT	CE		VU	VU
Birds	*Calidris ruficollis*	2	2	2	NT		P		IA
Birds	*Calidris tenuirostris*	2	2	2	EN	CE		VU	
Birds	*Charadrius leschenaultii*	1.9	2	2		VU		VU	VU
Birds	*Charadrius mongolus*	1.9	1.9	1.9		EN		VU	EN
Birds	*Ephippiorhynchus asiaticus*	1.8	1.8	1.8	NT				
Birds	*Esacus magnirostris*	1.9	2	1.9	NT		VU		
Birds	*Eulabeornis castaneoventris*	1.2	1.3	1.1			P		
Birds	*Grus antigone*	1.8	1.8	1.8			P		
Birds	*Limnodromus semipalmatus*	1.7	1.8	1.9	NT		P	VU	IA
Birds	*Limosa lapponica*	1.9	1.9	1.9	NT			VU	IA
Birds	*Limosa lapponica baueri*	1.7	1.7	1.8		VU			VU
Birds	*Limosa limosa*	2	2	2	NT		P	NT	IA
Birds	*Numenius madagascariensis*	1.9	1.9	1.9	EN	CE	VU	VU	VU
Birds	*Numenius phaeopus*	1.9	1.9	1.9			P	NT	IA
Birds	*Pluvialis squatarola*	1.8	1.8	1.9			P	NT	IA
Birds	*Rostratula australis*	2	2	2	EN	EN	VU	VU	

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Birds	*Tringa brevipes*	2	2	2	NT		P	NT	
Crustaceans	*Austrothelphusa tigrina*	0.7	0	0	VU				
Crustaceans	*Austrothelphusa valentula*	0.7	0	0	VU				
Crustaceans	*Austrothelphusa wasselli*	2	2	2	NT				
Crustaceans	*Euastacus balanensis*	0.3	0	0	EN				
Crustaceans	*Euastacus fleckeri*	1	1	0.5	EN				
Crustaceans	*Euastacus robertsi*	0.3	0	0	CE				
Crustaceans	*Macrobrachium rosenbergii*	2	2	2			P		
Fishes	*Anguilla bicolor*	0.6	0.7	0.6	NT				
Fishes	*Bostrychus zonatus*	1.3	1.3	1.3	DD				
Fishes	*Carcharhinus leucas*	1.8	1.5	1.7	NT				
Fishes	*Cinetodus froggatti*	1.8	1.8	1.9	DD				
Fishes	*Glossogobius bellendenensis*	0.4	0	0					
Fishes	*Glyphis glyphis*	0.5	0.2	0.1	EN	CE		VU	
Fishes	*Himantura dalyensis*	1.9	1.9	1.9			P		
Fishes	*Kurtus gulliveri*	1.4	1.4	1.7			P		
Fishes	*Megalops cyprinoides*	1.8	1.6	1.8	DD				
Fishes	*Melanotaenia eachamensis*	0.6	0	0	VU	EN			
Fishes	*Mogurnda mogurnda*	1.9	1.9	1.9			P		
Fishes	*Pingalla gilberti*	2	2	2			P		
Fishes	*Porochilus obbesi*	0.1	0	0				NT	
Fishes	*Pristis clavata*	2	1.9	1.9	EN	VU		VU	P1
Fishes	*Pristis pristis*	2	2	2	CE	VU		VU	
Fishes	*Scortum parviceps*	0.9	1.4	1.4	DD				
Fishes	*Stiphodon atratus*	0.8	0.5	0.5			VU		
Fishes	*Thryssa scratchleyi*	1.9	1.9	1.9	DD		P		
Frogs	*Hylarana daemeli*	0.9	0.6	0.4				NT/R R	

