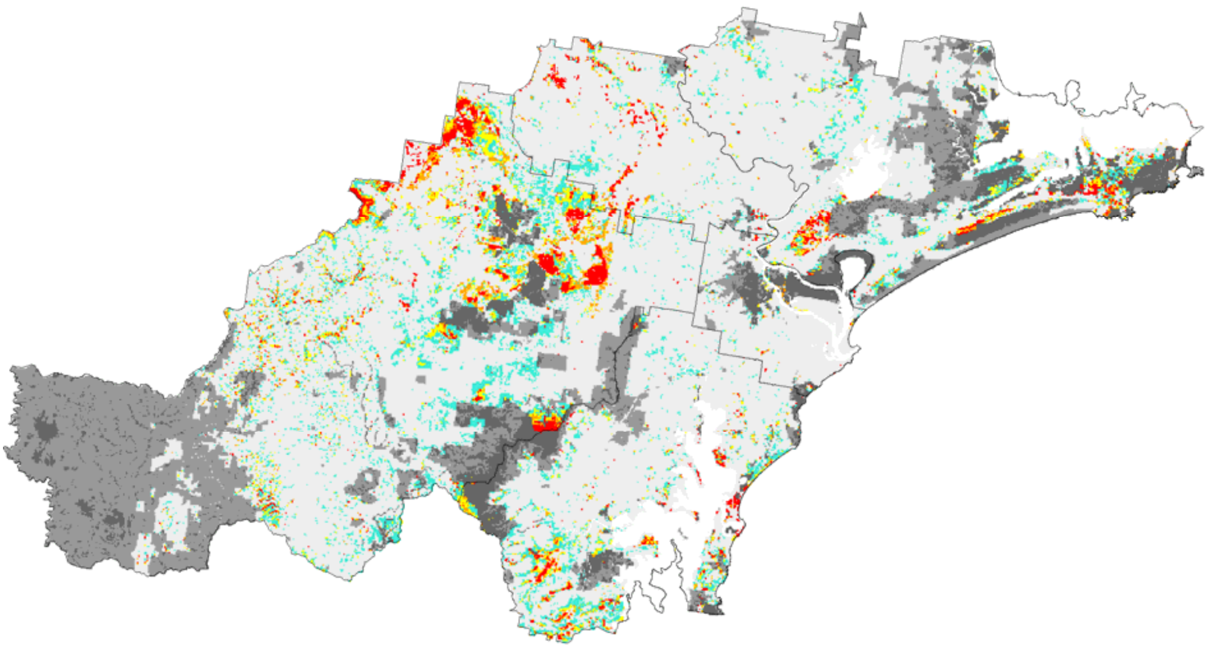
Identifying conservation priorities and assessing impacts and trade-offs of potential future development in the Lower Hunter Valley in New South Wales

A report by the NERP Environmental Decisions Hub

Heini Kujala, Amy L. Whitehead and Brendan A. Wintle
The University of Melbourne



The Environmental Decisions Hub is supported through funding from the Australian Government's National Environmental Research Program www.environment.gov.au/nerp and involves researchers from the University of Western Australia (UWA), The University of Melbourne (UM), RMIT University (RMIT), The Australian National University (ANU), The University of Queensland (UQ) and CSIRO .

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ISBN: 978-07340-5140-0 (PDF)
Hub Research Theme: 4.4 Regional Sustainability Plans (Hunter)
Enquiries to: Heini.Kujala@unimelb.edu.au

Please cite the report as follows:

Kujala H, Whitehead AL & Wintle BA (2015) Identifying conservation priorities and assessing impacts and trade-offs of potential future development in the Lower Hunter Valley in New South Wales. The University of Melbourne, Melbourne, Victoria. Pp. 100

Purpose of the Report
This report describes the framework and tools used to identify areas of high conservation priority in the Lower Hunter, and to assess the individual and cumulative impacts of potential future development scenarios. The report is an output of the Environmental Decisions Hub.

About the Authors
Dr Heini Kujala is a Research Fellow specialised in the use of spatial conservation tools to explore protected area effectiveness and resource optimisation, and building conservation recilience under climate change. Dr Amy Whitehead is an ecological modeller with interests in conservation planning and management across a wide range of taxa and ecosystems. Associate Professor Brendan Wintle is the deputy director of the Environmental Decisions Hub and specialises in uncertainty and environmental decision making.

Acknowledgements
We thank Ross Rowe, Dave Osborne, Huw Morgan, Jeremy Groves and Leanna Hayes (Department of the Environment); Meredith Laing, Ellen Saxon, Mary Greenwood, Bradley Nolan and Eva Twarkowski (HCCREMS); Paul Keighley, Amanda Wetzel and Dylan Maede (NSW Department of Planning and Environment); Mark Cameron, Sharon Molloy, Lucas Grenadier and David Paull (NSW Office of Environment and Heritage) for data, support and comments to this project.

This independent research is contributing to regional sustainability planning in the Lower Hunter Region, jointly undertaken by the Australian Government and the Government of NSW. The research was funded by the Australian Government through the Sustainable Regional Development Program and the National Environmental Research Program (NERP), which supports science that informs environmental policy and decision making. The report is an output from the Environmental Decisions Hub.

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Executive Summary

Description of the work

The aim of this work is to identify potential opportunities and priority areas for conservation, and to estimate the impacts and ecological trade-offs of planned and proposed development scenarios within the Lower Hunter Strategic Assessment (LHSA) region. The Lower Hunter Strategic Assessment (LHSA) will be undertaken within the local government areas of Newcastle, Maitland, Cessnock, Lake Macquarie and Port Stephens, collectively referred to as the 'Lower Hunter' in this document. The Lower Hunter is located 160 km north of Sydney and extends over 4,290 km^2 along the east coast of Australia within the State of New South Wales (NSW; Figure 1). Using publically available data, we map the distribution of 721 biodiversity features, including threatened flora and fauna, Matters of National Environmental Significance (MNES), and important biodiversity habitats, such as endangered ecological communities (EECs). These maps, which were based on a combination of species distribution models (SDMs) and mapped known occurrences, were then combined using systematic conservation planning and spatial prioritisation tools to identify areas of high conservation priority within extant native vegetation in the LHSA region (~280,149 ha, approximately 65% of the LHSA region; Figure 1). We report how well these high priority conservation areas are currently protected by national parks, nature reserves, heritage sites and other land tenures that offer varying levels of protection. Assessing how well the current protected area network protects biodiversity features within the LHSA region allows us to identify gaps in protection for MNES species and communities, and opportunities for improving protection. Finally, we investigate how the areas of high conservation priority are likely to be affected under five potential urban, infrastructure, agriculture and mining development scenarios provided by Hunter & Central Coast Regional Environmental Management Strategy (HCCREMS) and the NSW Department of Planning and Environment (DPE) (Table A). We assess the potential biodiversity impacts of these development scenarios by estimating the proportion of features' current distributions within LSA region likely to be lost to development and by identifying those species that are most strongly impacted. We also report the proportion of high priority conservation areas (across all features) and currently protected areas within the LHSA region at risk of being cleared in each scenario.

