Applying Avoidance Zone decision rules for development planning:

A Central Queensland case study

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Preamble

In 2022, the Federal Government flagged consideration of adopting a spatial-based approach to regional planning under the reformed Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). In late 2022, Queensland Conservation Council, WWF Australia, Australian Conservation Foundation, and Birdlife Australia commissioned a team from the University of Queensland and Griffith University to first generate a series of principles and rules for implementing spatial planning, and then to test these in a number of case study areas across Queensland. The research team first applied the principles to a south-east Queensland Case Study[1]. This report, commissioned by Queensland Conservation Council, considers the rules for a Central Queensland (CQ) case study, considering the impacts of renewable energy and mining infrastructure.

Other contributors:

John Zichy-Woinarski (Charles Darwin University), Martine Maron (University of Queensland), and Richard Fuller (University of Queensland) provided species-specific information on irreplaceable habitats for birds and mammals in this analysis.

Suggested citation:

Aska, Bora, Venegas Li, Ruben, Ward, Michelle, Watson, James E.M. (2025). Applying Avoidance Zone decision rules for development planning: a Central Queensland case study. University of Queensland and Griffith University, pages 102. doi: 10.6084/m9.figshare.30060109

[1] https://www.queenslandconservation.org.au/new_report_bioregional_planning

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Executive Summary

- Queensland's biodiversity is in decline[2] and federal and state nature laws are not working to protect species and ecosystems, as evidenced in the Samuels Review[3]. The 2022 Nature Positive Framework[4] offered bioregional planning as an important planning process to proactively protect biodiversity across Queensland by simultaneously identifying those areas that were not suitable for development and those areas that were more suitable for development.
- Using publicly available data from the State and Federal Governments, we demonstrate how foundational principles and subsequent decision rules [5] can be applied through a spatial framework to identify Avoidance Zones (those areas that need strict protection and where development must avoid due to containing irreplaceable features) to highlight their potential use in bioregional planning.
- Central Queensland served as our case study, using five of the nine Matters of National Environmental Significance under the EPBC Act 1999: World Heritage Areas, National Heritage Places, wetlands of international importance listed under the Ramsar Convention, threatened ecological communities (Critically Endangered and Endangered only) and threatened species (terrestrial birds and mammals only), and migratory species (terrestrial birds and mammals only).
- We used Central Queensland as a case study as it is subject to significant development interest from renewable energy, mining, and agricultural sectors.
- The Central Queensland case study showcases how these rules for identifying Avoidance Zones can be implemented to assess the potential impacts of major developments such as renewable energy infrastructure on biodiversity at a regional scale.
- We found that ~ 31% (80,643 km^2) of Central Queensland could be designated as an Avoidance Zone.
- We mapped infrastructure footprint maps for 34 solar projects (32 proposed and two under construction) and 14 wind projects (13 proposed and one under construction). In addition, 27 new or proposed coal mining areas were also analysed to create a fuller 'development footprint' in the region. We then overlapped these infrastructure maps with the Avoidance Zones map.

[2] https://www.oecd.org/en/publications/oecd-environmental-performance-reviews-australia-2019_9789264310452-en.html

[3] https://www.dcceew.gov.au/sites/default/files/documents/epbc-act-review-final-report-october-2020.pdf
[4] https://www.dcceew.gov.au/sites/default/files/documents/nature-positive-plan.pdf
[5] https://www.queenslandconservation.org.au/new_report_bioregional_planning

- When the footprint of the proposed renewable energy infrastructure was considered in Central Queensland, we found that 34%, 51%, and 50% of the total area required for renewable energy projects overlap with Avoidance Zones (when considering 100 m, 650 m, and 1 km buffer zones, respectively, for wind farms).
- Of the 1,000 km² of mapped coal mining project footprints, 29.9% (326 km²) overlapped with Avoidance Zones. Of the 27 coal mining projects mapped, 20 had an overlap greater > 1% of their area with Avoidance Zones, and the 27 coal mines ranged from 0.2% to 100%.
- The MNES with the highest overlap with the renewable energy infrastructure are Endangered and Vulnerable ecological communities, and Endangered and Vulnerable mammal species.
- These results highlight that it is possible to map areas that should be avoided when considering development projects that cause Environmental damage. However, more fine-scale spatial data is needed to directly inform regional planning efforts, alongside a process to engage a broader range of experts.

Background

In 2022, the Federal and Queensland Governments indicated that they were considering implementing a spatial-based approach to regional planning as part of the reforms to the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)[6]. The independent review of the EPBC Act highlighted the need for the Australian Government to change how it handles development project approvals, recommending assessing the cumulative impact of development at a landscape scale to protect, restore, and manage the environment, instead of relying on project-by-project approvals[7]. Regional Planning is a government initiative that aims to provide clear guidance on which areas are appropriate for protection, development, and which areas need caution. Consultations between the government and various stakeholders have taken place throughout 2023 and 2024 and are continuing.

A research team led by the University of Queensland, Griffith University, and Australian National University proposed a set of foundational principles and decision rules for implementing the EPBC Act regional planning (Appendix 1)[8]. We applied these in Central Queensland (CQ) to identify high-priority conservation areas, referred to here as Avoidance Zones. We then assessed their overlap with current or proposed developments (renewable energy and mining) to highlight their potential use in planning. While based on the best publicly available data on biodiversity and development, the Avoidance Zones identified in this study are approximate only, due to limitations in data coverage and resolution.

We used Central Queensland as a case study as it is subject to significant development interest from renewable energy, mining, and agriculture. We defined the study region using the boundaries described by the Queensland Government[7] and the data published by the Australian Bureau of Statistics[9] comprising ten local government areas (LGAs): Isaac Regional Council, Gladstone Regional Council, Barcaldine Regional Council, Rockhampton

[6] https://minister.dcceew.gov.au/plibersek/media-releases/regional-plans-transform-environmental-protection

[7] https://www.dcceew.gov.au/environment/epbc/epbc-act-reform/regional-planning

[8] https://www.queenslandconservation.org.au/new_report_bioregional_planning

[9] Australian Bureau of Statistics, 2021. Digital Boundary Files. Accessed here: https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/jul2021-jun2026/access-and-downloads/digital-boundary-files

Regional Council, Woorabinda Aboriginal Shire Council, Central Highlands Regional Council, Bundaberg Regional Council, Banana Shire, Livingstone Shire, and North Burnett Regional Council (Area = 255,789 km^2) (**Figure 1a**). Following the methods utilised in another case study[10], we extended the study area to include intertidal zones by merging the LGA boundaries with a map of the intertidal extent from Digital Earth Australia (DEA)[11] to produce a revised planning region (Area =256,300 km^2) (**Figure 1b**). The inclusion of the intertidal extent better captures the needs of some migratory bird species.

The region is subject to significant development interest from both the renewable energy and mining sectors. It includes nine existing, 32 proposed, and two under-construction solar farms; 19 proposed and one under-construction wind farms[12] (**Figure 2**); and 27 new or proposed coal mines.

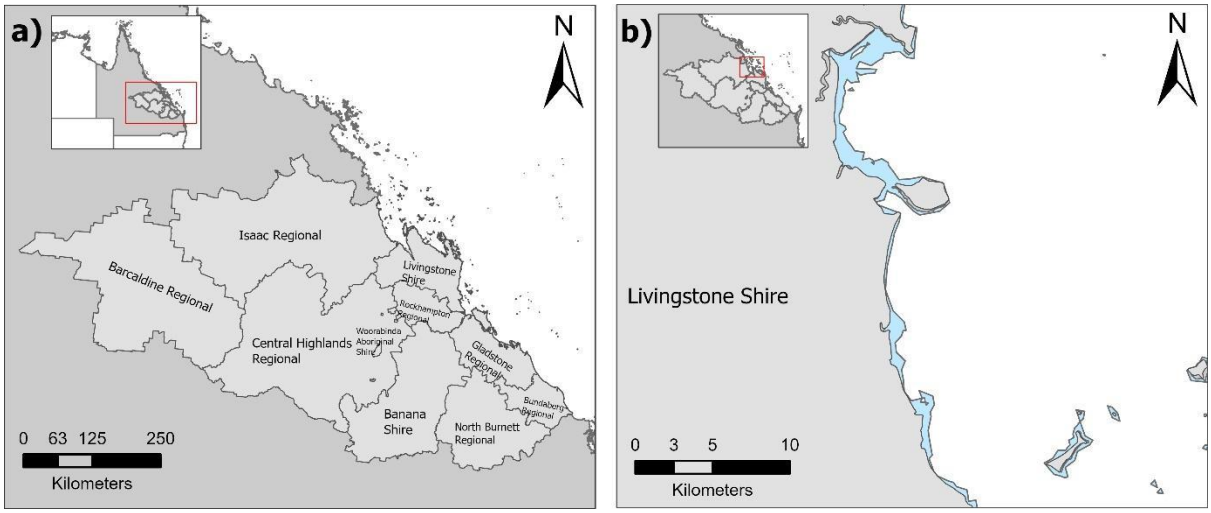

Figure 1. a) The boundaries for the Central Queensland case study and the boundaries for the ten local government areas within them. The Digital Boundary Files were obtained from the Australian Bureau of Statistics[13]. **b)** Close-up of the extended boundaries for Central Queensland to include the low tide areas needed for migratory species (shown in blue). The Intertidal Extents dataset[8] was merged with the Central Queensland boundaries.

[10] https://www.queenslandconservation.org.au/new_report_bioregional_planning

[11] https://www.dea.ga.gov.au/products/dea-intertidal-extents

[12] https://electricity-generation-map.epw.qld.gov.au/

[13] Australian Bureau of Statistics, 2021. Digital Boundary Files. Accessed here: https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/jul2021-jun2026/access-and-downloads/digital-boundary-files

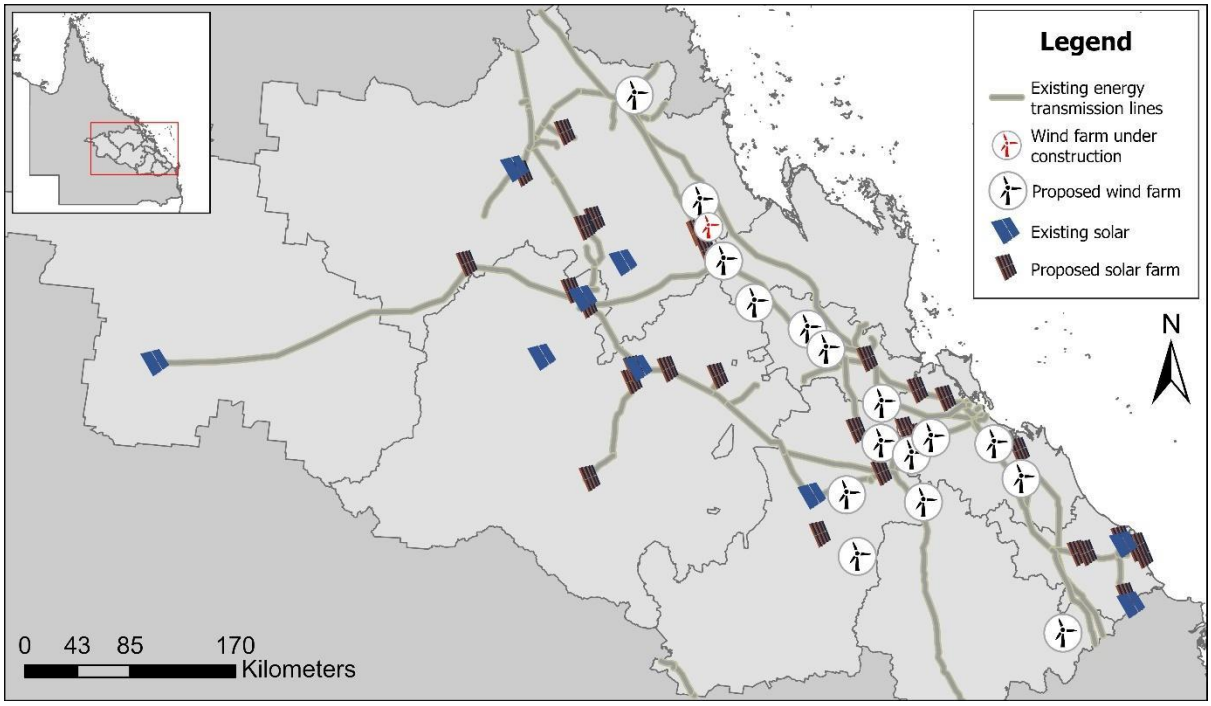

Figure 2. Existing and proposed renewable energy projects in Central Queensland (Power plant maps of Queensland, Queensland Government 2024)[14].

Decision rules

We applied a set of decision rules (**Appendix 2**) developed based on foundational principles (**Appendix 1**) to identify Avoidance Zones. This framework provides a base for identifying areas that should be considered 'no-go' for development based on current legislation. The rules were applied to five of the nine Matters of National Environmental Significance (MNES) under the EPBC Act 1999: World Heritage Areas, National Heritage Places, wetlands of international importance (listed under the Ramsar Convention), threatened ecological communities (Critically Endangered and Endangered only), threatened species (terrestrial birds and mammals only), and migratory species (terrestrial birds and mammals only). We excluded the remaining four MNES from this assessment: Commonwealth marine areas, the Great Barrier Reef Marine Park, nuclear actions (including uranium mining), and a water resource (concerning unconventional gas development and extensive coal mining development). However, we acknowledge the importance of incorporating them in future efforts, especially a marine-focused set of principles and rules.

[14] https://electricity-generation-map.epw.qld.gov.au/

We focused on MNES because any Federal regional planning approach must address these matters to prevent further biodiversity loss. However, we also recognise that many areas outside these MNES still require strict protection to conserve and recover places of high conservation value.

This Central Queensland case study demonstrates how the decision rules can be applied to assign land to Avoidance Zones utilising available data. In doing so, we also highlight the gaps in the current ecological knowledge that we encountered during the mapping. We note, however, that this is a preliminary application of the principles and does not include extensive region-specific expert input.

A key element of this analysis is the Federal government's commitment to a 'Nature Positive' approach. Central to this is the concept of irreplaceability, defined here as places or habitat elements biologically, physically, and/or technically, very difficult and/or impossible to restore, recreate, or replace in an ecologically relevant time frame. These sites are therefore essential for the maintenance and recovery of MNES. A place or habitat element is irreplaceable if there is no clear, peer-reviewed evidence supporting the ability to restore, re-create, or replace it within a timeframe relevant to the threat to the MNES in question. These timeframes are based on IUCN threat listing criteria, for which a Critically Endangered species/community has a 20% probability of extinction in 10 years or 5 generations (whichever is longer,100 years max.), an Endangered species has a 20% probability of extinction in 20 years or 5 generations (whichever is longer, 100 years max.), and a Vulnerable species has a 20% probability of extinction in 100 years. Examples of irreplaceable sites or habitat elements include:

- Habitat that takes a long time to recover or cannot be re-created - i.e., old-growth forests, tree hollows, or mudflats.
- High-condition state examples of most ecological communities or habitats.
- Refugia determined by abiotic, soil, water and geological factors – that is, areas defined by factors we have no leverage over. (e.g., obligate riffle zones for turtles)

These areas or habitat elements cannot be lost without causing an irreversible impact on the MNES, including their potential to recover. Hence, they must be designated as conservation zones in perpetuity. Stating this another way, any impacts to these irreplaceable sites will prevent the achievement of a net positive goal (or even a no net loss goal).

Applying Avoidance Zone decision rules for Central Queensland

Mapping Avoidance Zones

We applied the decision rules to all five selected MNES, but limited the assessment of threatened and migratory species to bird and mammal species. This was because birds and mammals are the most well-known taxonomic groups in the region, particularly when considering the available expertise within this first consultation. We suspect many Avoidance Zones for these groups will overlap with those for other taxonomic groups, so the proportional area may not change substantially when all groups are added. ArcGIS Pro Version 3.0.2 (GDA 1994 Australia Albers Projection) was used for the spatial analysis. A summary of all data we used, and the links to these data, are found in **Table S2 in Appendix 3.** We also add a footnote to every dataset we use the first time we mention it.

Data used for the implementation of the decision rules for World Heritage Areas, National Heritage Places, and Ramsar wetlands for Central Queensland

This section summarises the spatial data used to map the Avoidance Zones for World Heritage Areas, National Heritage Places, and Ramsar wetlands (**Table 1**).

World Heritage Areas

We obtained Federal Government spatial data on World Heritage Areas[15]. The World Heritage status is inscribed based on two criteria, namely cultural and natural heritage values. While there are currently 20 Australian properties inscribed on the World Heritage Area List, only one is found within Central Queensland, namely The Great Barrier Reef. The Great Barrier Reef is the world's most extensive coral reef system[16]. It encompasses 2,052 km^2 of terrestrial and low tide areas.

[15] https://fed.dcceew.gov.au/datasets/bd46da1431cc4250b6be4017958fc1c6/about

[16] https://www.dcceew.gov.au/parks-heritage/great-barrier-reef/world-heritage

National Heritage Places

We obtained spatial data on the sites nominated and included in the list of National Heritage Places, as determined by the Federal Government[17]. Central Queensland has two national heritage places, one of which is natural, namely The Great Barrier Reef.

The Tree of Knowledge and Curtilage site, listed for its historical and cultural values, was removed from the analysis.

Ramsar Wetlands

We obtained spatial data on Ramsar sites and filtered out only areas within the Central Queensland region[18]. There are five Ramsar sites in Queensland, with the Shoalwater and Corio Bays wetland being the only one in Central Queensland. Given the current rules regarding the zoning of Ramsar sites[19], we extended the boundary of the Shoalwater and Corio Bays wetland area to include a 500 m buffer. The Ramsar site encompasses 2,020 km^2 of terrestrial and marine areas without the buffer zone and 2,407 km^2 with the buffer zone. When filtered to Central Queensland's low tide boundary, the Ramsar wetland covered an area of 988 km^2 (including a 500 m buffer zone).

Table 1. The case study decision rules and data utilised for mapping World Heritage Area, Natural Heritage Places, and Ramsar wetland Avoidance Zones in Central Queensland.

MNES	Site/Species	Rules for determining Avoidance Zone status	Applied analysis undertaken
World Heritage Area	The Great Barrier Reef	Areas that have protected World Heritage values.	We used the Australian World Heritage dataset[12] and filtered to the Central Queensland region. This dataset includes polygons of the declared World Heritage properties and polygons of the managed buffer zones surrounding these properties. The Great Barrier Reef has no managed buffer zones. As a result, the Avoidance Zone only comprises the rainforest

[17] https://fed.dcceew.gov.au/datasets/erin::national-heritage-list-spatial-database-nhl-public/about

[18] https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={AC0B0BB0-535D-4BB3-8D7E-EDECF48F6D46}

[19] https://whc.unesco.org/en/series/25/

MNES	Site/Species	Rules for determining Avoidance Zone status	Applied analysis undertaken
			boundaries in Central Queensland. Dataset: Australian World Heritage Areas[12]
		Areas adjoining, connected, or near World Heritage Areas that are needed to sustain protected World Heritage values.	This rule was not mapped because the relevant spatial data does not currently exist.
National Heritage Places	The Great Barrier Reef	Areas that have protected National Heritage values, including only natural or cultural heritage values.	We used the Australian National Heritage dataset[14] and filtered to the Central Queensland region. The Australian National Heritage dataset includes polygons of the declared and nominated National Heritage areas. There are two sites on the National Heritage List. The Great Barrier Reef has been protected due to its natural and cultural values. Because the Tree of Knowledge and Curtilage site only fits the historic value criteria, it has been excluded from the analysis. Dataset: Australian National Heritage dataset[14]
		Areas adjoining, connected, or near National Heritage Areas that are needed to sustain protected National Heritage values.	This rule was not mapped because the relevant spatial data does not currently exist.

MNES	Site/Species	Rules for determining Avoidance Zone status	Applied analysis undertaken
Ramsar Wetlands	Shoalwater and Corio Bays Wetland	Areas within the boundaries of Ramsar wetlands.	We used the Australian Ramsar Wetlands dataset[15] filtered to only areas within Central Queensland. The dataset includes a polygon layer of the declared Ramsar sites. We added a 500m buffer zone because this is the international standard for protecting Ramsar sites. Dataset: Australian Ramsar Wetlands – Queensland[15]
		Areas adjoining, connected, or near Ramsar places are needed to sustain Ramsar wetland values.	This rule was not mapped because the relevant spatial data does not currently exist.

Data used for the implementation of the decision rules for Threatened Ecological Communities for Central Queensland

We used the Australian Threatened Ecological Communities dataset, publicly available at 1 km^2 resolution, and filtered it to communities within the Central Queensland region (**Table 2**)[20]. The dataset was divided into Critically Endangered and Endangered (**Table S3 in Appendix 2**). We found 14 Threatened Ecological Communities within Central Queensland, including three Critically Endangered and 11 Endangered Ecological Communities. We used the remnant vegetation[21] layer to help determine irreplaceable sites for these ecological communities and noted the limitation of this approach in the discussion. Remnant vegetation

[20] DCCEEW. Australia - Ecological Communities of National Environmental Significance Distributions (public grids) (DCCEEW, 2023).

[21] https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/remnant-vegetation#download

is classified here as irreplaceable, given these areas often have high ecological integrity and resilience to threats.

Table 2. The case study decision rules and data utilised for mapping Threatened Ecological Community Avoidance Zones in Central Queensland. Table S3 in Appendix 2 provides the specific names of those ecological communities considered.

MNES	Rules for determining Avoidance Zone status	Applied Analysis
Threatened Ecological Communities	Areas adjoining, connected, or near a threatened ecological community that are irreplaceable when considering the ongoing protection and maintenance of the threatened ecological community.	This rule was not mapped because we do not yet know what this might constitute.
	Sites that are irreplaceable when considering the recovery of the threatened ecological community, including under future climate change scenarios assessed as reasonably likely.	We used the National Environmental Significance Distribution dataset[17] filtered to only areas within Central Queensland. We used known to, likely to, maps only. All Critically Endangered and Endangered ecological communities were then filtered to remnant vegetation[18] (*See below for definition of remnant). Datasets: Ecological Communities of National Environmental Significance Distributions (public grids)[17] Remnant Vegetation of Queensland[18]
	All offset sites and areas set aside to conserve the community.	This rule was not mapped because the relevant spatial data does not currently exist.

