Priority areas in the Redlands for Koala Conservation: Building a Model of Spatial Prioritisation using Zonation

Final Report

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Acronyms used in this report

Abbreviation	Description
ABF	Additive Benefit Function
DS	Distribution Smoothing
GIS	Geographic Information System
NSI	North Stradbroke Island
QYAC	Quandamooka Yoolooburrabee Aboriginal Corporation
RCC	Redland City Council
SEQ	South east Queensland
SMBI	Southern Moreton Bay Islands
SPRP	SEQ Koala State Planning Regulatory Provisions

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Executive Summary

The Redland City Council (RCC) local government area (the Redlands) falls within south east Queensland (SEQ), a bioregion that has been identified as high priority refugia for koala conservation under climate change (Adams-Hosking *et al*., 2015). Furthermore, with well-documented declines in koala populations throughout Queensland (e.g. Seabrook *et al*., 2011; McAlpine *et al*., 2015; Adams-Hosking *et al*., 2016) and its listing as vulnerable under national environmental law, it is vital that every effort is made to protect this species, and even more so in predicted climate refugia regions such as the Redlands. However, with the rapid urban growth in this area over past decades, effectively protecting koalas is a particularly challenging objective.

During this time period, koala numbers have declined sharply and their habitat in the Redlands is now highly fragmented, incorporating multiple land-uses such as urban residential, commercial, agricultural, marine and mining activities and protected areas. This report provides the results of a spatial prioritisation study in the Redlands on the Mainland and islands, in particular North Stradbroke Island (NSI), the only Redlands island where koalas occur. The key aim of this report was to determine which areas are highest priority for koala conservation actions, thereby providing decision support to the RCC regarding protecting the remaining koala populations in the region.

This koala project used the Zonation meta-algorithm, a framework for conservation prioritisation, to identify areas that are important for retaining koala habitat quality and connectivity. Several ‘scenarios’ were developed by ranking grid cells across the Redlands landscape to identify the highest priority areas for koala conservation. The results of this project should be seen as an analysis of koala conservation value which feeds into a broader land use planning framework. The outputs (scenarios) provided here give information that can support koala conservation planning decisions. Optimally, they need further interrogation at a fine scale, for example by overlaying the models with other land-uses, and on-ground investigations.

1 Introduction

The Redland City Council local government area contains two koala (*Phascolarctos cinereus*) populations located across the mainland area of Redlands and on North Stradbroke Island. The Redlands Koala Conservation Strategy (2016) and the Koala Conservation Action Plan (2016-2021) were implemented to guide management actions to retain a viable koala population, and conserve and manage koala habitat both on the mainland and NSI.

This Zonation analysis develops a hierarchy of koala conservation prioritisation throughout the Redlands and produces a series of maps for easy visual interpretation. It is hoped that these results will inform koala conservation planning management decisions pertaining to the Redland Koala Conservation Action Plan 2016-2021 and help facilitate the persistence of viable koala populations in the Redlands. The SEQ Koala State Planning Regulatory Provisions (SPRP) currently provide some level of koala habitat protection, but any rezoning of land may lead to further loss of koala food trees.

1.1 High-Level Objective

To develop a hierarchy of priority-ranked maps of conservation areas that will inform koala conservation planning strategies in the Redlands Mainland and North Stradbroke Island

1.2 Zonation

Zonation (Moilanen *et al.*, 2005) is a tool for broad-scale, high-resolution spatial conservation planning using primarily GIS raster data. It is capable of data rich, large or small-scale, high resolution spatial conservation prioritization. For example, Zonation has used IUCN (International Union for the Conservation of Nature) distribution data for 8463 species of mammals, birds and amphibians in the Western Hemisphere (Moilanen *et al.*, 2013a), protected areas in Finland (Mikkonen and Moilanen 2013) and Melbourne's conservation areas (Gordon *et al.,* 2009). Although Zonation studies have been done on all continents, most studies are in countries that have a tradition of using ecological information in conservation decision making. Analysis can be equally done with high-resolution (e.g. 50 m grid cells) data or at coarse resolution (e.g. 100 km grid cells), with the number inside each grid cell telling the local occurrence level of each input feature.

Zonation's basic question: Where to protect?

According to metapopulation-dynamic principles (Hanski, 1998), Zonation assumes that species persistence is correlated with abundance and connectivity, and provides a number of ways of incorporating the connectivity of priority areas in a species-specific manner. When it is used in a real life planning context, it is a decision-support tool, rather than a decision-making tool. Zonation analyses are useful insofar as they can provide credible information that is relevant for the planning problem at hand. As with other similar modelling tools, Zonation will usually not provide a single correct answer, but rather a suite of alternative, and often closely related, answers (referred to as scenarios in this study) that should always be interpreted in the context of the goals and objectives defined. It produces a hierarchical prioritization of the landscape that is balanced across many factors. The outputs, primarily ranking maps, when viewed in conjunction with other research findings, can inform koala conservation planning decisions in the Redlands.

Zonation analyses typically require considerable time in the pre-processing and input of the spatial feature data. This is because of the complex interplay between setting of the high-level objectives, identifying the factors relevant for addressing these objectives and processing the actual data available for doing so (Fig. 1).

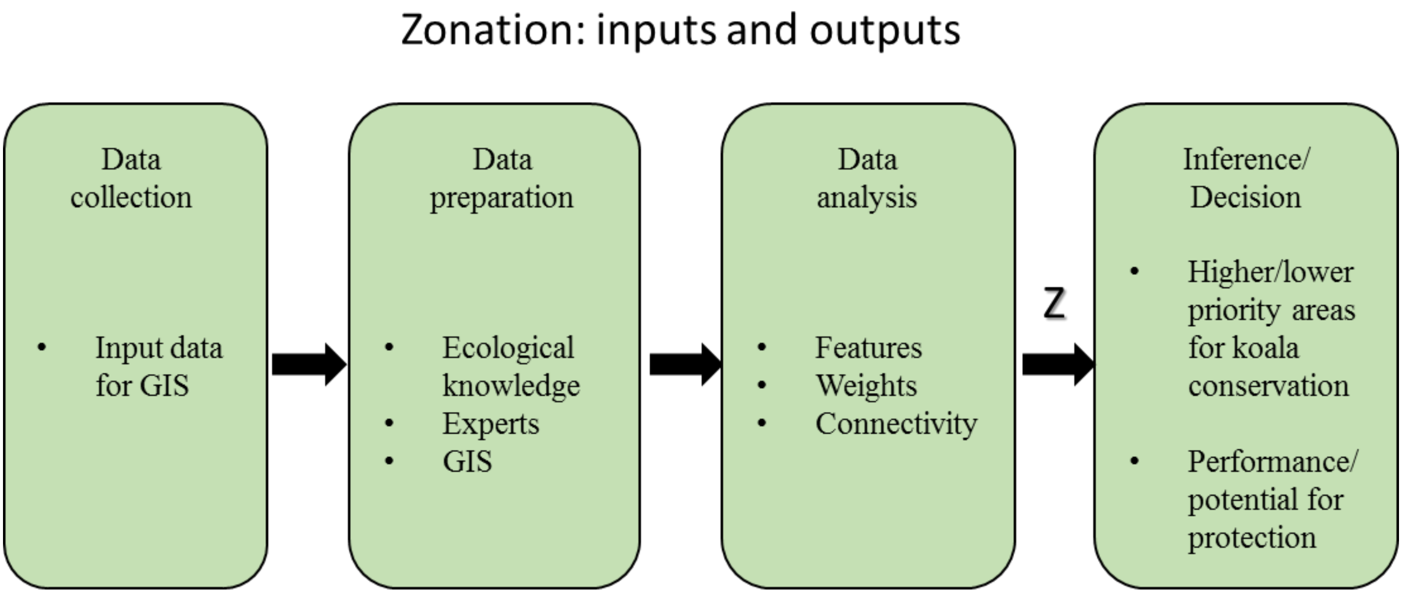

Figure 1 Schematic diagram of the Zonation process representing, from left to right: RCC data - biodiversity and threat features spatially represented as GIS layers for Zonation; pre-processing-calculating features in grid cells using GIS; running Zonation and analysis of results; visualization and interpretation of Zonation outputs and decision-making. Adapted from Moilanen *et al.*, (2013b).