This report is designed to provide guidance on how spatial conservation planning tools can be used to identify conservation opportunities and potential biodiversity losses due to development within the LHSA region. It does not examine whether the resultant changes to biodiversity distributions are adequate for the long-term persistence of populations, or whether development scenarios (and potential losses) are acceptable under State and Federal environmental legislation. It also does not consider the implications of conservation or development activities outside the LHSA boundary nor other potential threatening processes.

Points to consider when interpreting the results

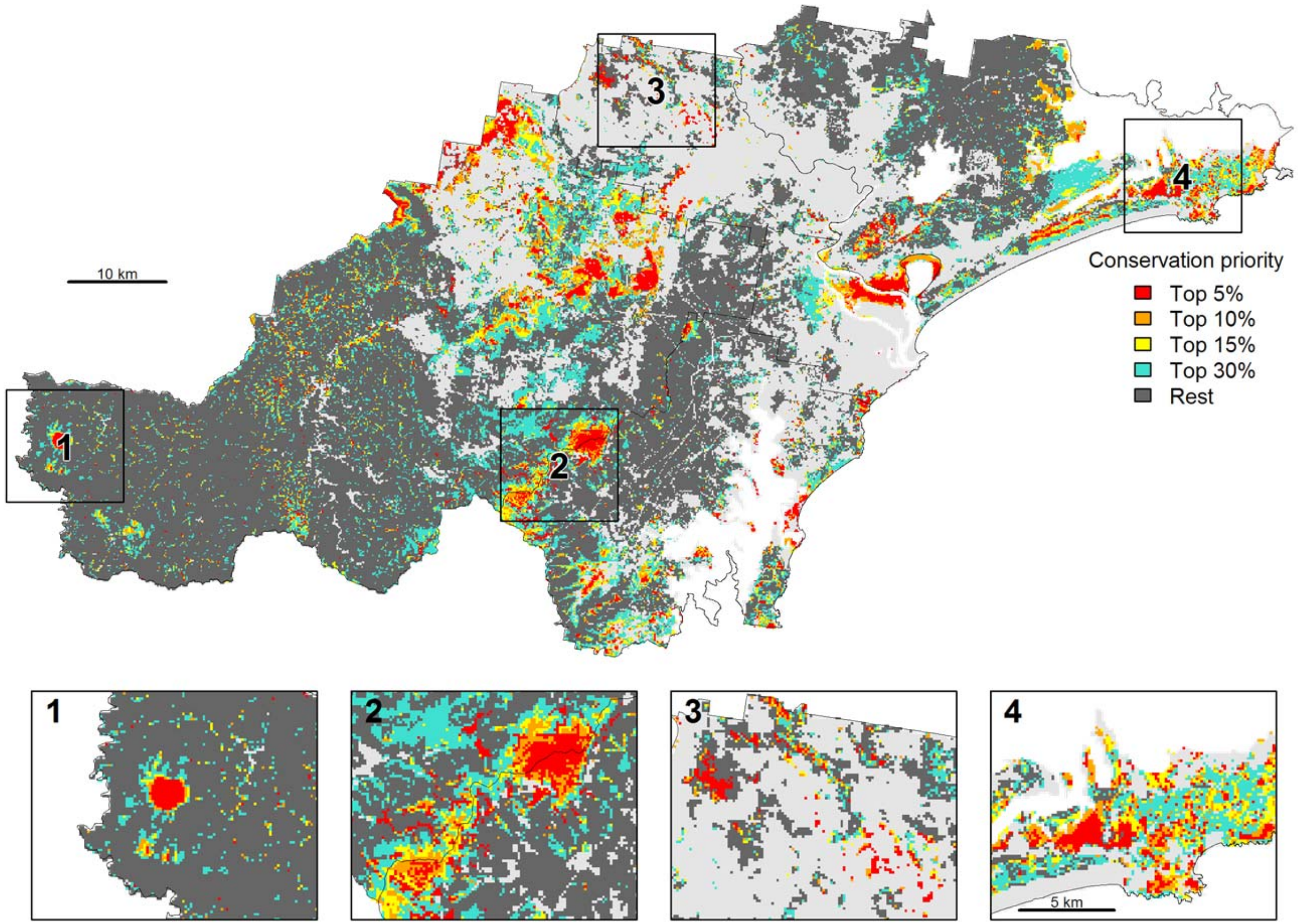
- The outputs from the analysis are only as good as the input data. Poor quality (i.e. inaccurate species data) or missing data may result in the identification of conservation priorities or potential development impacts that do not align with the real world. Our analysis was based on the best available data at the time of the analysis but verification of key results is recommended.
- The high priority conservation areas identified in this report are important at the scale of the LHSA region for the 721 species and communities included in the analysis. The relative importance of these areas would likely change if the analysis included a different suite of species or was undertaken at a different scale. However, we note that the approach used in this work is flexible in the sense that the results could be re-produced for any combination of biodiversity features and/or development scenarios.
- The currently zoned areas in the urban development scenario assessed in this report were based on spatial data released by DPE on February 15th 2015. It should be noted that these data may be subject to future small scale refinements. Consequently the predicted impacts on biodiversity reported here may differ from those expected under future refinements to the development footprints.
- The exact impact values for each scenario assume that all areas marked for development will no longer accommodate biodiversity values. For the most part, this is a reasonable assumption. However, there may be some impacted areas that maintain key habitat features, allowing MNES or other values to persist. Further local scale avoidance and mitigation could potentially reduce the impacts to biodiversity values (and increase the conservation opportunities) to some degree, however these can only be assessed on a case-by-case basis.
- Our analysis allows us to assess the extent of potential impacts in terms of loss of high priority conservation areas and the distributions of individual species and communities. However, we are not able to say, based on the current analysis, whether the remaining habitats are sufficient to support species persistence or what are the indirect impacts of development through, for example, noise and pollution. This means that despite the potential coarseness and errors in the footprint estimates, our approach is very likely to be a