*Remnant vegetation includes both woody and non-woody vegetation. Woody vegetation is mapped as remnant where the dominant canopy has > 70% of the height and > 50% of the cover relative to the undisturbed height and cover of that stratum and is dominated by species characteristic of the vegetation's undisturbed canopy. The Queensland Herbarium's two-step process for mapping remnant grasslands and other non-woody vegetation types is as follows: 1) Map the extent as remnant vegetation unless there is evidence from imagery of disturbance, e.g. cropping in the last 15 years; or 2) an on-site assessment disqualified it as remnant based on species composition or cover.[22]

[22] Queensland Government, 2024. Remnant regional ecosystem vegetation in Queensland. https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/remnant-vegetation

Data used for the implementation of the decision rules for non-threatened migratory birds of Central Queensland

For Central Queensland's migratory species, we used the Species of National Environmental Significance Distribution dataset[23]. The Avoidance Zones mapping for 15 threatened migratory species is considered in the threatened species section below (**Table 4**). A further 23 non-threatened migratory species were identified as occurring in Central Queensland, all of which were birds. Following consultations with experts, it was determined that Avoidance Zones for 14 non-threatened migratory bird species would not be mapped (more details in Table S4 in Appendix 3), and nine migratory bird species would be mapped (**Table 3**). The SNES data for these nine species were filtered to what we identified as irreplaceable habitats specific to each species (**Table S4** in **Appendix 3**). For migratory birds, mudflats were identified as irreplaceable habitats. These habitats were mapped using the DEA Intertidal Extents dataset[8] to map the boundaries of the tidal wetlands and mudflats zones. The dataset provides information on Australia's lowest (LOT) and highest (HOT) observed tides.

Table 3. The case study decision rules and data utilised for mapping non-threatened migratory species Avoidance Zones in Central Queensland. A summary of the specific methods used for each species to identify irreplaceable areas or habitat elements can be found in more detail in Table S4 in Appendix 3.

MNES	Species	Rules for determining Avoidance Zone status	Applied Analysis
Migratory Birds	**Species mapped:** Bar-tailed Godwit (*Limosa lapponica*) Grey-tailed Tattler (*Tringa brevipes*) Little Tern (*Sternula albifrons*) Marsh Sandpiper, Little Greenshank	All areas where the species is known to, likely to, may occur, or needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known to, likely to and may occur areas mapped).	We used the known to, likely to, and may occur habitats in the Species of National Environmental Significance (SNES) Distribution dataset[20] and filtered to only areas within the Central Queensland[7]. All migratory species habitats were then filtered to irreplaceable areas utilising the datasets below in Table S4.

[23] https://www.dcceew.gov.au/environment/environmental-information-data/databases-applications/snes

	(*Tringa stagnatilis*) Red-necked Stint (*Calidris ruficollis*) Broad-billed Sandpiper (*Limicola falcinellus*) Double-banded Plover (*Charadrius bicinctus*) Common Sandpiper (*Actitis hypoleucos*) Whimbrel (*Numenius phaeopus*) **Species not mapped because they are unlikely to have irreplaceable habitat:** Black-faced Monarch (*Monarcha melanopsis*) Fork-tailed Swift (*Apus pacificus*) Grey Wagtail (*Motacilla cinerea*) Little Curlew, Little Whimbrel (*Numenius minutus*)		Dataset: Migratory Species in Species of National Environmental Significance Distributions (public grids)[20] DEA Intertidal Extents[8]
		All offset sites and areas are set aside for the species conservation.	This rule was not mapped because the relevant spatial data does not currently exist.
		Areas adjoining, connected, or near species habitat are needed to sustain those irreplaceable sites identified for the species.	This rule was not mapped because the relevant spatial data does not currently exist.

	Pin-tailed Snipe (*Gallinago stenura*) Oriental Cuckoo, Horsfield's Cuckoo (*Cuculus optatus*) Pectoral Sandpiper (*Calidris melanotos*) Rufous Fantail (*Rhipidura rufifrons*) Satin Flycatcher (*Myiagra cyanoleuca*) Spectacled Monarch (*Monarcha trivirgatus*) Swinhoe's Snipe (*Gallinago megala*) Wandering Tattler (*Tringa incana*) Wood Sandpiper (*Tringa glareola*)		

Data used for the implementation of the decision rules for threatened birds and mammals in Central Queensland

We obtained data on threatened species from the Species of National Environmental Significance Distribution dataset (SNES)[20]. A total of 35 bird species were identified, including six Critically Endangered, 10 Endangered, and 19 Vulnerable species. Following consultations with experts, we included 14 threatened birds in this analysis, of which three were categorised as Critically Endangered, four as Endangered, and seven as Vulnerable

(**Table 4**). The reasons why the other 21 species were not included are summarised in **Table S5** in **Appendix 3.**

For mammals, a total of 19 species were identified, including one Critically Endangered, seven Endangered, and 11 Vulnerable species. We were able to spatially map eight threatened mammal species in the analysis, of which one was categorised as Critically Endangered, four as Endangered, and three as Vulnerable. The reasons why the other 11 species were not mapped are summarised in **Table S6** in **Appendix 3**. The range maps of these species were filtered to irreplaceable elements as identified by experts (**Table S5**, **Table S6**).

We used the Intertidal Extent dataset[8], Broad Vegetation Groups Dataset[24] and the Remnant Vegetation of Queensland Dataset[18] to map out irreplaceable areas or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe (**Table S4**, **Table S5** and **Table S6**). A summary of these areas or habitat elements and the methods used to identify them can be found in more detail in **Appendix 3**.

Table 4. The case study decision rules and data utilised for mapping threatened species Avoidance Zones in Central Queensland. A summary of the specific methods used for each species to identify irreplaceable areas or habitat elements can be found in more detail in Appendix 3 (Table S4-6).

MNES	Species	Rules for determining Avoidance Zone status	Applied Analysis
Critically Endangered Species	**Species mapped:** <u>Birds:</u> Coxen's Fig Parrot (*Cyclopsitta diophthalma coxeni*) Eastern Curlew, Far Eastern Curlew (*Numenius*	All 'known to occur' areas and any habitat within 2 km (applies when there are only 'known to occur' areas mapped).	This rule has not been mapped because all bird species had 'known to occur, likely to occur and may occur' habitats mapped.
		All areas where the species is known to, likely to, or may occur, or needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-	We used the known to, likely to, and may occur habitats in the Species of National Environmental Significance Distribution dataset[20] and filtered to only areas within the Central Queensland[7]. All threatened species habitats

[24] Broad Vegetation groups – pre-clearing and 2021 remnant Queensland series, The Queensland Government Department of Environment and Science, https://www.data.qld.gov.au/dataset/broad-vegetation-groups-pre-clearing-and-2021-remnant-queensland-series

	madagascariensis) **(migratory)** Curlew Sandpiper (*Calidris ferruginea*) **(migratory)** <u>Mammals:</u> Northern Hairy-nosed Wombat, Yaminon (*<u>Lasiorhinus krefftii</u>*) **<u>Species not mapped due to no irreplaceable habitat features identified at this time:</u>** <u>Birds:</u> Capricorn Yellow Chat, Yellow Chat (Dawson) (*Epthianura crocea macgregori*)	created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known, likely and may occur areas mapped or defined).	were then filtered to irreplaceable areas utilising the datasets below in Tables S5 and S6. Datasets: Threatened Species in Species of National Environmental Significance Distributions (public grids)[23] DEA Intertidal Extents[8] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]
		Areas adjoining, connected, or near species habitat that are needed to sustain those irreplaceable sites identified for the species.	This rule was not mapped because the relevant spatial data does not currently exist.
		All offset sites and areas set aside for the conservation of the species.	This rule was not mapped because the relevant spatial data does not currently exist.
Endangered Species	**Species mapped:** <u>Birds:</u> Nunivak Bar-tailed Godwit, Western Alaskan Bar-tailed Godwit (*Limosa lapponica baueri*)	All known to occur areas and any habitat within 1.5 km (applies when there are only 'known to' occur areas mapped).	This rule has not been mapped because no bird species had known to occur, likely to occur and may occur' habitats mapped.
		All areas where the species is known to, likely to, or may occur, or needed for recovery, that are irreplaceable or for which the relevant habitat elements cannot be re-	We used the known to, likely to, and may occur habitats in the Species of National Environmental Significance Distribution dataset[20] and filtered to only areas within the Central Queensland[7]. All threatened species habitats

	Black-tailed godwit (*Limosa limosa*) **(migratory)** Common Greenshank, Greenshank (*Tringa nebularia*) **(migratory)** Lesser Sand Plover, Mongolian Plover (*Charadrius mongolus*) **(migratory)** <u>Mammals:</u> Bridled Nail-tail Wallaby, Bridled Nailtail Wallaby (*Onychogalea fraenata*) Greater Glider (southern and central) *(Petauroides volans)* Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland population) *(Dasyurus maculatus maculatus)* Northern Quoll, Digul [Gogo-Yimidir],	created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known, likely and may occur areas mapped or defined).	were then filtered to irreplaceable areas utilising the datasets below in Table S5 and S6. Datasets: Threatened Species in Species of National Environmental Significance Distributions (public grids)[23] DEA Intertidal Extents[8] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]
		Areas adjoining, connected, or near species habitat that are needed to sustain those irreplaceable sites identified for the species.	This rule was not mapped because the relevant spatial data does not currently exist.
		All offset sites and areas set aside for the the species.	This rule was not mapped because the relevant spatial data does not currently exist.

	Wijingadda [Dambimangari], Wiminji [Martu] *(Dasyurus hallucatus)* Silver-headed Antechinus (*Antechinus argentus*) **Species not mapped due to no irreplaceable habitat features identified at this time:** <u>Mammals:</u> Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) *(Phascolarctos cinereus)* <u>Birds:</u> Red Goshawk (*Erythrotriorchis radiatus*) Australasian Bittern (*Botaurus poiciloptilus*) Australian Painted Snipe (*Rostratula australis*) Southern Black-throated		

	Finch (*Poephila cincta cincta*) **Species not mapped due to lack of spatial data:** <u>Mammals:</u> Large-eared Pied Bat, Large Pied Bat *(Chalinolobus dwyeri)*		
Vulnerable Species	**Species mapped:** <u>Birds:</u> Greater Sand Plover, Large Sand Plover *(Charadrius leschenaultia)* **(migratory)** Grey Plover (*Pluvialis squatarola*) **(migratory)** Great Knot (*Calidris tenuirostris*) **(migratory)** Red Knot *(Calidris canutus)* **(migratory)** Terek Sandpiper (*Xenus cinereus*) **(migratory)** Ruddy Turnstone	All known to occur areas and any habitat within 1 km (applies when only 'known to' occur areas are mapped or defined).	This rule has not been mapped because no bird species had known to occur, likely to occur and may occur' habitats mapped.
		All areas where the species is known to, likely to, or may occur, or needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known, likely and may occur areas mapped or defined).	We used the known to, likely to, and may occur habitats in the Species of National Environmental Significance Distribution dataset[20] and filtered to only areas within the Central Queensland[7]. All threatened species habitats were then filtered to irreplaceable areas utilising the datasets below in Table S5 and S6. Dataset: Threatened Species in Species of National Environmental Significance Distributions (public grids)[23] DEA Intertidal Extents[8] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]
		Areas adjoining, connected, or near species habitat that are needed to sustain those	This rule was not mapped because the relevant spatial data does not currently exist.

	(*Arenaria interpres*) **(migratory)** Sharp-tailed Sandpiper (*Calidris acuminata*) **(migratory)** <u>Mammals:</u> Yellow-bellied Glider (south-eastern) *(Petaurus australis australis)* Corben's Long-eared Bat, South-eastern Long-eared Bat *(Nyctophilus corbeni)* Semon's Leaf-nosed Bat, Greater Wart-nosed Horseshoe-bat (*Hipposideros semoni*) **Species not mapped due to no irreplaceable habitat features identified at this time:** <u>Birds:</u> Southern Whiteface (*Aphelocephala leucopsis*) Latham's Snipe, Japanese Snipe	irreplaceable sites identified for the species.	
		All offset sites and areas set aside for the conservation of the species.	This rule was not mapped because the relevant spatial data does not currently exist.

	(*Gallinago hardwickii*) **(migratory)** Asian Dowitcher (*Limnodromus semipalmatus*) **(migratory)** Black-breasted Button-quail (*Turnix melanogaster*) Grey Falcon (*Falco hypoleucos*) Painted Honeyeater (*Grantiella picta*) South-eastern Glossy Black-Cockatoo (*Calyptorhynchus lathami lathami*) White-throated needletail (*Hirundapus caudacutus*) **(migratory)** **Species not mapped due to lack of spatial data:** <u>Birds:</u> Diamond Firetail (*Stagonopleura guttata*)		

	Squatter Pigeon (southern) (*Geophaps scripta scripta*) <u>Mammals:</u> Water Mouse, False Water Rat, Yirrkoo *(Xeromys myoides)* Grey-headed Flying-fox *(Pteropus poliocephalus)* Brush-tailed Rock-wallaby *(Petrogale penicillata)* Ghost Bat *(Macroderma gigas)* Yellow-footed Rock-wallaby (central-western Queensland) (*Petrogale xanthopus celeris*)		

Mapping the infrastructure footprint of development projects

Renewable Energy infrastructure

To assess the potential overlap of renewable energy projects and Avoidance Zones, we first needed to map the land footprint of the proposed infrastructure. To do this, we used a dataset published by the Queensland Government[7] on solar and wind farm projects to obtain a list of these, with associated information on them such as the project's name, location (including approximate x, y coordinates), status, and expected electricity generation capacity. This dataset included 43 solar farm projects (9 existing, 32 proposed, and two 'under construction'), and 20 wind farm projects (19 proposed and one 'under construction') (see **Table S7** and **Table S8** in **Appendix 3**). Since the Queensland Government's data does not include maps of each project's infrastructure footprint, we had to search for these elsewhere. The following paragraphs detail the projects for which we obtained infrastructure footprint maps, and the sources of these maps (summarised in **Table S7** and **Table S8** in **Appendix 3).**

Mapping solar farms

We were able to obtain information to represent the infrastructure footprint for all 34 solar projects listed as proposed or under construction. For 11 projects, we obtained footprint data from the maps available through the EPBC referrals, accessible through the EPBC Act Public Portal[25]. The maps were georeferenced in ArcGIS Pro using the available coordinates and nearby infrastructure or landscape features as a reference. From these georeferenced maps, we digitised the footprint of each project as best as possible. For a further three solar farm projects, we found infrastructure footprint maps through their Town Planning Reports published on the Central Highlands Regional Council website[26]. For the remaining 20 solar farms for which maps were unavailable, we created a circular buffer around the project's location provided by the Queensland Government's data. The buffer area for each project is based on an estimate that an area of 0.025 km^2 is needed for every MW that the farm produces[27,28]. Therefore, we created the buffers for each of the proposed solar farms

[25] https://epbcpublicportal.awe.gov.au/all-referrals/

[26] https://www.chrc.qld.gov.au/

[27] https://www.nrel.gov/docs/fy13osti/56290.pdf

[28] https://www.solarlandlease.com/how-much-land-does-a-solar-farm-need

depending on the area required for each development, which was calculated by multiplying the estimated capacity of each project by 0.025 km²/MW.

Mapping wind farms

We found infrastructure footprint maps for 14 projects through the EPBC referrals. We could not find maps for six projects, and so these were not included in the spatial analysis. As with solar farms, the maps found in the EPBC Act referrals were georeferenced and the infrastructure footprint digitised as best as possible. We created centre-points and polyline features for the 14 georeferenced wind farm maps to estimate the footprint of wind turbines and linear infrastructure, respectively. The points and lines were created in what was approximated as their central location by visually inspecting the footprint polygons from the georeferenced maps. To convert these points and polylines into features with an area, we converted them into polygons by applying three different buffers of 100 m, 650 m, and 1000 m around them (**Figures 3** and **4**). A 100 m buffer is a conservative estimate of the land directly impacted by the built infrastructure that closely aligns with what is mapped in the EPBC referrals. The 650 m and 1000 m buffers assume that the infrastructure has indirect impacts on biodiversity, such as edge effects that expand further to the land directly converted by infrastructure[29]. We acknowledge that more research is needed to correctly identify the edge effects of renewable energy projects and therefore the most appropriate buffer range. We also note that georeferencing might not be accurate for several reasons, including poor quality or resolution of the source maps and geometric distortion in the image. Therefore, the digitised location of the wind turbines and linear infrastructure needs to be considered as an approximate location. To determine the total footprint of wind turbines and linear infrastructure, we merged the two layers for each of the buffer zones (100 m, 650 m, and 1 km).

In summary, we mapped 34 solar projects (32 proposed and two under construction) out of the 43 solar projects and 14 wind projects (13 proposed and one under construction) of the 20 wind projects proposed or underway in Central Queensland.

[29] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9827953/#:~:text=Additionally%2C%20infrastructure%20use%20may%20degrade,et%20al.%2C%202015).

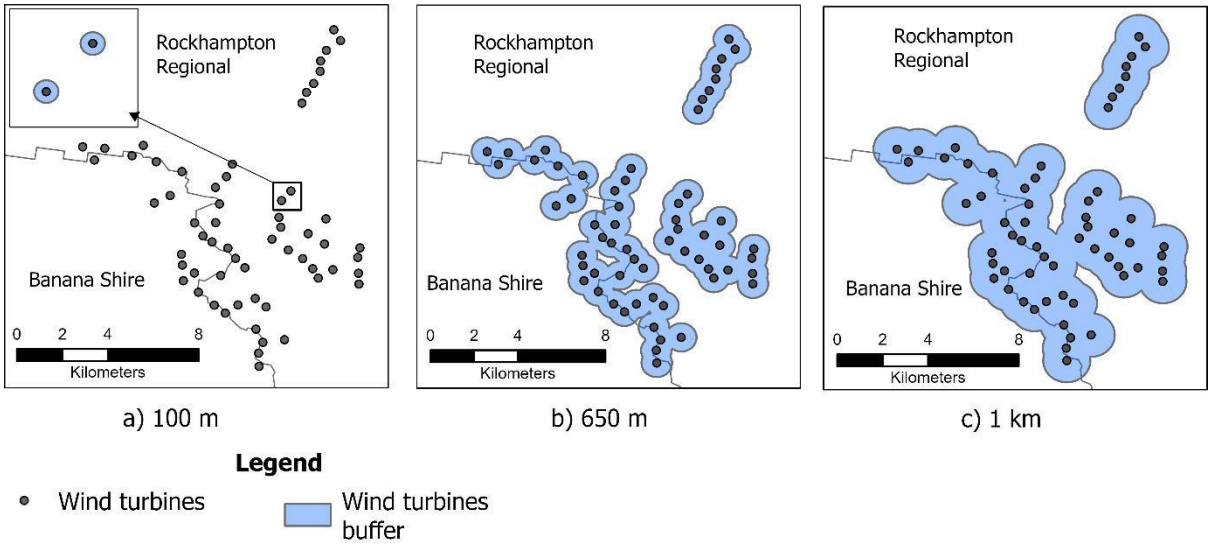

Figure 3. Example of the location of proposed wind turbines with different applied buffer zones of a) 100 m, b) 650 m, and c) 1 km.

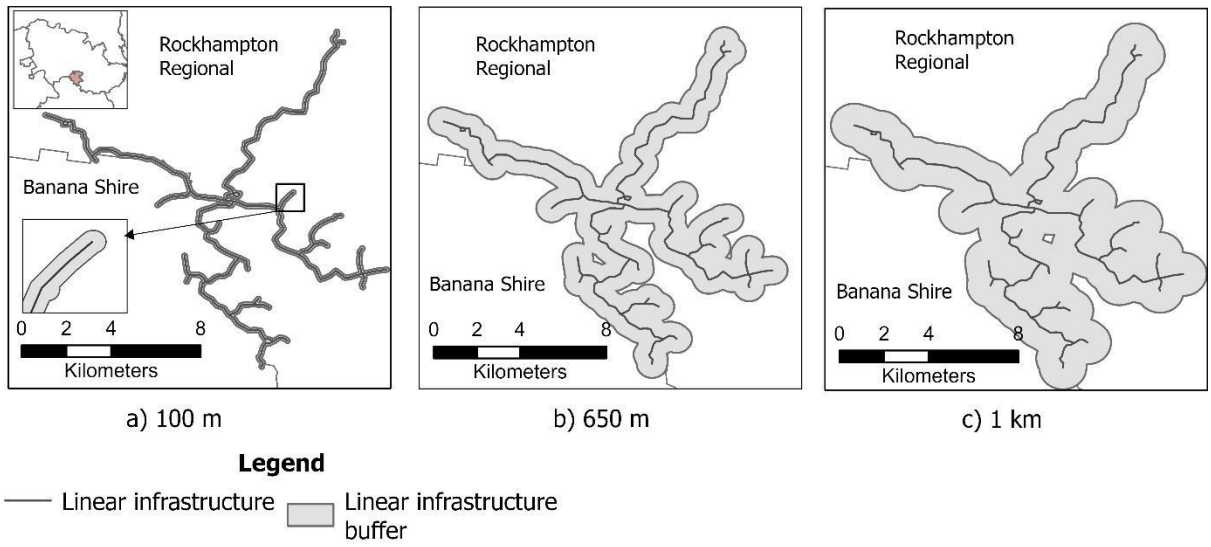

Figure 4. Example of the location of the proposed linear infrastructure of a wind farm project with different applied buffer zones of a) 100 m, b) 650 m, and c) 1 km.

Coal mining infrastructure

To assess the potential overlap between coal mining projects and Avoidance Zones, we mapped the infrastructure footprint of 27 new or expanding coal mines in the Bowen Basin, Central Queensland. These projects were identified from referrals submitted under the EPBC Act and accessed via the EPBC Public Portal. Where available, we georeferenced project impact drawings to delineate the expected surface disturbance area within the Mining Lease boundaries. In cases where only the coordinates of the Mining Lease were provided, we used

these to map the lease area, noting that this may overestimate the actual footprint of future operations. As with the wind farm projects described above, these georeferenced polygons should be considered approximate due to potential inaccuracies in the source maps or image distortions during georeferencing.

In total, the mapped footprint of the 27 coal mining projects covered approximately 1,000 km². Because coal mines are not typically associated with extensive linear infrastructure, and due to the uncertainty in final disturbance extents, we did not apply buffer zones around the mapped areas. It is likely that the actual area disturbed will be smaller than the total area mapped, particularly for projects where only Mining Lease boundaries were available.