Typical spatial (conservation) prioritization problems addressed with Zonation include:

- Identification of a well-balanced set of ecologically important areas for reserve network expansion
- Spatial allocation of habitat maintenance or restoration
- Identification of ecologically least important areas for impact avoidance of development projects
- Targeting of financial incentives for conservation
- Planning for climate change mitigation and adaptation
- Planning of biodiversity offsets when impact avoidance does not suffice

Trade-offs between biodiversity, socio-economic and political features can be defined in Zonation by assigning higher weights to beneficial factors and lower weights to constraint factors (features that should be minimized to avoid conservation conflicts) (Zwiener *et al*., (2017). In this koala project, beneficial factors include, for example, high value bushland patches, wildlife corridors and Land for Wildlife properties and constraint (or threat) factors include roads, areas of high dog ownership and areas with pre-existing approval for development.

2 Methods

2.1 Study area

The study was conducted within the Redland City Council local government area. This encompasses an area of approximately 520 km^2 with North Stradbroke Island comprising approximately 270 km^2 (Fig. 2).

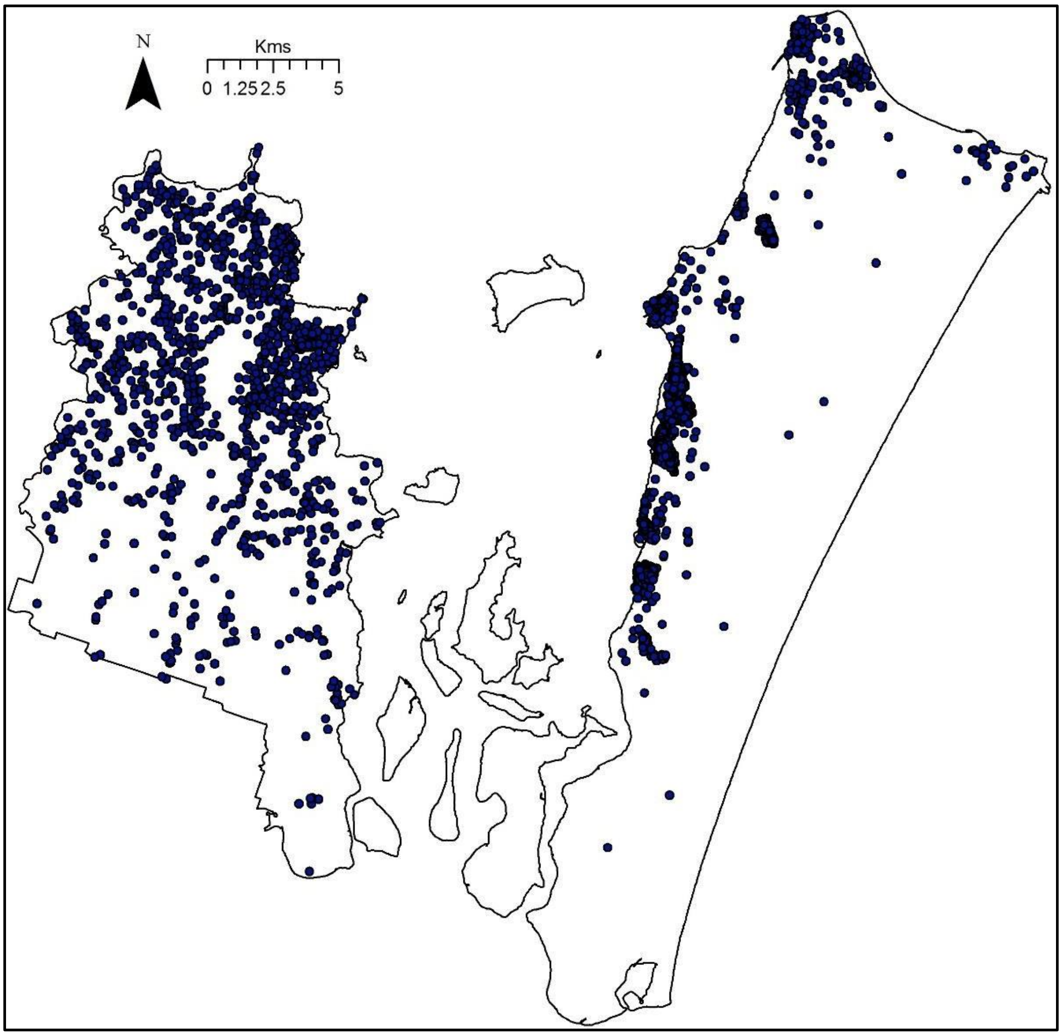

Figure 2 Redland City Council study area with koala records (2010-2017) on the Mainland and NSI indicated by dots.

2.2 Zonation meta-algorithm

Zonation Version 4 (Moilanen et al., (2014) was used for this project. The Zonation method comprises two separate components; the Zonation meta-algorithm and the cell removal rule (= definition of marginal loss). The meta-algorithm is described as:

1. Start from the full landscape. Set rank $r = 1$.
2. Calculate marginal loss following from the removal of each remaining site i, δi. Complementarity is accounted for in this step.
3. Remove the cell with smallest δi set removal rank of i to be *r*, set $r = r+1$, and return to 2 if there are any cells remaining in the landscape.

For a Zonation analysis, the landscape of interest which in this case is the Redlands, was divided into grid cells, (or planning units), and the spatial feature data (i.e. koala, biodiversity, and threat) were calculated for each grid cell using tools in ArcGIS. Grid cells can be any size, depending on the requirements of the project. For this koala study, a grid cell size of 50 x 50 m was decided upon because it aligned with the RCC Wildlife Connections Plan model mapping. Early cells that were removed had the lowest ranking and the cells removed last (top-ranked) had the highest conservation value in the landscape. This maintained structural connectivity in the remaining landscape (Moilanen *et al.*, 2005).

Zonation starts from the assumption that protecting everything would be best for conservation

2.3 Cell removal rule

The additive benefit function (ABF) cell removal rule was used for this analysis. The ABF calculates conservation value as additive across features and cells. An increase in number of occurrences of a feature across cells translates to an increase in the feature-specific value across cells (Arponen *et al.*, 2012). The cell with the smallest sum value will be removed first. The parameter for this cell removal rule was the exponent (x) of the species-specific power function (r_{jx}). The exponent x = 0.25 was selected. It determined the rate of loss of conservation value from the remaining landscape as cells were removed.

2.4 Data collection-biodiversity features and threats

After consultation with RCC personnel, ten koala biodiversity features and eight koala threat features (n = 18) supplied by RCC were chosen for the model (Tables 1, 2). Too many overlapping features can confound the Zonation analysis and some were therefore not included. For example, the road threat features used in the models acted as proxies for residential areas and district centres. Koala records were obtained from RCC (koala hospital data), records from RCC processed by Biolink, Sibelco and the Sunshine Coast University (n = 12,231). For this analysis, only more recent records (2010-2017) were utilised with the exception of some NSI records that were undated but considered important to include in the analysis due to the paucity of koala records on some areas of the island.

2.5 Data preparation-pre-processing

The absolute value of a raster cell in a given raster feature can only be meaningfully compared to the values of the other cells within that same feature grid. Here, binary presence/absence (0, 1) of a habitat/threat feature were calculated for each of the 18 feature data values in each 50 x 50 m grid cell (n = 218,774) using ArcMap 10.5.1. These files were then converted to raster format. All the spatial input data for Zonation needed to have exactly the same spatial extent and resolution.