conservative estimate of the full-scale ecological impacts of the assessed development plans. To understand how much habitat loss may result in severe population declines and an increase in the risk of local extinction, or how much protection is enough to ensure persistence, further analyses, such as species-specific population viability analyses (PVAs) will be required.

Key findings

Conservation priorities and current protection of biodiversity in the LHSA region

- The spatial analysis identified large areas within the LHSA region that are highly important for the conservation of the biodiversity features included in this assessment. These high priority conservation areas (considered here to be the most important 30% of the landscape in terms of their biodiversity value) are distributed across the entire region, with important areas in the localities of North Rothbury, Polkolbin, Abermain, Sawyers Gully, Pelaw Main (near Kurri Kurri), Yengo National Park, Watagans National Park, Heaton State Forest, Anna Bay, Koragang, and Tomago. (Box A). In many cases, these high priority conservation areas are small fragments of remnant habitat that may contain the last known occurrences of some biodiversity features. On average, the identified high priority conservation areas cover 50% of the LHSA distributions of all 721 species and communities included in this assessment and 68% of the LHSA distributions of MNES features.
- Thirty-three percent (92,762 ha) of the remnant vegetation within the LHSA region is currently protected under a variety of tenures with varying protection status. Of these 28% (78,239 ha) is protected by mechanisms of high legislative security (Level 1 protected areas: e.g. nature reserves, national parks, conservation parks etc.). While Level 2 (including e.g., protected locations within State Forests, Ramsar wetlands and SEPP areas) and Level 3 (e.g., wildlife refuges and registered property agreements) protected areas are quite small in size, covering only 4.5% and 0.7% of remnant vegetation, respectively, they currently protect biodiversity features that are not represented in the most secure protected areas.
- On average, 29% of all biodiversity features and 37% of MNES features LHSA distributions lie within the most secure Level 1 protected areas. However, there is substantial variation between species and communities, with 67 features (including seven MNES features) currently having no protection within the LHSA region and 79 biodiversity features (11 MNES) being protected only by the less secure Level 2 and Level 3 protected areas.



Box A. The high priority conservation areas identified within the LHSA region are based on the best 30% of the spatial prioritisation for the 721 species and communities considered in this analysis. The inset boxes highlight example areas of priority sites across the LHSA region. While many of these areas are currently protected, there exist significant opportunities to make conservation gains by strategically protecting areas that are currently unprotected or protected by insecure legislative mechanisms. Inset boxes: 1) Yengo National Park; 2) Watagans National Park and Heaton State Forest; 3) Luskintyre and Martinvale; 4) Anna Bay and One Mile.

- Of the identified high priority conservation areas over 70% are currently either unprotected (63%) or protected by only the intermediate and low security protected areas (7.6%). Therefore, significant conservation gains could be made by strengthening the level of protection of these sites, particularly where they host currently poorly protected features and are under threat from future development.

Potential impacts of development on biodiversity in the LHSA region

- We estimated the potential impacts of five development scenarios: 1) potential urban expansion within LHSA, ranging from currently zoned areas to proposed investigation areas; 2) recent construction of the Hunter Expressway; 3) potential expansion of intensive agriculture on areas of high agricultural value; 4) the cumulative impact of scenarios 1-3 and; 5) a hypothetical mining expansion scenario based on information on current mining titles and applications (Table A).
- In general, we did not find MNES to be more highly or less impacted by the potential development in any of the scenarios (Table A).
- The cumulative impact of all urban, infrastructure and agriculture development in LHSA region might lead to the loss of up to 38,000 ha (14%) of the region's native vegetation, when assuming that all vegetation within the development sites is cleared. As a result, 17% of biodiversity features LHSA distributions might be lost on average, but the impacts vary greatly between biodiversity features. Some 32 biodiversity features (four MNES) may be at risk of losing more than half of their known occurrences within the region, with 19 (two MNES) of these potentially at risk of losing all their known occurrences. The full development of these sites would also clear 17% of the identified high priority conservation areas and 2.2% of currently protected areas. Significant conflicts, where potential development overlaps with areas identified as within the most important 5% of the entire region, were found especially around Branxton-Rothbury (including Huntlee), Kurri Kurri, Rutherforth-Largs, Tomago-Heatherbrae and Southern Lake Macquarie (Box B).
- The potentially most highly impacted features are predominantly vagrant or rare species and communities in the LHSA region, with orchids forming the single largest taxonomic group within them. However, they also include the vulnerable MNES *Grevillea shiressii* and another six state-listed threatened features.
- Of the scenarios contributing to the cumulative development, the greatest biodiversity threat is posed by already zoned areas which still have native vegetation but have been zoned for land use types that are likely to lead to extensive clearing. The clearing of these areas would result in loss of up to 14,000 ha of native vegetation and, on average, an 8.2%

loss in features LHSA distributions. Under this scenario alone, 19 features may be at risk of losing more than half of their known occurrences in the LHSA region.

