Basin-wide Conservation Prioritisation for the Murray-Darling Basin

A Report prepared for the Murray Darling Basin Authority

An Australian Government initiative to drive innovative scientific research for the Murray–Darling Basin and its communities.

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Funded through the Murray–Darling Water and Environment Research Program

Basin-wide Conservation Prioritisation for the Murray-Darling Basin.

June 2024

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Citation

Wraith, J., Chauvenet, JA and Kennard, M (2024). Basin-wide Conservation Prioritisation for the Murray-Darling Basin. MD-WERP Deliverable T3.10.2, Griffith University, Australia.

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Executive Summary

The Murray-Darling Basin (MDB) faces critical challenges balancing resource needs with biodiversity conservation. This report builds on the earlier analysis of representation gaps and vulnerability assessment for biodiversity assets in the MDB (Wraith et al. 2023) to prioritise areas for efficient conservation management to inform the Murray-Darling Basin Authority (MDBA) and stakeholders.

Leveraging Systematic Conservation Prioritisation (SCP) and Marxan software, the study identified a priority network of sub-catchments representing different sets of biodiversity assets and critical freshwater habitats. Three overarching objectives guided the analysis, informed by stakeholder engagement and workshops:

1. Prioritise a set of areas for efficient conservation management to benefit priority native species.
    - Our results show that 1010 contracted catchments or 23% of the MDB would be required to meet a 30% target for this objective and to effectively protect priority native species and their habitats.
2. Prioritise critical wetland habitats for priority/threatened species and ecosystems within the Basin.
    - Our results show that 680 catchments or 17% of the MDB would be required to meet a 30% target for this objective and to effectively safeguard critical wetland habitats for threatened species and ecosystems.
3. Prioritise areas to conserve migratory species within CAMBA, JAMBA, ROKAMBA agreements, upholding Australia's commitments, and responsibilities.
    - Our results show that 45 catchments or 3% of the MDB would be required to meet a 30% target for this objective for the protection of migratory bird populations covered by international agreements.

Our study has identified key sub-catchments within the Murray-Darling Basin (MDB) that could be prioritised for management to achieve particular conservation objectives. The findings offer valuable insights for the Murray-Darling Basin Authority (MDBA) and other stakeholders, providing a solid base for making informed decisions on managing and conserving the Basin's natural resources.

To maintain transparency and reproducibility, all the input data layers and spatial outputs from the conservation prioritisation analyses have been included in an updated version of the spatial geodatabases (Wraith et al. 2024a), User Guide (Wraith et al. 2024b) and associated metadata (Wraith et al. 2024c). The user guide provides step-by-step instructions and guidance to assist users in accessing data within the spatial geodatabases.

Contents

Introduction

The Murray-Darling Basin

The Murray-Darling Basin (MDB) is Australia's largest river basin and one of its most significant and ecologically diverse regions. It covers over one million square kilometers, or about 14% of the Australian mainland, and spans four states and one territory. The MDB is home to a wide range of flora and fauna, including over 40,000 native plant and animal species. The Basin is also a vital economic and cultural asset for Australia, supporting millions of people and generating over $20 billion in economic activity each year (Hart et al. 2021).

The MDB is important for several reasons. For example, it is a significant water source for drinking, irrigation, and industry. Over 70% of the water used in the Basin is for irrigation, which supports a wide range of agricultural activities, including producing fruits, vegetables, cotton, and rice. The Basin is also a significant source of drinking water for over 3 million people in Australia. The Murray-Darling Basin (MDB) is one of the most biodiverse regions in Australia. It is home to over 40,000 native plant and animal species, many of which are found nowhere else in the world. The Basin's rivers, wetlands, and woodlands support many habitats, including forests, grasslands, woodlands, and deserts. These habitats provide homes for a diverse range of plants and animals. The MDB is also an important breeding and migratory ground for birds and waterbirds. Many of the Basin's wetlands are listed as Ramsar Sites, which are wetlands of international importance. The Basin's rivers and wetlands provide essential food and other resources for these waterbirds during their breeding and migratory seasons.

The MDB faces several challenges, including habitat loss, fragmentation, invasive species, and climate change. These challenges threaten the Basin's biodiversity, water resources, and cultural values. Conservation prioritisation is a vital tool for safeguarding the MDB's unique natural heritage and ensuring that it continues to provide benefits for future generations. Prioritisation is an essential tool for systematic conservation planning and is used to ensure that conservation efforts are targeted to areas or species most in need of protection or remediation. By identifying priority areas or species, conservation resources can be allocated in a way that maximises the effectiveness of conservation efforts and helps to achieve conservation goals and objectives.

Conservation prioritisation

Systematic conservation prioritisation (SCP) is a structured, data-driven approach for identifying and implementing conservation actions most efficiently and effectively (Figure 1). It involves setting conservation goals, identifying, and mapping biodiversity features, assessing the conservation value of different areas, identifying priority areas for conservation, and implementing conservation actions. SCP is a valuable tool for conservation practitioners because it helps them to make informed decisions about where to allocate limited resources. SCP has several advantages over other approaches to conservation planning. It is a transparent and objective driven process and is a flexible process that can be adapted to meet the specific needs of different conservation planning exercises (Figure 1). Objectives provide a framework for making decisions about how to allocate limited resources such as time, money, and human resources, to achieve conservation goals. Objectives provide a framework for these decisions by defining the desired outcomes of the conservation program and how success will be measured. Stakeholder engagement is a crucial component of objective setting, as it ensures that the process is guided by expert knowledge and that the objectives are aligned with the needs of the community.

SCP is a data-driven process that uses the best available scientific information to inform conservation decisions. SCP is increasingly being used to prioritise conservation actions in freshwater systems. Freshwater systems are among the most biodiverse ecosystems, but they are also among the most threatened. SCP can help to ensure that limited conservation resources are used to protect the most important freshwater biodiversity and ecosystems using algorithms such as Marxan.

Marxan

Marxan is a widely used software for systematic conservation planning. It was developed to assist conservationists, ecologists, and land-use planners make informed decisions about allocating conservation resources and designing protected areas. Marxan uses mathematical algorithms to determine the most efficient and effective locations for protected areas based on various ecological, economic, and social factors. The primary goal of Marxan is to find a spatial configuration of conservation areas that maximises the representation of biodiversity while minimising the overall cost of conservation (i.e., the size of a catchment). It considers various data inputs, such as species distributions and habitat suitability. Marxan is valuable for addressing complex conservation challenges, especially with limited resources such as environmental water allocation. It has been widely adopted in conservation planning and is instrumental in helping organisations and governments make data-driven decisions to protect and preserve natural ecosystems and species. This software has been used extensively to optimise conservation resources within freshwater landscapes and, as such, was chosen in this study to conduct a Basin-wide prioritisation analysis (Ball et al. 2009). Marxan can factor in connectivity which is a critical component of conservation planning in freshwater systems for example, to understand how different sites interact based on hydrological flow and to identify areas that are important for the movement of species. The output of Marxan is a set of spatial recommendations for where conservation or management efforts should be focused.

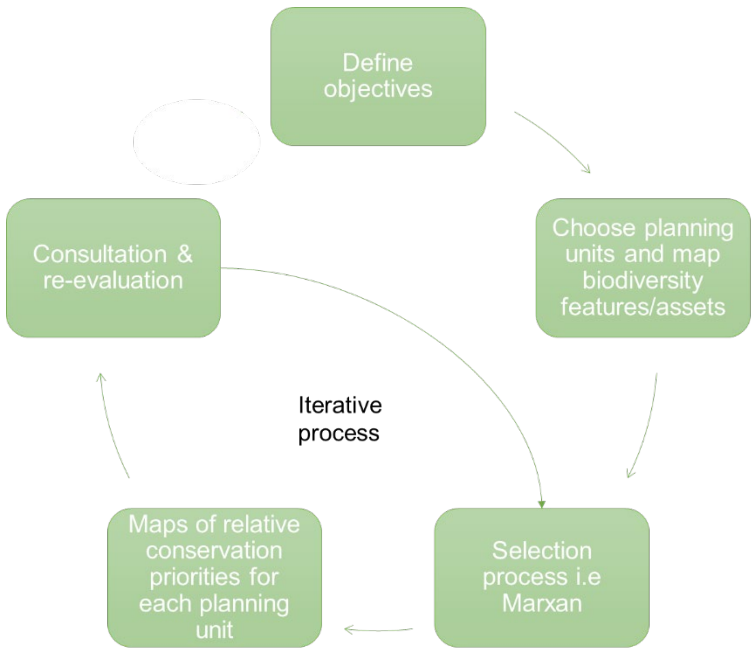


Figure 1. Steps within the conservation prioritisation process. Figure adapted from Linke et al. (2017).

Methods

Prioritisation Objectives

Three overarching objectives were chosen through a series of stakeholder engagement activities and workshops. These included:

1. Prioritise a set of areas for efficient conservation management to benefit priority native species.
2. Prioritise critical wetland habitats for priority/threatened species and ecosystems within the Basin.
3. Prioritise areas to conserve migratory species within CAMBA, JAMBA, ROKAMBA.

Stakeholders involved in the objective setting included members of the Research User Advisory Group (RUAG) which comprised personnel from the MDBA, CEWO and DCCEEW. The process for setting objectives involved an online workshop with RUAG members during which a draft list of objectives was defined that met the priorities of the RUAG members and could guide the prioritisation analysis. These were subsequently refined and circulated to RUAG members for endorsement.

Prioritisation Data

Important Biodiversity assets

We used the best available data to address the three prioritisation objectives. The datasets were collated as part of Representation Gap Analysis and Vulnerability Assessment (Wraith et al. 2023). This data includes a range of species distribution, habitat and wetland which represent important biodiversity assets within the Murray-Darling Basin which are also known as ‘conservation features’ in Marxan literature (Table 1).

In our analysis we ran Marxan for two different representation targets (30% and 10%, respectively) which were calculated based on the total area of occupancy of each conservation feature across the Basin. Setting scientifically defensible end ecologically meaningful targets (e.g., the number of populations or areas required to ensure species persistence species) is challenging, because minimum population sizes or minimum habitat requirements for most freshwater species are not known. The 30% target used in our analyses was aligned with global Convention on Biological Diversity target to achieve to the protection of at least 30% of the Earth's land and ocean by 2030, but we recognise this is somewhat arbitrary. We therefore also evaluated a lower representation target of 10%. There is no doubt that further research is required to identify more ecologically relevant conservation targets for the types of biodiversity surrogates tested here.

Table 1. Summary of data used in analysis to address the three overarching objectives.

Objective	Data	Notes
Objective 1a. Prioritise a set of areas for efficient conservation management to benefit priority (water dependent) native species.	• Water dependent Species of National Environmental Significance (SNES), listed under the Environment Protection and Biodiversity Conservation (EPBC) Act, 1999 (60 species). • Preferred ANAE classes for obligate waterbird foraging habitat (11 classes).	Water dependency was determined through research on each species. Only distributions that were deemed likely to occur were used in this analysis. The taxonomic groups include rodents, bats, a wide array of birds (such as waders, shorebirds, and raptors), reptiles, amphibians, insects, freshwater fish, and crustaceans. ANAE classes were pre-determined in a study by McGinness et al. (2023) and data was provided by the MDBA.
Objective 1b. Prioritise a set of areas for efficient conservation management to benefit priority native species using high quality species distribution models.	• Modelled native fish (32 species), plants (299 species) and macroinvertebrates (31 species).	Species models were provided by MD-WERP Project 11.4. Additional processing was conducted to determine native plants from a larger set of data and all modelled species were filtered to only include likely distributions based on their equal sensitivity and specificity threshold.
Objective 2. Prioritise critical wetland habitats for priority/threatened species and ecosystems within the Basin.	• ANAE wetland classes (70 classes)	
Objective 3. Prioritise areas to conserve migratory species within CAMBA, JAMBA, ROKAMBA.	• Water dependent Species of National Environmental Significance listed on JAMBA, CAMBA or ROKAMBA lists (18 water dependent species)	Data was sorted and matched with species listed one the EPBC act as well as listed on the JAMBA, CAMBA or ROKAMBA agreements (158 EPBC bird species, 92 occur in the MDB, 36 of those are listed on the JAMBA, CAMBA or ROKAMBA agreements (Department of the Environment 2024). Only species determined to be water dependent were analysed.

Spatial planning units

As this analysis was at a Basin-wide scale we used the Geofabric contracted catchments as spatial planning units (BOM 2022). Contracted catchments less than 5 hectares were removed prior to analysis as Marxan will likely choose small catchments of a small area due to low-cost value which may bias the results (Figure 2).

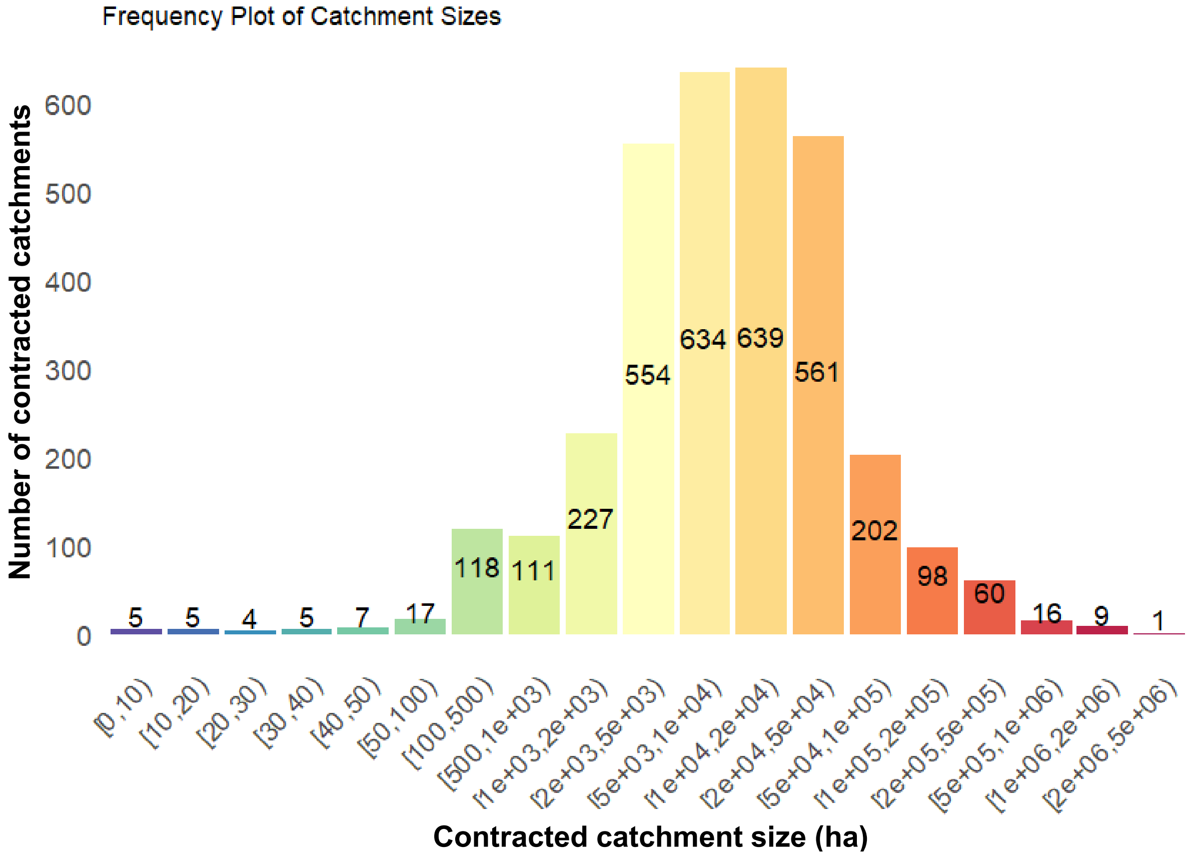


Figure 2. Distribution of catchment sizes (in hectares) depicted in a bar plot, highlighting the frequency of catchments within predefined size groups ranging from the smallest of 6 ha to the largest of 2,022,030 ha.