Estimating overlap between infrastructure from development projects and Avoidance Zones

To estimate the spatial overlap between proposed infrastructure from development projects and Avoidance Zones, we first generated Avoidance Zone maps for each MNES. We then overlaid both a combined Avoidance Zones for all MNES layer, and the MNES-specific Avoidance Zones with the proposed infrastructure footprints in ArcGIS Pro. For each type of development, we calculated: (i) the total area of Avoidance Zones overlapping with its footprint, (ii) the area of MNES-specific Avoidance Zones intersecting with its footprint, and (iii) the total area of the development footprint that overlaps with Avoidance Zones.

Results for each MNES

Avoidance Zones based on World Heritage Areas, Natural Heritage Places, and Ramsar wetlands across Central Queensland

We found that 2,822 km^2 (1.10%) of Central Queensland was mapped as Avoidance Zones when considering World Heritage Areas, National Heritage Places and Ramsar wetland sites (**Figure 5a-c**). The Avoidance Zones for World Heritage Areas, National Heritage Places and Ramsar wetland sites encompassed 2,053 km^2 (0.80%), 2,053 km^2 (0.80%) and 988 km^2 (0.39%) of Central Queensland's area, respectively.

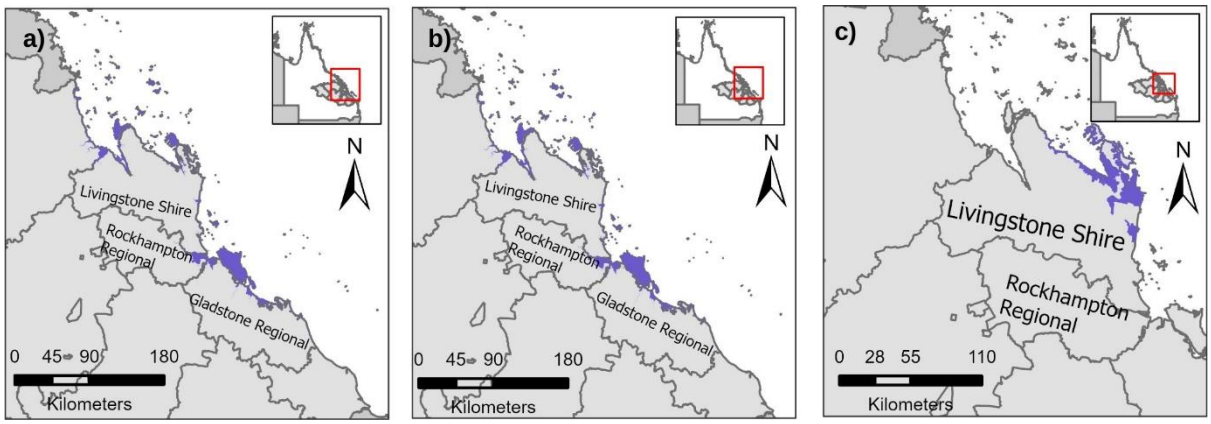

Figure 5. Areas identified as Avoidance Zones for World Heritage Areas (a), Natural Heritage Places (b) and Ramsar wetlands (c) across Central Queensland.

Avoidance Zones for Threatened Ecological Communities in Central Queensland

We found that 43,223 km^2 (16.90%) of Central Queensland was mapped as Avoidance Zones when considering threatened ecological communities (**Figure 6a-b**). The Avoidance Zones for Critically Endangered and Endangered Communities cover 671 km^2 (0.26%) and 42,612 km^2 (16.60%) of Central Queensland's areas, respectively.

Avoidance Zones for non-threatened migratory species in Central Queensland

We found that 970 km^2 (0.38%), or the entire intertidal area, of Central Queensland was mapped as Avoidance Zones when considering the needs of non-threatened migratory bird species (**Figure 7**).

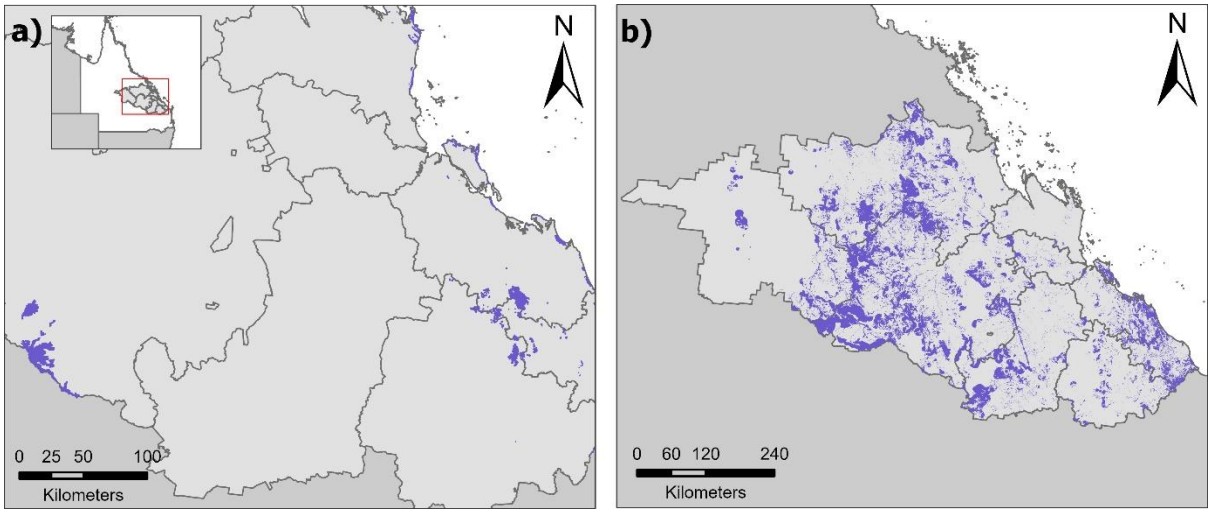

Figure 6. Areas identified as Avoidance Zones for Critically Endangered (3a) and Endangered (3b) ecological communities across Central Queensland.

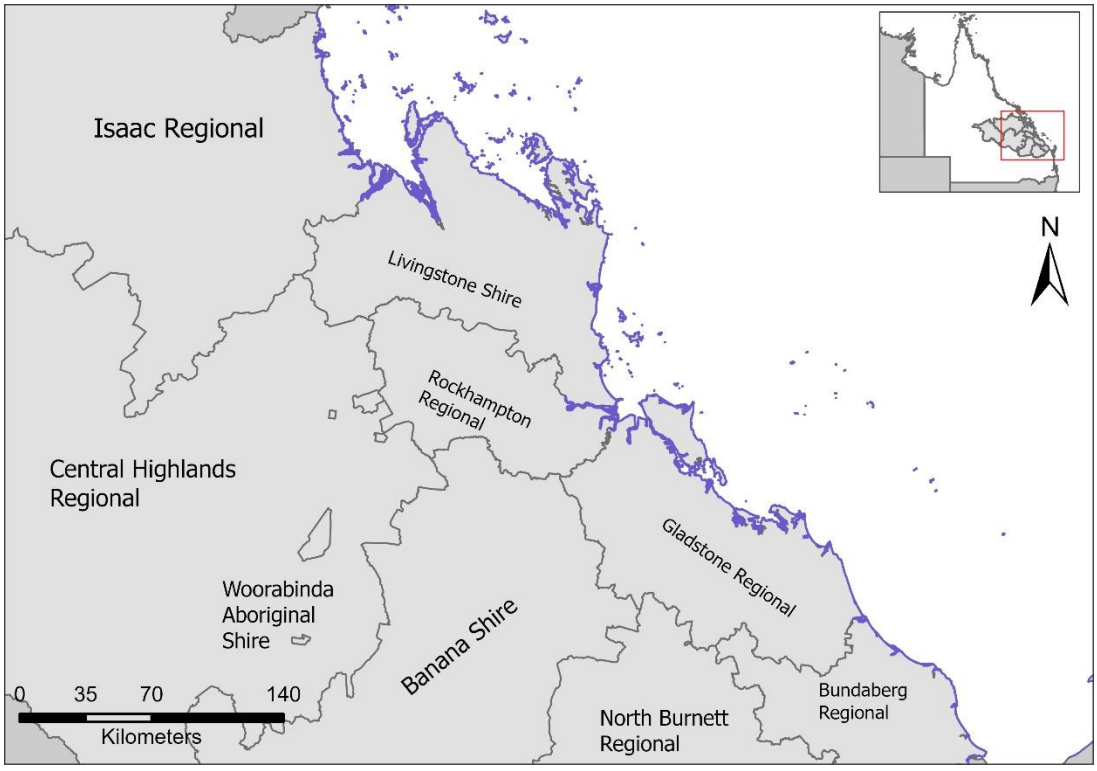

Figure 7. Areas identified as Avoidance Zones for non-threatened migratory birds across Central Queensland.

Avoidance Zones for threatened bird species in Central Queensland

We found that 1,169 km^2 (0.46%) of Central Queensland was mapped as Avoidance Zones when considering the needs of threatened bird species (**Figure 8a-c**). The Avoidance Zones for Critically Endangered, Endangered, and Vulnerable bird species encompassed 1,169 km^2 (0.46%), 933 km^2 (0.36%), and 970 km^2 (0.38%) of Central Queensland's areas, respectively.

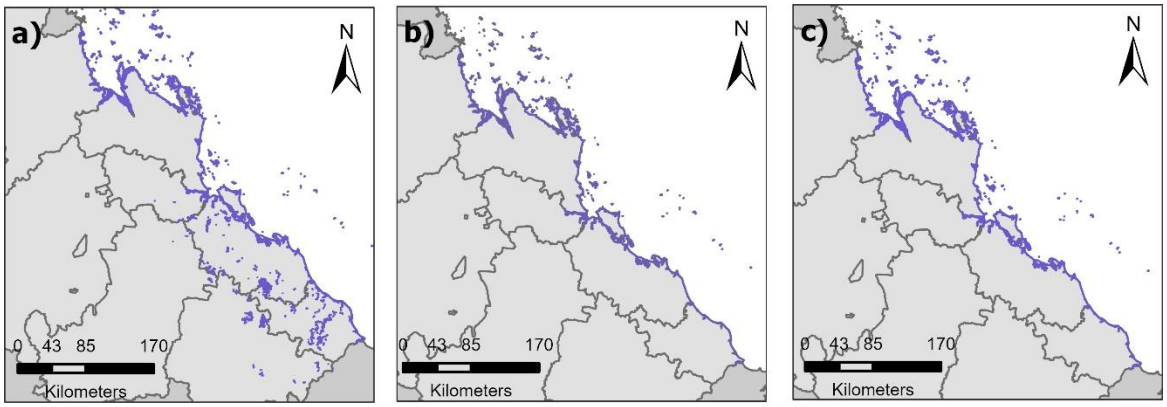

Figure 8. Areas identified as Avoidance Zones for Critically Endangered (6a), Endangered (6b), and Vulnerable (6c) bird species across Central Queensland.

Avoidance Zones for threatened mammal species in Central Queensland

We found that 63,766 km^2 (25%) of Central Queensland was mapped as Avoidance Zones when considering the needs for mammal species (**Figure 9a-b**). The Avoidance Zones for Vulnerable mammals cover 37,186 km^2 (14.51%), and those for Endangered mammals 38,037 km^2 (14.84%) of Central Queensland. Whereas the Critically Endangered mammals comprised only the Northern Hairy-nosed Wombat habitat (46 km^2), which makes up 0.02% of Central Queensland's area.

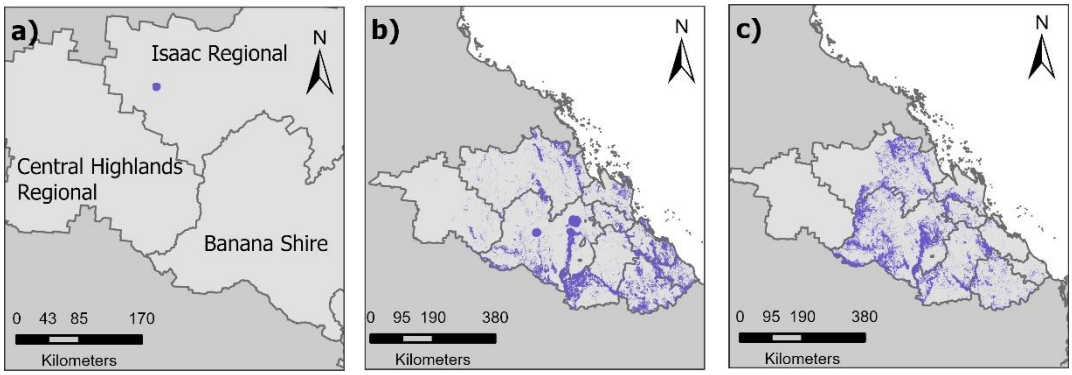

Figure 9. Areas identified as Avoidance Zones for Critically Endangered (7a), Endangered (7b), and Vulnerable (7c) mammal species across Central Queensland.

Mapped Avoidance Zones for Central Queensland

In total, 31% (80,643 km^2) of Central Queensland's area was mapped as Avoidance Zones (**Figure 10**). The area required to meet the needs of endangered ecological communities was the key MNES influencing the extent of Avoidance Zones in Central Queensland, covering 52.8% of the total Avoidance Zone (**Figure 10b**). Additionally, Endangered and Vulnerable mammal species comprise the second and third largest Avoidance Zone areas, each influencing approximately 40% of the Avoidance Zone areas.

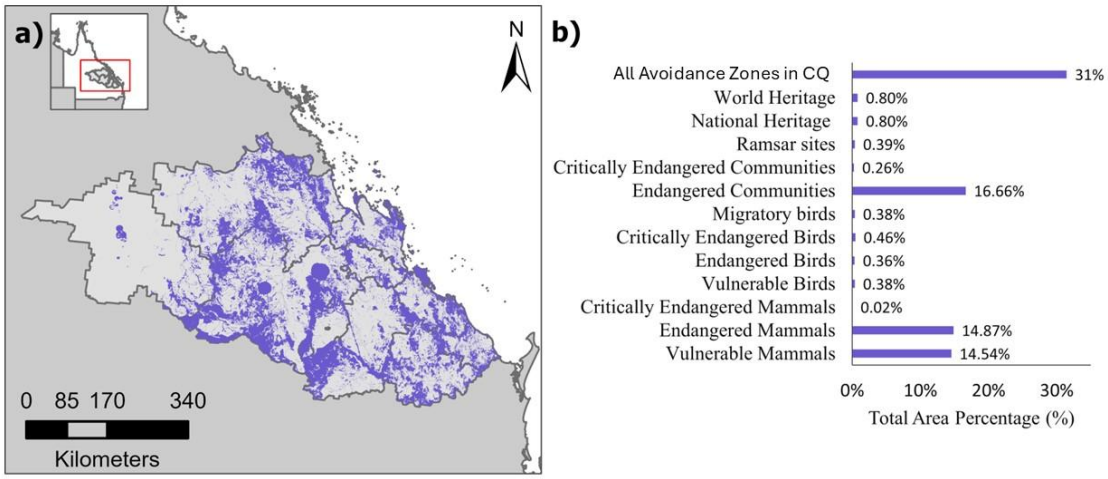

Figure 10. Map of Avoidance Zones identified for Central Queensland based on applying the principles and rules (for Avoidance Zones) for all MNES used in our case study (a). Area (%) of Central Queensland identified as Avoidance Zone based on each MNES and all MNESs together (10b).

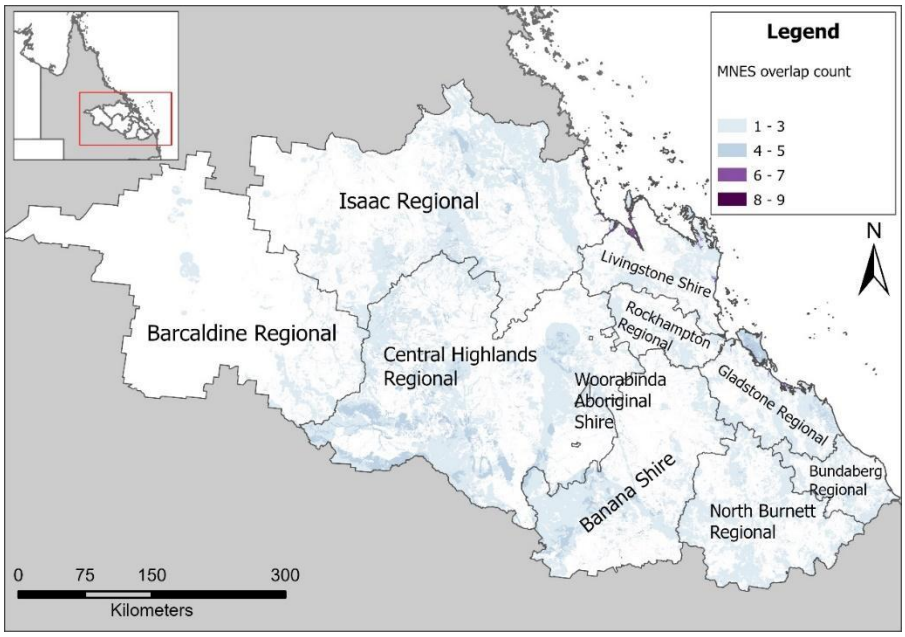

Figure 11. Number of MNES' Avoidance Zones overlapping in Central Queensland, based on applying the principles and rules for the subset of MNES used in our case study.

Avoidance Zones overlap with the development infrastructure footprint for Central Queensland

We mapped the footprint of 32 proposed solar farms, 2 solar farms under construction, 13 proposed wind developments, and a wind farm under construction (**Table S7** and **Table S8** in **Appendix 3**). The area required for solar farm development amounts to 304 km². A summary of the land area needed for the wind farm's footprint infrastructure (including turbines and linear infrastructure) is provided below (**Table 5**) for each assumed area of infrastructure impact on the natural environment.

We also mapped 27 proposed or expanding coal mining projects in the Bowen Basin based on available EPBC referrals. The total area of the mapped surface impact from coal mines is 998 km².

Table 5. The total area of the proposed wind farm projects' footprint in Central Queensland. The footprint was calculated as a 100 m, 650 m, and 1 km buffer from the mapped infrastructure.

Renewable energy infrastructure	**Buffer scenarios**		
	100 m	**650 m**	**1 km**
Wind Turbines footprint	38 km^2	1,057 km^2	1,636 km^2
Linear Infrastructure footprint	322 km^2	1,586 km^2	2,093 km^2
Total Wind infrastructure footprint (turbines and linear infrastructure)	322 km^2	1,626 km^2	2,136km^2

Overlap of renewable energy infrastructure and Avoidance Zones

We overlaid the mapped Avoidance Zones with the renewable energy infrastructure (RE) to assess the extent of overlap with areas of high conservation value (**Figure 12**). We found that 9% of the total footprint of proposed solar farms overlaps with the Avoidance Zones that we mapped (**Table 6**). For windfarms, between 56% and 58% of their footprint area overlaps with Avoidance Zones, depending on the assumed project footprint, which we represented using buffer distances from each project's centre point or centre line. This corresponds to

between 185 km² and 1,206 km² of Avoidance Zones potentially affected by wind farm developments.

So, in total, we found that 34%, 51% and 50% of the total area required for RE projects (both solar and wind developments) overlap with Avoidance Zones when considering 100 m, 650 m, and 1 km buffer zones, respectively, around wind farms (**Figure 13**). Note that bigger buffers result in a larger RE footprint area, and potentially a larger total area of overlap with Avoidance Zones; however, the percentage of the footprint overlapping Avoidance Zones is not necessarily larger.

Table 6. Estimated total area required for proposed renewable energy projects and infrastructure, and the percentage of area overlapping with Avoidance Zones.

Renewable energy type	Total Renewable Energy Development Area (km^2)	Overlap with Avoidance Zones (km^2)	Renewable Energy Development Area (%) that overlaps with Avoidance Zones
Solar	304	28	9%
Wind			
100 m	332	185	56%
650 m	1,626	940	58%
1000 m	2,136	1,206	56%

The main MNES overlapping with the renewable energy infrastructure were Endangered and Vulnerable mammal species, as well as Endangered ecological communities.

If all proposed wind energy projects go ahead, the endangered ecological communities would lose 0.09% of their Avoidance Zones for the 100 m buffer, 0.4% for the 650 m buffer, and 0.5% for the 1 km buffer. For endangered mammals, the projected loss would be 0.2%, 0.9, and 1.2%, and for vulnerable mammals, 0.3%, 1.6%, and 2%, across the same buffer zones (**Table S10**).

The results suggest that the Poplar Box Grassy Woodland on Alluvial Plains ecological community will experience the greatest impact, with 0.1%, 0.5%, and 0.6% of its Avoidance Zone in CQ affected across the three buffer distances. Among endangered species, the Northern Quoll will be the most affected, with 0.5%, 3.7%, and 4.6% of its Avoidance Zone in CQ overlapping with renewable energy areas for the respective buffer zones. For vulnerable species, Semon's Leaf-nosed Bat will face the highest impact, with 6%, 29%, and

33% of its Avoidance Zones overlapping with renewable energy areas across the three buffer zones (**Table S10**).

For the proposed solar energy projects, the Coastal Swamp Sclerophyll Forest, the Northern Quoll, and the Greater Glider would experience the greatest impact (**Table S9**).

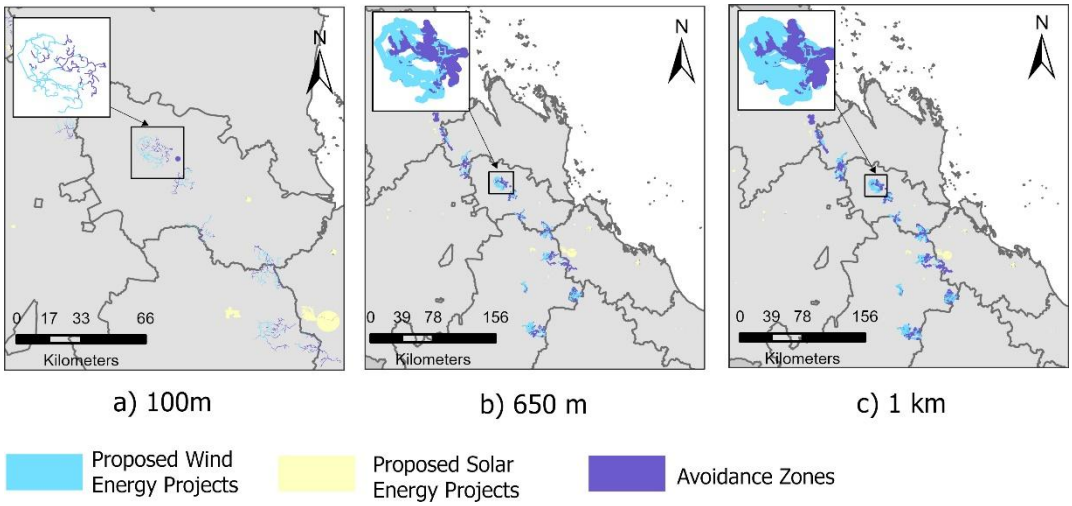

Figure 12. Map illustrating the overlap of Avoidance Zones with proposed solar and wind energy projects (including wind turbines and linear infrastructure).