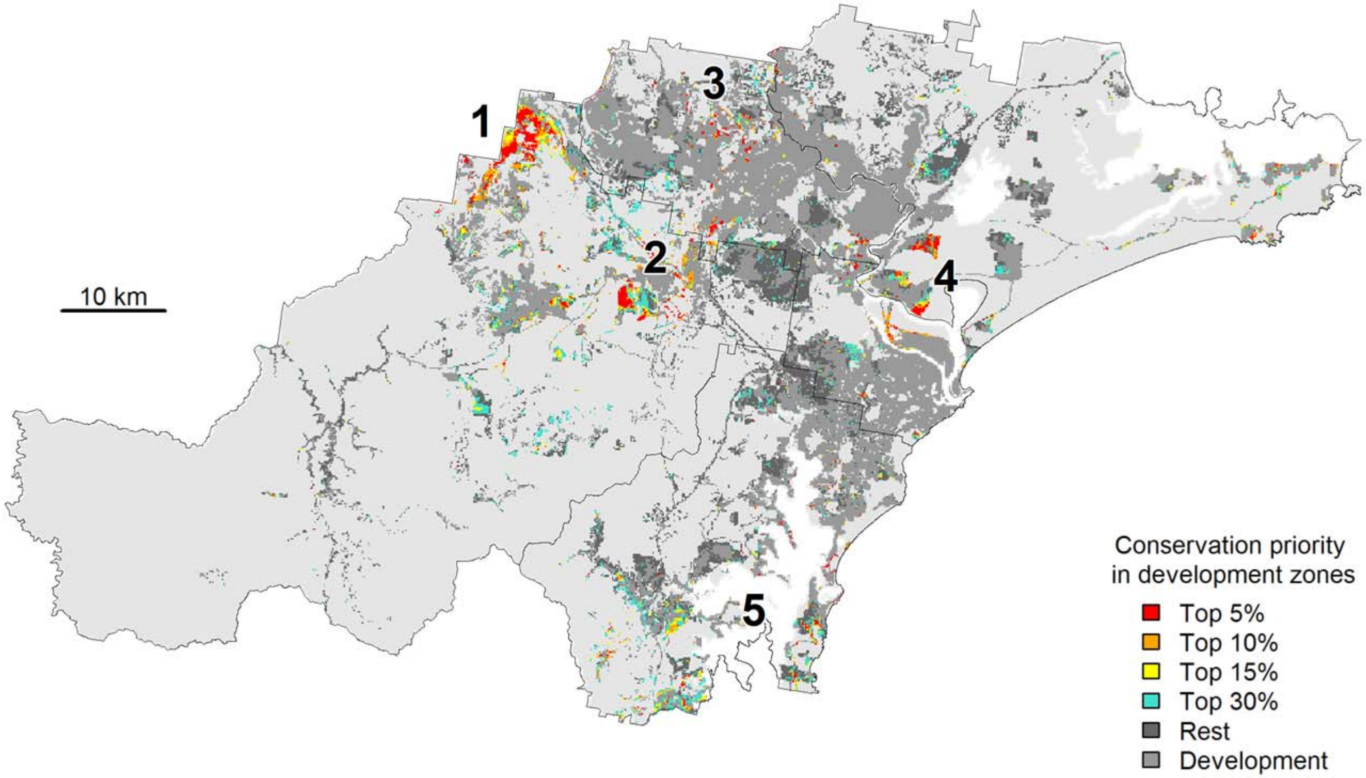
- The mining scenario highlighted potential future conflicts between mining industry and biodiversity protection. These are mostly located in the undeveloped parts of Cessnock and Lake Macquarie. Unlike the other scenarios, the mining titles have relatively high overlap with currently protected areas (10%). They also overlap with 21% of the high priority conservation areas.

Recommendations

- The results of this assessment highlight potential conflicts between development and biodiversity protection. These conflict areas should be examined in more detail to verify the existence of high conservation values, and to determine whether development activities in these areas should and can be avoided to prevent substantial biodiversity losses.
- There is significant conservation potential outside the existing protected areas with high security. For example, approximately 58,800 ha of the high priority conservation areas currently have sub-optimal protection status, providing a potential opportunity to expand the current protected area network and increase the protection of biodiversity values within the region.
- Many of the highest priority conservation areas occur in small fragments of vegetation. This arises because these small fragments often contain records of species or unique habitats that cannot be found anywhere else in the region. These habitats can make a long and lasting contribution to regional conservation objectives and have, in many instances, maintained threatened species and communities for long periods (since clearing and European settlement). These areas should not be discounted as low value conservation sites based on their size and isolation.
- Next steps should include verification of biodiversity values within high conservation priority areas (potentially including ground truthing), particularly in those areas that conflict with current development plans, verification of areas considered by stakeholders and scientists to be of high conservation value that were not indicated as such by our analysis, and implementation of PVAs for selected species of interest to assess impacts on extinction risk and to evaluate mitigation or offsetting proposals.

Table A. Predicted impact of each development scenario on the current distributions of features in the LHSA region, assuming that all native vegetation within the development sites are cleared. The first two columns show the mean and maximum losses of feature distributions within the LHSA region under each development scenario based on the modelled data or occurrence records used for each feature. The values in brackets give the mean impact to MNES species alone. The table also highlights the number of features that may be at risk of losing between 50-100% of their known LHSA distribution under each scenario, as well as the proportion of high priority conservation areas (Box A) and currently protected areas likely to be cleared. Feature-specific estimates of distribution loss can be found in Appendix 7.

Scenario	**Loss of LHSA distributions (%)**		**Number of features lost**	**Number of features losing at least**			**Priority conservation areas cleared (%)**			**Current protected areas cleared (%)**			
	Mean	Max		90%	75%	50%	Top 5%	Top 10%	Top 30%	Level 1	Level 2	Level 3	Total
1. Urban development													
Zoned	8.2 [8.4]	100	12	0	1	6	10.1	8.9	6.9	0.8	3.1	7.2	1.3
Zoned + Current strategies	9.8 [9.4]	100	16	0	2	6	10.7	10.0	8.2	0.8	3.8	10.6	1.5
Zoned+ Current strategies + Other investigation areas	12.7 [11.7]	100	18	0	2	8	12.9	12.3	11.0	1.0	4.7	12.0	1.8
2. Hunter Expressway	0.18 [0.18]	1.5	0	0	0	0	0.3	0.3	0.2	0.0	0.0	0.0	0.0
3. Important Agricultural Lands	5.6 [5.2]	100	2	0	1	3	8.4	7.6	6.7	0.0	1.6	7.4	0.4
4. Cumulative development	17.1 [16.0]	100	19	0	3	10	18.7	18.1	16.7	1.1	6.1	19.1	2.2
5. Mining	24.9 [24.0]	100	22	0	1	7	16.4	17.2	21.2	7.5	14.5	76.4	10.3



Box B. The conservation value of areas within the LHSA region at risk of being developed under the Cumulative Development scenario. The high priority conservation areas (coloured red to cyan) represent sites of high conservation value based on the best 30% of the LHSA region for the 721 biodiversity features included in this assessment. 1) Branxton-Rothbury (including Huntlee), 2) Kurri Kurri, 3) Rutherforth-Largs, 4) Tomago-Heatherbrae and 5) Southern Lake Macquarie. Development in these locations should be avoided if possible to avoid significant biodiversity losses. Areas in dark grey (Rest) have lower conservation value and represent areas where development is likely to have a lower overall impact on biodiversity features included in this assessment, although individual species may still be affected. Light grey represents areas within the development footprint that are already cleared of native vegetation.