Connectivity

We used connectivity to incorporate how different sites interact based on hydrological flow into the SCP. We used the "catchstats"(http://www.github.com/nickbond/catchstats) package in R to calculate the pairwise distance of streams between all contracted catchments across the Basin. Data was sourced from two shapefiles the Geofrabric DEM Streams Network identifiers (Stein & Stein 2012) containing detailed stream network data, and the Surface Catchments, which provided site-specific pour point (sub-catchment outlet) information at a contracted catchment level. Data preprocessing steps involved matching the pour point ID with those in the stream network. We then created a comprehensive matrix of all pairs of sites to evaluate connectivity (distance in km) between them. Pairs with no connectivity were assigned a value of 0. The distance values were then inversed (1/distance km) to provide an asymmetric connectivity value for each pair as per Beger et al. (2010). The output file (connectivity.dat) was then used to represent connectivity in the systematic conservation planning workflow using Marxan algorithms.

Marxan

The CLUZ (Conservation Land Use Zoning) QGIS plugin was used to transform species distribution data into Marxan-compatible abundance data (Ball et al. 2009). Using this tool, species presence and abundance information were mapped onto planning units, enabling the generation of spatial data that represents species or community abundances within each unit. The plugin facilitated data cleaning, formatting, and alignment, ensuring data met Marxan requirements.

The Marxan software (version 2.43) was used to run analysis for each objective (see Appendix 1 for detailed specifications). Marxan produces two key result maps, a map of the selected planning units (contracted catchments) and a map of the irreplaceability of each catchment within the Basin.

The selected planning units (contracted catchments) map shows the optimal configuration of contracted catchments that should be prioritised to meet the predefined objective and biodiversity targets within the constraints of the data.

The irreplaceability map compliments the selected planning units map and offers a broader perspective on the importance of each contracted catchment across multiple iterations (in our analysis we ran 1000 iterations). Marxan generates numerous possible solutions to achieve the set goals, and the selection frequency map records how often each catchment is chosen across these solutions. This frequency serves as an indicator of the area's relative importance and irreplaceability in meeting the targets.

The richness or count of each important biodiversity asset within each of the contracted catchments was calculated and visualised in a series of maps for transparency and repeatability (Appendix 2). A series of maps (selected planning unit map and irreplaceability map) for each biodiversity asset and representation target (10% and 30%) is available in Appendix 3.

Post hoc analysis

Management opportunities and Vulnerabilities

Not all the selected contracted catchments are equal, so further analysis was required. We dove into the potential opportunities for management by analysing the potential overlap with protected and managed areas (Birdlife Australia 2018, Australian Government 2022c, Australian Government 2023) as well as potentially waterable areas (Bunn et al. 2014). We also assessed the vulnerability of the selected contracted catchments to threats by calculating the average change in climate velocity for both temperature and precipitation (km/yr) (climate velocity measures how fast selected climate indicators, such as average temperature or precipitation, are shifting spatially over time; Chauvenet 2023), the overall River Disturbance Index (RDI) (Stein et al. 2012), and the predominant land use (ABARES 2022), within each of the selected contracted catchments.

Schematic overview of analysis

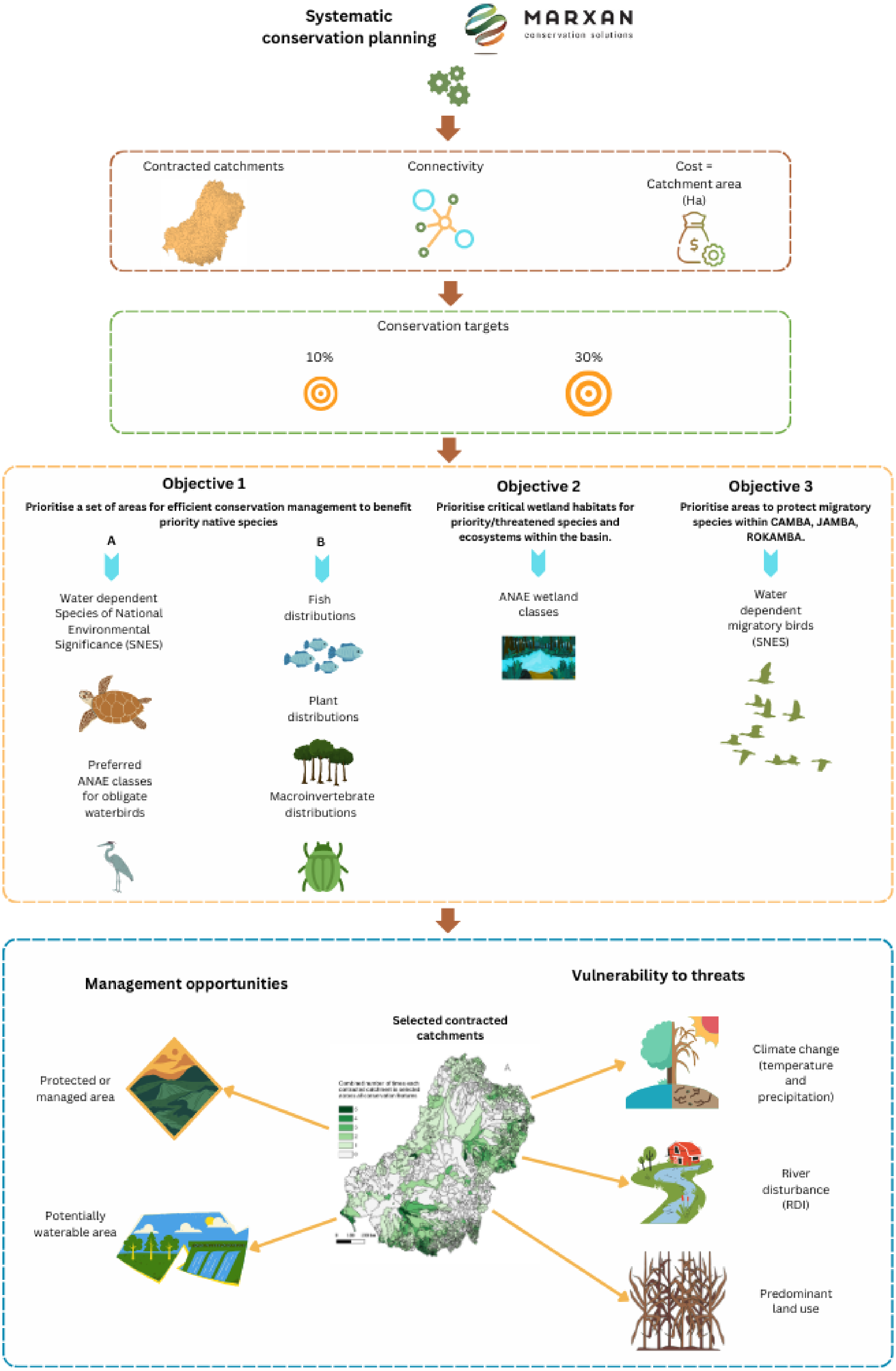


Figure 3. Schematic overview of the Marxan workflow for this study.

Results

Summary

Our study has provided a recommended a set of contracted catchments for potential management of freshwater biodiversity across the Murray-Darling Basin for a 30% target for each of the three objectives (Table 2). Below is summary of the total area of the catchments, the number of contracted catchments, and the percentage of the MDB area they represent:

Objective 1. Conservation Management for Priority Native Species:

a. For water dependent Species of National Environmental Significance (SNES) and Waterbird preferred ANAE foraging habitat, the best solution includes 24,620,222 hectares, which requires 1010 contracted catchments and covers 23% of the MDB area.

b. High accuracy modelled native plants, fish, and macroinvertebrates are encompassed within 42,248,785 hectares in the best solution, involving 1928 contracted catchments and constituting 39% of the MDB.

Objective 2. Critical Wetland Habitats for Priority/Threatened Species and Ecosystems:

To prioritise critical wetland habitats, the analysis determined that 17,942,474 hectares are required. This area is divided into 680 contracted catchments and makes up 17% of the MDB.

Objective 3. Migratory Species Conservation under CAMBA, JAMBA, ROKAMBA:

The prioritisation of areas for conservation management of water-dependent migratory birds covered under international agreements—CAMBA, JAMBA, and ROKAMBA—yields a best solution that encompasses 3,190,695 hectares. This relatively smaller area consists of only 45 contracted catchments, covering 3% of the MDB.

Table 2. Summary of best solution Marxan prioritisation results for each of the three objectives.

Objective	Total catchment area (hectares) in best solution	Number of planning units required	% Area of MDB
1- Identify a minimum set of areas for efficient conservation management to benefit priority native species			
a. Water dependent Species of National Environmental Significance and Waterbird preferred ANAE foraging habitat	24,620,222	1010	23%
b. High accuracy modelled native plants, fish, and macroinvertebrates	42,248,785	1928	39%
2- Prioritise critical wetland habitats for priority/threatened species and ecosystems within the Basin	17,942,474	680	17%
3- Prioritise areas to conserve water dependent migratory species within CAMBA, JAMBA, ROKAMBA.	3,190,695	45	3%

Combining the results across all conservation prioritisation objectives (Table 2) many of the contracted catchments are never selected in the Marxan analyses (794 catchments), many are selected once (1523) or twice (732) and few are selected across three or four prioritisation objectives (220 and 4 catchments, respectively) (Figure 4).

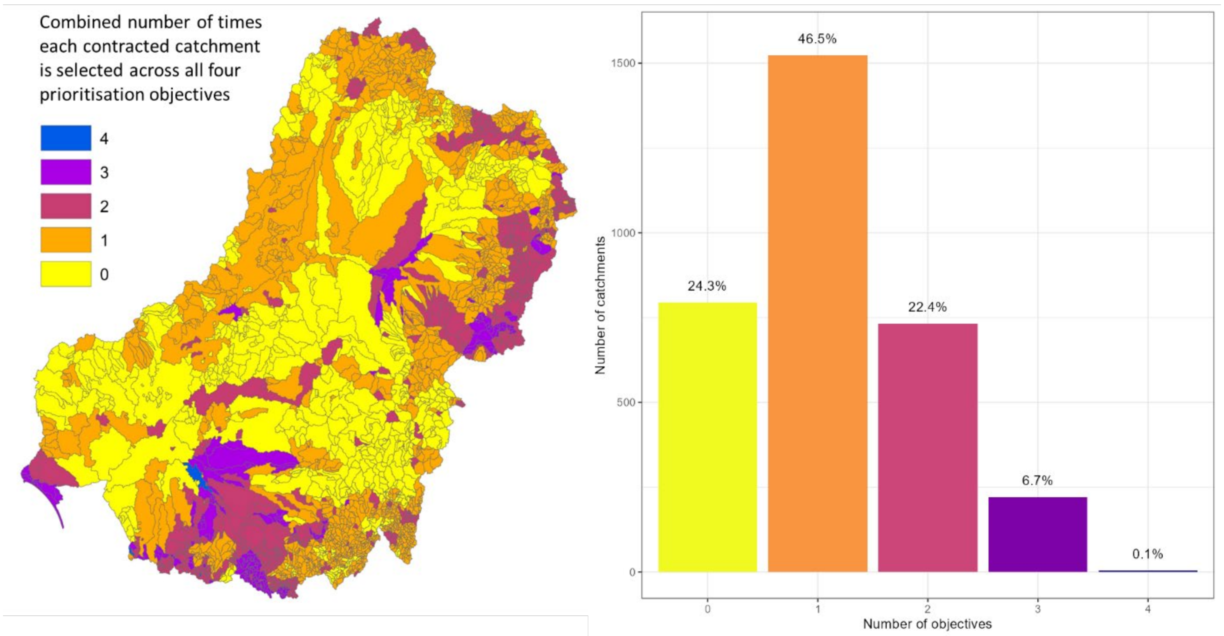


Figure 4. Map (left) and plot (right) of the number of times each contracted catchment is selected across all four prioritisation objectives based on Marxan analyses of conservation features (30% targets).

Objective 1- Minimum set of areas for efficient conservation management to benefit priority native species.

A. Water dependent Species of National Environmental Significance and Waterbird preferred ANAE foraging habitat

This objective aimed to identify important catchments for SNES, which are species recognised for their environmental significance within Australia, and those identified as having a dependence on aquatic ecosystems for survival. To meet the 30% area target for each of these 61 species plus 11 ANAE classes, 1010 planning units we selected (Figure 5).

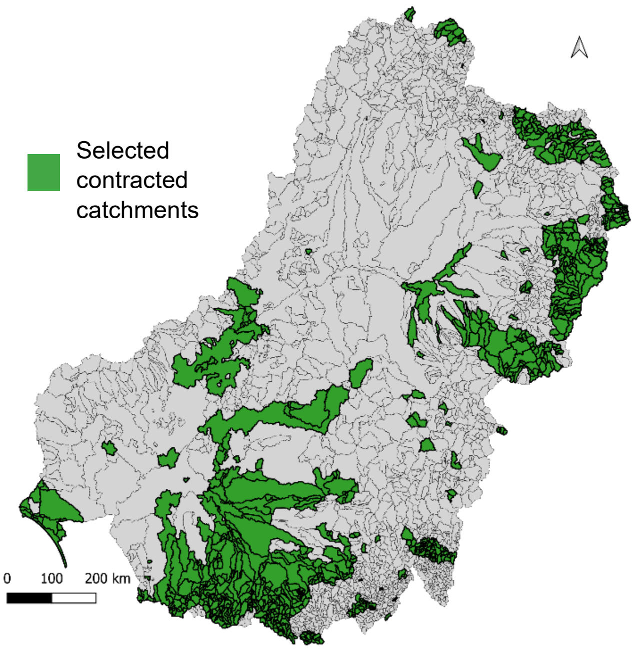


Figure 5. Results of the Marxan analysis for water dependent Species of National Environmental Significance (SNES) and Waterbird preferred ANAE foraging habitat showing the best combined solution with 30% target

Opportunities for management

The study indicates that out of the total 'best solution' area of 24,620,222 hectares, 4,028,312 hectares (16%) are protected and managed areas. Additionally, 5,755,854 hectares (23%) of the total area, are identified as potentially waterable (Figure 6).