2.6 Weight parameter

Weight-setting is not an exact science because subjective valuation is involved. It can, for example, be a political decision or based on expert opinion, and there is no general method for determining correct weights. In this case, weight setting was decided upon after consultation with relevant RCC personnel and using the Zonation operator's knowledge of landscape ecology and koala ecology. However, while weight-setting can be made arbitrarily complex, the construction of the Zonation algorithm is such that a sensible and efficient balance between features is obtained even with the use of equal weighting for all features. For this analysis, equal weights and varied weights were used to generate a range of solutions (Tables 1, 2).

Table 1 Biodiversity features used in the analysis, weighting assigned and reasons for selection

Biodiversity Feature	Weight	Rationale
Koala presence	1	Species of interest
Koala Primary Habitat (RE's)	1	New City Plan Existing habitat
Koala Secondary Habitat (RE's)	1	New City Plan Existing habitat
Wildlife Connections Plan	1	New City Plan Existing habitat
Urban Koala Tree Mapping	1	New City Plan Existing Habitat
Mining lease	1	Existing/future habitat (rehab/natural regen)
Koala habitat protection program.	0.5	Landholder sympathy - not necessarily existing habitat
Koala SPRP mapping (GHD Bushland High Value)	0.5	Used in Redland Planning Scheme V 7.1
Koala SPRP mapping (GHD Bushland Medium Value)	0.5	Used in Redland Planning Scheme V 7.1
Koala SPRP mapping (GHD Bushland High value Rehabilitation)	0.5	Used in Redland Planning Scheme V 7.1

Table 2 Threat features used in the analysis, weighting assigned and reasons for selection. They may be either emerging or existing threats.

Threat Feature	Weight	Rationale
Roads (major)	0.25	Direct threat, proxy for urban areas
Dogs	0.25	Direct threat
Roads (minor)	0.25	Direct threat, proxy for urban areas
Train line	0.25	Direct threat
Priority Development	0.25	Will increase traffic, encroach on open space
Emerging Urban Community	0.25	Will increase traffic, dogs, encroach on open space
Island Industry	0.25	Encroaches on open space/conservation areas
Community Purposes	0.25	Encroaches on open space/conservation areas

2.7 Connectivity-Distribution Smoothing

Distribution smoothing (DS) was chosen for the analysis because this parameter assumes that fragmentation is generally bad for all features and it always favours uniform areas over patchy ones. It is a feature-specific aggregation method which retains areas that are well connected to others, thus resulting in a more compact solution. Cells that are surrounded by many occupied cells receive a higher value than the isolated ones. Due to the fragmented nature of koala habitat in the Redlands, two narrow but realistic (e.g. Cristescu *et al*., 2011; Dique *et. al*., 2003) dispersal distances were chosen to represent: 1) 150 m and 2) 1 km. This was calculated in metres as alpha. 150 <- 2 / 150 = 0.0133 and alpha. 1000 <- 2 / 1000 = 0.002. A three km dispersal distance was eliminated after conducting the sensitivity analysis.

2.8 Sensitivity analysis

More than 20 different priority ranking scenarios were generated during the initial Zonation sensitivity analysis, using dispersal distances of 150 m, 1 km and 3 km. These were combined with different weightings, and incorporated both biodiversity features only and biodiversity features combined with threat features. The koala feature was also omitted to assess if this was introducing bias into the models due to sighting records often being concentrated in certain areas. The 3 km dispersal distance was eliminated because it produced results that were too coarse in this fragmented landscape. The six final Zonation models chosen for this report (Table 3) were considered to represent a range of decision-support scenarios that can be compared and examined post-processing in further detail.

Table 3 Final Scenarios presented for the Zonation analysis. Biodiversity features as shown in Table 1 (above) and threat features as shown in Table 2 (above).

Scenario	Features	Smoothing (m)	Weighting
1	Biodiversity features and threats (n = 18)	150	As per Tables 1& 2
2	Biodiversity features and threats (n = 18)	1000	As per Tables 1& 2
3	Biodiversity features omitting koala (n = 9)	150	As per Table 1
4	Biodiversity features omitting koala (n = 9)	1000	As per Table 1
5	Biodiversity features including koala (n = 10)	150	As per Table 1
6	Biodiversity features including koala (n = 10)	1000	As per Table 1

2.9 Performance curves

Performance curves were automatically produced and exported for each feature during the Zonation analysis. These curves were directly linked with the priority rank map. The performance curves described how the coverage of the distribution (summed occurrences) of the features declined when the part of the landscape under conservation became smaller. Performance curves start from 1.0 because the full landscape included the full distribution of the biodiversity features. At the other end, no areas were chosen, and correspondingly, the protection level for the feature was zero.

3 Results

Scenarios 1 (Fig. 3), 3 (Fig. 5) and 5 (Fig. 7), with the dispersal distance of 150 m, identified finer-scale, more patchy priority rankings in the landscape, while Scenarios 2 (Fig, 4), 4 (Fig. 6) and 6 (Fig. 8), with the dispersal distance of 1000 m (1 km), provided more smoothed results. Scenario 1, which incorporated all biodiversity features and threat features, selected more highly-ranked areas for example in Thorneside, Birkdale and Wellington Point than Scenario 5 that incorporated biodiversity features only. When koalas were omitted from the model (Scenarios 3, 4) there were reduced areas of high priority such as Ormiston and Cleveland compared with Scenarios 5 and 6 where koalas were included.

On North Stradbroke Island the scenarios were influenced by the presence or absence of the koala feature, medium quality habitat mapping and mining areas, which were weighted as biodiversity features due to their habitat rehabilitation potential.

The performance curves showed that all scenarios indicated a threshold of approximately 80% for protected landscape, after which the proportion of biodiversity distributions declined sharply as more protected landscape was removed (see Appendix 1).