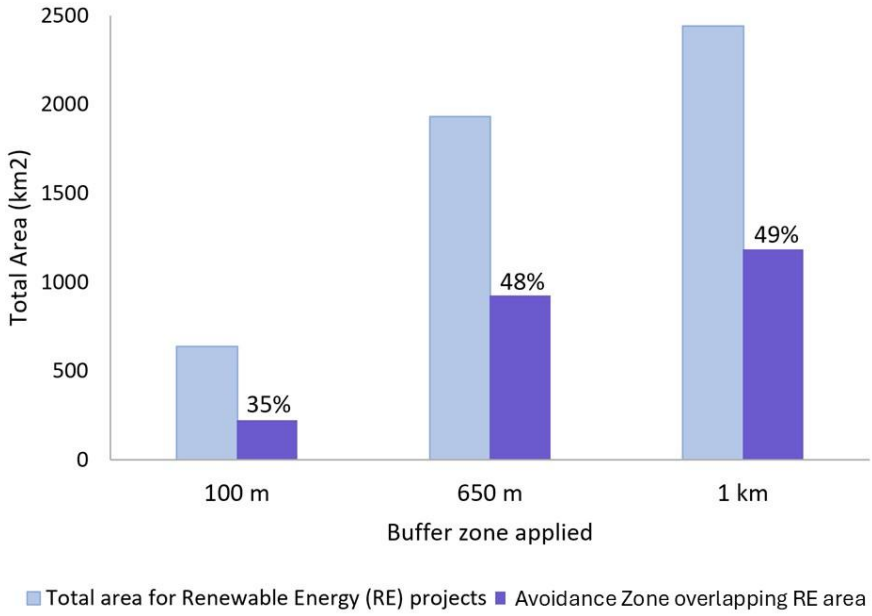

Figure 13. The figure illustrates the total area (in km²) required for both solar and wind renewable energy (RE) projects, represented in blue, and the total area of overlap of the projects' area with Avoidance Zones, shown in purple (the number is the percentage area of overlap). This is presented for each of the applied buffer zones used to represent wind farm footprints (100 m, 650 m, and 1 km).

In addition to renewable energy projects, we assessed the potential overlap between coal mining projects and Avoidance Zones. Of the 1,000 km² of mapped coal mining project footprints, 29.9% (326 km²) overlapped with Avoidance Zones. Of the 27 coal mining projects mapped, 20 had an overlap greater than 1% of their area with Avoidance Zones, ranging from 0.2% to 100% (**Figure 14**).

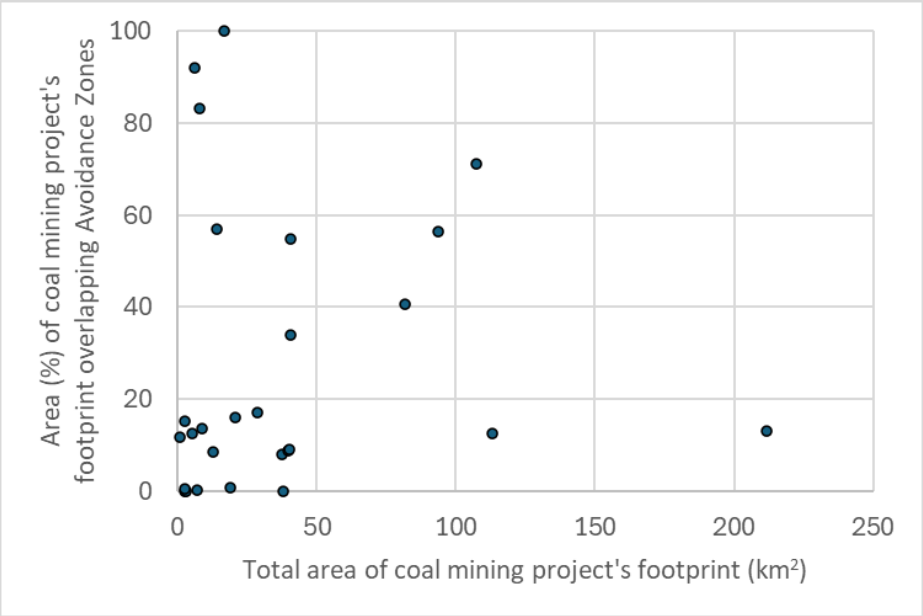

Figure 14. Area of each mapped coal mining project's footprint overlapping Avoidance Zones in relation to its total footprint area.

The impacted areas include Avoidance Zones for endangered mammals (105 km², 0.25% of their total Avoidance Zone area), vulnerable mammals (194 km², 0.48%), and endangered ecological communities (300 km², 0.64%). Table 7 details the total area of each MNES that overlaps with coal mining projects, and how much this represents of their total Avoidance Zones.

In total, when combining the proposed renewable energy and coal mining developments, we estimate that up to 1,560 km² of Avoidance Zones could be impacted. This represents approximately 2% of the total Avoidance Zone area across Central Queensland. While coal mining projects accounted for a smaller proportion of the total development area, they still contributed 326 km² of overlap, compared to up to 1,206 km² from wind and solar infrastructure combined. These findings underscore the cumulative pressure that current development proposals may exert on areas of high conservation value, regardless of project type.

Table 7. Overlap between the assessed Matters of National Environmental Significance and the new and proposed potential coal mining footprint in Central Queensland.

MNES		Area of Avoidance Zone overlapping coal mining km^2	Area of Avoidance Zone overlapping coal mining (%)
Endangered mammals	Northern Quoll (*Dasyurus hallucatus*)	3	0.15
Endangered mammals	Greater Glider (*Petauroides volans*)	83	0.22
Endangered mammals	Bridled Nailtail Wallaby (*Onychogalea fraenata*)	18	1.02
Vulnerable mammals	Yellow-bellied Glider (*Petaurus australis australis*)	11	0.43
Vulnerable mammals	Corben's Long-eared Bat (*Nyctophilus corbeni*)	194	0.49
Endangered threatened community	Brigalow (Acacia harpophylla dominant and co-dominant)	37	0.87
Endangered threatened community	Natural Grasslands of the Queensland Central Highlands and northern Fitzroy Basin	10	0.22
Endangered threatened community	Poplar Box Grassy Woodland on Alluvial Plains	284	0.83
Endangered threatened community	Semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar Bioregions	13	0.57
Endangered threatened community	Weeping Myall Woodlands	15	0.34

Discussion

Key findings

In total, the Central Queensland region comprises 80,643 km^2, which was mapped as Avoidance Zones, or 31% of its area. Depending on the buffer zone applied to wind infrastructure (100 m, 650 m, and 1 km), approximately half of the renewable energy footprint area that we mapped is of high conservation value; that is, it contains a mapped Avoidance Zone (**Figure 13**).

While the percentages are relatively high, in terms of overlap, the actual numbers of MNES are low. Five vulnerable mammal species were found to be potentially impacted (**Table S9** and **Table S10**), with the species most at risk being the Northern Quoll and the Semon's Leaf-nosed Bat, with a significant range of their Avoidance Zones found within Central Queensland being impacted by renewable energy infrastructure developments. The Northern Quoll has been shown to be sensitive to habitat loss and fragmentation due to its large habitat requirement[30]. They also show a strong negative response to the loss of certain habitat features, including tree hollows and logs used for shelter that take a long time to form and are often found in remnant vegetation[31]. The Semon's Leaf-nosed Bat is less studied and there is a lack of population data. However, their habitat loss and fragmentation are known to be concerning for their survival[32]. Also, the remnant areas of Poplar Box Grassy Woodland on the Alluvial Plains ecological community in Central Queensland will be most impacted. Loss of habitat for grazing, cropping and infrastructure projects has left behind small, fragmented and isolated patches of the Poplar Box Grassy Woodland ecosystem community, with only 25% of its pre-colonial coverage remaining[33]. These species continue to be threatened not only by development but also by invasive species, inappropriate fire regimes and climate change.

In addition to renewable energy developments, our analysis found that 29.9% of the mapped coal mining footprints intersect with Avoidance Zones, a proportion comparable to that of

[30] https://www.publish.csiro.au/am/pdf/AM21002

[31] https://depws.nt.gov.au/__data/assets/pdf_file/0005/255074/2008WoinarskiJ.C.Z.andWestawayJ.pdf

[32] https://www.nespthreatenedspecies.edu.au/publications-and-tools/a-brief-history-of-the-northern-quoll-dasyurus-hallucatus-a-systematic-review

[33] https://hsi.org.au/blog/legal-recognition-for-threatened-woodlands-at-long-last

renewable energy zones. These overlaps include direct impacts to habitat for multiple MNES, including the Northern Quoll, Semon's Leaf-nosed Bat, and several threatened ecological communities. Notably, 20 of the 27 coal mining projects analysed overlapped > 1% of their footprint with Avoidance Zones, with some exceeding 70%. These results highlight the utility of the framework used to identify Avoidance Zones from a regional planning perspective, which considers cumulative pressures across all development types in order to protect high conservation value areas.

Limitations of the current analysis

We note that out of the 16 possible decision rules for Avoidance Zones, we could only map nine of them. Currently, there is no available data on seven decision rules, and as such we have missed Avoidance Zones across Central Queensland. Some of these limitations can be overcome, for example with the release of offset sites across the region. Others, such as 'sites that are irreplaceable when considering the recovery of the Critically Endangered and Endangered ecological community, including under future climate change scenarios assessed as reasonably likely', will need the engagement of local experts and will likely be site or species-specific. We could not map any decision rule dealing with the recoverability of species or communities, as there is still an ongoing debate on what recoverability means among conservation scientists and practitioners.

Some important limitations to the analysis include data access and the complexity of mapping irreplaceable habitat features, as discussed in a Southeast Queensland case study report[3]. First, we could not utilise finer-scale threatened species, migratory species, and ecological community maps, which are not open access. The resolution difference between the maps we used (1 km^2) and what is available (100 m^2), as used in prior studies, is significant when considering the Avoidance Zones we identified. While we cannot make any predictions about the results if finer scale resolution was used, it is a possibility that the Avoidance Zones identified for species and ecological communities would be reduced in their overall extent.

Another limitation related to the lack of publicly available fine-scale datasets was the treatment of the boundaries of threatened ecological communities. We filtered out the dataset to communities found only within remnant vegetation[18], as without this specification, most of the area in Central Queensland (>90%) would be mapped as an Avoidance Zone. More information on where these communities currently and formerly occur is necessary to obtain more accurate results.

The complexity of mapping natural habitat features imposes another important issue. Some examples include the hollows of old trees, caves, and the habitat of rock-dwelling fauna such as the Yellow-footed Rock Wallaby. These microhabitats play a crucial role in supporting a wide range of species. Yet, the identification and conservation of such features require extensive ground-based surveys, deploying significant resources and time to accurately locate and assess them.

We also excluded several species that slightly overlapped with Central Queensland's boundaries, and based on the expert consultations, the species are not known to occur in the region (see **Table S5** and **Table S6** in **Appendix 3**). However, excluding these species did not impact the results given that their mapped distributions barely occur in the region.

We also note that we only mapped 34 solar projects (32 proposed and two under construction) out of the 43 solar projects and 14 wind projects (13 proposed and one under construction) of the 20 wind projects proposed or underway in Central Queensland. So, our estimate of the total potential impact is an underestimate.

Conclusion

The work outlined in this case study showcases that the principles and decision rules set against the five MNES can be used to guide assessments into the impacts of future development projects. The results presented here are not to be relied upon beyond a demonstration of these principles. More focused work with wider expert input and review would be required if using these rules to underpin a particular regional plan that is to be implemented. Our work shows that it is possible to map Avoidance Zones utilising publicly available data, and the maps were considered useful (i.e., of high enough resolution and quality) to determine the potential cumulative impacts of renewable energy and coal mining developments on biodiversity at a regional scale rather than a project-by-project case. Given that most of these projects are in the early stages (81% of projects are proposed for RE), a regional planning process would be able to provide proponents with clear environmental indications and thresholds, including stopping said projects where an area is of high conservation value.

Appendix 1. Planning principles for deriving zoning rules

Eight principles were identified through the consultations. The zoning rules must:

1. Be evidence-based, scientifically defensible, and clear.

2. Recognise that some areas within MNES assets are 'irreplaceable' in that they cannot be replaced or restored in a meaningful timeframe. These areas or habitat elements cannot be lost without accruing an irreversible impact to the MNES and must be zoned as conservation in perpetuity.

3. Include high-resolution mapping appropriate for the size of the region and the MNES assessed, as far as possible, recognising that some important habitat or habitat elements cannot be effectively mapped.

4. Be robust to scientific uncertainties, and responsive to improvements in knowledge and any increases in threats to matters outside the scope of land use decisions. Specifically, in areas where uncertainties limit zoning decisions, land is zoned as 'Zone 2' (Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter), and these uncertainties must be resolved before rezoning land to either 'Zone 3' (Development allowed without an EPBC Act approval, but conditions may apply) or 'Zone 1' (Avoidance area: development is not allowed).

5. Be based on the precautionary principle, whereby if there are threats of serious or irreversible environmental damage, lack of complete scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. If the risk to the environment is high, but scientific certainty of the risk eventuating is low, the precautionary principle can fill the gap and essentially requires decision-makers to act as though the risk to the environment will eventuate.

6. Follow the logic of the internationally accepted 'Mitigation Hierarchy' [34]to ensure we first Avoid, then Minimise, then Restore and finally Offset (where things are offsetable) in order to reduce development impacts and control any negative effects on the

[34] https://www.thebiodiversityconsultancy.com/our-work/our-expertise/strategy/mitigation-hierarchy/

environment. We note that the logic of the mitigation hierarchy is embraced by the Federal government, at least in principle[35].

7. Use the best available scientific knowledge but it needs to be recognised that imperfect data exists for many species and ecosystems, and there is a need to incorporate uncertainties by applying sensible areal thresholds around potential impact for these species and, at the same time, fully acknowledge this uncertainty.

8. Assign the highest level of protection if an area is identified as multiple zones. For example, if an area is identified as both Zone 1 and Zone 2 under different rules, Zone 1 (Avoidance Zone) is automatically assigned to the area.

[35] https://www.dcceew.gov.au/environment/epbc/approvals/offsets/guidance/mitigation-hierarchy

Appendix 2. Zoning Rules for the five MNES considered

Decision rules for five Matters of National Environmental Significance (MNES) are provided but noting that threatened species were further divided according to their levels of endangerment. These rules were generated based on consultations with experts[1]. In total, 32 unique decision rules were identified across three zones (16 for the Avoidance Zone, 15 for Zone 2, and one for Zone 3). In this report, we only map the Avoidance Zone.

Table S1. Decision rules for five Matters of National Environmental Significance (MNES) are provided but noting that threatened species were further divided according to their levels of endangerment. These rules were generated based on consultations with experts (Appendix 3).

Matters of National Significance	**Avoidance Zone or Zone 1:** **development is not allowed**	**Zone 2:** **Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).**	**Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.**
World Heritage Areas	Areas that have protected World Heritage values. Areas adjoining, connected, or near World Heritage places that are needed to sustain protected World Heritage values.	Areas within World Heritage places that do not have protected World Heritage values, other than areas where all relevant natural or cultural heritage values have been lost to hard infrastructure, unless that infrastructure forms part of the World Heritage values. Areas adjoining, connected, or near World Heritage places that require assessment as they may be needed for the ongoing protection and maintenance of the protected World heritage values. Areas that do not meet the category for Avoidance, but are not adequately surveyed enough to ensure there are no World Heritage values and the loss of these areas will not impede on the long-term persistence of these values.	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.

Matters of National Significance	**Avoidance Zone or Zone 1:** **development is not allowed**	**Zone 2:** **Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).**	**Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.**
National Heritage Places	Areas that have protected National Heritage values, including only natural or cultural heritage values. Areas adjoining, connected, or near National Heritage places that are needed to sustain protected National Heritage values.	Areas within National Heritage places without protected National Heritage values, other than areas where all relevant natural heritage values have been lost. Areas adjoining, connected, or near National Heritage places that require assessment as they may be needed for the ongoing protection and maintenance of the protected heritage values. Areas that do not meet the category for Avoidance Zone but are not adequately surveyed enough to ensure there are no National Heritage values and the loss of these areas will not impede on the long-term persistence of these values.	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.
Wetlands of international importance	Areas within the boundaries of Ramsar wetlands. Areas adjoining, connected, or near Ramsar places that are needed to sustain protected Ramsar values.	Areas adjoining, connected, or near Ramsar wetlands that require an assessment to understand if it is needed to ensure the ongoing protection, recovery, and maintenance of their Ramsar values. Areas that do not meet the category for Avoidance Zone but are not adequately surveyed for Ramsar values.	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.
Critically Endangered, Endangered ecological communities	Areas adjoining, connected, or near a Critically Endangered or Endangered ecological	Sites that require assessment to determine if it is needed to ensure recovery, including under future climate change impacts. Sites that still require adequate assessment to determine if it is	Areas that are adequately surveyed and do not meet the criteria of Zones

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	community that are irreplaceable when considering the ongoing protection and maintenance of the ecological community. Sites that are irreplaceable when considering the recovery of the Critically Endangered or Endangered ecological community, including under future climate change scenarios assessed as reasonably likely. All offset sites and areas set aside for the conservation of the community.	irreplaceable or contains irreplaceable elements. Areas adjoining, connected, or near threatened ecological communities that require assessment to determine if they are needed for the ongoing protection and maintenance of the ecological community values. Areas that do not meet the category for Avoidance Zone but are not adequately surveyed for threatened ecological communities.	1 and 2 for any MNES.
Migratory species	All 'known to occur' areas and any habitat within 2 km (applies when there are only 'known to occur' areas mapped). All areas where the species is	Sites where the species is known to, likely to, or may occur, for which there is evidence that the relevant habitat values can be re-created or restored within a biologically meaningful timeframe (i.e., are not irreplaceable or information is inadequate to determine irreplaceability).	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	known to, likely to, may occur, or is needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known to, likely to and may occur areas mapped). Areas adjoining, connected, or near species habitat that are needed to sustain those irreplaceable sites identified for the species. All offset sites and areas set aside for the conservation of the species.	Areas adjoining, connected, or near species habitat that are needed for the ongoing protection and maintenance of the species, including under future climate change impacts. Sites that still require adequate assessment to determine if it is irreplaceable or contains irreplaceable elements.	
Critically Endangered species	All 'known to occur' areas and any habitat within 2 km (applies	Sites that require assessment to determine if they are irreplaceable or contain irreplaceable elements.	Areas that are adequately surveyed and do not meet the

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	when there are only 'known to occur' areas mapped). All areas where the species is known to, likely to, may occur, or needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known to, likely to and may occur areas mapped). Areas adjoining, connected, or near species habitat that are needed to sustain those irreplaceable sites identified for the species. All offset sites and areas set aside for the	Sites that require assessment to determine if they are needed to ensure recovery, including under future climate change impacts. Sites where the species is known to occur, likely to occur, may occur, or needed for recovery, for which there is evidence that the relevant habitat values can be re-created or restored within a biologically meaningful timeframe (i.e., are not irreplaceable or information is inadequate to determine irreplaceability). Areas adjoining, connected, or near threatened species habitat that are needed for the recovery of the species.	criteria of Zones 1 and 2 for any MNES.

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	conservation of the species.		
Endangered species	All known to occur areas and any habitat within 1.5 km (applies when there are only 'known to' occur areas mapped). All areas where the species is known to, likely to, may occur, or needed for recovery, that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known, likely and may occur areas mapped). Areas adjoining, connected, or near species habitat that are needed to sustain those	Sites that require assessment to determine if they are irreplaceable or contain irreplaceable elements. Sites that require assessment to determine if they are needed to ensure the recovery, including under future climate change impacts. Sites where the species is known to, likely to, may occur, or needed for recovery, for which there is evidence that the relevant habitat values can be re-created or restored within a biologically meaningful timeframe (i.e., are not irreplaceable or information is inadequate to determine irreplaceability). Areas adjoining, connected, or near threatened species that are needed for the recovery of the species.	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	irreplaceable sites identified for the species. All offset sites and areas set aside for the conservation of the species.		
Vulnerable species	All known to occur areas and any habitat within 1 km (applies when there are only 'known to' occur areas mapped). All areas where the species is known to, likely to, may occur, or needed for recovery that are irreplaceable or for which the relevant habitat elements cannot be re-created within a biologically meaningful timeframe with all its natural features and functions (applies when there are known, likely and	Sites that require assessment to determine if it is irreplaceable or contains irreplaceable elements. Sites that require assessment to determine if they are needed to ensure the recovery, including under future climate change impacts. Sites where the species is known to, likely to, may occur, or needed for recovery, for which there is evidence that the relevant habitat values can be re-created or restored within a biologically meaningful timeframe (i.e., are not irreplaceable or information is inadequate to determine irreplaceability). Areas adjoining, connected, or near threatened species that are needed for the recovery of the species.	Areas that are adequately surveyed and do not meet the criteria of Zones 1 and 2 for any MNES.

Matters of National Significance	Avoidance Zone or Zone 1: development is not allowed	Zone 2: Development is allowed subject to no unacceptable impacts: application of National Environmental Standards and the mitigation hierarchy; and net gain for each impacted listed matter (e.g., Phascolarctos cinereus or Kairi).	Zone 3: Development allowed without an EPBC Act approval, but conditions may apply.
	may occur areas mapped). Areas adjoining, connected, or near species habitat that are needed to sustain those irreplaceable sites identified for the species. All offset sites and areas set aside for the conservation of the species.		

Appendix 3. Supporting Tables of the Methodology

Table S2. A summary of the different data sources used in the Central Queensland case study.