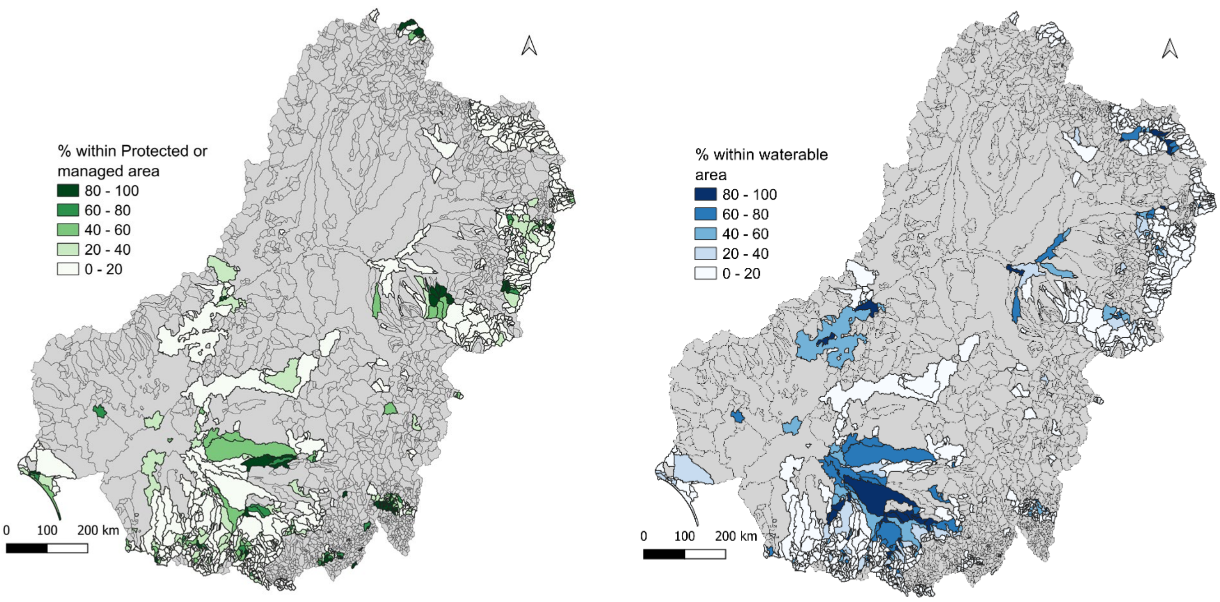


Figure 6. The percent of each selected contracted catchment that occurs within A) a protected or managed area including protected areas, Key biodiversity areas and Ramsar wetlands B) the potentially waterable area.

Vulnerability assessment

The most predominant land use types for the selected contracted catchments are production from relatively natural environments and from dryland agriculture and plantations. The selected catchments vary in terms of potential climate change impacts. For example, selected catchments near the lower Darling River and the Murrumbidgee will likely see a shift from 3-5 km based on temperature and precipitation velocity, and have a relatively high River Disturbance Index (0.56-0.75 RDI). Whereas catchments on the Murray River, the Coorong, and the northeast portion of the Basin will see little change and are likely more suitable for future climate (Figure 7).

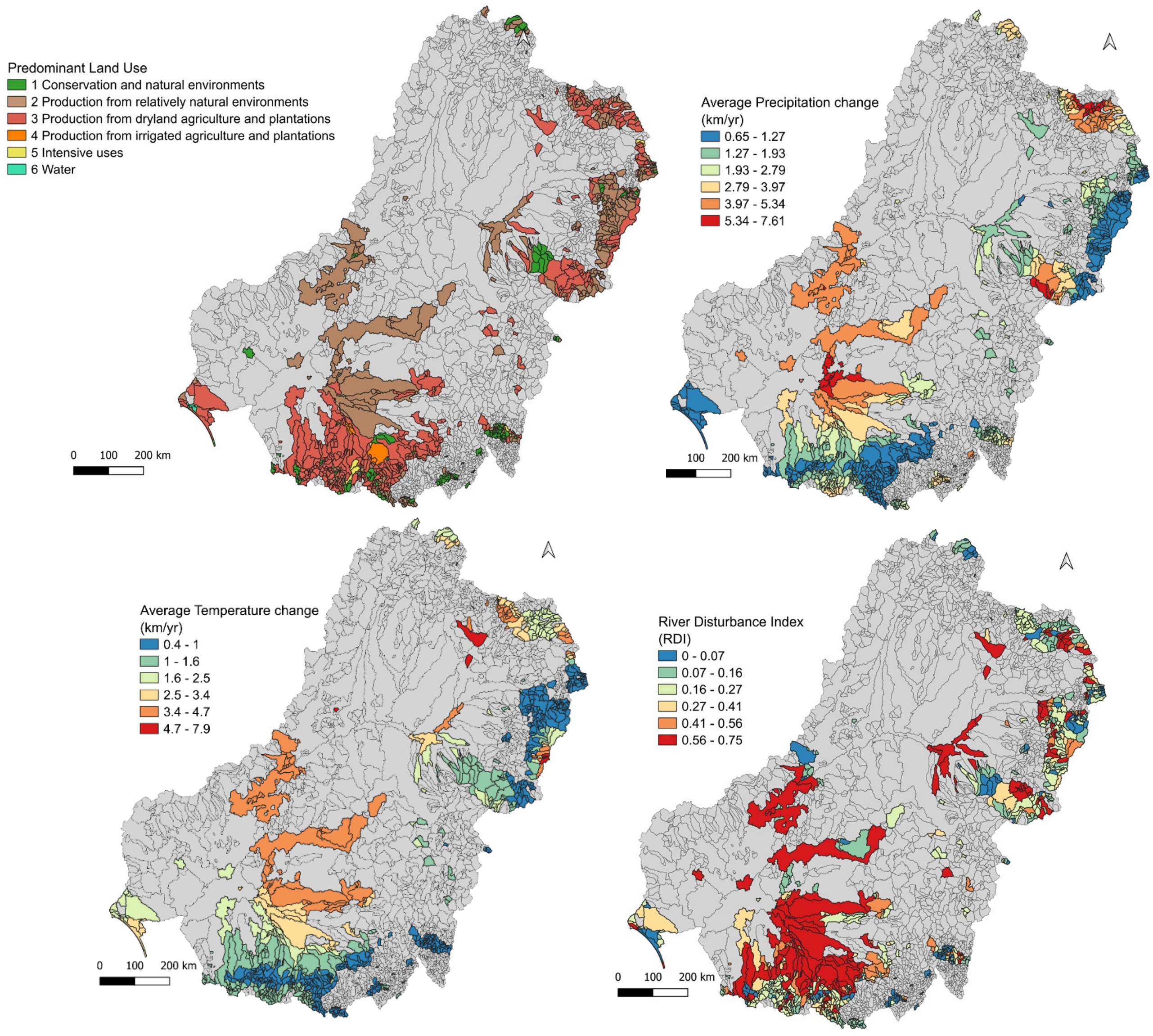


Figure 7. A) The predominant land use type for selected contracted catchments for Objective 1a, (B) Selected catchments coloured by their average climate velocity shift in km/year for Precipitation, (C) Selected catchments coloured by their average climate velocity shift in km/year for temperature and (D) Selected catchments coloured by their River Disturbance Index values.

B. Modelled fish, plants and macroinvertebrates

This objective aimed to identify important catchments for native species based on high quality modelled distributions. This diverse assemblage spans multiple taxonomic groups including native plants, fish, and macroinvertebrates. To meet the 30% area target for each of these 299 plant species, 32 fish species and 31 macroinvertebrates species, 1928 planning units were selected (Figure 8). The area required is quite large and covers a range of catchments within the Basin. Many of these catchments overlap with the previous results (Figure 8) however this scenario highlights more catchments in the northern part of the Basin.

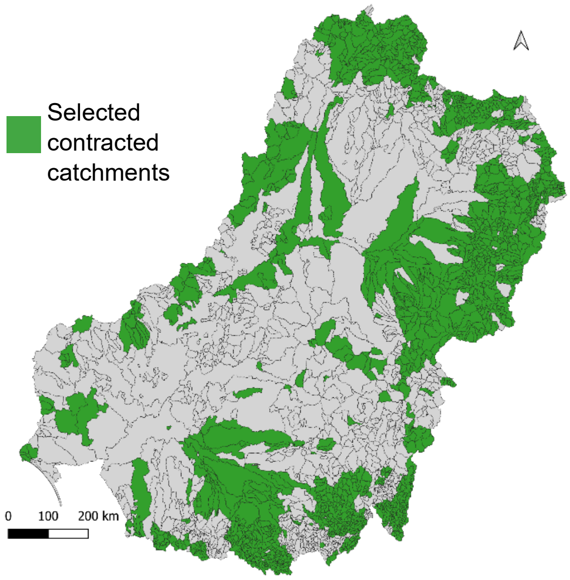


Figure 8. Results of the Marxan analysis for high accuracy modelled species including native plants, fish, and macroinvertebrates with a 30% target.

Opportunities for management

The study indicates that out of the total 'best solution' area of 42,248,785 hectares, 5,241,170 hectares (12%) are protected and managed areas. Additionally, 7,643,078 hectares (18%) of the total area, are identified as potentially waterable (Figure 9).

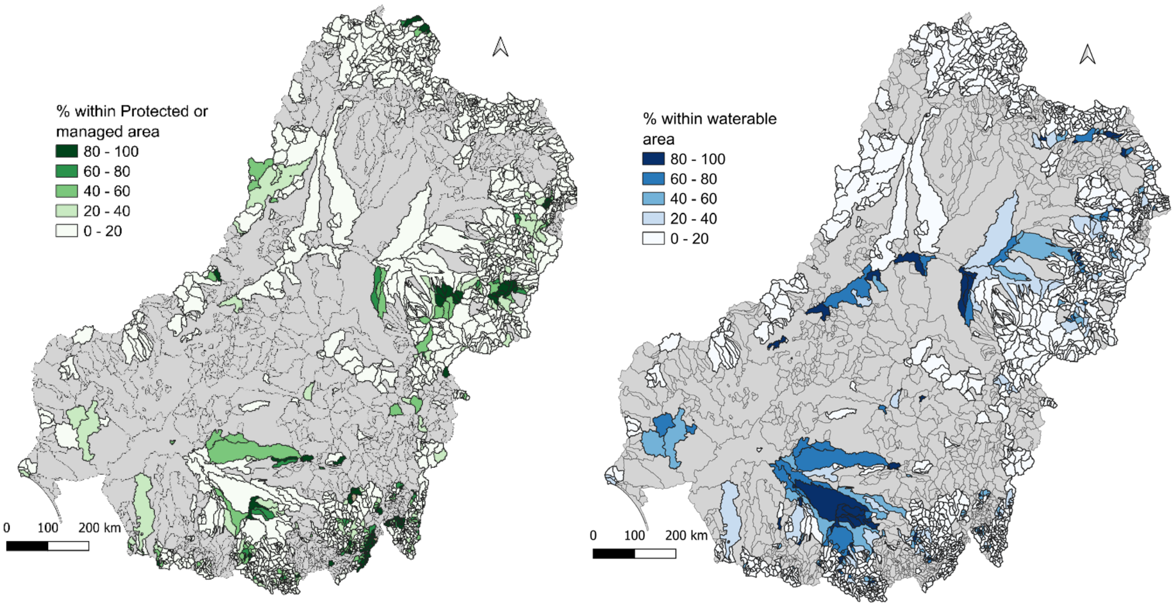


Figure 9. The percent of each selected contracted catchment that occurs within A) a protected or managed area including protected areas, Key biodiversity areas and Ramsar wetlands B) the potentially waterable area.

Vulnerability assessment

Many contracted catchments in the Condamine and Warrego catchments are selected which have a relatively low impact of climate change and low river disturbance. These occur in mixed land use areas including production form dryland agriculture and plantations as well as production from natural environments (Figure 10).