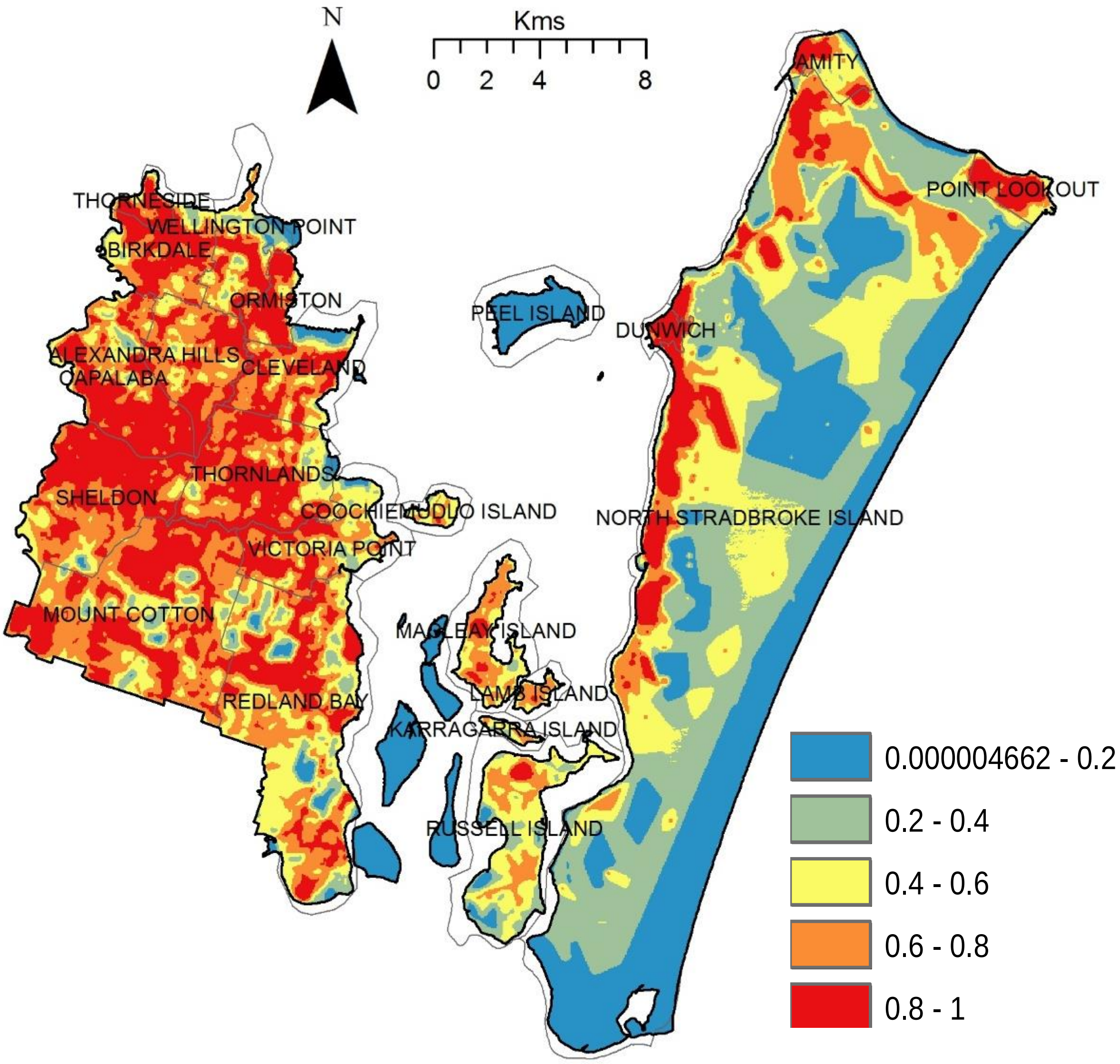

Figure 3 Zonation ***Scenario 1*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features and threats were included (Table 3 above) with weights as per Tables 1 & 2 above and a smoothing dispersal distance of 150 m.

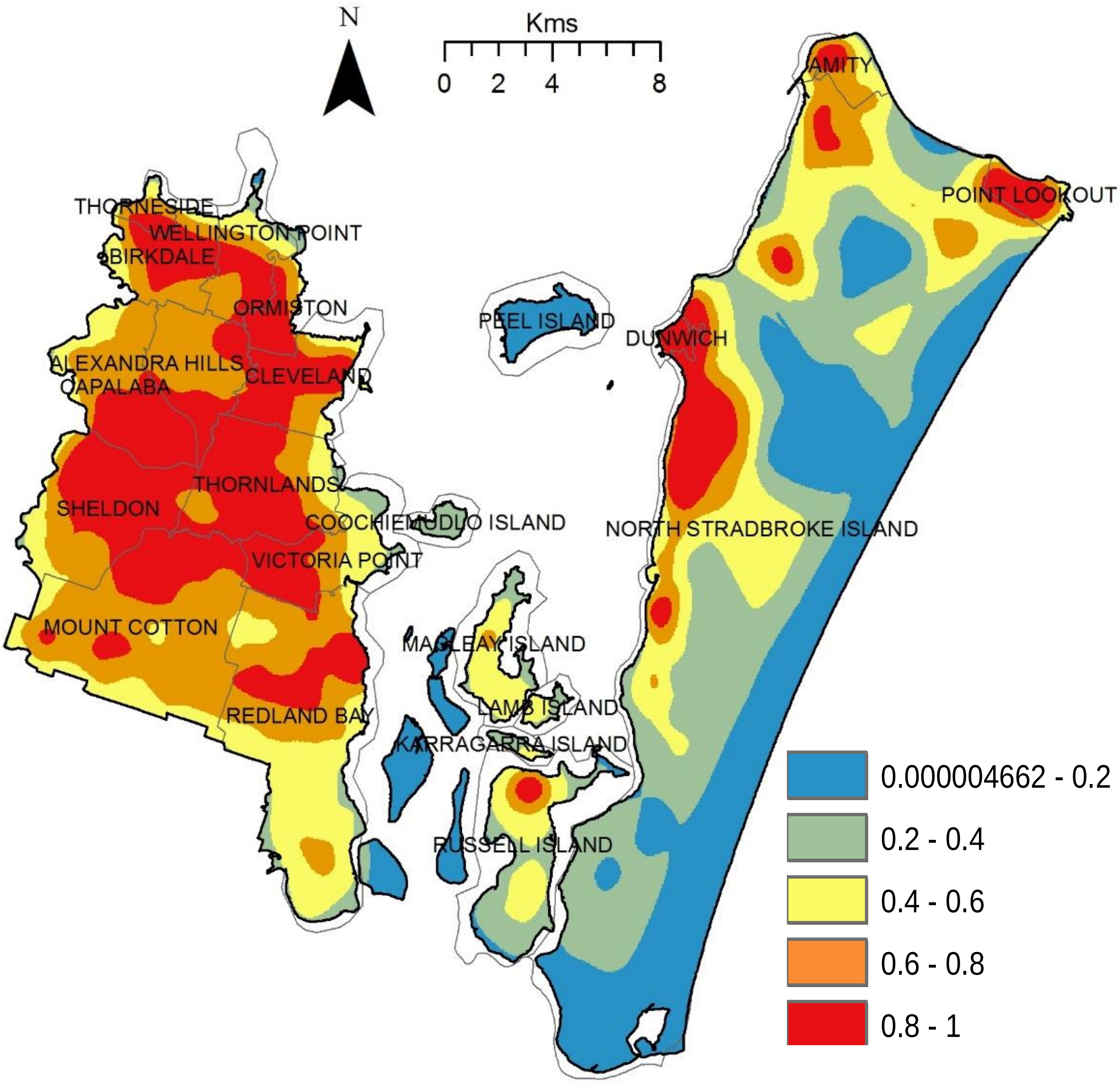

Figure 4 Zonation ***Scenario 2*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features and threats were included (Table 3 above) with weights as per Tables 1 & 2 above and a smoothing dispersal distance of 1000 m.