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Frogs	*Litoria cryptotis*	1.9	2	2				LC/R R	
Frogs	*Litoria dayi*	0.6	0	0	EN	EN	EN		
Frogs	*Litoria jungguy*	0.6	0	0	NT				
Frogs	*Litoria longirostris*	0	0	0			NT		
Frogs	*Litoria lorica*	0.6	0	0	CE	CE	EN		
Frogs	*Litoria nannotis*	1	0	0.5	EN	EN	EN		
Frogs	*Litoria nyakalensis*	0.6	0	0	CE	CE	EN		
Frogs	*Litoria platycephala*	0.5	0	0.7				LC/R R	
Frogs	*Litoria rheocola*	0.6	0	0	EN	EN	EN		
Frogs	*Litoria serrata*	0.6	0	0			VU		
Frogs	*Notaden nichollsi*	0.7	0	1			P		
Mammals	*Hydromys chrysogaster*	2	2	2					NT(P 4)
Mammals	*Mormopterus cobourgianus*	0.7	1	1					
Mammals	*Mormopterus halli*	1.7	1.9	1.6					
Mammals	*Ornithorhynchus anatinus*	1.4	1.1	1.1	NT				
Mammals	*Taphozous australis*	0.3	0	0	NT		NT		
Mammals	*Xeromys myoides*	0	0	0	VU	VU	VU		
Molluscs	*Corbicula australis*	2	2	2	DD				
Molluscs	*Gabbia carinata*	2	2	2	DD				
Molluscs	*Jardinella thaanumi*	0.7	0	0	DD				
Molluscs	*Pisidium australiense*	0.7	0	0	DD				
Plants	*Acacia aulacocarpa*	1.6	1.8	1.5	NT				
Plants	*Acacia homaloclada*	0	0	0			VU		
Plants	*Acrostichum aureum*	0.9	0.5	0.5					P1
Plants	*Aldrovanda vesiculosa*	1.8	1.8	1.8	EN				P2
Plants	*Aphyllorchis queenslandica*	0.3	0	0			NT		
Plants	*Aponogeton bullosus*	0	0	0		EN	EN		
Plants	*Arenga australasica*	0.7	0.4	0.4			VU		
Plants	*Avicennia integra*	0.1	0.1	0.1	VU				

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Plants	*Blechnum indicum*	0.7	0.1	0					P1
Plants	*Boea kinnearii*	0.6	0	0			EN		
Plants	*Bolbitis quoyana*	0.7	0	0				VU/R R	
Plants	*Calochilus caeruleus*	1	1.1	0.5				VU	
Plants	*Cephalomanes obscurum*	1.7	1.7	1.5				EN/R R	
Plants	*Cladium mariscus*	0.7	0.7	0.6				LC/R R	
Plants	*Clerodendrum inerme*	2	2	2					P1
Plants	*Colubrina asiatica*	1.9	1.9	1.9					
Plants	*Colubrina asiatica asiatica*	1.9	1.9	1.9					P1
Plants	*Corymbia paractia*	0.1	0.1	0.1					P1
Plants	*Crinum uniflorum*	1.9	2	1.9					P1
Plants	*Crotalaria quinquefolia*	1.7	1.8	1.7					P1
Plants	*Crudia abbreviata*	0	0	0			NT		
Plants	*Cyperus digitatus*	1.9	2	1.9					P1
Plants	*Cyperus haspan*	2	2	2					
Plants	*Cyperus haspan haspan*	2	2	1.9					P1
Plants	*Cyperus unioloides*	2	2	2				LC/R R	
Plants	*Cyperus victoriensis*	2	2	2					P1
Plants	*Dienia montana*	0.6	0	0					
Plants	*Dioclea hexandra*	0.4	0	0			VU		
Plants	*Diospyros calycantha*	1.2	1.6	0.8					P1
Plants	*Drosera fulva*	0.2	0.4	0.2				DD	
Plants	*Drosera kenneallyi*	0.1	0	0					P1
Plants	*Dryopteris sparsa*	0.6	0	0			VU		
Plants	*Dryopteris wattsii*	0.6	0	0			VU		
Plants	*Eleocharis acutangula*	1	1.1	0.6					P1
Plants	*Eleocharis retroflexa*	0.5	0	0		VU	VU		
Plants	*Enteropogon minutus*	2	2	2					P1

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Plants	*Eragrostis confertiflora*	1.8	1.7	1.8					P1
Plants	*Eriachne burkittii*	1.7	1.9	1.5					P1
Plants	*Eriocaulon carsonii*	2	2	2		EN	EN		
Plants	*Eugenia reinwardtiana*	1	0.7	0.7					P1
Plants	*Fimbristylis dictyocolea*	0.7	0.3	0.3					P1
Plants	*Freycinetia marginata*	0.5	0	0			VU		
Plants	*Fuirena nudiflora*	2	2	2					P1
Plants	*Germainia capitata*	0	0	0		VU	VU		
Plants	*Habenaria rumphii*	0.5	0.1	0			NT	EN	
Plants	*Hernandia nymphaeifolia*	0.5	0.3	0.2				VU/R R	
Plants	*Hibiscus fryxellii*	0.2	0.1	0.1				DD/R R	
Plants	*Hollandaea riparia*	0.1	0	0			VU		
Plants	*Hullsia argillicola*	0.5	0	0.7					P1
Plants	*Hydrolea zeylanica*	2	2	2					P1
Plants	*Hymenophyllum digitatum*	0.7	0	0			VU		
Plants	*Intsia bijuga*	0.4	0	0	VU			CE/R R	
Plants	*Ischaemum rugosum*	1.8	2	1.7					
Plants	*Ischaemum rugosum rugosum*	1.8	2	1.7					P1
Plants	*Labichea brassii*	1.8	1.8	1.8			NT		
Plants	*Lepturus geminatus*	0.7	0.5	0.4			NT		
Plants	*Livistona concinna*	0	0	0			NT		
Plants	*Livistona drudei*	0.4	0	0	EN		VU		
Plants	*Lobelia leucotos*	2	2	2					P1
Plants	*Lobelia membranacea*	2	2	2			NT		
Plants	*Macrothelypteris torresiana*	1.9	2	1.9				EN	P1
Plants	*Marsdenia hemiptera*	0.8	0.6	0.5					P1