Data name	**Link to where data can be obtained**
Intertidal area extent	Sagar, S., Roberts, D., Bala, B., & Lymburner, L. (2017). Extracting the intertidal extent and topography of the Australian coastline from a 28-year time series of Landsat observations. *Remote Sensing of Environment*, *195*, 153–169. https://doi.org/10.1016/j.rse.2017.04.009
National dataset of Australian properties on the World Heritage Areas List	Australia, World Heritage Areas, Federal Government Department of Climate Change, Energy, the Environment and Water, https://fed.dcceew.gov.au/datasets/bd46da1431cc4250b6be4017958fc1c6/about
Australia's National Heritage Places List	National Heritage List Spatial Database (NHL) – public, Federal Government Department of Climate Change, Energy, the Environment and Water, https://fed.dcceew.gov.au/datasets/erin::national-heritage-list-spatial-database-nhl-public/about.
Ramsar sites for Queensland	Ramsar sites – Queensland, The Queensland Government, The Department of Environment and Science, https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={AC0B0BB0-535D-4BB3-8D7E-EDECF48F6D46}
Ecological Communities of National Environmental Significance Distributions (public grids)	Australia - Ecological Communities of National Environmental Significance (Public Grids), Federal Government Department of Climate Change, Energy, the Environment and Water, https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B184A3793-2526-48F4-A268-5406A2BE85BC%7D
Species of National Environmental Significance (SNES) Distributions (public grids)	Australia - Species of National Environmental Significance Distributions (public grids), Federal Government Department of Climate Change, Energy, the Environment and Water, https://fed.dcceew.gov.au/datasets/erin::australia-species-of-national-environmental-significance-distributions-public-grids/about
Remnant vegetation cover – 2021 Queensland	Remnant vegetation cover – 2021 Queensland, The Queensland Government, The Department of Environment and Science, https://www.data.qld.gov.au/dataset/remnant-vegetation-cover-2021-queensland

Broad Vegetation Group dataset	Broad Vegetation groups – pre-clearing and 2021 remnant Queensland series, The Queensland Government Department of Environment and Science, https://www.data.qld.gov.au/dataset/broad-vegetation-groups-pre-clearing-and-2021-remnant-queensland-series
Power Plant Map of Queensland	Electricity generation map, Queensland Government, https://www.business.qld.gov.au/running-business/support-assistance/mapping-data-imagery/maps/electricity-generation

Table S3. The threatened ecological communities considered in the Central Queensland case study.

Threatened category	**List of threatened ecological communities by category**
Critically Endangered	Littoral Rainforest and Coastal Vine Thickets of Eastern Australia Lowland Rainforest of Subtropical Australia White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland.
Endangered	Brigalow (Acacia harpophylla dominant and co-dominant) Broad leaf tea-tree (Melaleuca viridiflora) woodlands in high rainfall coastal north Queensland Natural Grasslands of the Queensland Central Highlands and northern Fitzroy Basin Weeping Myall Woodlands Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin Semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar Bioregions Subtropical eucalypt floodplain forest and woodland of the New South Wales North Coast and South East Queensland bioregions Coastal Swamp Sclerophyll Forest of New South Wales and South East Queensland Coastal Swamp Oak (Casuarina glauca) Forest of New South Wales and South East Queensland ecological community Poplar Box Grassy Woodland on Alluvial Plains

Table S4. Species-specific application of the decision rules and data utilised for mapping non-threatened migratory species Avoidance Zones in Central Queensland.

Species	Irreplicable areas or notes on habitat elements	Data used	Data Description
Black-faced Monarch (*Monarcha melanopsis*)	This species inhabits rainforests, eucalypt woodlands, coastal scrub and damp gullies.	NA	The species has no Avoidance Zones that could be identified at this time.
Fork-tailed Swift (*Apus pacificus*)	This is an almost exclusively aerial species. Hence, no irreplaceable habitat features can be mapped. See discussion for more details.	NA	The species has no Avoidance Zones that could be identified at this time.
Grey Wagtail (*Motacilla cinerea*)	Vagrant in QLD.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
Little Curlew, Little Whimbrel (*Numenius minutus*)	This species inhabits short, dry grassland and sedgeland, including dry floodplains and blacksoil plains	NA	The species has no Avoidance Zones that could be identified at this time.
Satin Flycatcher (*Myiagra cyanoleuca*)	This species mainly inhabits eucalypt forests, often near wetlands or watercourses.	NA	The species has no Avoidance Zones that could be identified at this time.
Oriental Cuckoo, Horsfield's Cuckoo (*Cuculus optatus*)	This species can be found in open forest types and farmland with scattered trees.	NA	The species has no Avoidance Zones that could be identified at this time.
Pectoral Sandpiper (*Calidris melanotos*)	This species is found in coastal lagoons, estuaries, bays, swamps, lakes, inundated grasslands, saltmarshes, river pools, creeks, floodplains and artificial wetlands.	NA	The species has no Avoidance Zones that could be identified at this time.

Rufous Fantail (*Rhipidura rufifrons*)	Mostly found in rainforests, dense wet forests, and swamp woodlands.	NA	The species has no Avoidance Zones that could be identified at this time.
Pin-tailed Snipe (*Gallinago stenura*)	Vagrant in QLD	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
Spectacled Monarch (*Monarcha trivirgatus*)	This species inhabits subtropical or tropical moist lowland forests, subtropical or tropical mangrove forests, and subtropical or tropical moist montane forests.	NA	The species has no Avoidance Zones that could be identified at this time.
Swinhoe's Snipe (*Gallinago megala*)	Vagrant in QLD.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
Wandering Tattler (*Tringa incana*)	This species is regularly found on rocky coasts with reefs and platforms, points, spits, piers, offshore islands and shingle beaches or beds.	NA	The species has no Avoidance Zones that could be identified at this time.
Wood Sandpiper (*Tringa glareola*)	This species inhabits well-vegetated, shallow, freshwater wetlands, such as swamps, billabongs, lakes, pools and waterholes.	NA	The species has no Avoidance Zones that could be identified at this time.
Yellow Wagtail (*Motacilla flava*)	This is an irregular visitor to SEQ and prefers a wide variety of habitats.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
Bar-tailed Godwit (*Limosa lapponica*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES)	The Intertidal Extents dataset[9] was used to map the areas that include critical feeding habitats

		Distributions (public grids)[20] Intertidal Extents[8]	for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur[23] was filtered to the LOT layer to map irreplaceable habitats.
Broad-billed Sandpiper (*Limicola falcinellus*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[9]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Common Sandpiper (*Actitis hypoleucos*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then,

			the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Double-banded Plover (*Charadrius bicinctus*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[9] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Grey-tailed Tattler (*Tringa brevipes*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map

			irreplaceable habitats.
Little Tern (*Sterna albifrons*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Marsh Sandpiper, Little Greenshank (*Tringa stagnatilis*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Red-necked Stint (*Calidris ruficollis*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance	The Intertidal Extents dataset[8] was used to map the areas that include critical

		Distributions (public grids)[2-] Intertidal Extents[8]	feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.
Whimbrel (*Numenius phaeopus*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur was filtered to the LOT layer to map irreplaceable habitats.

Table S5. Species-specific application of the decision rules and data utilised for mapping threatened bird species Avoidance Zones in South-eastern Queensland.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
Critically Endangered Species	Coxen's Fig Parrot (*Cyclopsitta diophthalma coxeni*)	Old growth rainforest, old growth figs, low land old growth	Species National Environmental Significance (SNES) Distributions (public grids)[20] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	We filtered Broad Vegetation Group dataset[21] for areas where the dominant vegetation was broadly described as 'wet lowland forests' and comprised of specific tree species (e.g., BVG1M = 2a/d, 3a, 4a/b, 6a,7a, 22c and 28a). These areas were filtered to the Remnant Vegetation of Queensland dataset[18] to create a new layer of irreplaceable habitat for the species. The areas where species are known to, likely to, or may occur[20] were then filtered to the irreplaceable habitat layer to create Avoidance Zones for the species.
	Swift Parrot (*Lathamus discolor*)	Old growth of particular tree species (coastal areas), Grey box, yellow box, swamp mahogany, forest red gum.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the region. Hence, it was not included in the analysis.
	Regent Honeyeater (*Anthochaera Phrygia*)	Old growth of particular tree species (wet lowland areas), Wet lowland areas with swamp mahogany and spotted gum.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
				the region. Hence, it was not included in the analysis.
	Eastern Curlew, Far Eastern Curlew (*Numenius madagascariensis*) **migratory**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Curlew Sandpiper (*Calidris ferruginea*) **migratory**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occurwere filtered to the LOT layer to map irreplaceable habitats.
	Capricorn Yellow Chat, Yellow Chat (Dawson) (*Epthianura crocea macgregori*)	No irreplaceable habitat.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that the species does not occur in the region. The species also does not have any irreplaceable habitat features identified at this time. Hence, it was not included in the analysis.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
Endangered Species	Nunivak Bar-tailed Godwit, Western Alaskan Bar-tailed Godwit (*Limosa lapponica baueri*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance Distributions (SNES) (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Black-tailed godwit (*Limosa limosa*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Common Greenshank, Greenshank (*Tringa nebularia*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Lesser Sand Plover, Mongolian Plover (*Charadrius mongolus*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
			(public grids)[20] Intertidal Extents[8]	to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Major Mitchell's Cockatoo (eastern), Eastern Major Mitchell's Cockatoo, Pink Cockatoo (eastern) (*Lophochroa leadbeateri leadbeateri*)	Old growth with hollows within Cyprus pines.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that the species does not occur in the region. Hence, it was not included in the analysis.
	Australasian Bittern (*Botaurus poiciloptilus*)	Regularly found breeding in large areas in artificial habitats (rice crops).	NA	The species has no Avoidance Zones that could be identified at this time.
	Australian Painted Snipe (*Rostratula australis*)	This species inhabits wetlands, including temporary and permanent lakes, swamps and claypans.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
	Red Goshawk (*Erythrotriorchis radiatus*)	The specific habitat requirements of this species are unknown.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.
	Southern Black-throated Finch (*Poephila*	The specific habitat requirements of this species are unknown.	NA	This species was not mapped as it is unclear what areas are irreplaceable for it in the region.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	cincta cincta)			
	Star Finch (eastern), Star Finch (southern) (*Neochmia ruficauda ruficauda*)	EXTINCT	NA	This species was not mapped as it is extinct.
Vulnerable Species	Brown Treecreeper (south-eastern) (*Climacteris picumnus victoriae*)	Large old dead trees, dead litter on the ground. Remnant eucalypt woodland.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the region. Hence, it was not included in the analysis.
	Great Knot (*Calidris tenuirostris*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Greater Sand Plover, Large Sand Plover (*Charadrius leschenaultia*) **(migratory)**	Tidal wetlands, mudflats	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
				filtered to the LOT layer to map irreplaceable habitats.
	Grey Plover (*Pluvialis squatarola*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Masked Owl (northern) (*Tyto novaehollandiae Kimberli*)	Old growth with hollows within tall open woodland, along riparian zones (50m).	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the region. It is only known to occur in Far North Queensland. Hence, it was not included in the analysis.
	Red Knot, Knot (*Calidris canutus*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Ruddy Turnstone (*Arenaria interpres*)	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	(migratory)		Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Sharp-tailed Sandpiper (*Calidris acuminata*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Terek Sandpiper (*Xenus cinereus*) **(migratory)**	Tidal wetlands, mudflats (feeding habitat)	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Intertidal Extents[8]	The Intertidal Extents dataset[8] was used to map the areas that include critical feeding habitats for migratory birds using information on the lowest observed tides (LOT). Then, the areas where the species is known to, likely to, or may occur were filtered to the LOT layer to map irreplaceable habitats.
	Asian Dowitcher (*Limnodromus semipalmatus*) **(migratory)**		NA	The species has no Avoidance Zones that could be identified at this time.
	Latham's Snipe, Japanese Snipe	Species can be found in wetland and grassland areas. These	NA	The species has no Avoidance Zones that could be identified at this time.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	(*Hirundapus caudacutus*) **(migratory)**	habitats are not considered irreplaceable.		
	White-throated needletail (*Hirundapus caudacutus*) **(migratory)**	This species occurs in most types of habitats, most often above wooded areas, including open forests and rainforests. These habitats are not considered irreplaceable.	NA	The species has no Avoidance Zones that could be identified at this time.
	Black-breasted Button-quail (Turnix melanogaster)	This species is found mostly in rainforests and vine thickets but can be found in a wide variety of lantana and plantation habitats. There are no irreplaceable habitat areas or features.	NA	The species has no Avoidance Zones that could be identified at this time.
	Diamond Firetail (*Stagonopleura guttata*)	Areas with intact native ground cover layers without invasive grasses.	NA	There is no fine-scale data on intact native grass cover layers or invasive grasses. The Avoidance Zones cannot be mapped.
	Grey Falcon (*Falco hypoleucos*)	Species is known to frequent acacia shrublands. It has also been observed hunting in treeless areas	NA	The species has no Avoidance Zones that could be identified at this time.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
		and frequenting tussock grassland and open woodland. Mostly known through opportunistic observations and little research[36].		
	Painted Honeyeater (*Grantiella picta*)	Found in mistletoes in eucalypt forests/woodlands, riparian woodlands of black box and river red gum, box-ironbark-yellow gum woodlands, acacia-dominated woodlands, paperbarks, casuarinas, callitris, and trees on farmland or gardens[37].	NA	There are very few records of the Painted Honeyeater occurring in CQ. They might be occasional visitor in CQ. They are mistletoe dependent species with no core habitat requirements.
	South-eastern Glossy Black-Cockatoo (*Calyptorhynchus lathami lathami*)	This species is found mainly in coastal woodlands and drier forest areas, open inland woodlands or timbered watercourses, which are not irreplaceable.	NA	South-eastern Glossy Black Cockatoo feed on sheoak seeds and it does not need to be old growth.

[36] https://environment.gov.au/biodiversity/threatened/species/pubs/929-conservation-advice-09072020.pdf

[37] https://www.environment.gov.au/biodiversity/threatened/species/pubs/470-conservation-advice.pdf

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
		Hollow-bearing trees are irreplaceable however cannot be mapped across this scale.		
	Southern Whiteface (*Aphelocephala leucopsis*)	This species occurs in a wide range of open woodlands and shrublands with an understorey of grasses, shrubs, or both.	NA	The Avoidance Zones cannot be mapped.
	Squatter Pigeon (southern) (*Geophaps scripta scripta*)	Areas with intact native ground cover layers without invasive grasses.	NA	There is no fine-scale data on intact native grass cover layers or invasive grasses. The Avoidance Zones cannot be mapped.

Table S6. Species-specific application of the decision rules and data utilised for mapping threatened mammal species Avoidance Zones in South-eastern Queensland.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
Critically Endangered Species	Northern Hairy-nosed Wombat, Yaminon (*Lasiorhinus krefftii*)	Now highly restricted in two sites, both irreplaceable. Some potential for further translocations. Potential habitat likely to be far more extensive than currently occupied sites.	Species of National Environmental Significance (SNES) Distributions (public grids)[20]	The areas where species are known/likely to and may occur were used to map the irreplaceable habitat layer to create Avoidance Zones for the species.

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
Endangered Species	Bridled Nail-tail Wallaby, Bridled Nailtail Wallaby (*Onychogalea fraenata*)	Restricted to one remnant site, translocated to 1-2 others; threatened by cats and foxes, no irreplaceable habitat features.	Species of National Environmental Significance (SNES) Distributions (public grids)[20]	The areas where species are known/likely to and may occur were used to map the irreplaceable habitat layer to create Avoidance Zones for the species.
	Greater Glider (southern and central) *(Petauroides volans)*	The species inhabits big old hollows in old eucalypt forest (>100 years). In SEQ the species has shown a strong preference for den-tree species (E. acmenoides (broad-leaved white mahogany), E. fibrosa (red ironbark) and E. tereticornis (forest red gum)) due to their availability as hollow-bearing trees[38].	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	We filtered Broad Vegetation Group dataset for areas where the dominant vegetation comprised specific tree species were 'wet eucalypt open forests' (e.g. BVG1M = 8a-c); 'eucalypt woodland to open forest (e.g. BVG1M = 9a-h, 10a-b, 12a) and 'eucalypt open forest to woodland (e.g. BVG1M = 16a/c) to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset[18] and to the areas where species are known to, likely to, or may occur to create Avoidance Zones for the species.
	Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland	The species inhabits old growth of wet eucalypt forest, closed forest, (including	Species of National Environmental Significance (SNES) Distributions	We filtered Broad Vegetation Group dataset for areas where the dominant vegetation comprised specific tree species were 'closed forests/woodland on

[38] Conservation advice for Petauroides Volans (greater glider (southern and central)), DCCEEW, https://www.environment.gov.au/biodiversity/threatened/species/pubs/254-conservation-advice-05072022.pdf

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	population) *(Dasyurus maculatus maculatus)*	temperate and sub-tropical rainforest), tall eucalypt forests, open woodlands, open forests, drier rainshadow woodlands and coastal heathlands with rocky terrain[39].	(public grids)[20] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	rocky hills/terrain', 'coastal heathlands' and 'temperate and subtropical rainforest' (e.g. BVG1M = 5c, 7a/b, 8a/b, 11a/b, 29a/b, and 28e) to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset and to the areas where species are known to, likely to, or may occur to create Avoidance Zones for the species.
	Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] *(Dasyurus hallucatus)*	The species inhabits hollows in rocky areas with old growth eucalypt vegetation and open forest and woodland[40].	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Broad Vegetation Group dataset[24] Remnant Vegetation of Queensland[18]	We filtered Broad Vegetation Group dataset for rocky areas dominated by eucalypt forest and woodlands and rainforests or sandy lowlands and beaches, shrubland, grasslands and desert (e.g. BVG1M = 7a/b,8a, 16d and 22a) to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset[18] and to the areas where species are known to, likely to, or may occur to create Avoidance Zones for the species.

[39] Conservation advice for Dasyurus maculatus maculatus (southeastern mainland population), Threatened Species Scientific Committee, https://www.environment.gov.au/biodiversity/threatened/species/pubs/75184-conservation-advice-01092020.pdf

[40] Conservation advice for Northern Quoll (Dasyurus hallucatus), DCCEEW, https://www.dcceew.gov.au/environment/biodiversity/threatened/assessments/dasyurus-hallucatus-2005

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	Silver-headed Antechinus (*Antechinus argentus*)	Highly restricted, irreplaceable sites where it occurs; critical habitat features may not be readily mappable.	Species of National Environmental Significance (SNES) Distributions (public grids)[20]	The areas where species are known/likely to and may occur were used to map the irreplaceable habitat layer to create Avoidance Zones for the species.
	Large-eared Pied Bat, Large Pied Bat *(Chalinolobus dwyeri)*	The species roosting sites (caves) are irreplaceable. However, there is no data available to map these features.	NA	There is no fine-scale data on roosting sites. The Avoidance Zones cannot be mapped.
	Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) *(Phascolarctos cinereus)*	The species has no irreplaceable features that can be identified.	NA	The species has no Avoidance Zones that could be identified at this time.
Vulnerable Species	Long-nosed Potoroo (northern) *(Potorous tridactylus tridactylus)*	The species inhabits ranges of wet eucalypt forest (including wet and dry sclerophyll forests) and heathlands with dense understorey[41].	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the

[41] Conservation advice for Potorous tridactylus tridactylus (long-nosed Potoroo (SE Mainland)), Threatened Species Scientific Committee, https://www.environment.gov.au/biodiversity/threatened/species/pubs/66645-conservation-advice-31102019.pdf

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
				region. Hence, it was not included in the analysis.
	Yellow-footed Rock-wallaby (central-western Queensland) (*Petrogale xanthopus celeris*)	Inhabits caves and rock crevices. It is closely associated with rugged rocky areas, along the edges of low sandstone tablelands and hills, typically with low Acacia woodlands or shrublands.	NA	The Avoidance Zones cannot be mapped.
	Yellow-bellied Glider (south-eastern) *(Petaurus australis australis)*	The species occupies tree hollows in old forest like eucalypt-dominated woodlands and forests, including both wet and dry sclerophyll forests[42].	Species of National Environmental Significance (SNES) Distributions (public grids)[20] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	We filtered Broad Vegetation Group dataset for areas where the dominant vegetation comprised specific tree species were 'eastern eucalypt woodland to open forest' (e.g. BVG1M = 9a, 9g, 9h and 10a-b) and 'woodland open forest or open woodland' (e.g. BVG1M = 18a-b and 20a)' to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset[18] and to the areas where species are known to, likely to, or may occur to create

[42]Conservation Advice for Petaurus australis australis (yellowbellied glider (south-eastern), Department of Agriculture, Water and the Environment, https://www.environment.gov.au/biodiversity/threatened/species/pubs/87600-conservation-advice-02032022.pdf

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
				Avoidance Zones for the species.
	Greater Glider (northern), Greater Glider (north-eastern Queensland) (*Petauroides minor*)	Big old hollows >100 years eucalypt forest, dominant species comprise of *Eucalyptus acmenoides* (white mahogany) and *Corymbia citriodora* (lemon-scented gum).	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the region. Hence, it was not included in the analysis.
	Grey-headed Flying-fox *(Pteropus poliocephalus)*	For the species, colonial roosting sites should be pivotal, of which some are permanent. Persistence will also require maintenance of large areas of foraging habitat. However, foraging sites are not irreplaceable.	NA	We obtained data from ALA records[43], QLD's government Flying Fox camps in QLD[44] and Flying Fox Monitoring Program[45]. Flying Fox Monitoring Program Dataset could be filtered to only account for where grey-headed flying fox was present for at least 2 sampling periods. Currently, we cannot confidently determine permanent sites. Hence, the species' Avoidance Zones were not mapped.
	Brush-tailed Rock-wallaby	The species inhabits	NA	The Avoidance Zones cannot be mapped.