Glossary of Terms

Algorithm	A mathematical process that systematically solves a problem using well-defined rules or processes.
Area under the receiver operator curve (AUC)	A measure of how well species distribution models predict a species' known occurrences. Values greater than 0.7 are considered to be informative (Swets 1988).
Biodiversity features	Species, threatened ecological communities and other key elements selected for inclusion in spatial conservation planning.
Complementarity	The degree to which a set of sites complement each other, typically in terms of their species composition, in order to represent the full scale of regional biodiversity.
Ecological community	Naturally-occurring biological assemblage that occurs in a particular type of habitat.
Endangered ecological communities	Ecological communities listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) or Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as critically endangered, endangered or vulnerable, depending on their risk of extinction, distribution patterns and/or significant conservation value.
Grid cell	One rectangular cell within a raster grid data layer.
Heuristic algorithm	General class of sub-optimal algorithms that are commonly used for complex problem solving that are too large to solve by exact mathematical methods. These algorithms use rules-of-thumbs and time-saving shortcuts which do not guarantee to find the single most optimal solution but typically perform very near to it.
High priority conservation areas	Set of areas that together as network best represent regional biodiversity of the target region. Each individual site contains high biodiversity values in terms of relative representation of a given biodiversity feature (such as last occurrences of very rare species or the core habitats of species). In this assessment high priority conservation areas were defined as a set of sites that together represent the best 30% of the biodiversity values within the Lower Hunter Strategic Assessment region.
Irreplaceability	A measure of how easily a site can be replaced if lost.
Normalised kernel density layer	A smooth density surface created by assigning a larger value to spatial features of interest, dropping away more quickly from those points.
Population Viability Analysis (PVA)	A forecast of a population's health and extinction risk based on the species' characteristics and environmental variability. PVA is usually unique to each species population.
Raster (data) layer	Rasters are uniform grids of rectangular shape and commonly used in GIS based analyses. They typically describe characters of an area or distribution of features, each grid cell having one value within one raster layer.
Threatened species	Species listed under the NSW *Threatened Species Conservation Act 1995* (TSC Act) or Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as critically endangered, endangered or vulnerable based on their risk of extinction, distribution patterns and/or their significant conservation value.

Description of threat categories

List of Commonwealth and state threat categories and their respective abbreviations used in this report. *Migratory Bird* and *Priority Assessment* status are only used under Commonwealth legislation. *Protected* status is only used under New South Wales legislation.

CE	Critically endangered
E	Endangered
V	Vulnerable
P	Protected
C	China-Australia Migratory Bird Agreement
J	Japan-Australia Migratory Bird Agreement
K	Republic of Korea-Australia Migratory Bird Agreement
FPAL	Finalised Priority Assessment List

Frequently Used Abbreviations

ALA	Atlas of Living Australia
CAMBA	China–Australia Migratory Bird Agreement
DPE	NSW Department of Planning and Environment
DoE	Department of the Environment
EEC	Endangered Ecological Community
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
GIS	Geographic Information System
GHVMv4	Greater Hunter Vegetation Mapping (version 4)
HCCREMS	Hunter & Central Coast Regional Environmental Management Strategy
IBRA	Interim Biogeographic Regionalisation of Australia
IUCN	International Union for Conservation of Nature
JAMBA	Japan–Australia Migratory Bird Agreement
LEP	Local Environment Plan
LGA	Local Government Area
LHSA	Lower Hunter Strategic Assessment
MNES	Matters of National Environmental Significance
NERP	National Environmental Research Program
OEH	NSW Office of Environment and Heritage
ROKAMBA	Republic of Korea–Australia Migratory Bird Agreement
SEPP	State Environmental Planning Policy
TSC Act	NSW Threatened Species Conservation Act 1995

Chapter 1 Introduction

1.1. Purpose of the research project

The National Environmental Research Program (NERP) Environmental Decisions Hub has undertaken a study to identify conservation priorities in the Lower Hunter Valley region and to help understand the potential impacts of potential future development on the regions' biodiversity. This independent research will inform the regional sustainability planning and strategic assessment process for the Lower Hunter (hereafter referred to as the Lower Hunter Strategic Assessment or LHSA), jointly undertaken by the Australian Government and the Government of New South Wales. This report describes the data and methods used in the work, and the key findings. The purpose of this report is to highlight how spatial conservation planning tools can be used to identify priority areas for conservation, and to estimate expected biodiversity impacts arising from development, and how these can provide highly necessary information for input into the strategic assessment process. This research is funded by the Australian Government through the Sustainable Regional Development Program and National Environmental Research Program (NERP), which supports science that informs environmental policy and decision making.

The aim of this research project was to identify the impacts and ecological trade-offs of planned and proposed development scenarios in the LHSA region, using state-of-the-art systematic conservation planning and spatial prioritisation tools. As part of the project we mapped the habitat suitability and distribution of 721 biodiversity features, including threatened flora and fauna, Matters of National Environmental Significance (MNES), and important biodiversity habitats, such as endangered ecological communities (EECs), and important breeding or roosting habitat for a set of selected species. We identified areas of high conservation priority in the LHSA region, reporting how these areas are currently represented in protected areas and how the representativeness of the current reserve network could be most effectively improved. Finally, we assessed how the areas of high conservation value are likely to be affected under a set of planned and proposed development scenarios, looking at both the individual and cumulative impacts of the scenarios. For each development scenario we report the overlap of areas of potential development with areas of high conservation priority, and the expected losses to biodiversity. **Throughout the study we report losses to biodiversity as the proportion of feature's known occurrences or suitable habitat <u>within the LHSA region</u> that is likely to be lost as a result of the potential development**. In this report we summarise the results by providing both the average and maximum proportion across all included features that is likely to be lost due to development in each scenario. We also report the status and impacts separately for Matters of National Environmental Significance (MNES). The Appendices provided together with this report further list the analysis results for all included 721 features individually.