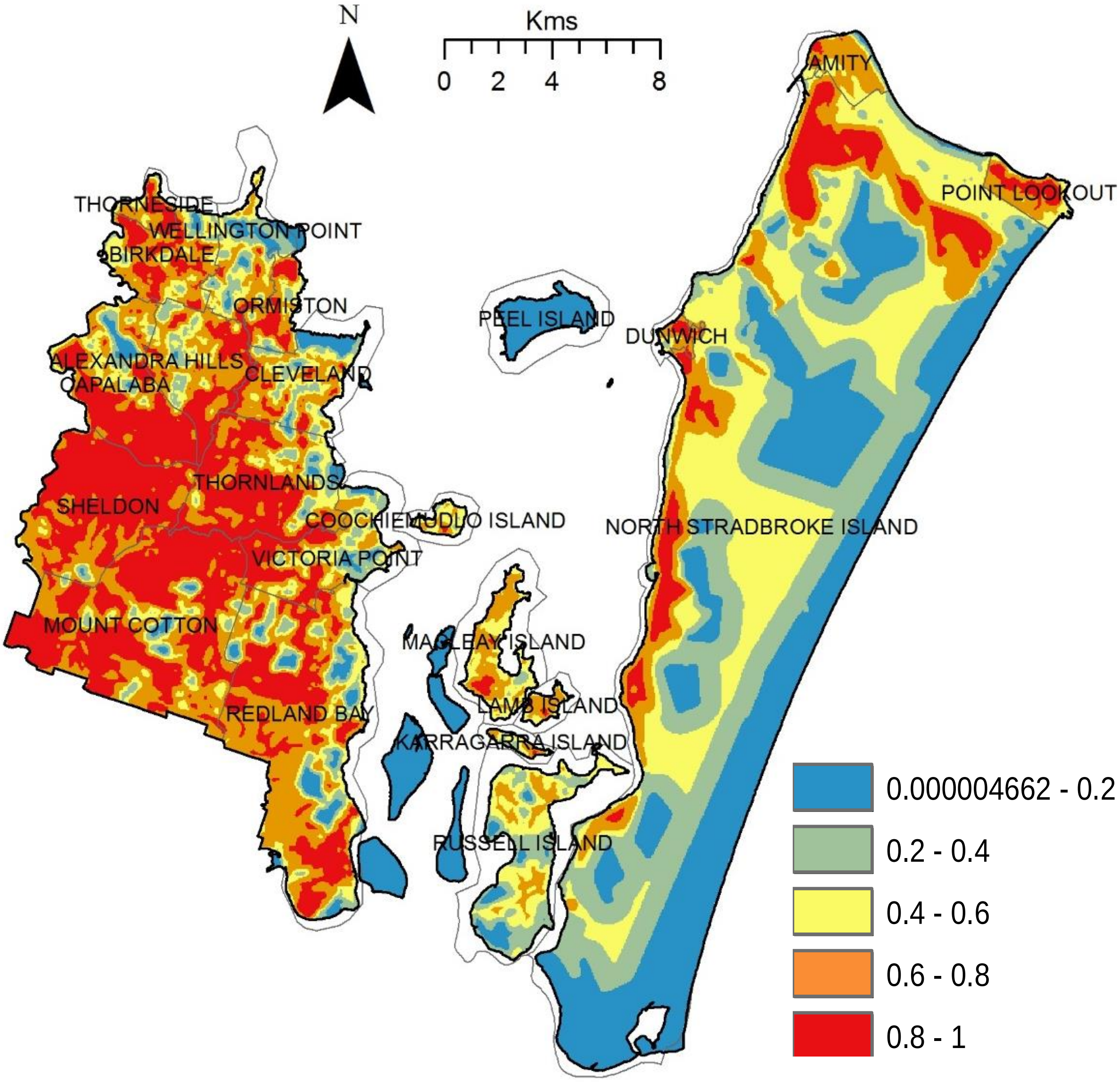

Figure 5 Zonation ***Scenario 3*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features except the koala were included with weights as per Table 1 above and a smoothing dispersal distance of 150m.

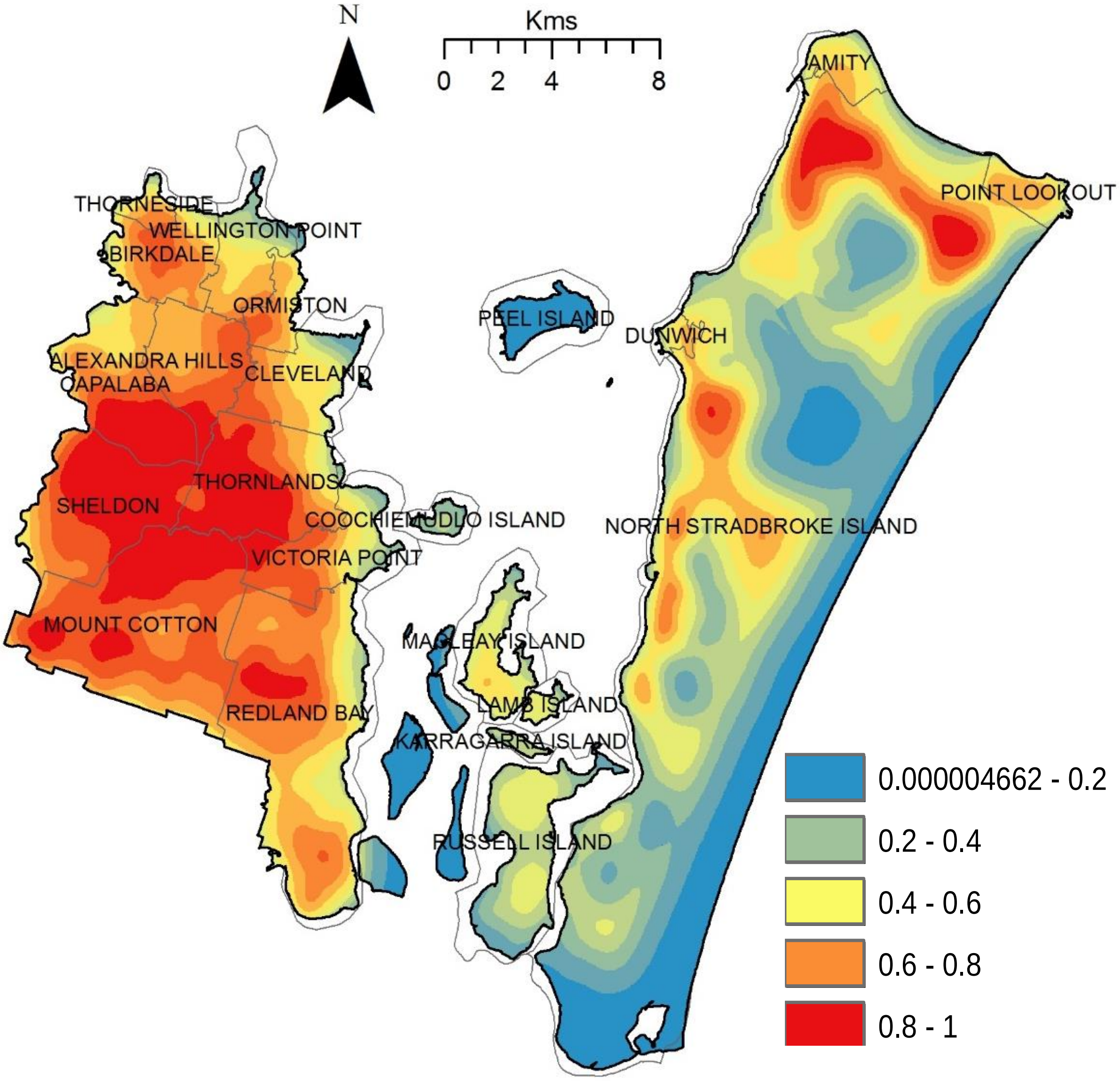

Figure 6 Zonation ***Scenario 4*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features except the koala were included with weights as per Table 1 above and a smoothing dispersal distance of 1000 m.