[43] https://www.ala.org.au/

[44] https://www.data.qld.gov.au/dataset/flying-fox-monitoring-program/resource/2079912d-72ac-4116-9e12-08e068064bff

[45] https://www.data.qld.gov.au/dataset/flying-fox-monitoring-program

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	(Petrogale penicillata)	hollows in rocky terrain. These features cannot be mapped.		
	Ghost Bat *(Macroderma gigas)*	The species inhabits caves and is commonly found along adits. These habitat features cannot be mapped due to the lack of data. Roosting sites are important; some can be recreated.	NA	The Avoidance Zones cannot be mapped.
	Water Mouse, False Water Rat, Yirrkoo *(Xeromys myoides)*	The species is found in near-coastal wetlands, saltmarshes, mangroves. However, irreplaceable habitat features are not well resolved. There is only a limited number of occupied sites, which are all vital.	NA	The species range maps are very broad and known to occur sites are not publicly available (SNES). Sites vital to species cannot be identified at the time.
	Corben's Long-eared Bat, South-eastern Long-eared Bat	The species inhabits hollows with a preference for older woodlands. These include	Species of National Environmental Significance (SNES) Distributions	We filtered Broad Vegetation Group dataset[21] for areas where the dominant vegetation comprised specific tree species were 'wet eucalypt open forest'

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
	(Nyctophilus corbeni)	box / ironbark / cypress pine woodlands, Buloke woodlands, Brigalow woodland, Belah woodland, smooth-barked apple woodland, river red gum forest, black box woodland, and various types of tree mallee. more common in box / ironbark / cypress-pine vegetation that occurs in a north-south belt along the western slopes and plains of New South Wales and southern Queensland[46].	(public grids)[20] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	(e.g. BVG1M = 8a), 'eastern eucalypt woodland to open forest' (e.g. BVG1M = 11a, 12a/b, 13a-d and 15a), 'woodlands and open woodlands with specific species' (BVG1M = 16b/c), 'eucalypt dry open woodlands' (BVG1M = 17a-c, 18a/b, 19a-f) and 'open woodlands'(BVG1M = 20a) to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset[18] and to the areas where species are known to, likely to, or may occur[20] to create Avoidance Zones for the species.
	Julia Creek Dunnart (*Sminthopsis douglasi*)	Tussock grasslands, crackling clay, more restricted than their habitat, fewer cattle and cats.	NA	The SNES known/likely to or may occur distribution maps overlap with the Central Queensland's boundaries. However, the area is very small, and after expert consultations it was determined that species does not occur in the

[46] Conservation advice for Nyctophilus corbeni (South-easten long-eared bat), Threatened Species Scientific Committee, https://www.environment.gov.au/biodiversity/threatened/species/pubs/83395-conservation_advice-01102015.pdf

MNES	Species	Irreplicable areas or habitat elements	Data used	Data Description
				region. Hence, it was not included in the analysis.
	Semon's Leaf-nosed Bat, Greater Wart-nosed Horseshoe-bat (*Hipposideros semoni*)	Roosts in caves and hollows; mainly rainforests and riparian areas. Old growth of rainforest.	Species of National Environmental Significance Distributions (public grids)[23] Broad vegetation groups pre-clearing[21] Remnant Vegetation of Queensland[18]	We filtered Broad Vegetation Group dataset[21] for areas where the dominant vegetation type was 'rainforest, scrubs' (e.g. BVG1M = 1a to 7b) to create a new layer of habitat for the species. These areas were filtered to the Remnant Vegetation of Queensland dataset[18] and to the areas where species are known to, likely to, or may occur[20] to create Avoidance Zones for the species.

Table S7. Summary of the proposed wind farm projects for Central Queensland

Name	Technology	Status	Capacity	Resource used for mapping the footprint (EPBC Referral no.)
Lotus Creek	Wind	Proposed	341	2020/8867
Clarke Creek Stage 1	Wind	Under construction	800	2018/8141
Boulder Creek	Wind	Proposed	360	2020/8772
Boomer Range	Wind	Proposed	1100	2022/09396
Moonlight Range	Wind	Proposed	450	2023/09715
Moah Creek	Wind	Proposed	500	2023/09620
Kariboe	Wind	Proposed	1000	2022/09428
Clarke Creek Wind Farm Stage 2	Wind	Proposed	400	2018/8141
Specimen Hill	Wind	Proposed	336	2020/8864
Calide	Wind	Proposed	400	2021/9057
Stony Creek	Wind	Proposed	160	2022/09333
Mount Hopeful	Wind	Proposed	350	2021/9137
Banana Range	Wind	Proposed	280	2019/8503
Theodore Wind Farm	Wind	Proposed	850	2024/09842
Fiery Creek Wind Farm	Wind	Proposed	70	No further information available.
Favian Super Hybrid Project	Wind	Proposed	1800	No further information available.
Inveragh Renewable Energy Project	Wind	Proposed	540	No further information available.
Offshore Gladstone Wind Farm	Wind	Proposed	6000	Excluded from the analysis.
Wooderson Wind Farm	Wind	Proposed	816	No further information available.

Bowen Renewable Energy Hub (Eungella Wind Farm)	Wind	Proposed	500	No further information available.
Mount Rainbow Wind Farm	Wind	Proposed	270	No further information available.

Table S8. Summary of the existing and proposed solar farm projects for Central Queensland

Name	Technology	Status	Capacity	Resource used for mapping the footprint (EPBC Referral no.)
Clermont (Phase 1)	Solar	Existing	93	Not included in the analysis.
Lilyvale	Solar	Existing	100	Not included in the analysis.
Middlemount	Solar	Existing	34	Not included in the analysis.
Childers	Solar	Existing	120	Not included in the analysis.
Moura	Solar	Existing	110	Not included in the analysis.
Emerald	Solar	Existing	72	Not included in the analysis.
Bundaberg Solar Farm	Solar	Existing	93	Not included in the analysis.
Barcaldine	Solar	Existing	42	Not included in the analysis.
Rugby Run Phase Stage 1	Solar	Existing	65	Not included in the analysis.
Childers Solar Farm (DDN)	Solar	Proposed	25	0.25 km^2/MV buffer applied
Innes Park Solar Farm	Solar	Proposed	25	0.25 km^2/MV buffer applied
Aldoga	Solar	Proposed	600	2020/8773
Crinum Creek Solar Farm	Solar	Proposed	100	0.25 km^2/MV buffer applied
Dingo Solar Farm	Solar	Proposed	85	https://www.chrc.qld.gov.au/wp-content/uploads/2017/07/401.2017.13-Development-Application-Material.pdf
Clarke Creek	Solar	Under construction	200	2019/8386 and 2018/8150

Callide Solar Power Station Project	Solar	Proposed	200	2024/09863
Clermont (Phase 2)	Solar	Proposed	75	0.25 km^2/MV buffer applied
Rolleston	Solar	Proposed	90	2017/8125
Theodore	Solar	Proposed	70	2019/8588
Rugby Run Solar Farm Stage 2	Solar	Proposed	105	0.25 km^2/MV buffer applied
Three Chain Solar Farm (Stage 1)	Solar	Proposed	40	0.25 km^2/MV buffer applied
Bluff Solar Farm	Solar	Proposed	85	https://www.chrc.qld.gov.au/wp-content/uploads/2016/10/400.2017.4-Development-Application.pdf
Gregory Solar Farm	Solar	Under construction	215	2017/8098
Bundaberg Solar Farm	Solar	Proposed	78	0.25 km^2/MV buffer applied
Bouldercombe Solar Farm	Solar	Proposed	200	0.25 km^2/MV buffer applied
Upper Calliope	Solar	Proposed	1000	2023/09752
Banksia	Solar	Proposed	68	2021/8893
Broadlea Solar Farm	Solar	Proposed	100	0.25 km^2/MV buffer applied
Dysart Solar Energy Farm	Solar	Proposed	100	0.25 km^2/MV buffer applied
Rodds Bay Solar Farm	Solar	Proposed	300	2024/09802
Pacific Solar Hydrogen	Solar	Proposed	3600	0.25 km^2/MV buffer applied
Bundaberg Solar Farm Denzo	Solar	Proposed	58	0.25 km^2/MV buffer applied
Three Chain Solar Farm (Stage 2)	Solar	Proposed	36	0.25 km^2/MV buffer applied

Blair Athol Solar Power Station	Solar	Proposed	60	0.25 km^2/MV buffer applied
Raglan Solar Farm	Solar	Proposed	240	0.25 km^2/MV buffer applied
Dysart Solar Farm	Solar	Proposed	130	0.25 km^2/MV buffer applied
Smokey Creek	Solar	Proposed	600	2021/9030
Broadsound Solar Farm	Solar	Proposed	360	2019/8559
Moah Creek	Solar	Proposed	200	0.25 km^2/MV buffer applied
Gladstone Abattoir Solar Farm	Solar	Proposed	78	0.25 km^2/MV buffer applied
Bullyard Solar Farm	Solar	Proposed	109	0.25 km^2/MV buffer applied
Comet Solar Farm	Solar	Proposed	285	0.25 km^2/MV buffer applied
Blackwater Solar Farm	Solar	Proposed	150	https://www.chrc.qld.gov.au/wp-content/uploads/2016/10/400.2017.3-Development-Application.pdf

Appendix 4. Supporting tables of the Results

Table S9. Summary of MNES overlapping with proposed solar renewable energy projects and the total area of the Avoidance Zone in Central Queensland before and after the proposed projects go ahead.

MNES	Area of Avoidance Zone in Central Queensland (km^2)	Area impacted by solar farm projects (km^2)	Area of Avoidance Zone left if projects go ahead (km^2) (% Decrease in Area)
Endangered Ecological Communities	**42,612**	**13**	**42,599 (0.03%)**
Poplar Box Grassy Woodland on Alluvial Plains	31,253	7	31,246 (0.02%)
Weeping Myall Woodlands	4,045	4	4,041 (0.1%)
Coastal Swamp Sclerophyll Forest of New South Wales and South East Queensland	817	6	811 (0.7%)
Endangered Mammals	**38,037**	**20**	**38,024 (0.05%)**
Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] (*Dasyurus hallucatus*)	2,121	0.4	2,120 (0.05%)
Greater Glider (southern and central) (*Petauroides volans*)	34,193	19	34,174 (0.06%)
Vulnerable Mammals	**37,186**	**9**	**37,177 (0.02%)**
Corben's Long-eared Bat, South-eastern Long-eared Bat (*Nyctophilus corbeni*)	36,319	8	36,311 (0.02%)
Yellow-bellied Glider (south-eastern) (*Petaurus australis australis*)	2,347	1	2,346 (0.04%)

Table S10. Summary of MNES overlapping with proposed wind infrastructure (wind turbines and linear infrastructure) and the total area of the Avoidance Zone in Central Queensland before and after the proposed projects go ahead.

MNES	**Area of Avoidance Zone in Central Queensland (km^2)**	**Area impacted by solar farm projects (km^2)**			**Area of Avoidance Zone left if projects go ahead (km^2) (% Decrease in Area)**		
		100 m	**650 m**	**1 km**	**100 m**	**650 m**	**1 km**
Endangered Ecological Communities	**42,612**	**38**	**179**	**230**	**42,574 (0.09%)**	**42,433 (0.4%)**	**42,382 (0.5%)**
Poplar Box Grassy Woodland on Alluvial Plains	31,253	34	159	202	31,219 (0.1%)	31,094 (0.5%)	31,051 (0.6%)
Weeping Myall Woodlands	4,045	0.72	6	10	4,044.28 (0.02%)	4,039 (0.1%)	4,045 (0.2%)
Semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar Bioregions	2,172	0.34	3	4	2,171.66 (0.02%)	2,169 (0.1%)	2,168 (0.2%)
Brigalow (Acacia harpophylla dominant and co-dominant)	3,826	0.4	4	5	3,825.6 (0.01%)	3,822 (0.1%)	3,821 (0.1%)
Subtropical eucalypt floodplain forest and woodland of the New South Wales North Coast and South East Queensland bioregions	4,486	0.15	1	3	4,485.9 (0.003%)	4,485 (0.02%)	4,483 (0.07%)
Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions	224	0	0.06	0.06	224 (0%)	223.94 (0.03%)	223.94 (0.03%)
Endangered Mammals	**38,037**	**69**	**349**	**445**	**37,968 (0.2)**	**37,688 (0.9%)**	**37,592 (1.2%)**

Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] (*Dasyurus hallucatus*)	2,121	12	78	98	2,109 (0.5%)	2,043 (3.7%)	2,094 (4.6%)
Greater Glider (southern and central) (*Petauroides volans*)	34,193	57	272	347	34,136 (0.2%)	33,921 (0.8%)	33,846 (1%)
Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland population) (Dasyurus maculatus maculatus)	193	<0.01	0.7	1.2	192.99 (0.005%)	192.3 (0.4%)	191.8 (0.6%)
Vulnerable Mammals	**37,186**	**118**	**608**	**787**	**37,068 (0.3%)**	**36,578 (1.6%)**	**36,399 (2%)**
Corben's Long-eared Bat, South-eastern Long-eared Bat (*Nyctophilus corbeni*)	36,319	110	570	743	36,209 (0.3%)	35,749 (1.6%)	35,576 (2%)
Semon's Leaf-nosed Bat, Greater Wart-nosed Horseshoe-bat (Hipposideros semoni)	129	8	38	43	121 (6%)	91 (29%)	86 (33%)
Yellow-bellied Glider (south-eastern) (*Petaurus australis australis*)	2,347	7	12	13	2,340 (0.3%)	2,335 (0.5%)	2,334 (0.6%)
Critically Endangered Birds Coxen's Fig Parrot (*Cyclopsitta diophthalma coxeni*)	**1,169**	**0.2**	**3**	**5**	**1,168.8 (0.02%)**	**1,166 (0.3%)**	**1,164 (0.4%)**

Appendix 5. Supporting Figures

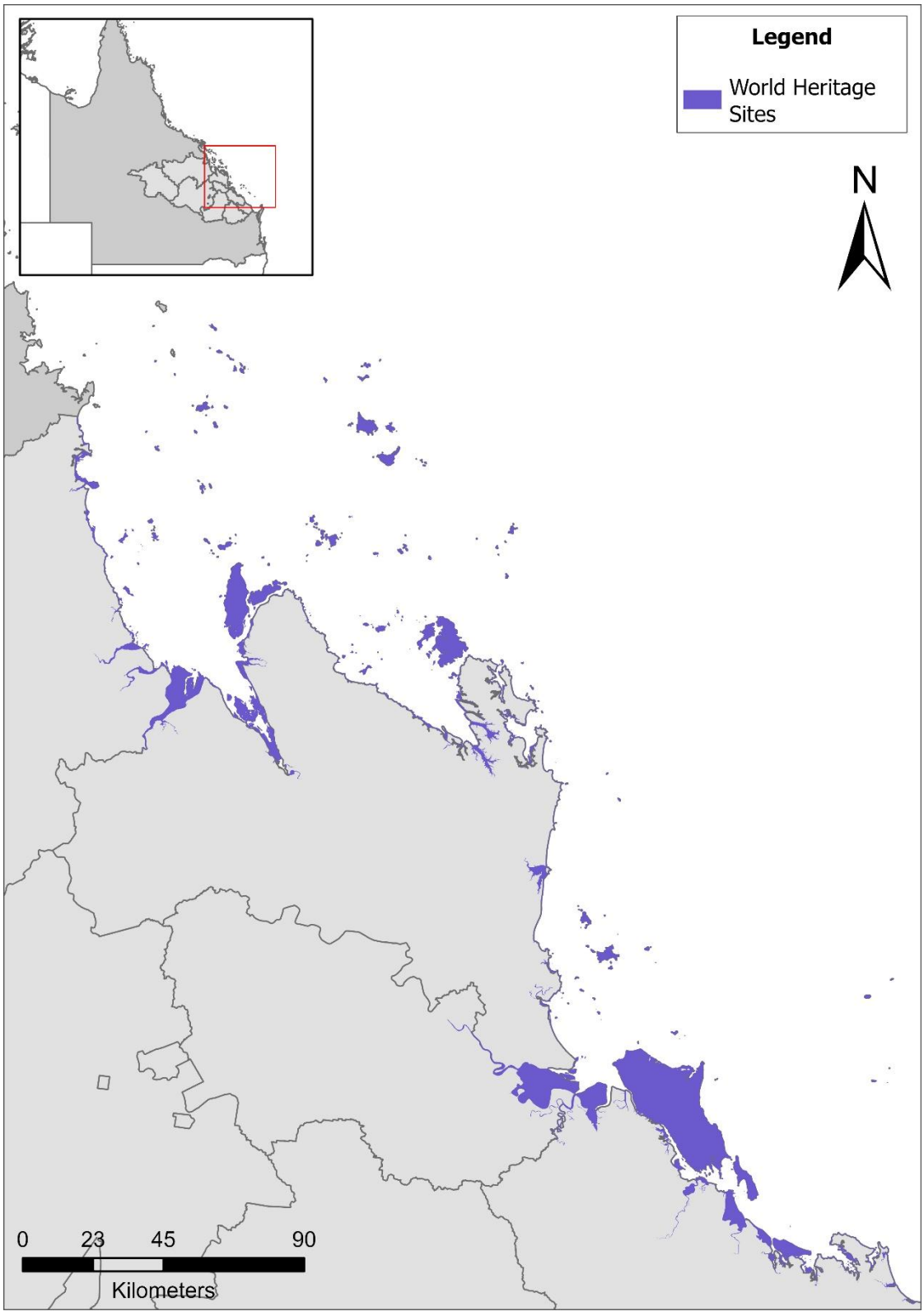

Figure S1. Areas zoned as Avoidance Zones for World Heritage Areas across Central Queensland.

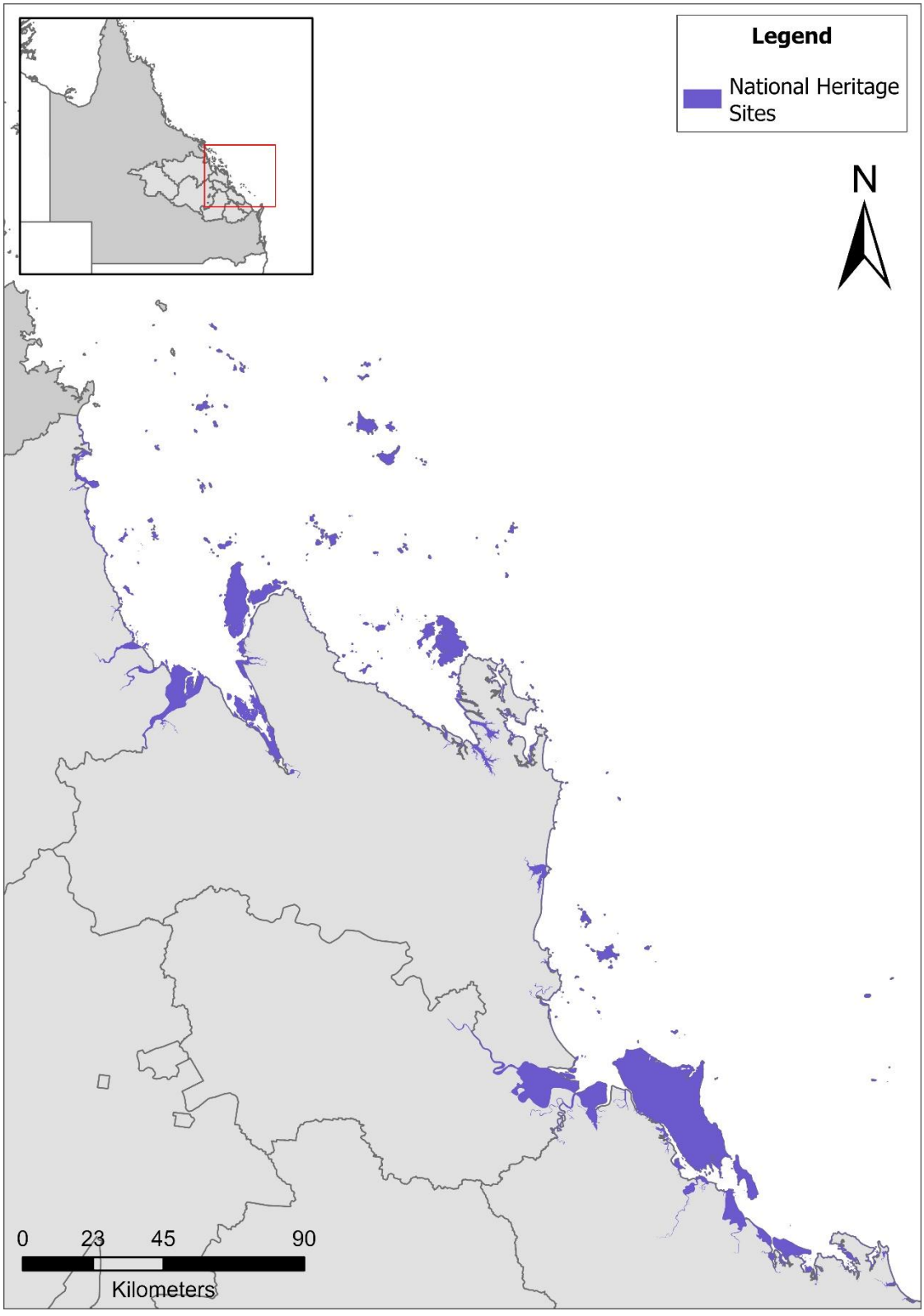

Figure S2. Areas zoned as Avoidance Zones for National Heritage Areas across Central Queensland.