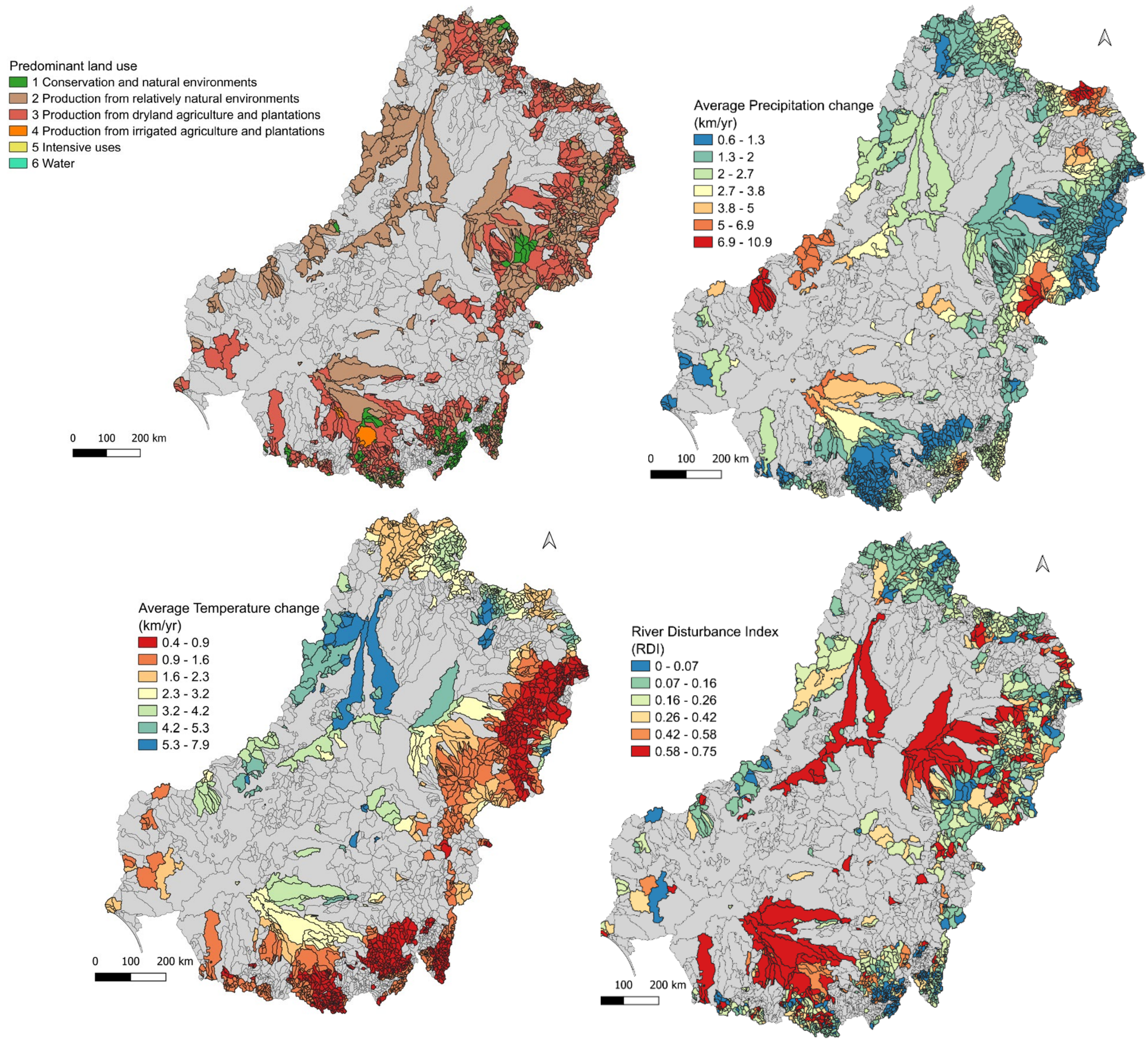


Figure 10. A) The predominant land use type for selected contracted catchments for Objective 1b, (B) Selected catchments coloured by their average climate velocity shift in km/year for Precipitation, (C) Selected catchments coloured by their average climate velocity shift in km/year for temperature and (D) Selected catchments coloured by their River Disturbance Index values.

Objective 2 - Prioritise critical wetland habitats for priority/threatened species and ecosystems within the Basin

This objective aimed to identify important catchments for wetland habitats based on important wetlands represented by ANAE classes. To meet the 30% target of ANAE wetland habitats 680 contracted catchments were selected (Figure 11).

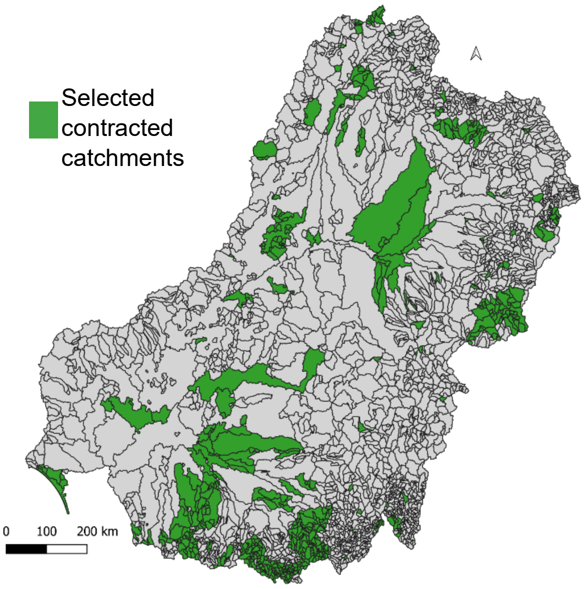


Figure 11. Results of the Marxan analysis for critical wetland habitats within the Basin with 30% target

Opportunities for management

This scenario indicates that out of the total selected contracted catchments (17,942,474 hectares), 2,450,920 hectares (13%) are within protected and managed areas. Additionally, 5,771,707 hectares (32%) of the total area, are identified as potentially waterable (Figure 12). These catchments are distributed across different areas of the Basin. For example, two large catchments in the northern part of the Basin near Lightning Ridge and St George. These catchments fall almost entirely in the potentially waterable area and have very little area protected.

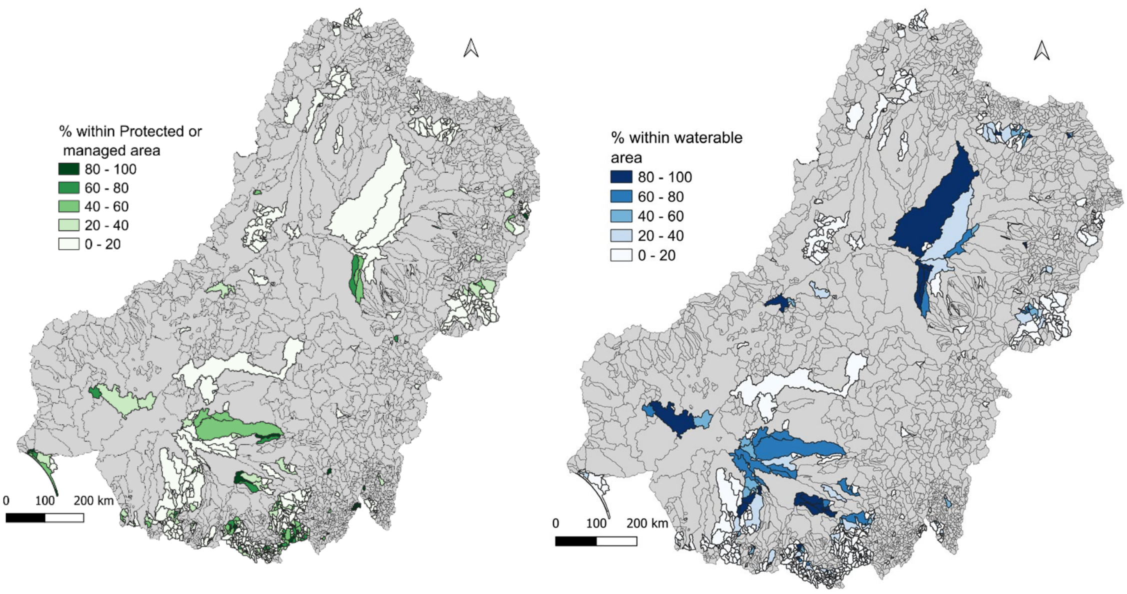


Figure 12. The percent of each selected contracted catchment that occurs within A) a protected or managed area including protected areas, Key biodiversity areas and Ramsar wetlands B) the potentially waterable area.

Vulnerability assessment

The two large catchments in the northern part of the Basin near Lightning Ridge and St George will likely see a significant change in temperature shift but less change in precipitation and have a high River Disturbance Index (0.64 RDI). The catchments predominant land use is production primary from natural environments (Figure 13).

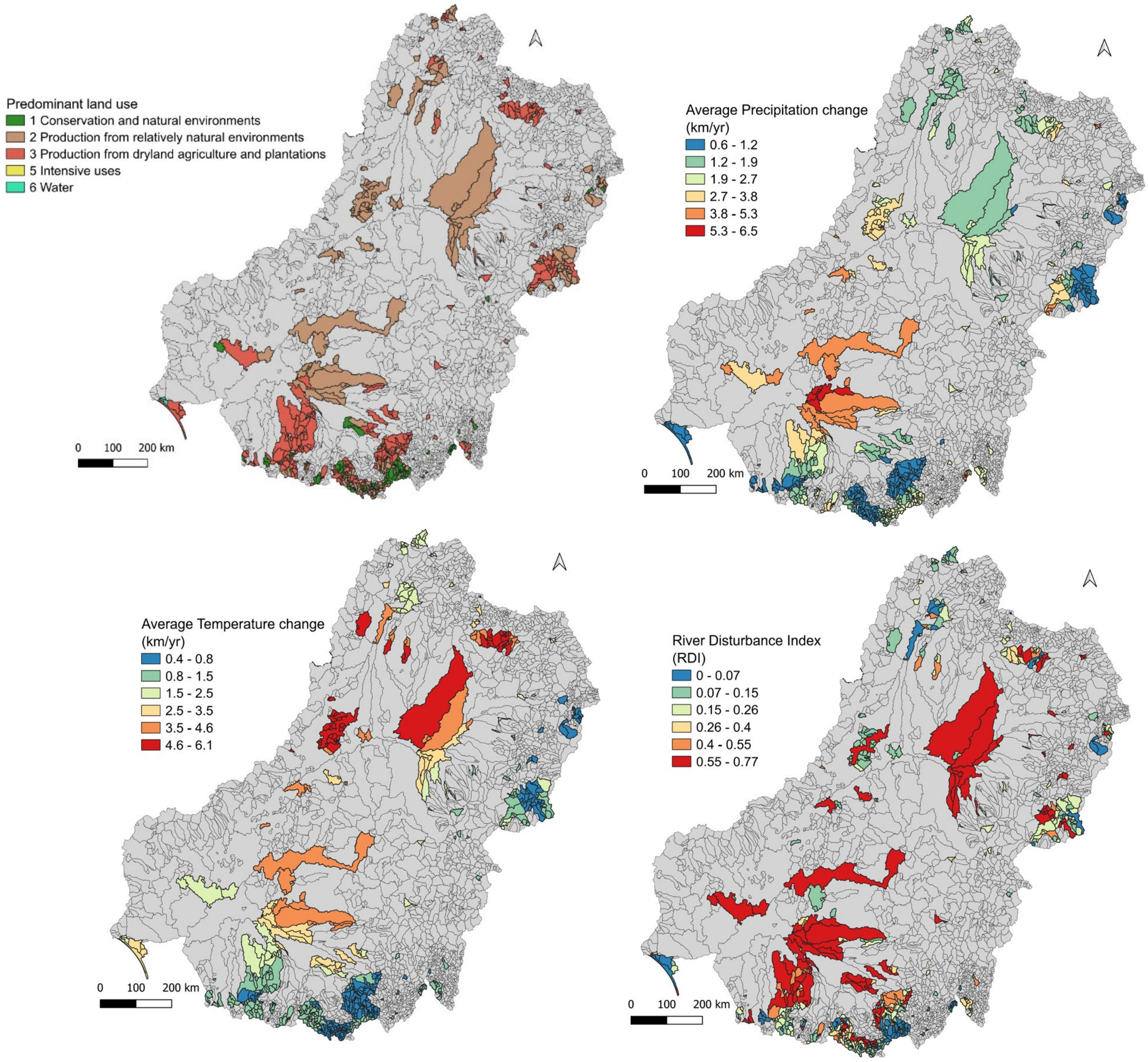


Figure 13. A) The predominant land use type for selected contracted catchments for Objective 2, (B) Selected catchments coloured by their average climate velocity shift in km/year for Precipitation, (C) Selected catchments coloured by their average climate velocity shift in km/year for temperature and (D) Selected catchments coloured by their River Disturbance Index values.

Objective 3- Prioritise areas to conserve water dependent migratory species within CAMBA, JAMBA, ROKAMBA.

This objective aimed to identify important catchments for water dependent migratory birds listed on the CAMBA, JAMBA, ROKAMBA agreements. To meet the 30% target of water dependent migratory bird distributions 45 contracted catchments, need to be selected. The largest catchment in this scenario is in the Paroo catchment, including many important wetlands for water dependent birds including the Yantabulla Swamp which is part of Paroo River and Cutteburra Creek, noted to be the most important waterbird breeding site in north-west New South Wales (MDBA 2023). Other selected catchments highlighted for migratory birds are those in those in the Lower Murray catchment, largely surrounding the Coorong (Figure 14).

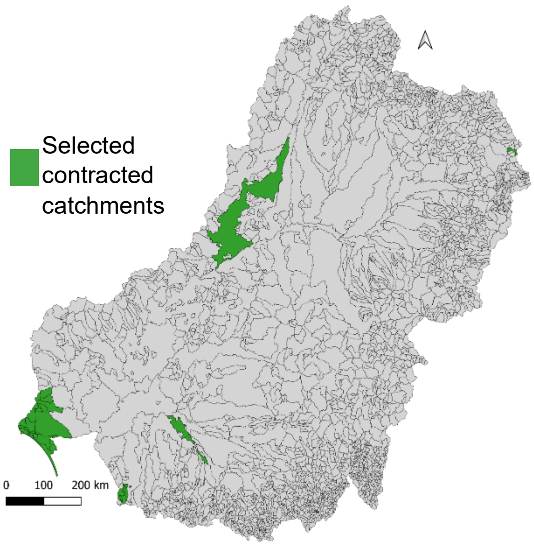
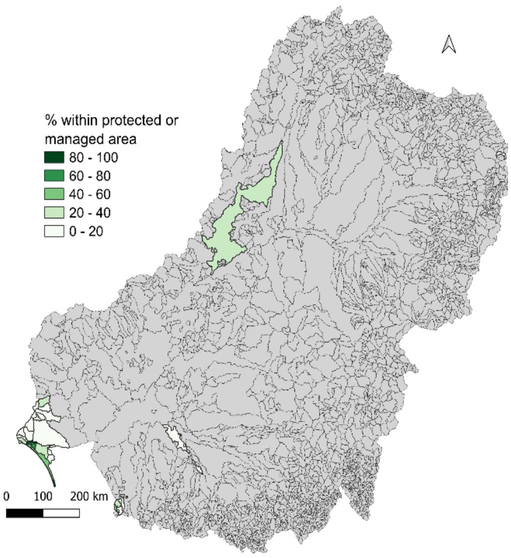


Figure 14. Results of the Marxan analysis showing the selected contracted catchments for areas to protect water dependent migratory species within CAMBA, JAMBA, ROKAMBA based on 18 bird species with 30% target.

Opportunities for management

This scenario indicates that out of the total selected contracted catchments which has an area of 3,190,695 hectares, 736,276 hectares (23%) are protected and managed areas. Additionally, 447,866 hectares (14%) of the total area, are identified as potentially waterable (Figure 15). The contracted catchment within the Paroo catchment does not fall within the potential waterable area and has little coverage in protected areas (30% with a PA).



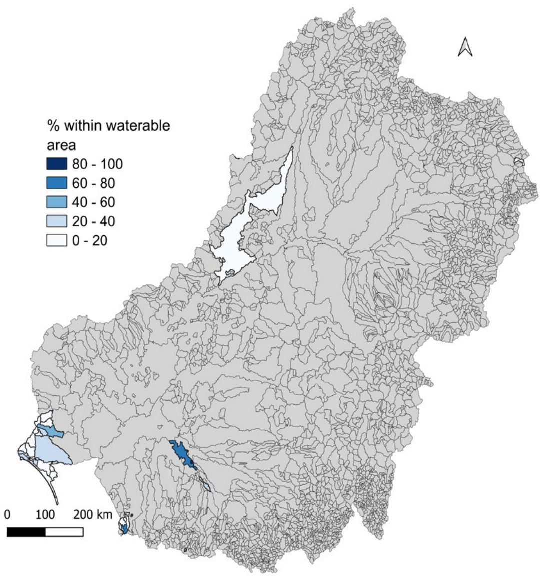


Figure 15. The percent of each selected contracted catchment that occurs within A) a protected or managed area including protected areas, Key biodiversity areas and Ramsar wetlands B) the potentially waterable area.