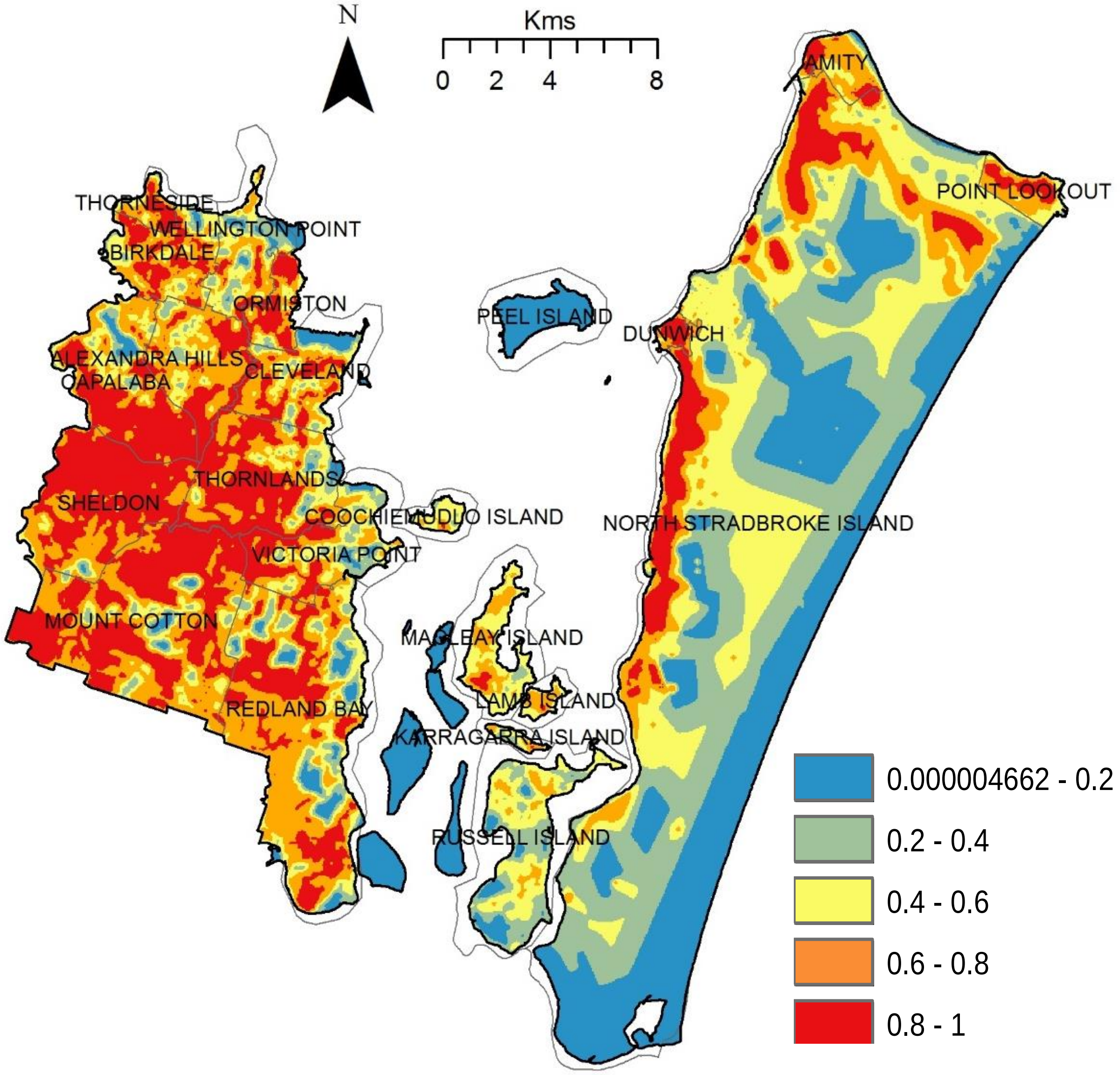

Figure 7 Zonation ***Scenario 5*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features and the koala were included with weights as per Table 1 above and a smoothing dispersal distance of 150 m.

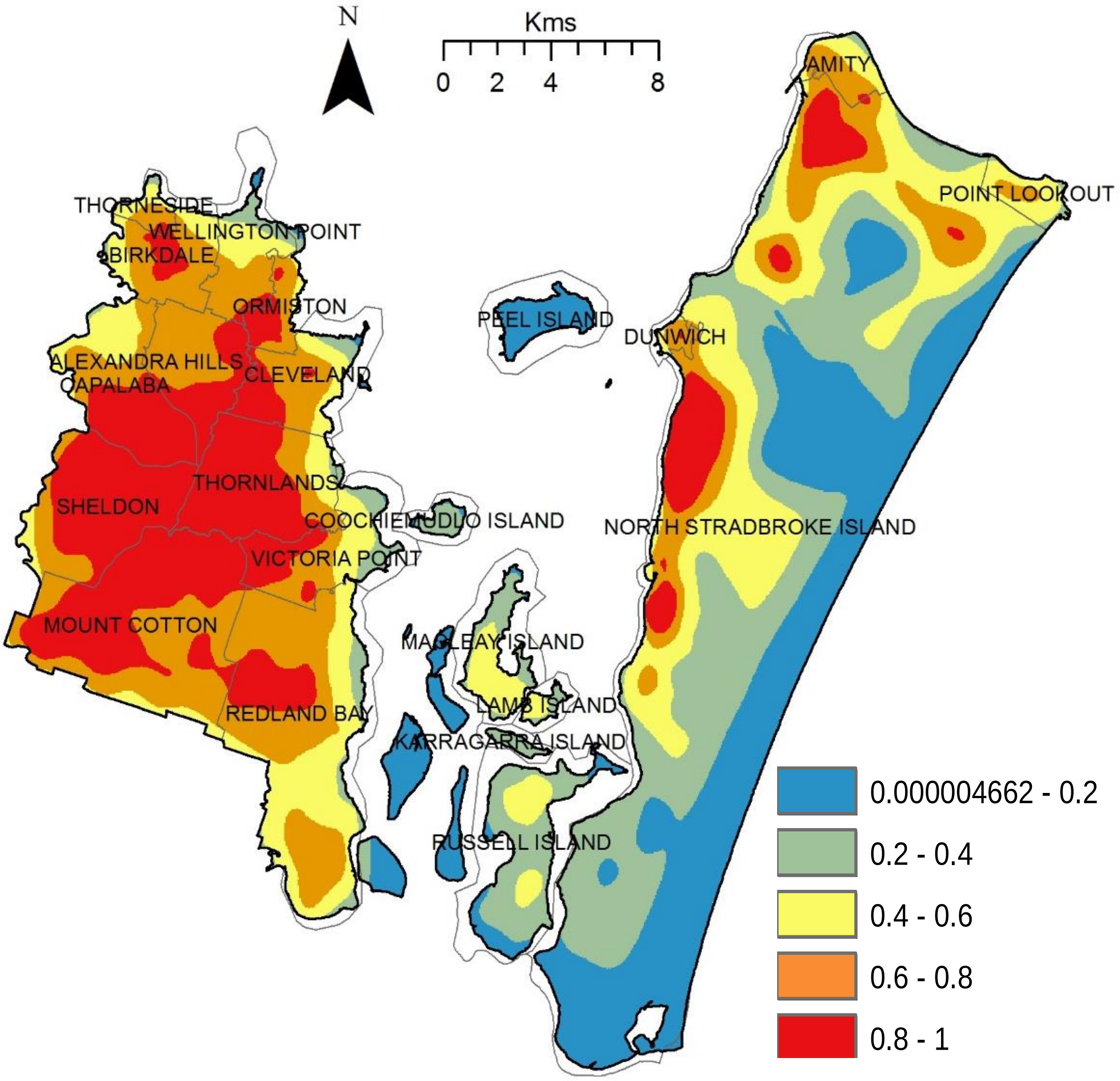

Figure 8 Zonation ***Scenario 6*** with top 20% priority-ranked areas in red and lowest ranked areas in blue. All biodiversity features and the koala were included with weights as per Table 1 above and a smoothing dispersal distance of 1000 m.

4 Advantages and Limitations

Some key advantages of the Zonation approach are the hierarchy of balanced solutions, which promotes stability, and its ability to balance a large number of different factors in spatial conservation prioritization. Zonation is different to other conservation planning software because it follows the general principles of aggregating conservation value, where trade-offs are implicitly defined between biodiversity features via priorities (weights) and connectivity responses. Zonation also offers a smooth workflow with GIS and its main results can be summarized and easily visualised in a map and a graph.

Zonation does not do statistical species distribution modelling, meaning that it does not predict the probability of a species occurring in a particular place.
A limitation of Zonation is that it is based on analysis of static biodiversity patterns, and the analysis process does not involve any dynamic process-based model of biodiversity. In relation to this koala study, it is not concerned with dispersal processes or stochastic events such as disease or an extreme weather event. Finally, as is the case with any similar modeling tools, Zonation depends on available and good quality data, or the analysis may be compromised.

5 Discussion

Spatial conservation prioritization, as conducted for this koala project, is usually done within a wider decision-making context in which the needs of many land users and stakeholders are acknowledged (Ferrier and Wintle, 2009). Spatial priority maps generated using a tool such as Zonation would usually be only one component influencing conservation resource allocation and action, and inputs from experts and stakeholders would influence the ultimate decisions. Urban planners require tools to assist with strategic decision making, based on a scientific understanding of landscape patterns, species requirements and development pressures (Gordon *et al.,* 2009).

One of the targets of the National Reserve System Strategy 2009-2030 is to have core areas established for the long-term survival of threatened ecosystems and threatened species habitats in each of Australia's bioregions by 2030 (Australian Government, 2018). The Redlands is in the south east Queensland bioregion and can make a significant contribution to the persistence of the bioregion's threatened koala population by taking steps to conserve adequate habitat for koalas, and protect them from cars and dogs. Scientific evidence supports full protection of at least 30% of the world's ocean to reverse existing adverse impacts (IUCN, 2017) and Target 11 of the Aichi Biodiversity Targets states that by 2020, at least 17 per cent of terrestrial and inland water areas are protected (Convention on Biological Diversity, 2010). Based on these guidelines, an aim to protect between 20-30% of Zonation's top-ranked koala habitat in the Redlands may be realistic and achievable.