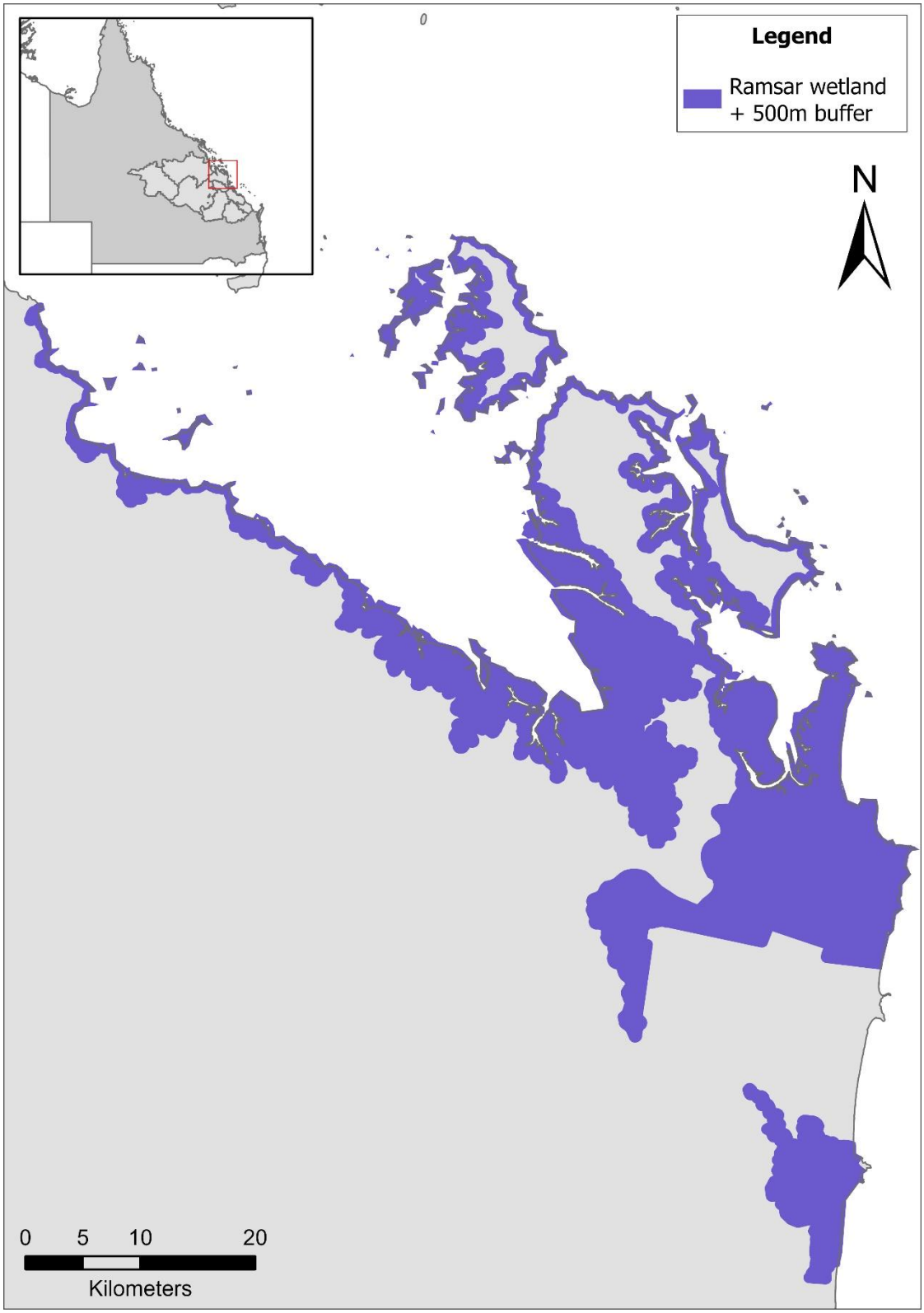

Figure S3. Areas zoned as Avoidance Zones for Ramsar Wetlands Areas across Central Queensland.

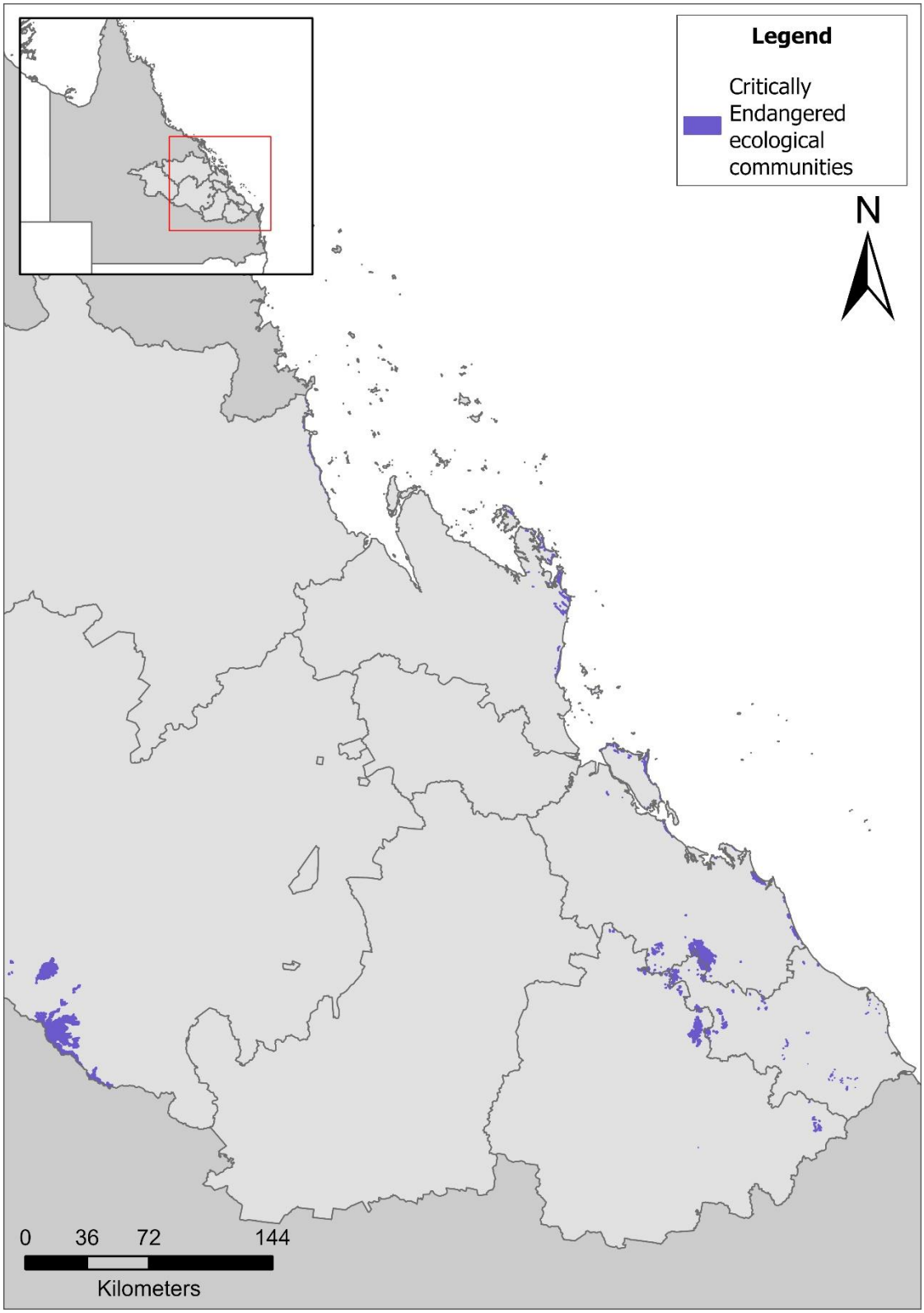

Figure S4. Areas zoned as Avoidance Zones for Critically Endangered ecological communities across Central Queensland.

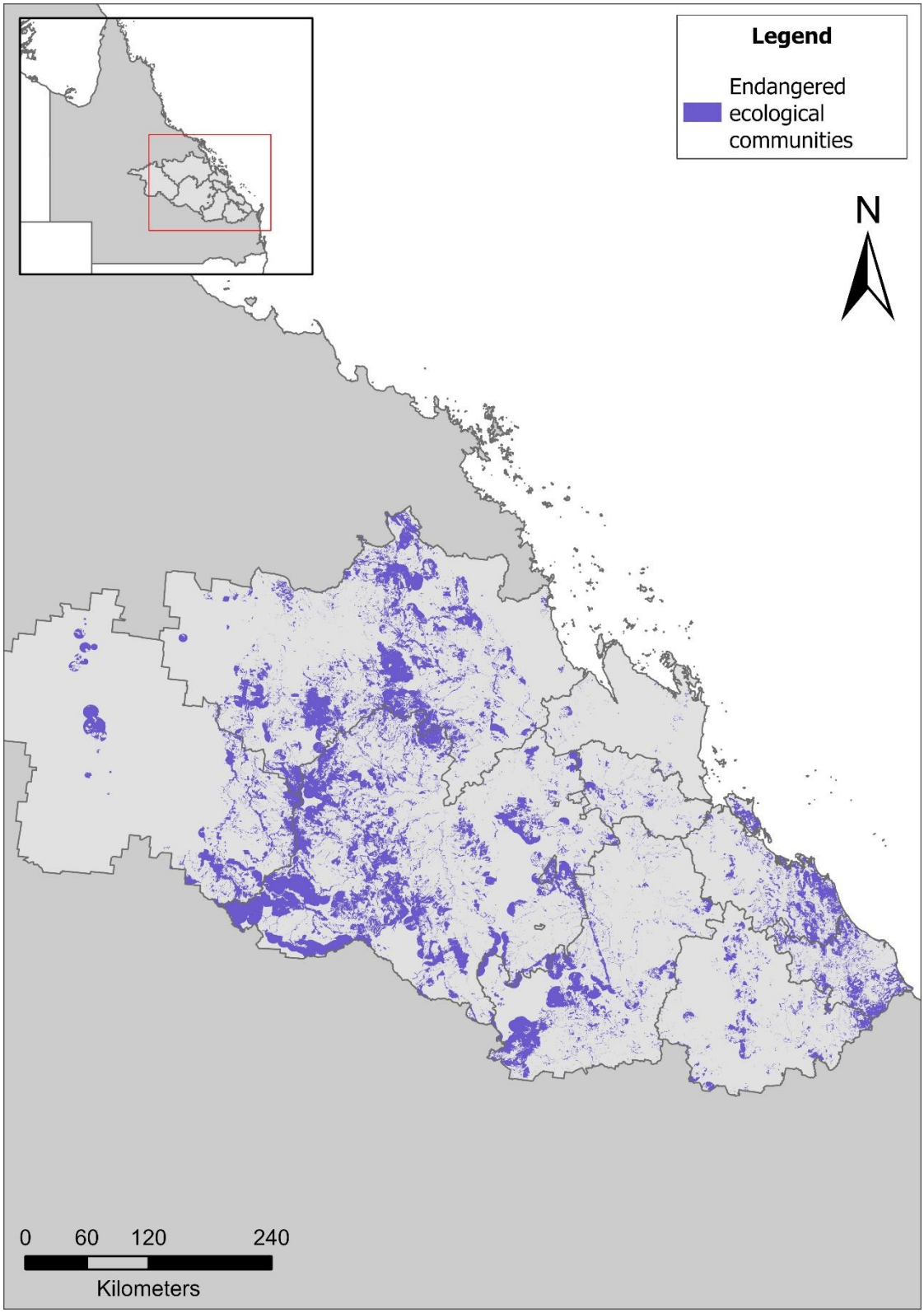

Figure S5. Areas zoned as Avoidance Zones for Endangered ecological communities across Central Queensland.

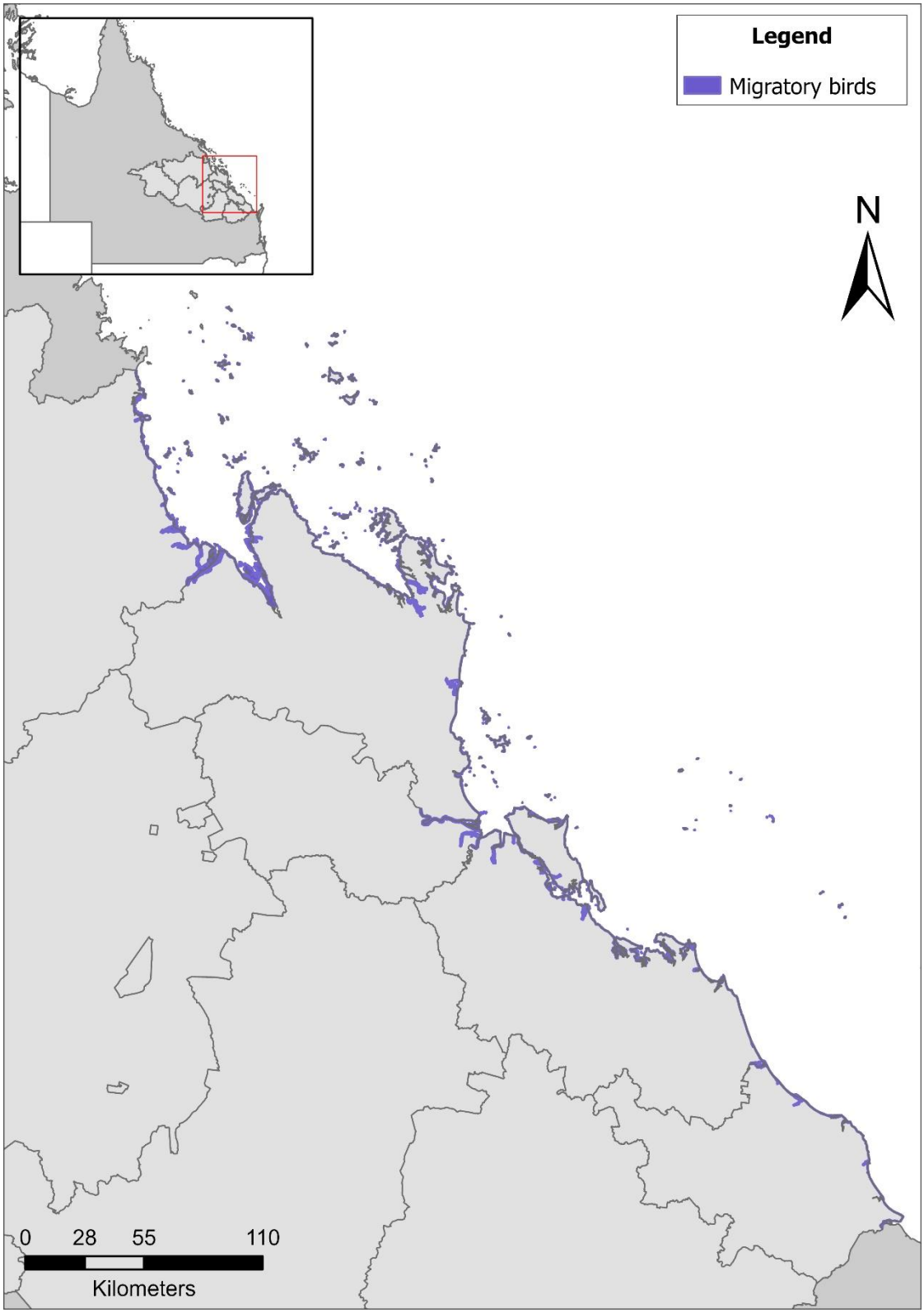

Figure S6. Areas zoned as Avoidance Zones for Migratory bird species across Central Queensland.

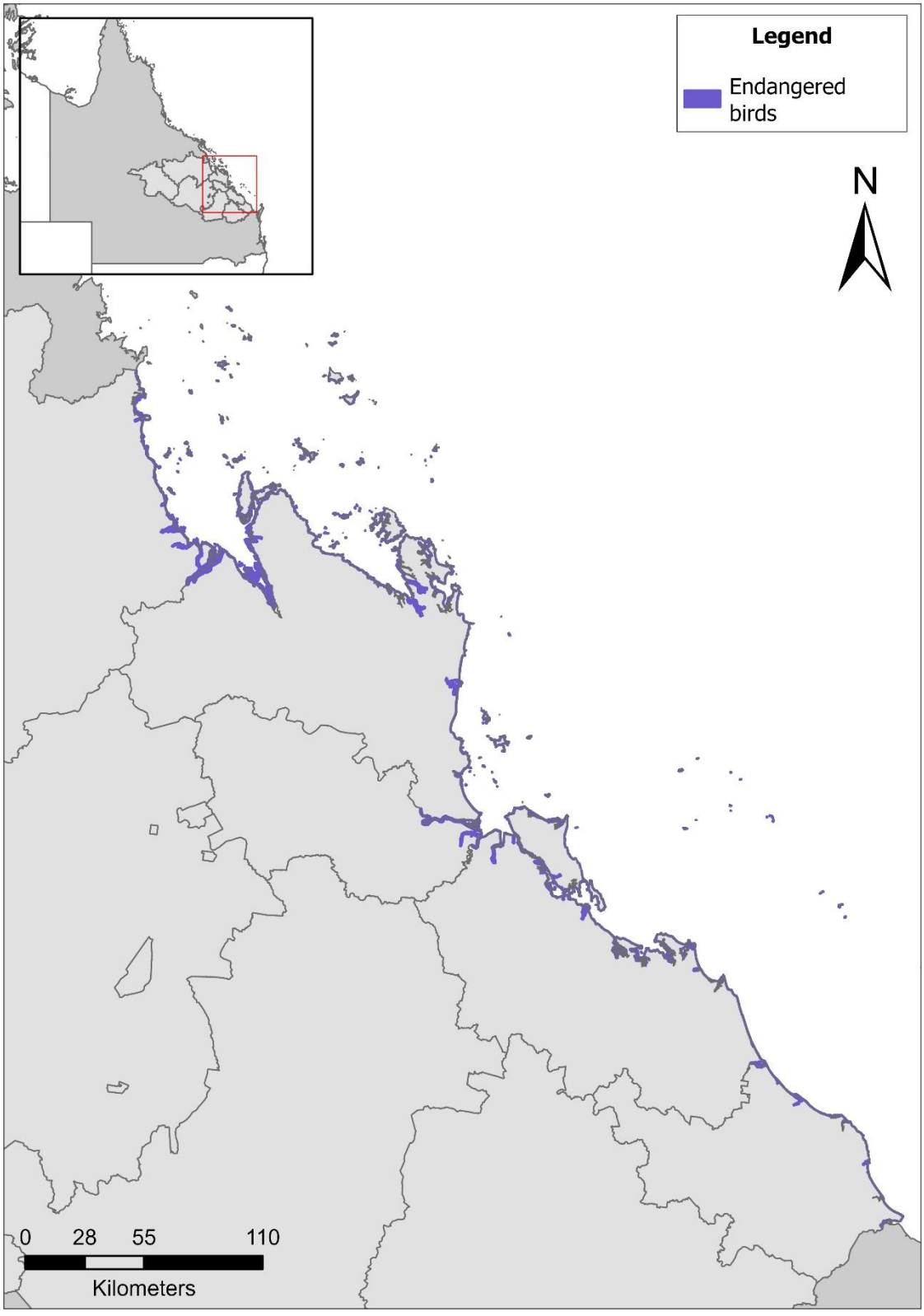

Figure S7. Areas zoned as Avoidance Zones for Endangered bird species across Central Queensland.

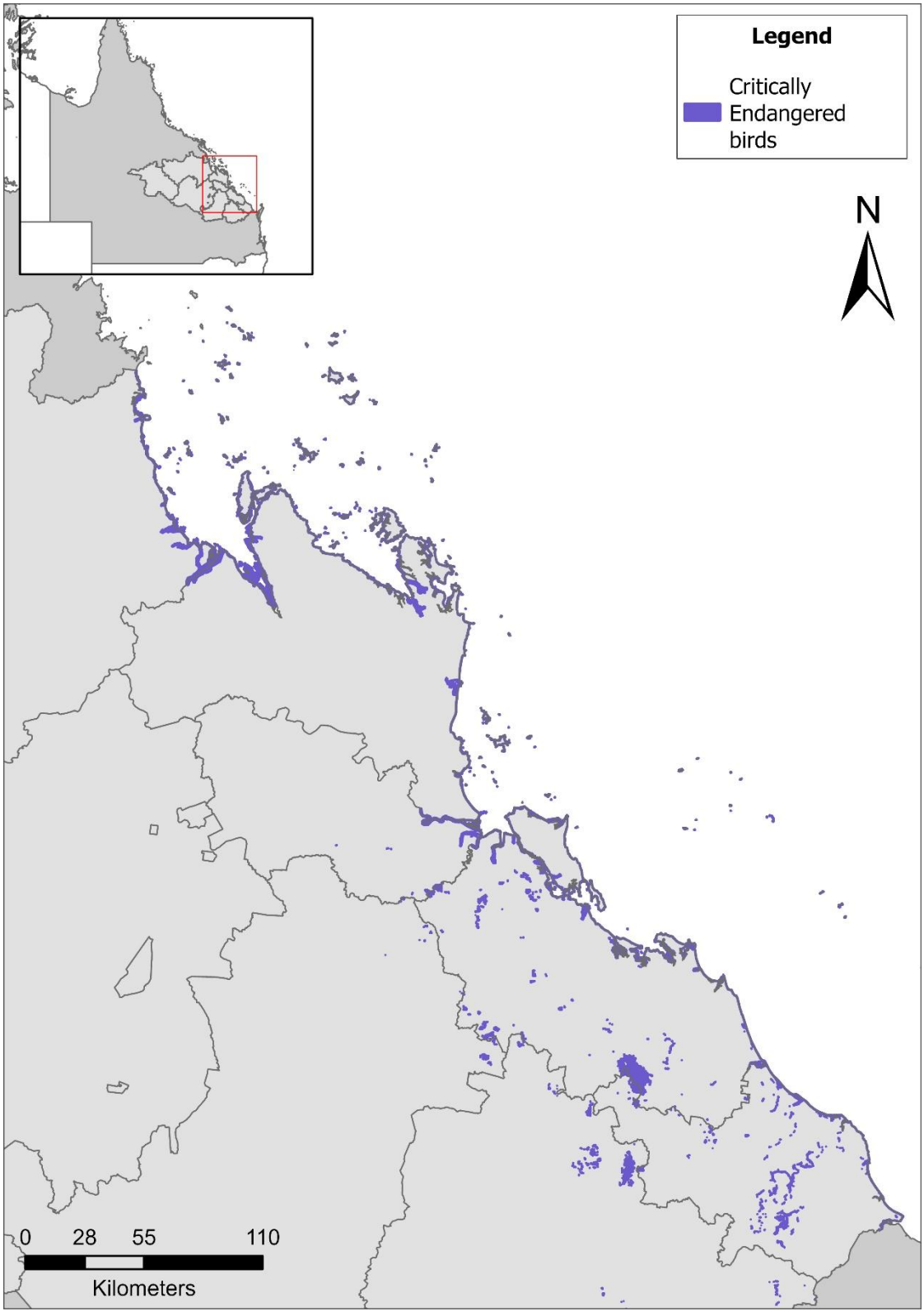

Figure S8. Areas zoned as Avoidance Zones for Critically Endangered bird species across Central Queensland.