Vulnerability assessment

The contracted catchment within the larger Paroo catchment is likely to see a moderate shift in precipitation (3 km/yr) and a high shift in temperature (5.3km/yr) but has moderate to low River Disturbance (RDI 0.4). Land use in this catchment is predominantly production from relatively natural environment as well as form dryland agriculture and plantations further south in catchments near the Coorong (Figure 16).

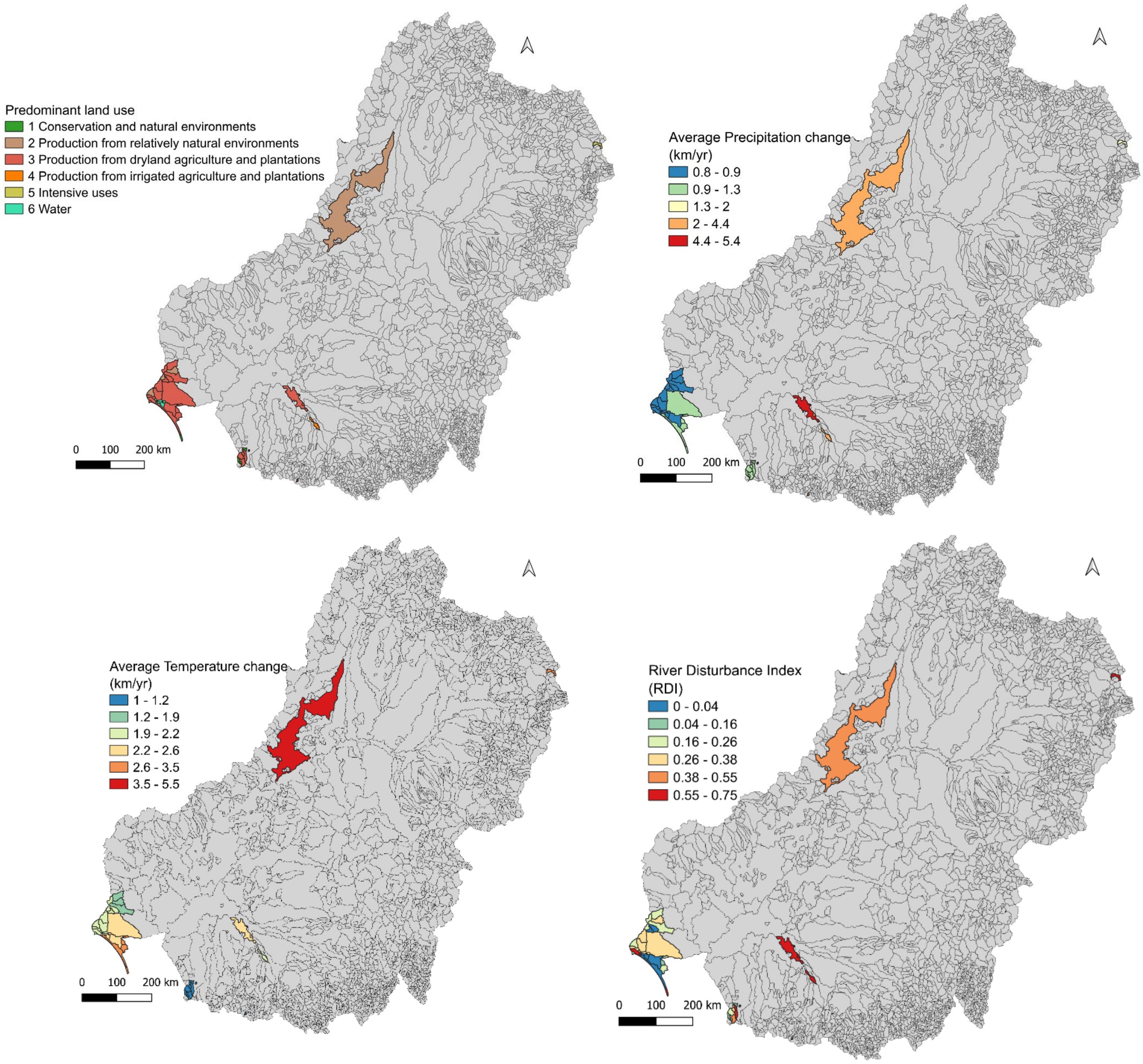


Figure 16. A) The predominant land use type for selected contracted catchments for Objective 3 (B), Selected wetlands coloured by their average climate velocity shift in km/year for Precipitation, (C) Selected wetlands coloured by their average climate velocity shift in km/year for temperature and (D) Selected wetlands coloured their average River Disturbance Index values.

Discussion

Spatial prioritisation to inform conservation management objectives in the Basin

A key objective of the Basin Plan is to ‘protect and restore’ the Basin’s water-dependent ecosystems. However, recent severe droughts and widespread fish kills in the Basin have highlighted the significant challenges ahead in adaptively managing Basin ecosystems (and environmental water) to achieve environmental outcomes under a changing climate (Sheldon et al. 2022). Increasing water scarcity and competition for limited water resources underscores the need for spatial prioritisation of environmental assets for targeted water management and complementary measures to sustain and restore their ecological values.

This study has identified key sub-catchments within the Murray-Darling Basin (MDB) that could be prioritised for management to achieve particular conservation objectives. Through detailed spatial analysis and prioritisation, this study addressed three main stakeholder driven objectives including identifying a minimum set of priority catchments for conservation management of priority native species, wetland habitats and ecosystems, and migratory species. The findings offer important insights for the Murray-Darling Basin Authority (MDBA) and other stakeholders, providing a solid base for making informed decisions on managing and conserving the Basin's natural resources. This includes future updates to the Basin-wide Environmental Watering Strategy[1] and Basin Annual Environmental Watering Priorities[2], as well as informing the Basin Plan Review[3] by 2026. Broad scale conservation prioritisations such as undertaken in our study, provide critical context for future studies that could focus on identifying and prioritising on-ground conservation actions over smaller spatial extents and finer grain sizes (e.g. Carwardine et al 2012, Cattarino, et al 2018).

Conservation management of priority areas: opportunities, constraints and next steps

The identification of priority areas is just part of the process of conservation practice (Hermoso et al. 2016). Empowerment and resourcing of individuals and institutions and securing effective action has been recognised as essential for the adequate implementation of conservation management (Barmuta et al. 2011). Further work at a finer spatial scale is required to understand how much of the Basin’s aquatic ecological assets can benefit from the various water management strategies such as environmental water delivery through managed releases from dams, water shepherding, water buy-backs to reduce water extraction/interception and groundwater management. However, these water management options alone are unlikely to deliver restoration benefits given the altered state of many wetlands and hence requires consideration of opportunities for additional complementary management interventions (Schweizer et al. 2022). These may include pest control, infrastructure modifications, habitat restoration, addressing cold water pollution, enhancing fish passage, improving water quality, nutrient cycling and sediment transport (Baumgartner et al. 2019, Schweizer et al. 2022).

Effective conservation management in the Basin will require that a set of conservation actions be identified to mitigate or prevent current and future threats to freshwater ecosystem assets and values. This study focussed on two conservation management opportunities relating to environmental watering and protected area management. However, only a very small fraction of the Basins’ aquatic ecosystems occurs within protected areas

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[1] https://www.mdba.gov.au/publications-and-data/publications/basin-wide-environmental-watering-strategy
[2] https://www.mdba.gov.au/publications-and-data/publications/basin-annual-environmental-watering-priorities
[3] https://www.mdba.gov.au/water-management/2026-basin-plan-review

such as national parks (Bond et al. 2020, Wraith et al. 2023). Moreover, of those that do receive some form of formal or informal protection, most remain impacted by upstream influences (Stein and Nevill, 2011). Active conservation management both outside and within protected areas is therefore required for restoring the condition of aquatic ecosystems (Chessman 2013, Bond et al. 2020).

For particular catchments identified as conservation priority areas in this study (e.g., Figure 17), some are more likely to situated in areas potentially able to be managed through delivery of environmental water, whereas other priority areas will need alternative approaches to ensure sufficient water is available to sustain their ecological values (such as through reductions in water extraction/interception and restrictions on groundwater extraction). Opportunities for managing other threats through complementary actions will in part, depend on land tenure and could involve working with Protected Area managers and/or with local landholders and communities to implement on ground actions (Figure 17).

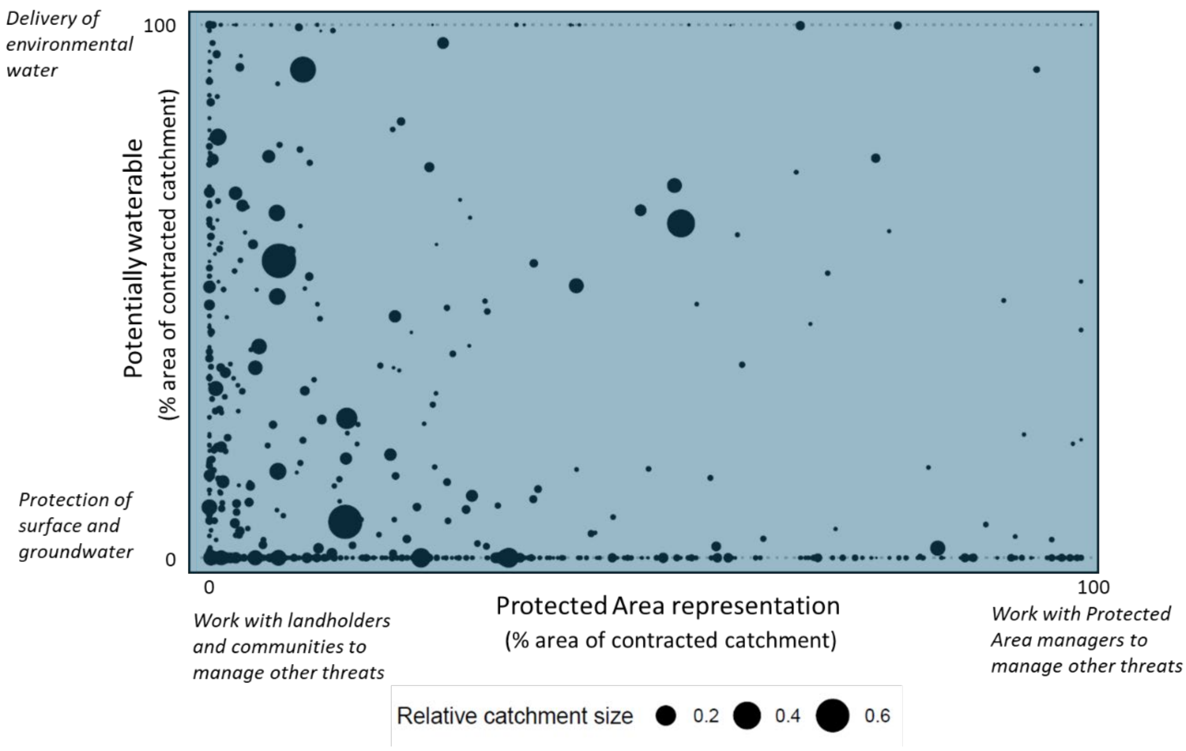

Figure 17. Priority catchments identified from Objective 1 with respect to their representation within protected areas (x-axis) and representation within potentially waterable areas (y-axis). Conservation management opportunities for threat management within and outside protected areas and delivery of environmental water versus other water management options are indicated at respective ends of each axis.

Synthesis and Recommendations

Our study has identified key contracted catchments within the Murray-Darling Basin (MDB) that could be prioritised for management to achieve particular conservation objectives. Through detailed spatial analysis and prioritisation, this study addressed three main stakeholder driven objectives including providing a minimum set of contracted catchments protecting native species, wetland habitats, and migratory species. The findings offer valuable insights for the Murray-Darling Basin Authority (MDBA) and other stakeholders, providing a solid base for making informed decisions on managing and conserving the Basin's natural resources.

To maintain transparency and reproducibility, all the input data layers and spatial outputs from the conservation prioritisation analyses have been included in an updated version of the spatial geodatabases (Wraith et al. 2024a), User Guide (Wraith et al. 2024b) and associated metadata (Wraith et al. 2024c). The user guide provides step-by-step instructions and guidance to assist users in accessing data within the spatial geodatabases.

Our conservation prioritisation results can inform future Basin planning and related conservation management strategies. By doing so, biodiversity conservation will become a central aspect of water resource management in the MDB, ensuring that the ecological integrity of the Basin is maintained alongside its economic and social uses. We also encourage active collaboration between policymakers, conservationists, and researchers to update and refine management strategies based on the latest scientific findings. A collaborative approach will ensure that policies remain adaptive and responsive to new data and environmental changes.

We recommend focusing on the identified priority areas for implementing or strengthening conservation management measures such as habitat restoration, pollution control, and invasive species management. These actions will bolster the resilience of these ecosystems against threats and enhance their biodiversity value. The conservation priority areas identified in our study can also inform spatial priorities for environmental water (E-water) delivery. By leveraging this detailed spatial analysis, E-water could be directed towards areas where it will significantly benefit ecosystem health and species preservation.

This study provides extensive results at Basin wide scale; however, it is likely necessary to understand the complexities within a contracted catchment at a more local scale. This should include engaging with local communities, including landholders, managers, and Traditional Owners, to gather insights and support for conservation initiatives at the catchment level. This engagement is crucial for understanding local issues, integrating traditional knowledge into conservation planning, and fostering relationships among those directly impacted by or involved in land and water management.

It would be beneficial to conduct granular, site-specific studies within the identified contracted catchments to understand the unique ecological dynamics and threats at a local scale. These assessments will allow for the fine-tuning of conservation strategies to address specific challenges and opportunities within each catchment.

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Appendix 1

Technical details

Marxan files

Marxan requires a suit of text files that define the conservation planning problem and settings. We created several Marxan files to define the conservation planning problem and settings. The "pu.dat" file contains a list of planning units, with their unique ID, coordinates, and status (available or not). The "spec.dat" file contains a list of conservation features, with their unique ID, targets, and penalties for each planning unit. The "puvsp.dat" file contains the costs associated with each planning unit. The "sporder.dat" file specifies the order in which the conservation features are added to the reserve network. The "bound.dat" file specifies the boundary length modifier (BLM) value for each conservation feature. The BLM adjusts the contribution of boundary length to the cost of a solution. It is a multiplier of the length of edges shared between selected planning units and unselected planning units.