Our work provides a better understanding of what drives different biodiversity outcomes, and how ecological and economic trade-offs can be balanced to achieve required outcomes for MNES and sustainable development in the LHSA region. The approach used in this work ensures that the best data and science is available to inform the Lower Hunter Regional Sustainability Planning process, which is being undertaken by the New South Wales and Australian Governments. The results will also assist the development of other strategic approaches to environmental impact assessment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), as well as improve scenario-modelling tools to support future strategic assessments and regional sustainability plans.

1.2. Outline of the report

This report is divided into six chapters that describe the major sections of the project. Chapter 1 describes the study area and outlines the analysis framework and the basic steps of the assessment. It also provides a brief background to systematic conservation planning, to regional sustainability planning including the strategic assessment process and other biodiversity assessments previously conducted in the Lower Hunter region. Chapter 2 explains the origins of the input data for species, EECs and other biodiversity features used in the analyses, while Chapter 3 outlines the species distribution modelling methods used to predict the distribution of biodiversity features across the LHSA region. Chapter 4 details the spatial prioritisation approach and identifies high priority areas for conservation within LHSA region. We also evaluate how well the high priority conservation areas are currently protected and examine how the representativeness of the existing protected area network within LHSA region could be most efficiently improved. In Chapter 5, we identify the high priority conservation areas at risk of development under five development scenarios and quantify the potential impacts to biodiversity. Chapter 6 summarises the main findings of the report and discusses potential limitations and uncertainties that should be considered when interpreting the results.

1.3. Systematic conservation planning and spatial prioritisation – planning strategically for biodiversity

The assessment presented in this report utilises the principles and tools of systematic conservation planning and spatial prioritisation. Systematic conservation planning is a relatively new discipline in science that has emerged in the past few decades to guide efficient allocation of scarce resources for biodiversity protection (Soulé 1985; Noss 1990; Margules & Pressey 2000). The discipline was developed to address the problem of reserve design, with the aim of securing as much of biodiversity within protected areas as quickly and with as little cost as possible. Within its brief history, the field of systematic conservation planning has produced various approaches to aid more strategic protection of biodiversity, and has expanded into far more complex problems such as reserve management, restoration and the socio-economic aspects of conservation.

Some of the key principles of cost-efficient and strategic conservation planning are the concepts of comprehensiveness, complementarity and irreplaceability. *Comprehensiveness* (also known as *representativeness*) describes the overarching goal of conservation, that is, that all components of biodiversity should be protected and the resulting protected area network should be representative of the full range of biodiversity. A network of protected areas that includes all biodiversity features (such as species or habitats) is most cost-effectively built using the principle of *complementarity* (i.e. by selecting sites that complement each other). By targeting complementary sites for protection we ensure that scarce conservation resources are used to protect currently under or un-protected biodiversity features, which improves the protection of biodiversity most efficiently. As conservation resources are far from adequate to protect all biodiversity (see e.g. McCarthy et al. 2012), it is typical that protection of sites needs to be prioritised. *Irreplaceability* is often used as one of the guiding principles to prioritise actions across complementing sites, reflecting how important a site is for achieving the set conservation goals. For example, if a site contains a unique occurrence of a biodiversity feature, it is considered to be irreplaceable and has to be protected in order to achieve a comprehensive network of protected areas. From this, it follows that sites that host rare or very narrowly distributed features are more irreplaceable (i.e. there are very few or no sites that could replace them if the original sites got lost due to development). Under restricted conservation budgets these sites are more highly prioritised over sites that host more common features.

The majority of conservation problems are by definition of a spatial nature – that is, they involve deciding where in the landscape to act. Spatial conservation prioritisation (sensu Moilanen et al. 2009) is a subfield within conservation planning which helps to identify the locations where desired conservation actions should be targeted once goals and targets have been defined, typically using the general principles explained above. Complementarity-based conservation planning differs notably from some of the more traditional approaches which use summary statistics, such as species richness or other component indices, to rank sites for conservation actions. These so called scoring approaches have been proven to be inefficient as they often waste conservation resources by selecting sites that protect some features multiple times and leave others without any protection (Kirkpatrick 1983; Pressey & Tully 1994). Using the principle of complementarity comes with the cost that information about the biodiversity values of all candidate sites are evaluated jointly instead of independently, which can be a computationally complex process when prioritising sites across large landscapes and for multiple features, such as species or habitats. However, with increasing computing capacity, complementarity-based spatial prioritisation approaches have experienced increasing popularity, particularly with the development of readily-accessible and efficient tools such as Marxan (Ball et al. 2009) and Zonation (Moilanen et al. 2012), the latter of which was used in this assessment. These tools are now applied to a range of problems globally, including the identification of priorities for protected areas (Kremen et al. 2008), management actions (Lentini et al. 2013) and integration with land-use planning (Gordon et al. 2009).

1.4. Regional Sustainability Planning and Strategic Assessment in Hunter Valley

In 2012, the Australian and New South Wales governments entered into an agreement to undertake regional sustainability planning and a collaborative strategic assessment of the Lower Hunter region. Regional sustainability planning is a collaborative process involving all levels of government working together to foster economic prosperity, liveable communities and environmental sustainability. In the Lower Hunter, the regional sustainability planning process has two main stages. In the first stage, the Australian and NSW governments have been working together to identify key knowledge gaps and scientific research to inform sustainability planning for the Lower Hunter region. This work will complement and inform the NSW Government review of the NSW Lower Hunter Regional Strategy and Lower Hunter Regional Conservation Plan. The second stage will be to undertake a strategic assessment of proposed urban development and related infrastructure corridors. The purpose of strategic assessments is to deliver a comprehensive evaluation of future development plan impacts on environmental, social and economic sustainability aspects that would otherwise be assessed on project by project basis. Strategic assessments under the EPBC Act encourage a bigger picture approach to assess how biodiversity, environmental and heritage values that are MNES can be protected, while allowing sustainable development. They also aim to provide greater certainty on the long-term land supply for urban and industrial development, and on the obligations required for environmental mitigation to assure the long term persistence of MNES.