The variation between the six scenarios developed for this study demonstrates the importance of investigating various scenarios to find commonalities in prioritised areas. All scenarios in the sensitivity analysis and chosen for final examination suggest a general pattern of high priority 'hotspot' areas in the Redlands. Furthermore, on North Stradbroke Island, the closures of mines and evidence of koalas inhabiting these regenerating areas suggests that NSI may be a stronghold for koalas now and in the future.

While no koalas inhabit the Southern Moreton Bay Islands (SMBI), primary koala habitat exists on some, so it was decided to model these areas also, in case of future planning. For example in Tasmania, insurance populations of healthy Tasmanian devils are being held on Maria Island, an area they are not thought to have originally inhabited (Tasmanian Government, 2018) prior to being reintroduced to suitable areas of habitat in Tasmania. Furthermore, a genetic study found that to enable the island devil population to retain 95% gene diversity until 2056, provided the translocated animals breed, ten new females should be introduced every 3 years (McLennan *et al.*, 2018).

Zonation's scenarios 1 and 3 indicated high priority areas on the SMBIs of Macleay and Russell Islands. Assisted colonisations are increasingly being used to recover endangered or functionally extinct species and high quality habitat at release sites is known to improve the success of assisted colonisations (Rendall *et al.*, 2018). As in the Tasmanian example, translocations can be seen as temporary measures to safeguard animals while improving their health and genetic diversity prior to relocating them to appropriate habitats in their former ranges. It is acknowledged that any translocations/assisted colonisations of koalas would require exhaustive prior investigations, including incorporating the cost of these actions (Helmstedt & Possingham, 2016). Furthermore, extensive ground-truthing and ecological assessments as well as genetic management would be essential components of any translocation programs.

Climate change has exacerbated the use of human-assisted colonization for species. It is now being adopted by some conservationists but remains controversial (Abeli *et al.*, 2014). Some negative aspects of assisted colonisation include the risk of the translocated species becoming invasive, the risk of accidental introduction of pathogens and pests associated with the translocated species, disruption of ecosystem functioning resulting when species separated by geographical and evolutionary distance are suddenly brought together and low long-term successful rate of translocations (Abeli *et al.*, 2014).

The purpose of utilising a decision-support tool such as Zonation is not always to produce a detailed conservation plan for a region. In this case for the Redlands, it has been used to identify priority areas of the landscape that could be subjected for more detailed analysis and planning together with stakeholders.

The Redland Koala Conservation Strategy 2016 aims to implement actions for koala conservation on the Redlands Mainland and on North Stradbroke Island through numerous actions such as community engagement, education, minimising threats to koalas and enhancing and protecting koala habitat (Redland City Council, 2016). This study in particular addresses the last point by identifying areas of highest priority for koala conservation in the Redlands. It is useful to note that Zonation can also be used to identify the areas of the landscape where human activity would cause the *least* harm to koalas.

This study demonstrates how high priority areas for koalas in the Redlands can be incorporated into the various stages of urban landuse planning to achieve better outcomes for this vulnerable species. Further spatial examination can be achieved dynamically by using GIS programs to overlay the priority rank maps with distribution maps of other features of interest, for example urban residential and future development areas. Viewing the results in Google Earth is another useful way of interpreting the Zonation outputs (see Appendix 2).

As Redland City Council strives to balance urban growth with protecting the region's remaining koalas, it is recommended that these priority maps be used to guide ground-truthing, in conjunction with consideration of the complex factors involved in multiple land-use demands.

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6 References

Abeli, T., Dalrymple, S.E., Mondoni, A., Orsenigo, S., Rossi, G. (2014) Integrating a biogeographical approach into assisted colonization activities is urgently needed, *Plant Biosystems*, **148** (6), 1355-1357.

Adams-Hosking, C., McAlpine, C.A., Rhodes, J.R., Moss, P.T. & Grantham, H.S. (2015) Prioritizing Regions to Conserve a Specialist Folivore: Considering Probability of Occurrence, Food Resources, and Climate Change, *Conservation letters*, **8 (3)**, 162-170.

Adams-Hosking, C., McBride, M.G., Baxter, G., Burgman, M., de Villiers, D., Kavanagh, Rodney, Lawler, I., Lunney, Daniel, Melzer, Alistair, Menkhorst, Peter, Molsher, Robyn, Moore, Ben D., David Phalen, David, Jonathan R. Rhodes, Jonathan R., Todd, Charles, Whisson, Desley and Clive A. McAlpine (2016) Use of expert knowledge to elicit population trends for the koala (*Phascolarctos cinereus*), *Diversity and Distributions*, **22**, 249–262.

Australian Government, Department of Environment and Energy (2018) *National Reserve System protected area requirements*. Available from: https://www.environment.gov.au/land/nrs/about-nrs/requirements. Accessed November, 2018.

Convention on Biological Diversity (2010) *Aichi Biodiversity Targets*. Available from: https://www.cbd.int/sp/targets/default.shtml. Accessed November 2018.

Cristescu, R., Ellis, W., de Villiers, D., Lee, K., Woosnam-Merchez, O., Frere, C., Banks, P.B., Dique, D., Hodgkison, S., Carrick, H., Carter, D., Smith, P. & Carrick, F. (2011) North Stradbroke island: an island ark for Queensland's koala population? *Proceedings of the Royal Society of Queensland*, 309-334.

Dique, D.S., Thompson, J., Preece, H.J., de Villiers, D.L., & Carrick, F.N. (2003) Dispersal patterns in a regional koala population in south-east Queensland, *Wildlife Research*, **30**, 281-290.

Ferrier, S., & Wintle, B.A. Quantitative approaches to spatial conservation prioritization: matching the solution to the need. In: A. Moilanen, K.A. Wilson, H.P. Possingham (Eds.), *Spatial Conservation Prioritization: Quantitative Methods & Computational Tools*, Oxford University Press, Oxford (2009), 1-13.

Gordon, A., Simondson, D., White, M., Moilanen, A., Bekessy, S.A. (2009) Integrating conservation planning and landuse planning in urban landscapes, *Landscape and Urban Planning*, **91**, 183–194.

Hanski, I., (1998) Metapopulation dynamics. *Nature* **396**, 41–49.

Helmstedt, K.J & Possingham, H.P. (2016) Costs are key when reintroducing threatened species to multiple release sites, *Animal Conservation* **20**, 331–340.

IUCN International Union for the Conservation of Nature (2017) *IUCN World Conservation Congress 2016*. Available from: https://portals.iucn.org/congress/motion/053 Accessed November 2018.

McAlpine, C.A., Lunney, D., Melzer, A., Menkhorst, P., Phillips, S., Phalen, D., Ellis, W., Foley, W., Baxter, G., de Villers, D., Kavanagh, R., Adams-Hosking, C., Todd, C., Whisson, D., Molsher, R., Walter, M., Lawler, I., Close, R. (2015) Conserving koalas: A review of the contrasting regional trends, outlooks and policy challenges. *Biological Conservation*, **192**, 226-236.

McLennan, E.A., Gooley, R.M., Wise, P., Belov, K., Hogg, C.J., Grueber, C.E. (2018) Pedigree reconstruction using molecular data reveals an early warning sign of gene diversity loss in an island population of Tasmanian devils (Sarcophilus harrisii). *Conservation Genetics*, **19** (2), 439-450.

Mikkonen, Ninni & Moilanen, Atte (2013) Identification of top priority areas and management landscapes from a national Natura 2000 network. *Environmental Science & Policy,* **27**, 11-20.

Moilanen, A., Franco, A.M.A., Early, R.I., Fox, R., Wintle, B. & Thomas, C.D. (2005) Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems, *Proc. R. Soc. Lond Ser. B. Biol. Sci*., **272**, 1885-1891.