The CLUZ QGIS plugin was used to develop most of these, including:

- **pu.dat:** A file containing a list of planning units, with their unique ID, coordinates, and status (available or not).
- **spec.dat:** A file containing a list of conservation features, with their unique ID, targets, and penalties for each planning unit.
- **puvsp.dat:** A file containing the costs associated with each planning unit
- **sporder.dat:** A file specifying the order in which the conservation features are added to the reserve network.
- **bound.dat:** This file specifies the boundary length modifier (BLM) value for each conservation feature. The BLM adjusts the contribution of boundary length to the cost of a solution. It is a multiplier of the length of edges shared between selected planning units and unselected planning units.

Other Marxan files needed to be created manually or using R. For example, Marxan is an executable program that runs in the terminal or command line. The program requires an input file that specifies the settings such as iterations and seeds as well as the associated file directories. The following files were created manually:

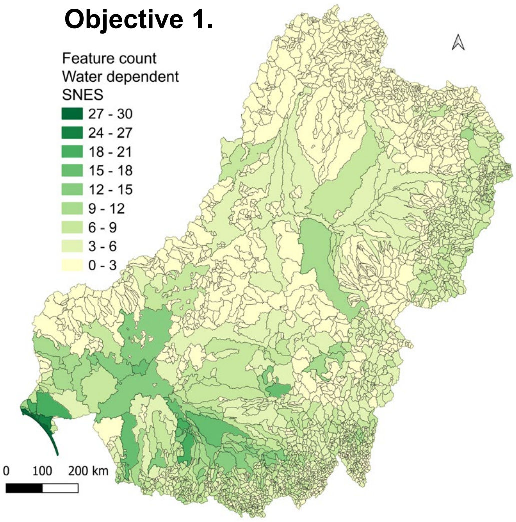
- **input.dat**: A file containing various parameters, such as the number of solutions to run and the algorithm to use (Appendix 2).
- **Connectivity.dat**: A file containing information on the degree of connectivity between planning units.

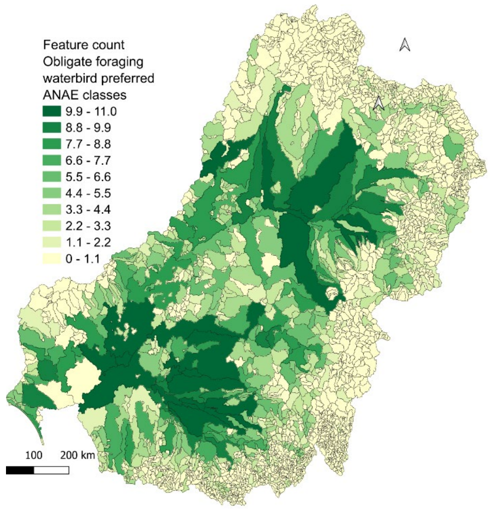
Appendix 2

Conservation feature richness count

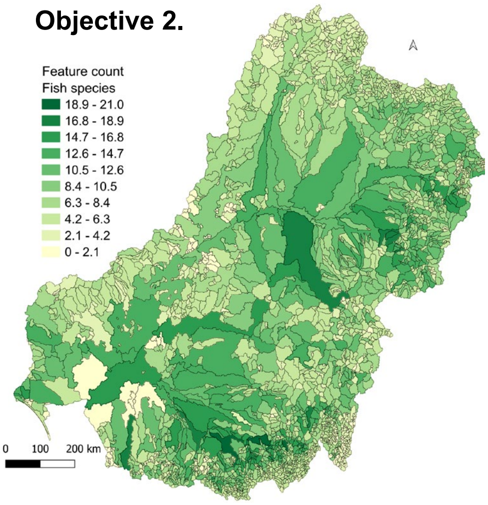
The following maps shows the richness or count of each important biodiversity asset used in this analysis per contracted catchment (Figure 18).

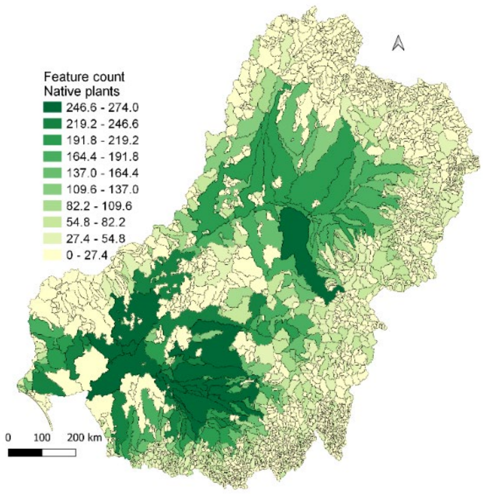
Objective 1.

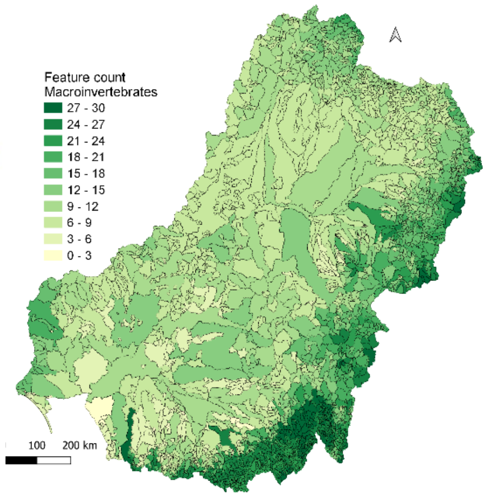




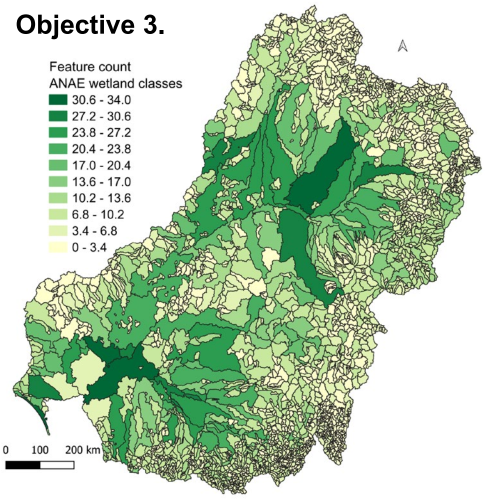
Objective 2.







Objective 3.



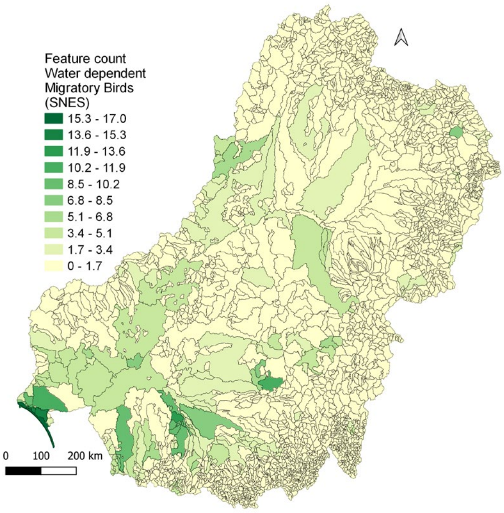


Figure 18. The richness or count for each biodiversity asset including A) water dependent, SNES, B) waterbird foraging ANAE class, C) fish, D) plants, E) macroinvertebrates, F) ANAE wetland classes, G) water dependent migratory birds.

Appendix 3

Below are a series of selected planning unit maps and irreplaceability maps for each of the important biodiversity assets, under the heading of the corresponding objective.

Objective 1- Priority areas for efficient conservation management to benefit priority native species.

Water dependent Species of National Environmental Significance (SNES)

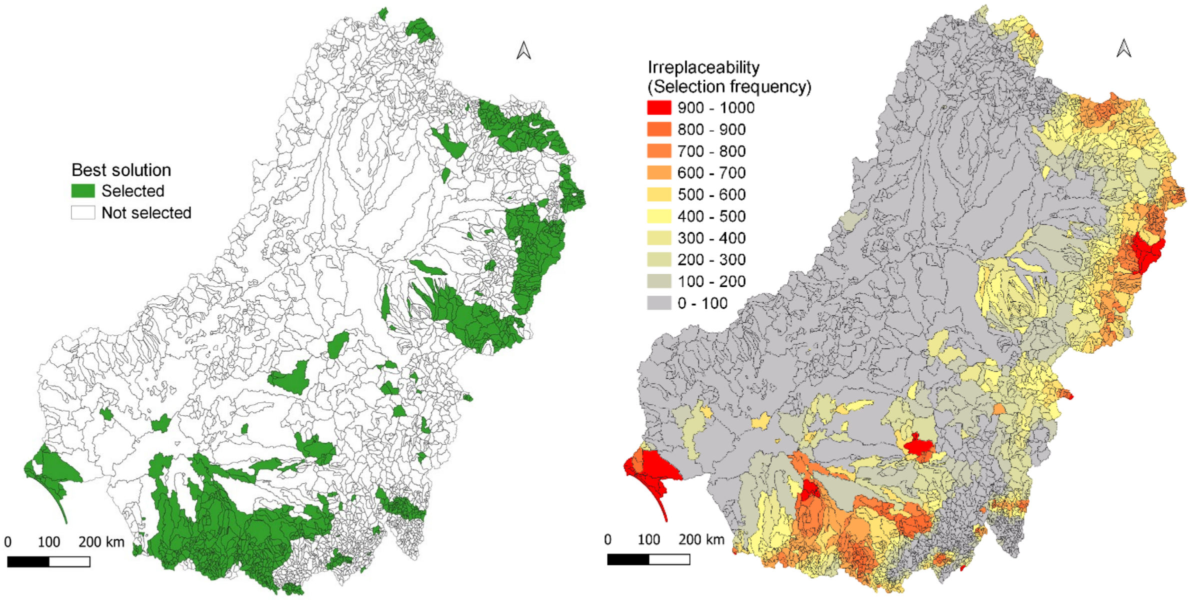


Figure 19. Marxan results showing the selected contracted catchments and irreplaceability score for water dependent SNES with a 30% target.

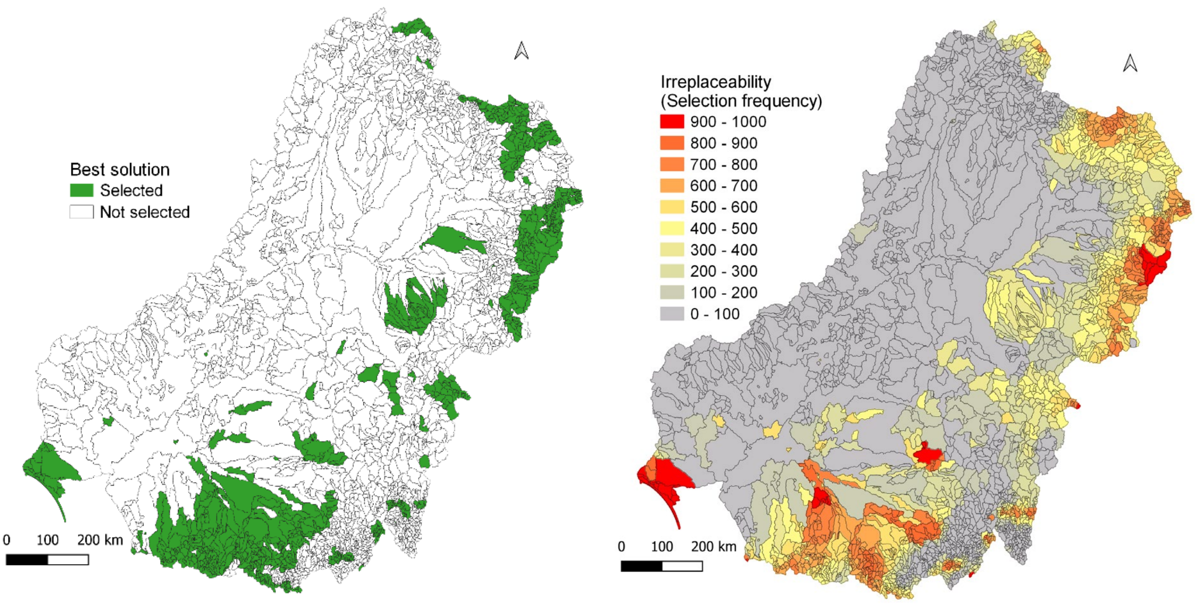


Figure 20. Marxan results showing the selected contracted catchments and irreplaceability score for water dependent SNES with a 10% target.

Obligate waterbird foraging habitat (preferred ANAE classes)

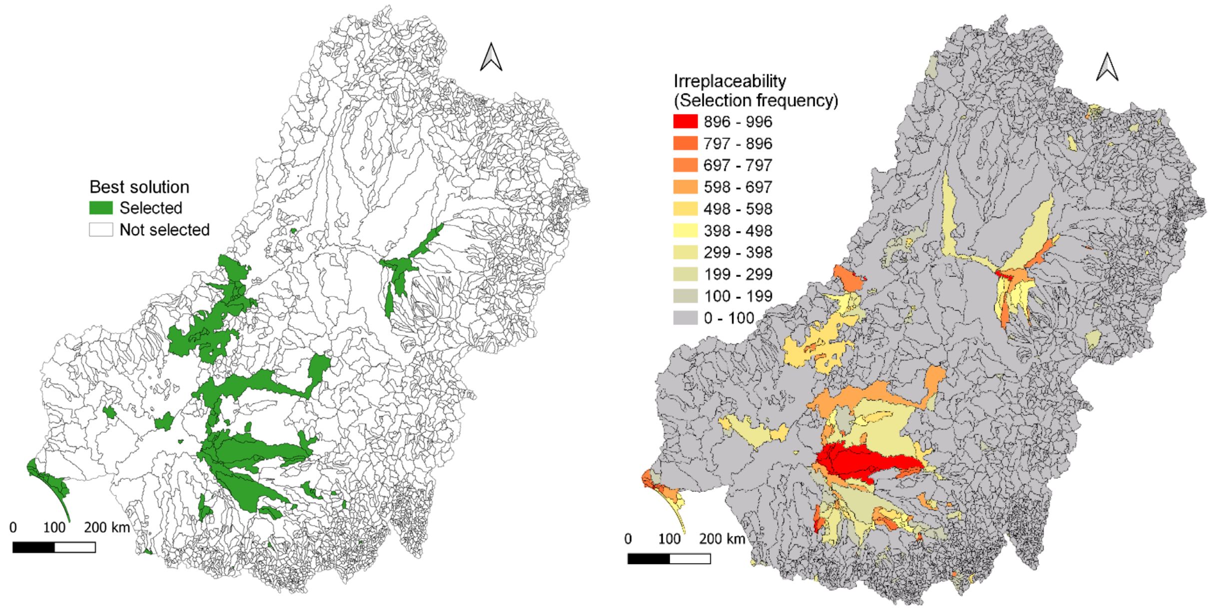


Figure 21. Marxan results showing the selected contracted catchments and irreplaceability score for obligate waterbird preferred ANAE foraging class with a 30% target.