Another strategic assessment is currently being undertaken in the Upper Hunter Valley to estimate to potential impacts of expanding mining activity in the next 20-30 years. While this is a separate process from the Lower Hunter strategic assessment, it is worth noting that the Upper Hunter strategic assessment region overlaps to some degree with the one of Lower Hunter (Figure 1), and future development on both of these regions might have cumulative impacts that are not estimated in this work.

1.5. Study area

The Lower Hunter Strategic Assessment (LHSA) will be undertaken within the local government areas of Newcastle, Maitland, Cessnock, Lake Macquarie and Port Stephens, collectively referred to as the ‘Lower Hunter’ in this document. The Lower Hunter is located 160 km north of Sydney and extends over 4,290 km^2 along the east coast of Australia within the State of New South Wales (NSW; Figure 1). With more than half a million residents, the Lower Hunter region is Australia’s seventh largest urban settlement with ongoing strong economic growth due to its diverse and stable business sector, good national and international infrastructure and recent boom in natural resources extraction in the Upper Hunter coalfields (NSW Government 2013). As a result, the region has undergone a rapid expansion of housing and industry with 35,000 lots re-zoned for housing since 2008 and 3% increase in number of jobs in the past decade. The population of the Lower Hunter Valley is projected to increase to 670,000 by 2031 (NSW Government 2013), maintaining high demand on the urban resources such as housing supply, services, and roads and transport.

The natural environment in the Lower Hunter region is characterised by a mixture of river valley floors fringed in the south-west and north-east by the ranges of Cessnock and Maitland LGAs. The coast contains the expansive lake system of Lake Macquarie, the mouth of the Hunter River at Newcastle and the extensive dune systems and estuary of Port Stephens. At present, approximately 65% of Lower Hunter has native vegetation cover and the region supports one of the three largest river valley systems in eastern NSW, including wetlands of international and national significance (DECCW 2009). The Lower Hunter region is home to a number of state and federally-listed threatened species, and the outer edges of many northern and southern ecological communities come to meet within its borders. The area has been highlighted as a significant transition zone for many animal and plant species between the sub-tropical influences of the north and the cooler, less fertile conditions to the south (DECCW 2009).

Vegetation clearing in Lower Hunter has been most extensive on the valley floor, particularly in Maitland and Newcastle, and most of the remaining native vegetation is restricted to the slopes and ranges, with some large vegetated areas still present elsewhere. The vegetation on the valley floor outside of these core areas is highly fragmented, with the cleared areas considered to have little significant conservation value. Therefore, we restricted our analyses to only consider areas that are currently covered in native vegetation considered to be important for native species (~280,149 ha or 65% of the LHSA region; Figure 1). This *prioritisation footprint* was generated using the best available data for native vegetation for the LHSA region based on an updated version of the Lower Hunter vegetation mapping produced by Parsons Brinkerhoff (Cockerill et al. 2013a; updated by Mark Cameron, OEH, June 2014). All polygons within this layer that were assigned a Keith Formation were included in the prioritisation footprint and converted to a raster grid with 100 m grid cells.