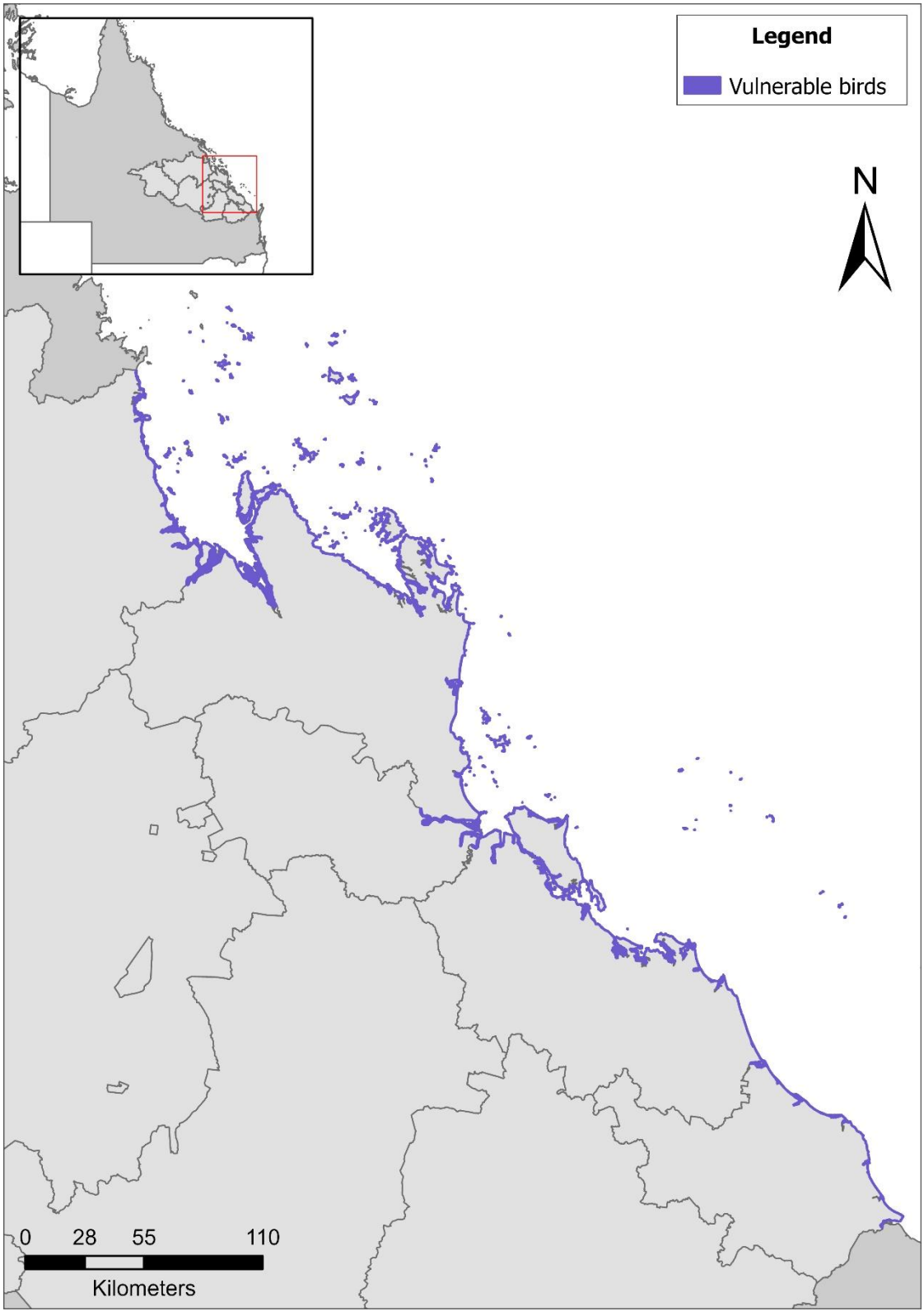

Figure S9. Areas zoned as Avoidance Zones for Vulnerable bird species across Central Queensland.

Figure S10. Areas zoned as Avoidance Zones for Critically Endangered mammal species across Central Queensland.

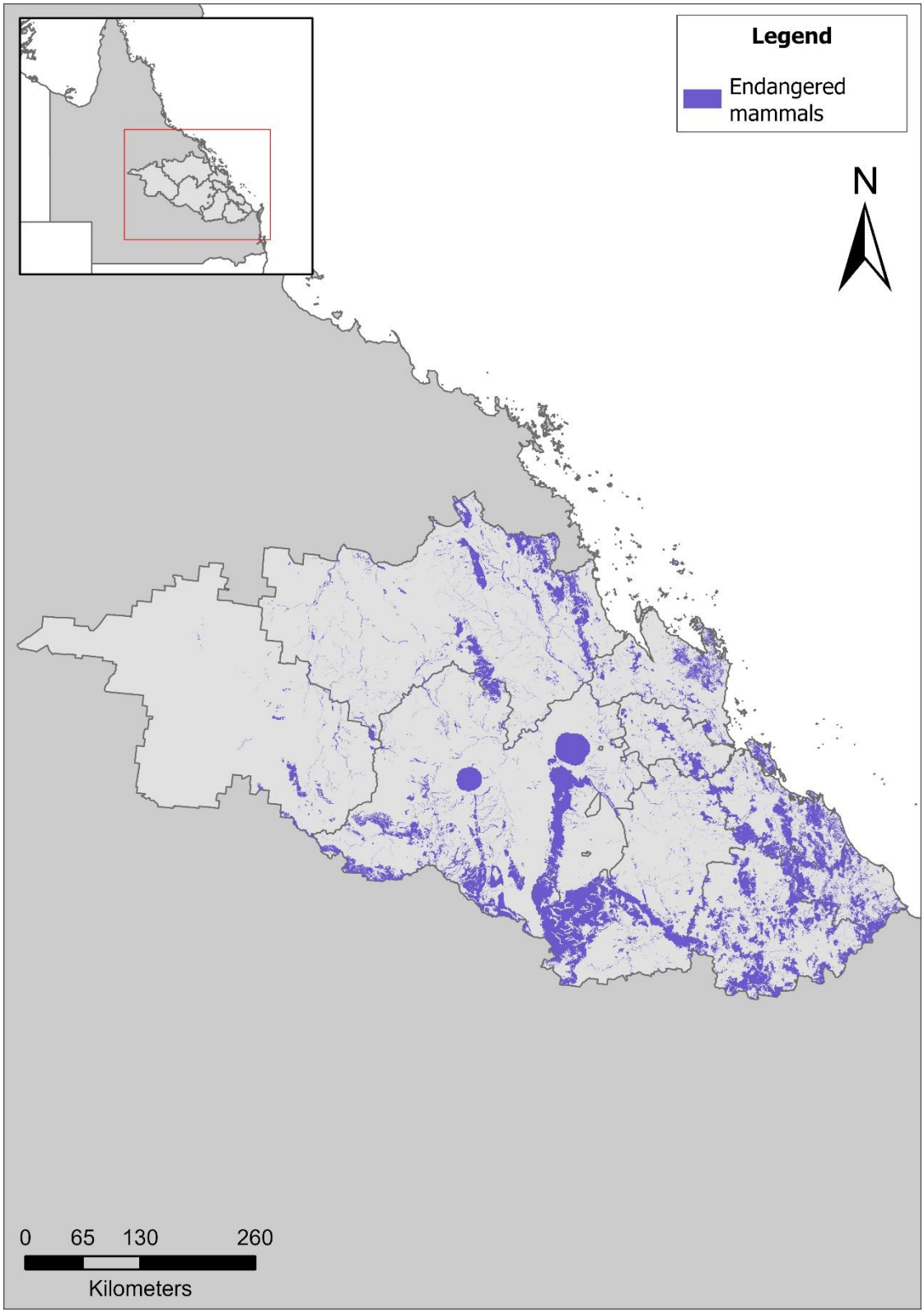

Figure S11. Areas zoned as Avoidance Zones for Endangered mammal species across Central Queensland.

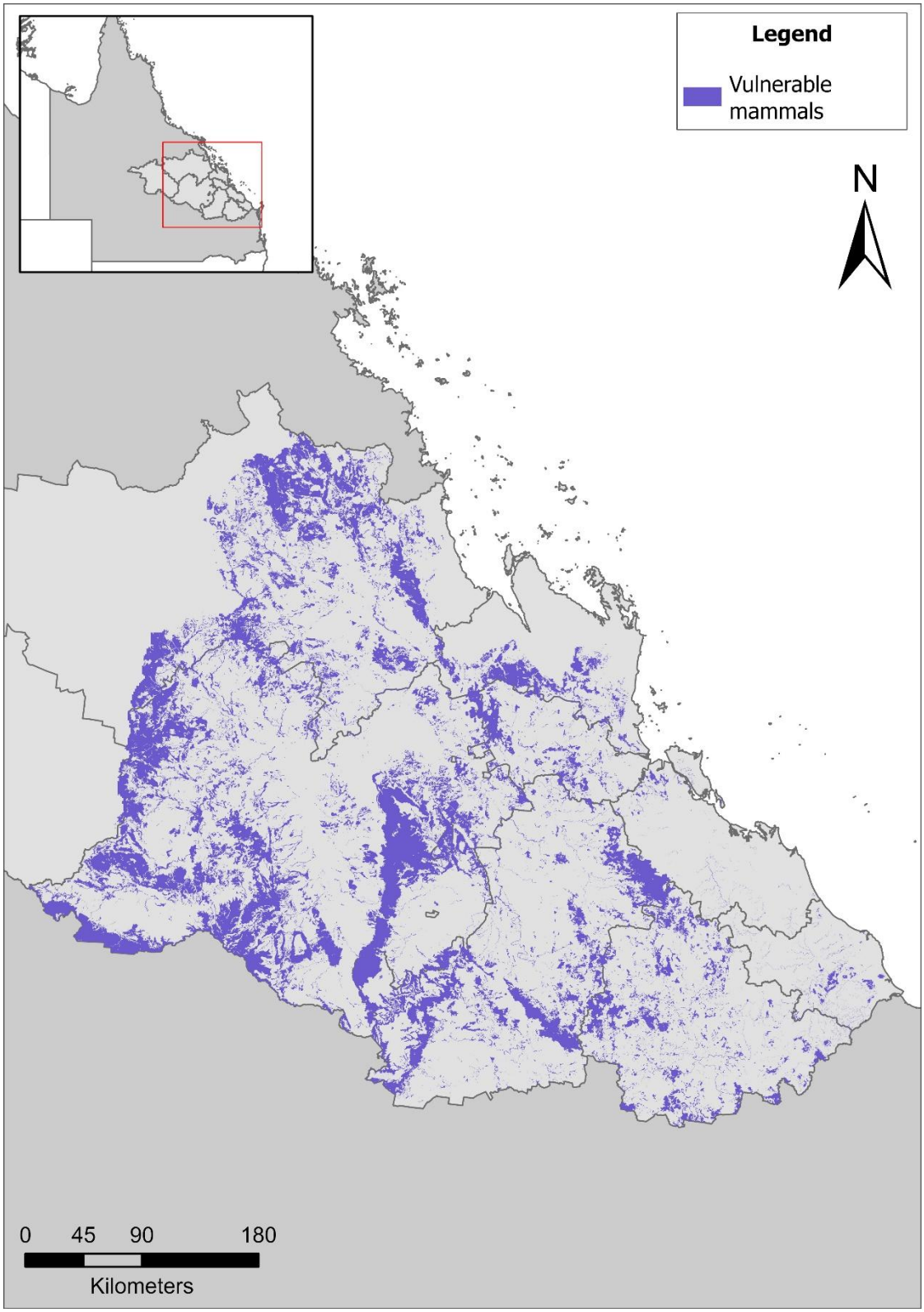

Figure S12. Areas zoned as Avoidance Zones for Vulnerable mammal species across Central Queensland.

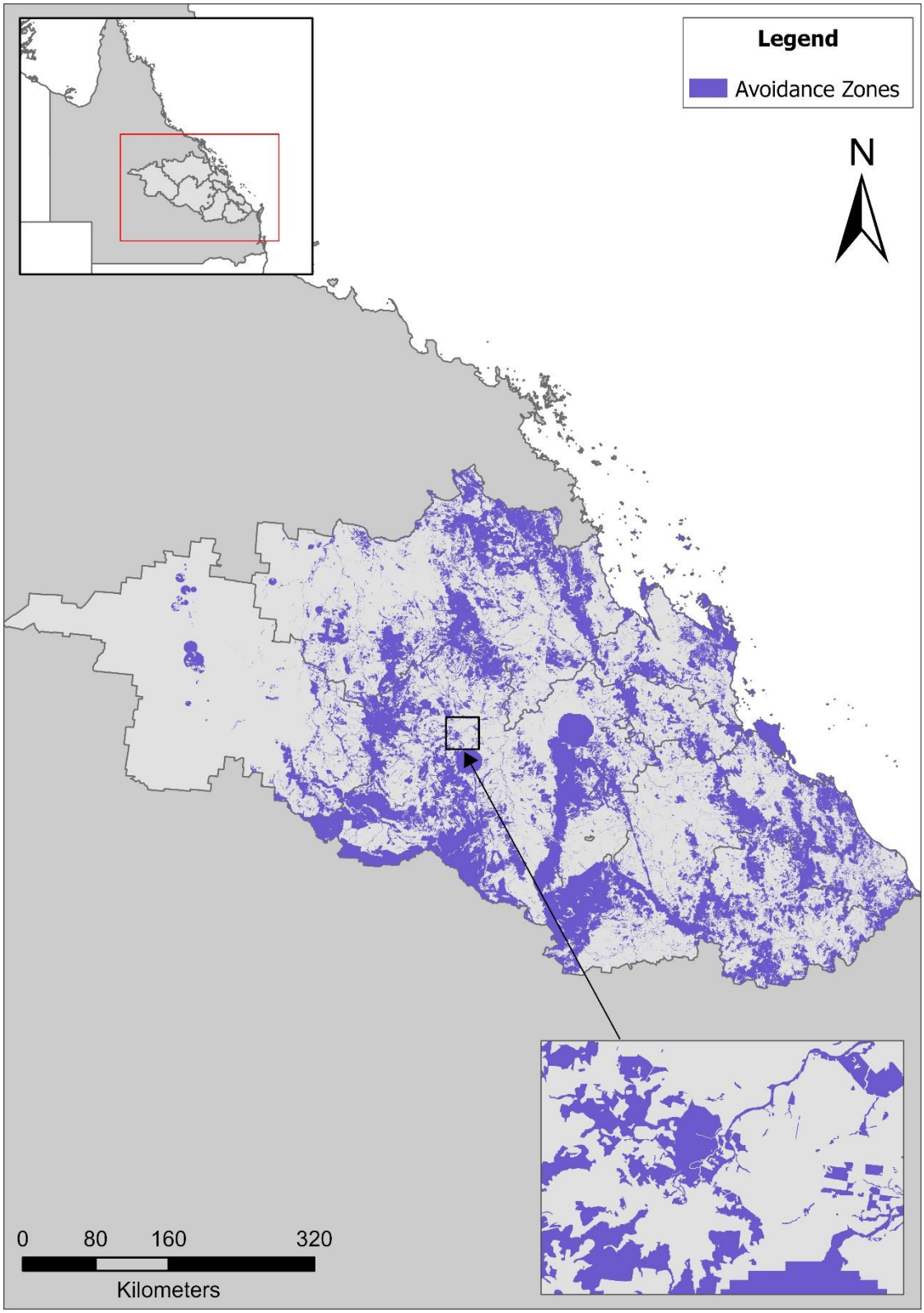

Figure S13. Total Avoidance Zones across Central Queensland.

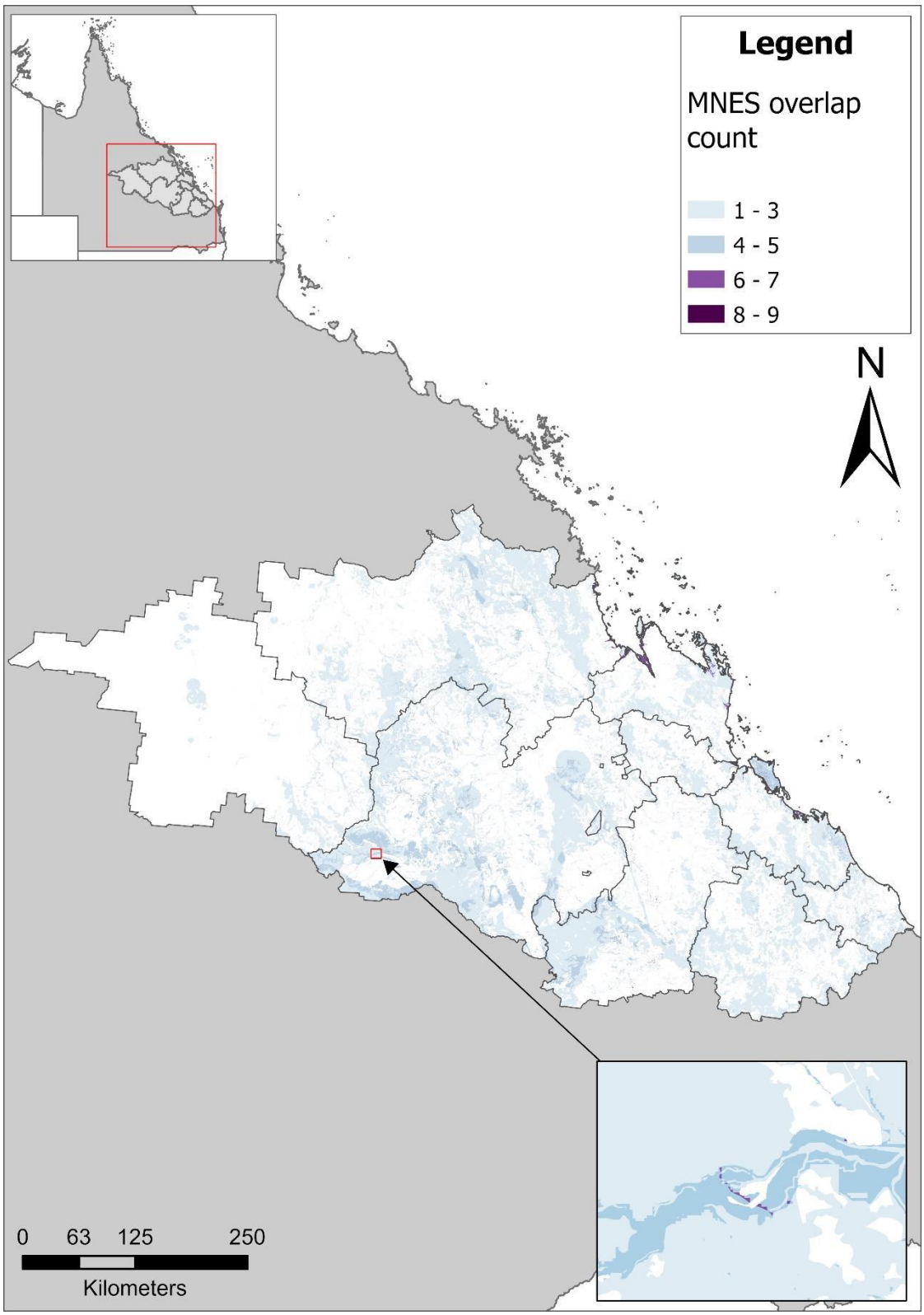

Figure S14. Overlap count for areas zoned as Avoidance Zones across Central Queensland.

Glossary and examples of how these terms are applied

Adequate Survey: <10% chance of occupancy given a survey effort prescribed by a known (or estimated with data) detection probability.

We know that for many species, ecologists need to look very hard, very often, and usually over multiple seasons to be sure the species is not being missed when it is actually present. For example, some orchids are extremely hard to detect even when they're flowering, and they only flower once every few years. Once enough systematic (repeat) surveys are complete for a species, we can put probabilities on statements about occurrence/absence. E.g., Given that we have conducted N CQuential surveys (with known single-visit detectability = 0.X), we can say there is a less than 10% chance the species is present given it has not been detected.

Areas adjoining, connected to, or near: this is concept-specific. For instance, in terms of a wetland, it would mean areas that include riparian zones along waterways that flow to the wetland.

Examples/parts/instances of an Ecological Community: is simply an area containing an Ecological Community.

Habitat: the biophysical medium or media:

- occupied (continuously, periodically, or occasionally) by an organism or group of organisms; or
- once occupied (continuously, periodically, or occasionally) by an organism, or group of organisms, and into which organisms of that kind have the potential to be reintroduced; or
- that may reasonably be expected to become occupied in the future through natural processes, environmental change, habitat restoration, or conservation translocation.

Known to occur: The 'species known to occur' distribution comprises the habitat of the species within 1.5km of government records. A conservative buffer has also been applied to the known, likely, and may extents to ensure that spatial inaccuracies in the reference data are

accounted for and any suitable habitat in the immediate surrounds of these extents is preserved in the distribution.

Likely to occur: The 'species likely to occur' distribution comprises the suitable habitat of the species within 5km of validated records.

May occur: The 'species may occur' distribution comprises the broader environmental range that could provide habitat for the species and has been defined by statistical modelling with regional environmental conditions (Maxent).

Ecological character: We follow the wording in the MNES standard of 'ecological character' - the combination of the ecosystem components, processes, and benefits/ services that characterise the wetland at a given point in time.

Net gain: A target for a development project in which the impacts on biodiversity caused by the project are balanced or outweighed by measures taken to avoid and minimise the project's impacts, to undertake on-site restoration, and finally, to offset the residual impacts, so that no loss remains. Where the gain exceeds the loss, the term 'net gain' may be used instead of no net loss.

Offset sites: A secured site managed and protected in perpetuity to replace each environmental matter significantly impacted at a different site. Our assumption here is that offset sites will meet best practices.

Irreplaceable (pertaining to sites or habitat elements): places or habitat elements biologically, physically, and/or technically, very difficult and/or impossible in an ecologically relevant time frame to restore, recreate, or replace, and therefore are essential for maintenance and recovery of MNES. Places or habitat elements are irreplaceable if there is no clear, ideally peer-reviewed, evidence of an ability to restore, recreate, or replace them within a timeframe relevant to the threat to the MNES in question. Timeframes are based on IUCN threat listing criteria, for which a Critically Endangered species/community has a 20% probability of extinction in 10 years (or 5 generations, whichever is longer (100 years max.), an Endangered species has a 20% probability of extinction in 20 years (or 5 generations, whichever is longer (100 years max.), and a Vulnerable species has a 20% probability of extinction in 100 years. Examples include:

- Habitat that takes a long time to recover or cannot be re-created - i.e., old-growth forests, tree hollows, or mudflats.

- High condition state examples of most ecological communities or habitats.
- Refugia determined by abiotic, soil, water and geological factors – that is, areas defined by factors we have no leverage over (e.g., obligate riffle zones for turtles)

Recovered: means the area, community, or species has met the criteria for delisting and is no longer declining. We note that this is not the traditional definition of recovery; however, as delisted entities are outside the remit of the Federal Government, we have used this definition. The traditional definition of Recovery is cited in Redford et al. (2011), where a successfully conserved (recovered) species will: (a) be self-sustaining demographically and ecologically, (b) be genetically robust, (c) have healthy populations, (d) have representative populations distributed across the historical range in ecologically representative settings, (e) have replicate populations within each ecological setting, and (f) be 'resilient' across the range.

Recovery: means the journey towards 'recovered', noting that 'recovered' may never be achieved by some species, communities, or areas.

Well surveyed: meets all best practice survey guidelines for all relevant MNES.