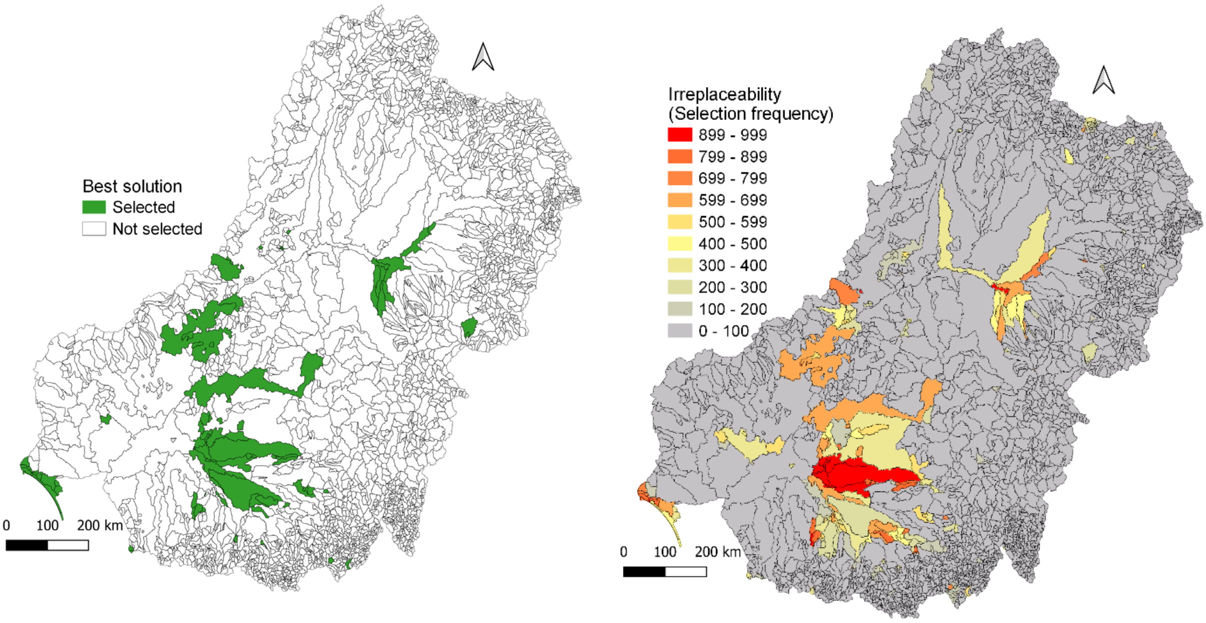


Figure 22. Marxan results showing the selected contracted catchments and irreplaceability score for obligate waterbird preferred ANAE foraging class with a 10% target.

Fish distributions

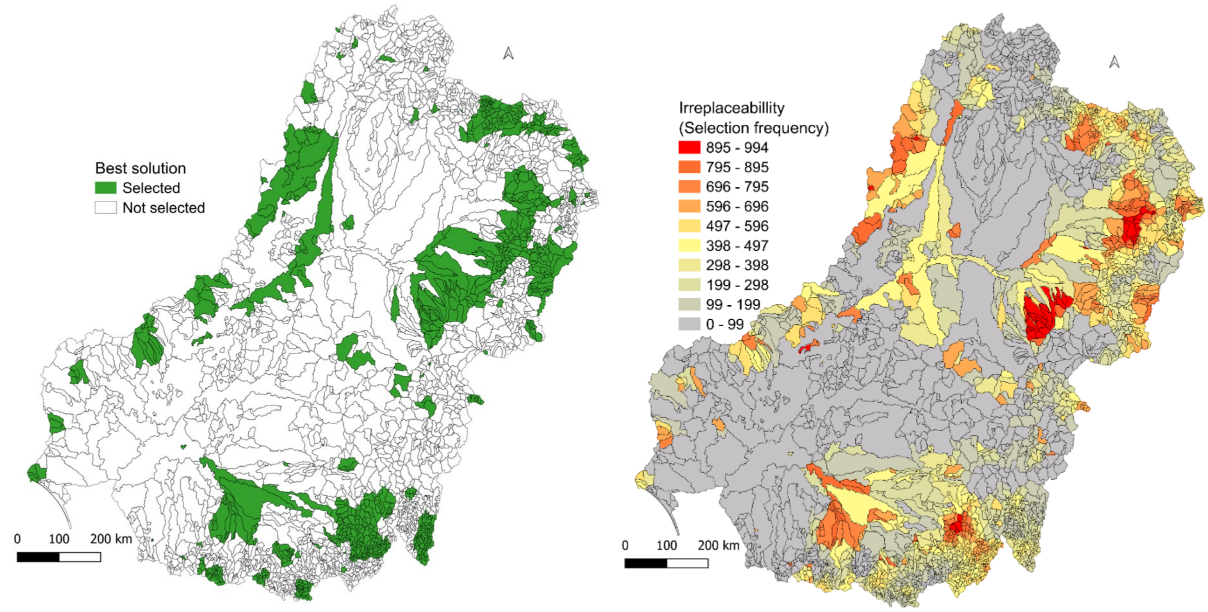


Figure 23. Marxan results showing the selected contracted catchments and irreplaceability score for high quality fish distributions with a 30% target.

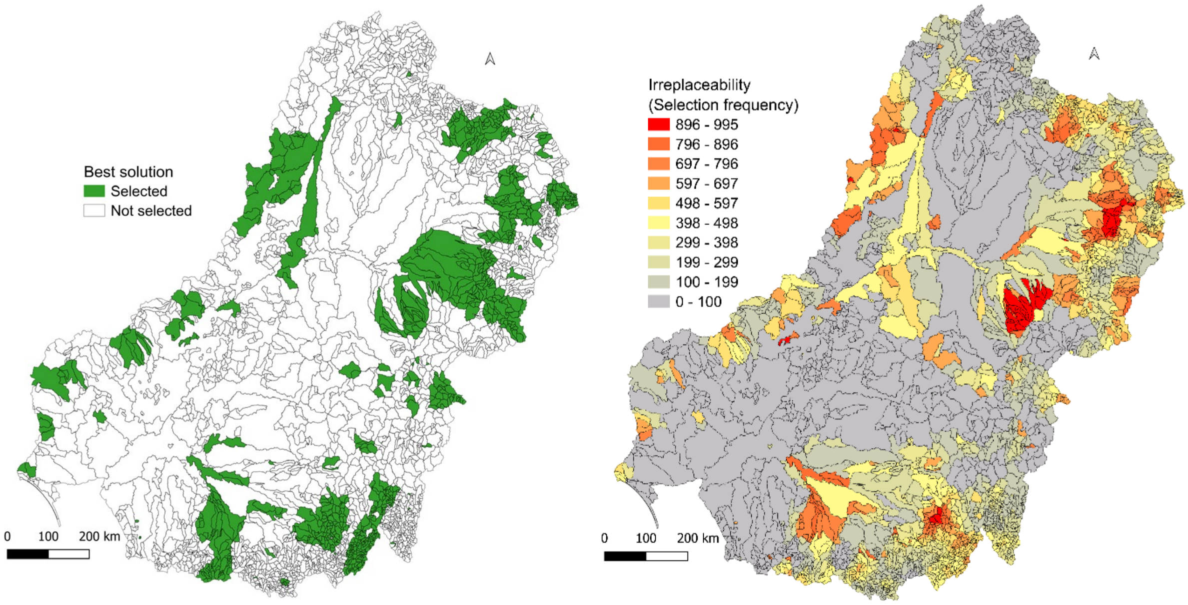


Figure 24. Marxan results showing the selected contracted catchments and irreplaceability score for high quality fish distributions with a 10% target.

Native plants

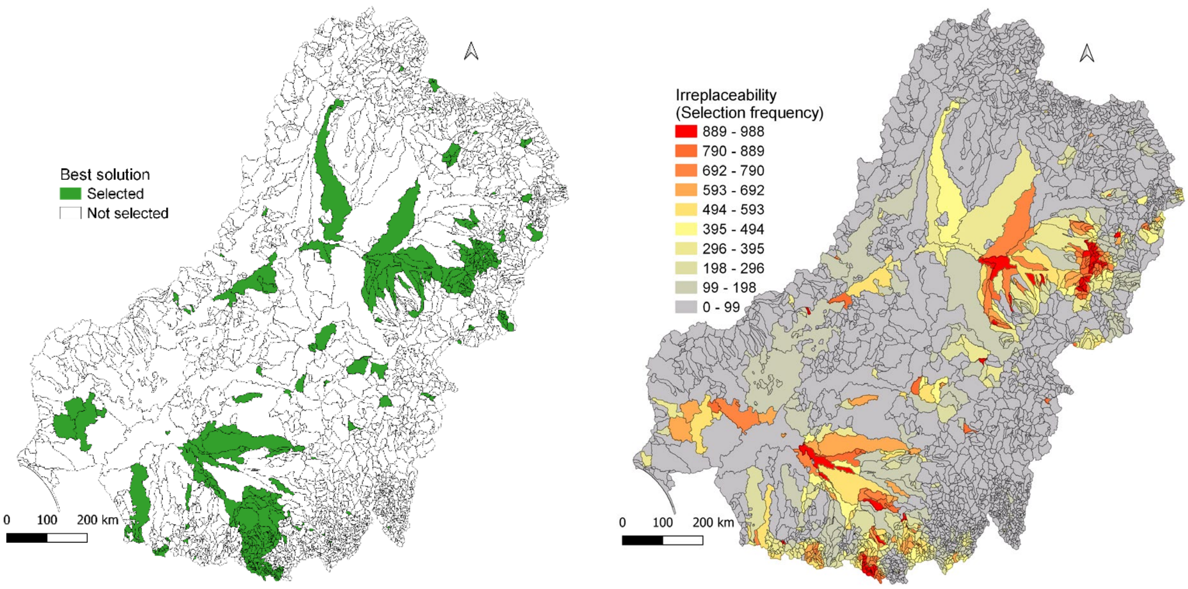


Figure 25. Marxan results showing the selected contracted catchments and irreplaceability score for native plants (299 species) with a 30% target.

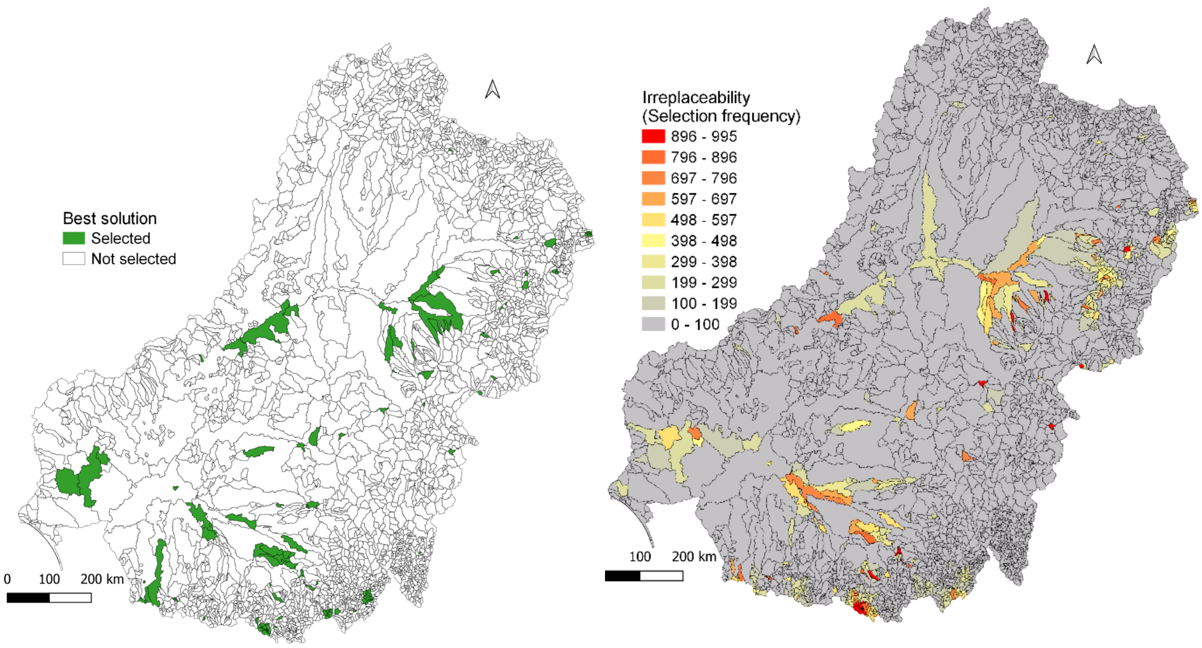


Figure 26. Marxan results showing the selected contracted catchments and irreplaceability score for native plants (299 species) with a 10% target.

Macroinvertebrates

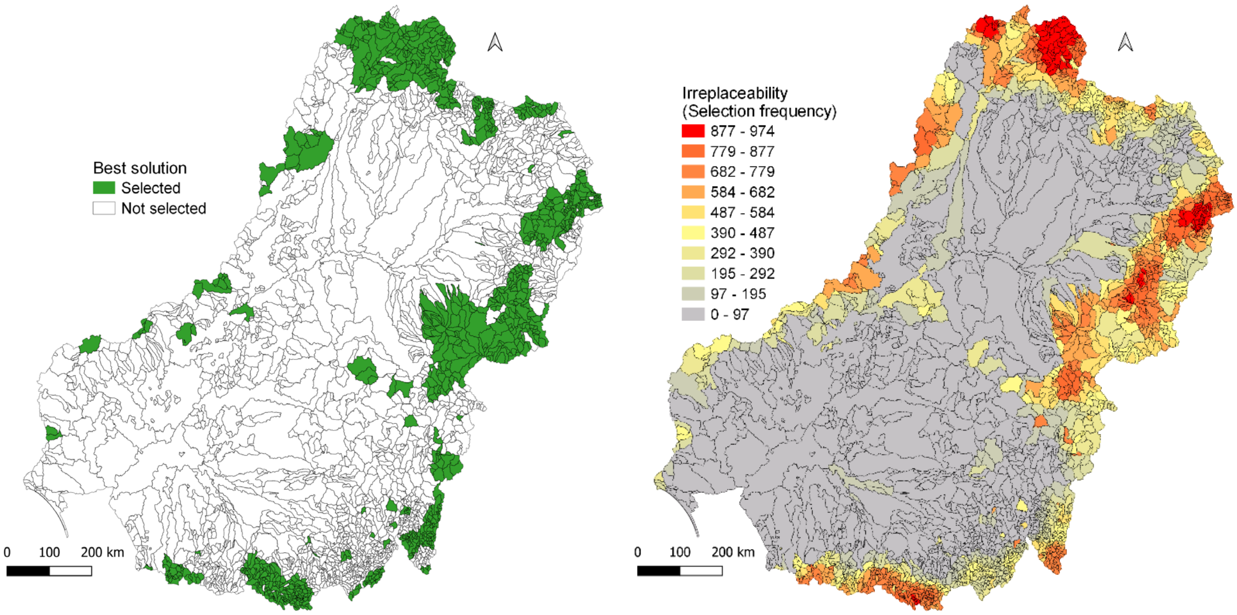


Figure 27. Marxan results showing the selected contracted catchments and irreplaceability score for macroinvertebrates (31 species) with a 30% target.