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Plants	*Nymphoides parvifolia*	1.8	1.8	1.7					P1
Plants	*Oenanthe javanica*	0.9	1	0.5			NT		
Plants	*Oldenlandia polyclada*	0.6	0	0			NT		
Plants	*Paspalidium udum*	1.4	1.8	1.3			VU		
Plants	*Phaius pictus*	0.5	0	0		VU	VU		
Plants	*Phalaenopsis rosenstromi*	0.6	0	0		EN	EN		
Plants	*Phlegmariurus squarrosus*	0.9	0.8	0.4		CE	VU		
Plants	*Phlegmariurus tetrastichoides*	0.6	0	0		VU	VU		
Plants	*Potamogeton octandrus*	2	2	2					P1
Plants	*Rorippa eustylis*	1.8	1.6	1.8					P1
Plants	*Rotala tripartita*	2	2	2					P1
Plants	*Salacia chinensis*	0.5	0.1	0.1					P1
Plants	*Scleria levis*	0.6	0.1	0.1					P1
Plants	*Scleria polycarpa*	0.7	0.5	0.3					P1
Plants	*Scleria psilorrhiza*	1.6	1.4	1.4					P1
Plants	*Solanum pugiunculiferum*	2	2	2					P1
Plants	*Sorghum plumosum*	1.8	1.8	1.8					
Plants	*Spathoglottis paulinae*	0.7	0	0			NT		
Plants	*Sphaeranthus africanus*	2	2	2					P1
Plants	*Sphaerantia chartacea*	0.1	0	0			VU		
Plants	*Sphenoclea zeylanica*	2	2	2					P1
Plants	*Sterculia holtzei*	0	0	0					P1
Plants	*Sticherus flabellatus*	1.9	1.8	1.9					
Plants	*Sticherus flabellatus compactus*	0.6	0	0				VU	
Plants	*Thespidium basiflorum*	2	2	2					P1
Plants	*Triplarina nitchaga*	0.5	0	0		VU	VU		
Plants	*Tylophora rupicola*	0.6	0	0		EN	EN		

Taxonomic group	Species	M	G	F	IUCN	EPBC	Qld Govt	NT Govt	WA Govt
Plants	*Utricularia arnhemica*	0.3	0.5	0.3					P1
Plants	*Utricularia stellaris*	2	2	2					P1
Plants	*Utricularia subulata*	0.4	0	0				NT/RR	
Plants	*Utricularia tubulata*	0.2	0.1	0.1					P1
Plants	*Xanthostemon graniticus*	0.6	0	0			VU		
Plants	*Xylosma spA*	0.6	0	0			VU		
Plants	*Zeuxine oblonga*	1	1	0.5				VU	
Reptiles	*Carlia dogare*	0.7	0.3	0.1			P		
Reptiles	*Chelonia mydas eggs*	1.5	1.6	1.5	EN	VU	VU	NT	VU
Reptiles	*Crocodylus johnstoni*	1.9	1.9	1.9					OS
Reptiles	*Crocodylus porosus*	1.7	1.7	1.7			VU		OS
Reptiles	*Dermochelys coriacea eggs*	0.1	0.1	0.1	VU	EN	EN	CE	VU
Reptiles	*Elseya lavarackorum*	0.5	0	0.7		EN	VU		
Reptiles	*Emydura subglobosa*	1	0.5	1.3					
Reptiles	*Emydura subglobosa worrelli*	0.6	0	1			NT		
Reptiles	*Eretmochelys imbricata eggs*	0.7	0.7	0.6	CE	VU	VU	VU	VU
Reptiles	*Natator depressus eggs*	1.7	1.6	1.6		VU	VU		VU
Reptiles	*Varanus indicus*	0	0	0				NT	
Reptiles	*Varanus mertensi*	1.9	1.8	1.9				VU	
Reptiles	*Varanus mitchelli*	1.8	1.4	1.7				VU	