Moilanen, A., Anderson, Barbara J., Arponen, Anni, Pouzols, Federico M., & Thomas, Chris D., (2013a) Edge artefacts and lost performance in national versus continental conservation priority areas. *Diversity and Distributions* 19, 171–183.

Moilanen, A., Lehtomäki, J., Kujala, H., Pouzols, F.M., Leppänen, J., Meller, L., & Veach, V. (2013b) *Conservation resource allocation and the Zonation framework,* C-BIG Conservation Biology Informatics Group Department of Biosciences, University of Helsinki, Finland.

Moilanen, E., Pouzols, F.M., Meller, L., Veach, V., Arponen, A., Leppanen, J. & Kujala, H., (2014) *Zonation - Spatial conservation planning methods and software. Version 4. User Manual*, C- BIG Conservation Biology Informatics Group Department of Biosciences University of Helsinki, Finland.

Redland City Council (2016) *Koala Conservation Strategy 2016*, Redland City Council, Cleveland.

Rendall, A.R., Coetsee, A.L., Sutherland, D.R. (2018) Predicting suitable release sites for assisted colonisations: A case study of eastern barred bandicoots. *Endangered Species Research*, **36**, 137-148.

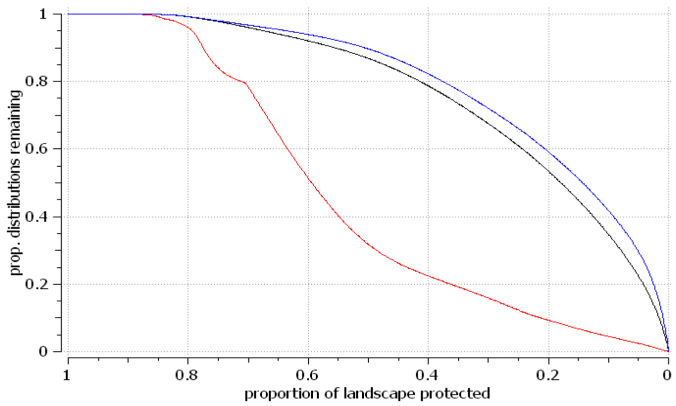
Seabrook, L., McAlpine, C., Baxter, G., Rhodes, J., Bradley, A. & Lunney D. (2011) Drought-driven change in wildlife distribution and numbers: a case study of koalas in south west Queensland. *Wildlife Research*, 38, 509-524.

Tasmanian Government (2018) Maria Island Translocation Project
Available at: http://dpipwe.tas.gov.au/wildlife-management/save-the-tasmanian-devil-program/about- the-program/maria-island-translocation-project. Accessed June 2018.

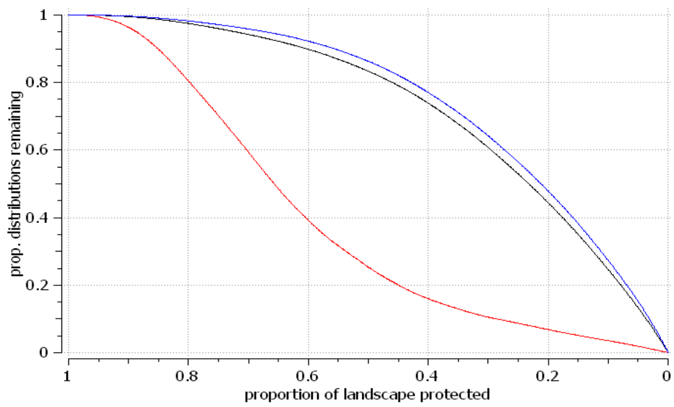
Zwiener V.P., Padial A.A., Marques M.C.M., Faleiro F.V., Loyola R. & Peterson A.T. (2017) Planning for conservation and restoration under climate and land use change in the Brazilian Atlantic Forest. *Diversity and Distributions*, **23**, 955–966.

Appendix 1 Zonation-generated performance curves, shown as averages for groups of features. They quantify the proportion of the original occurrences retained for each biodiversity feature, at each top fraction of the landscape chosen for conservation. Average (blue and black) and minimum (red).

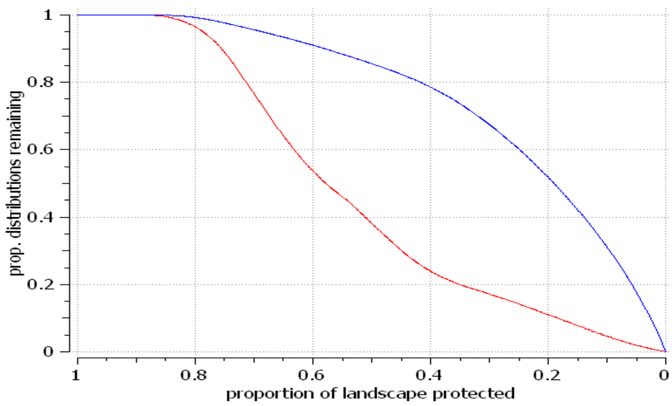
Scenario 1



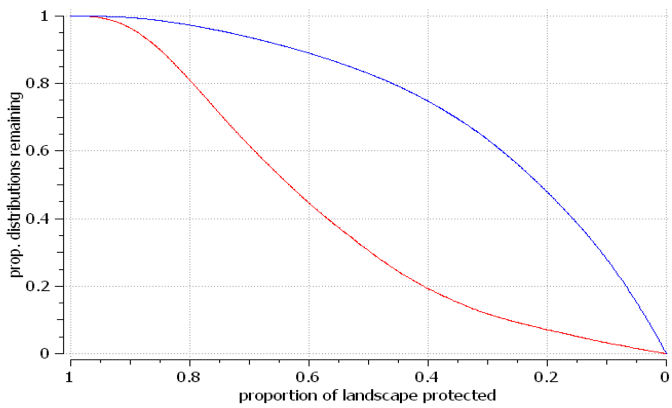
Scenario 2



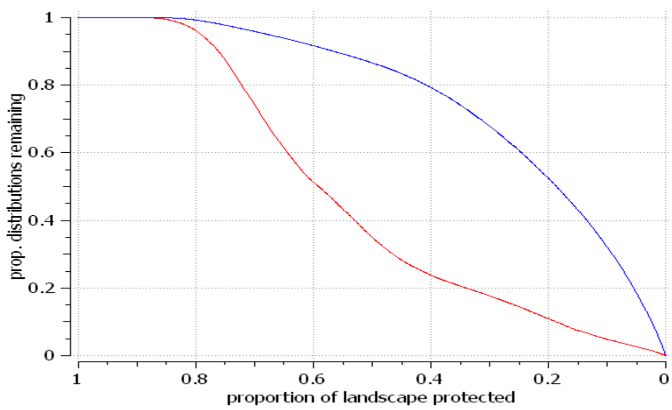
Scenario 3



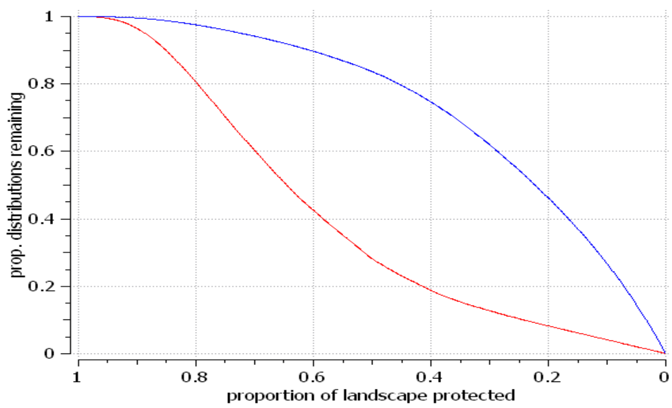
Scenario 4



Scenario 5



Scenario 6



Appendix 2 An alternative way of viewing the Zonation scenarios. Example of Scenario 1 as a KML file, overlayed on Google Earth. Highest ranked areas are shown in red.

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