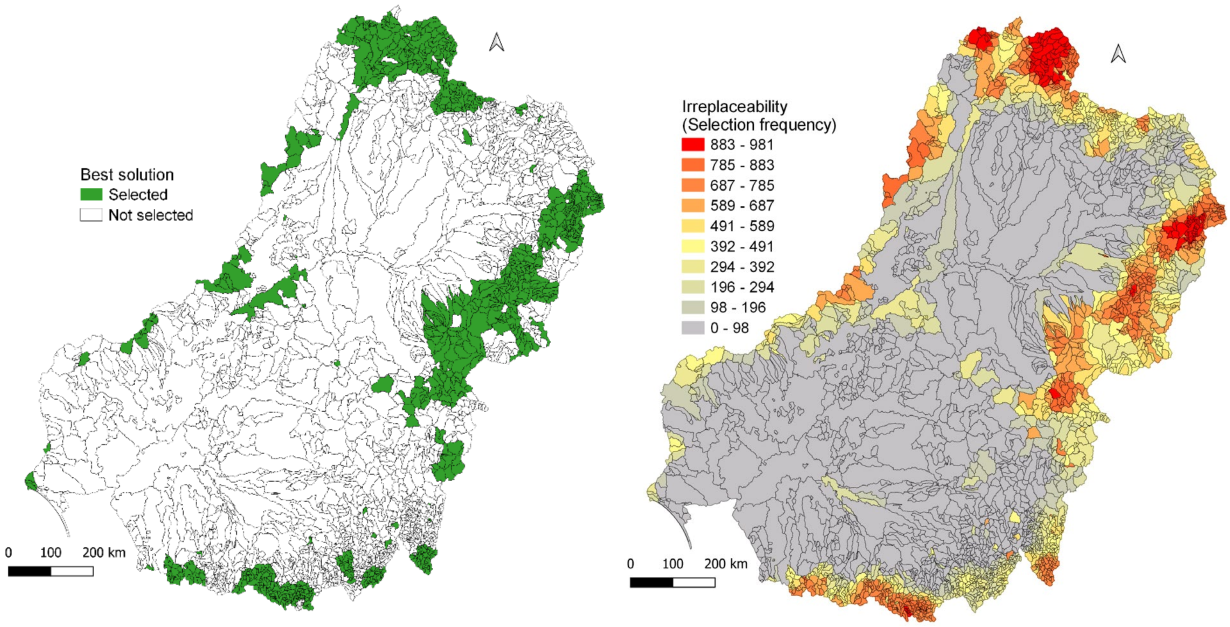


Figure 28. Marxan results showing the selected contracted catchments and irreplaceability score for macroinvertebrates (31 species) with a 10% target.

Objective 2- Priority wetland habitats for priority/threatened species and ecosystems within the Basin

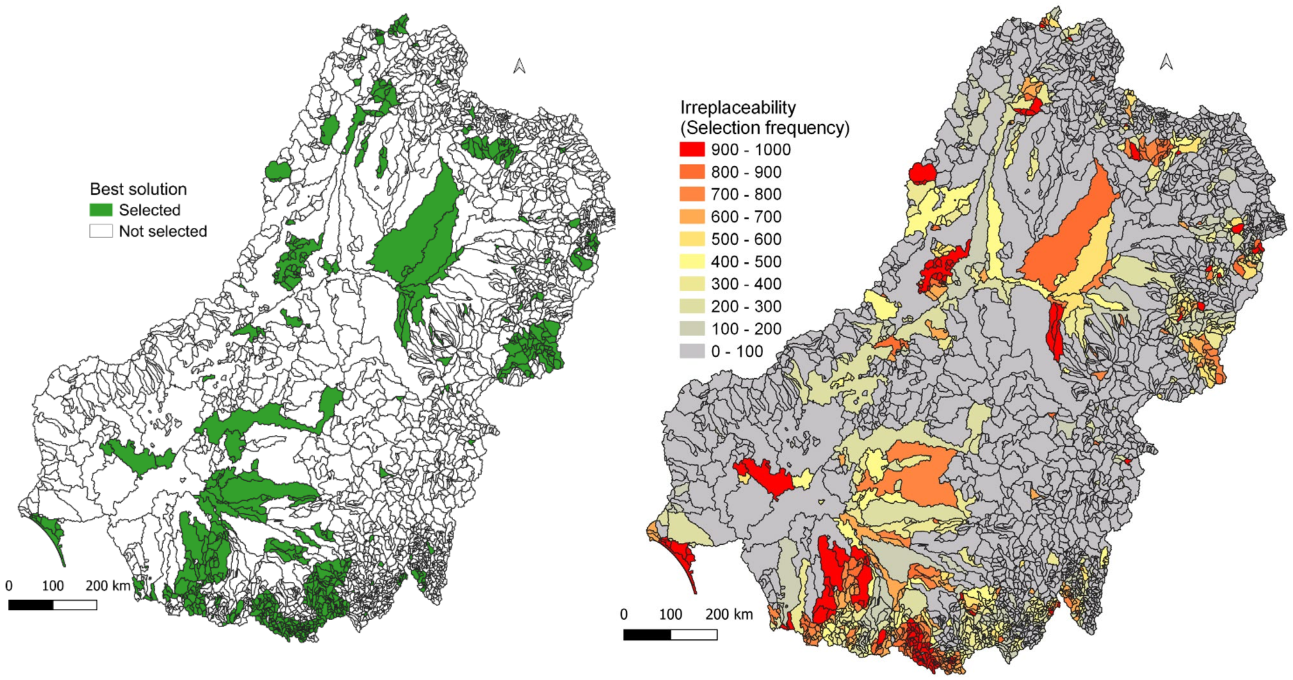


Figure 29. Marxan results showing the selected contracted catchments and irreplaceability score for wetland classes with a 30% target.

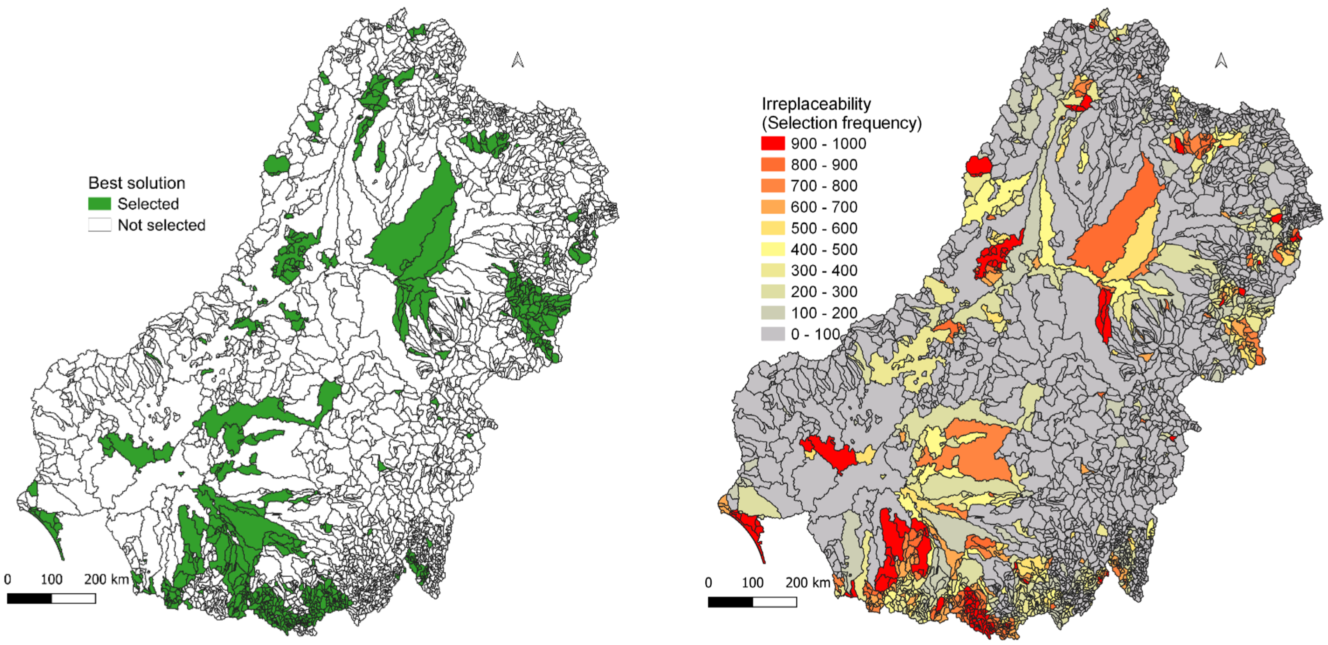


Figure 30. Marxan results showing the selected contracted catchments and irreplaceability score for ANAE wetland classes with a 10% target.

Objective 3- Priority areas for migratory species within CAMBA, JAMBA, ROKAMBA

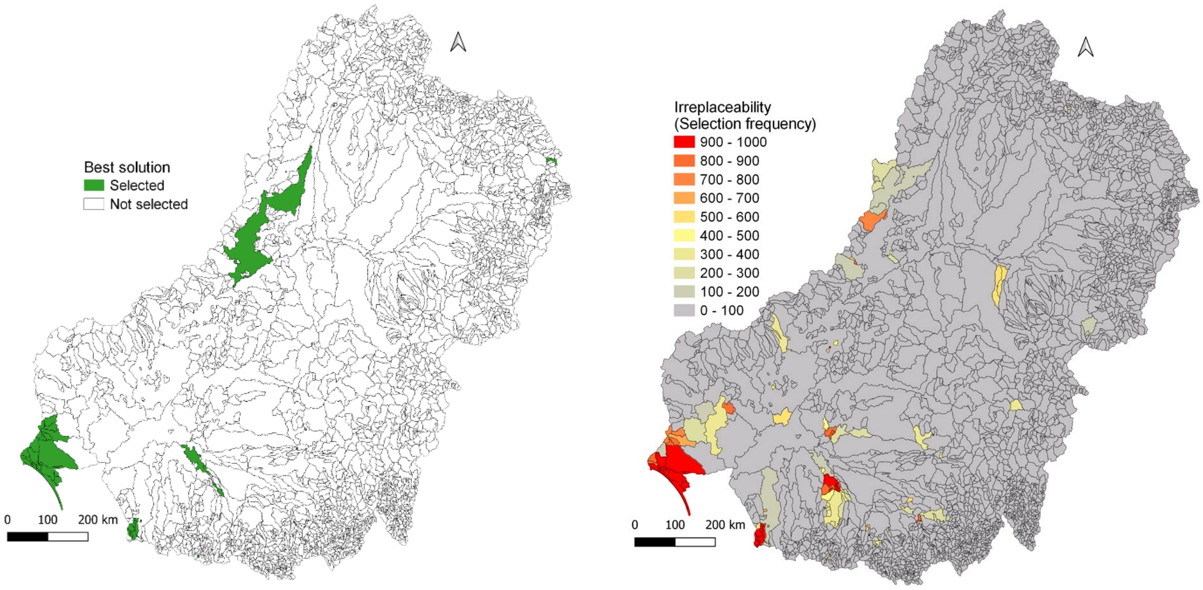


Figure 31. Marxan results showing the selected contracted catchments and irreplaceability score for water dependent migratory bird species with a 30% target.

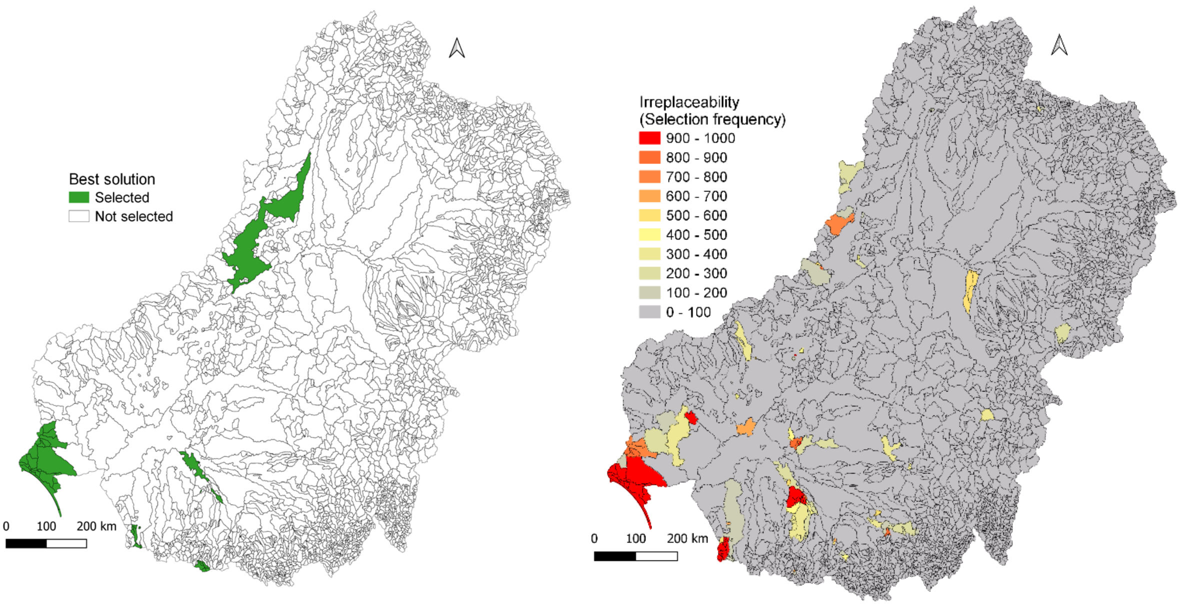


Figure 32. Marxan results showing the selected contracted catchments and irreplaceability score for water dependent migratory bird species with a 10% target.