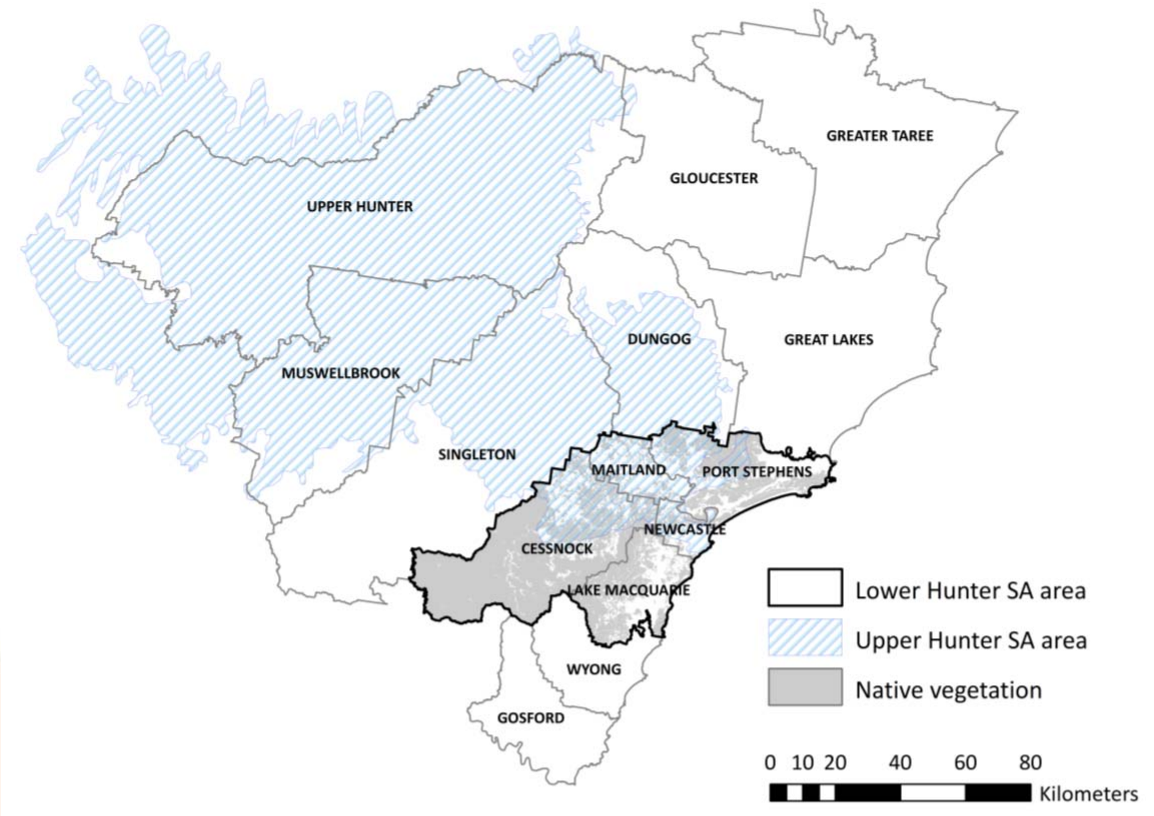


Figure 1. Map of Greater Hunter and the Local Government Area (LGA) boundaries. The Lower Hunter Strategic Assessment (LHSA) region encompasses the five LGAs of Cessnock, Lake Macquarie, Maitland, Newcastle and Port Stephens. The dark grey areas within the LHSA boundary show the distribution of extant native vegetation, used as a *prioritisation footprint* to identify locations of high conservation priority. The Upper Hunter Strategic Assessment area, showed in blue, overlaps with the LHSA region.

1.6. Framework for mapping biodiversity patterns and prioritising options under development scenarios

This research used a two-step framework to map the distribution of biodiversity features within the LHSA region and identify the potential impacts of development. Here we briefly describe each step, with further details provided in subsequent chapters.

Firstly, we identified all biological features within the region that were considered to be of conservation importance, including protected species and threatened ecological communities (Chapter 2). Spatial data for protected species were obtained as point locations from online public databases (Atlas of Living Australia, BioNet), while endangered ecological community data was either extracted as points from the Greater Hunter Vegetation Mapping (Sivertsen et al. 2011) or provided as polygons by DoE. We then produced species distribution maps using MaxEnt, (Phillips et al. 2006; Elith et al. 2011) or boosted regression trees (Elith et al. 2008), which give the likelihood of observing a species in each pixel, given the environmental conditions that exist there relative to the environmental conditions in pixels where the species is known to occur (Phillips & Dudík 2008). All SDMs were produced at the scale of the Greater Hunter, using raster grids with a grid cell resolution of 100m. The larger spatial extent for modelling was used to increase the amount of available records for species and communities but also to better capture the full range of their natural environments and therefore improve the performance of the models (Hernandez et al. 2006). The larger region also forms a logical ecological boundary within which environmental data were readily available. For each modelled species or EEC, the modelled output was then clipped to the LHSA area and used in subsequent analyses (Figure 2; see Chapter 3 for more details). The point locations for species with less than 20 records within the LHSA region and the polygon data representing the endangered ecological communities and certain other biodiversity features were also converted to raster grids for subsequent analyses (for details on all biodiversity data used in this assessment see Chapter 2).

In the second phase, we used the conservation prioritisation software Zonation v.4.0 (Moilanen et al. 2005, 2012) to identify areas of high conservation priority within the LHSA region (Chapter 4). Zonation uses information about biodiversity features, their relative occurrences and biological needs to create a hierarchal conservation ranking of sites across any given landscape. The conservation priorities were then compared to a set of proposed development scenarios to assess the potential impacts each of the scenarios would have on the region's biodiversity and to quantify the feature-specific losses in terms of known occurrences or potential habitat (Chapter 5). Data describing potential future development was provided by DoE, HCCREMS, DPE and OEH.

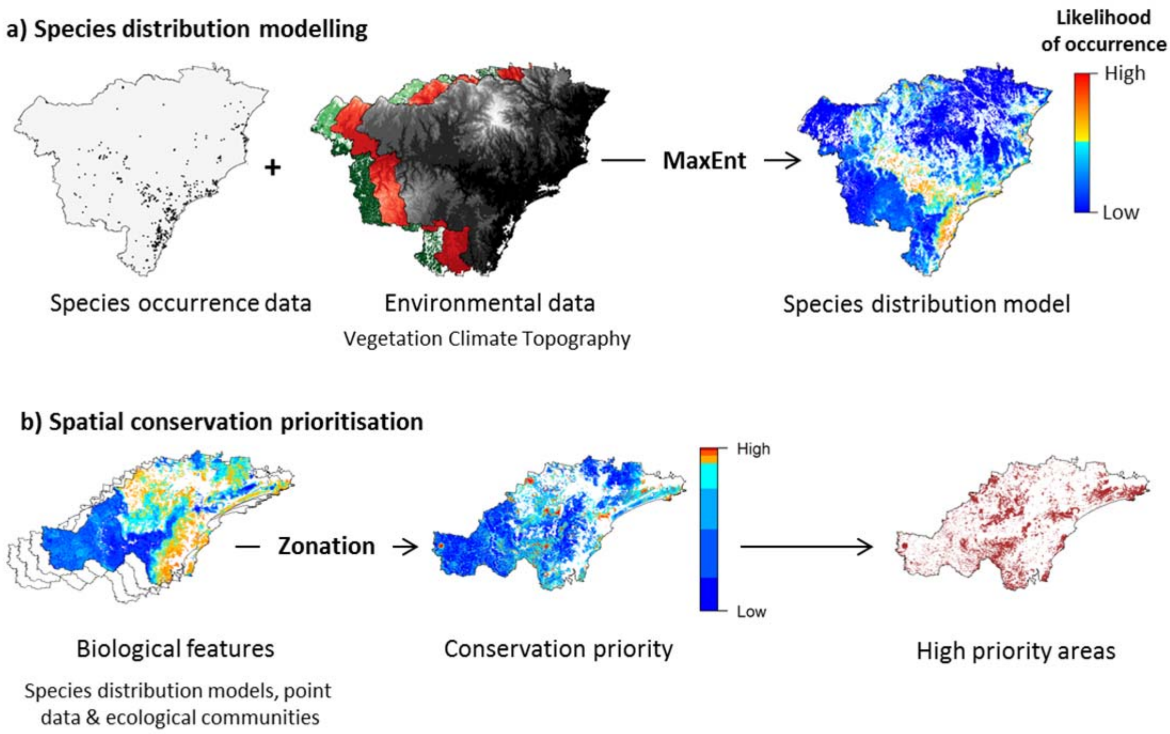


Figure 2. Schematic diagram representing the two-step modelling process used to generate the conservation prioritisation. A) Occurrence data for species and endangered ecological communities (EECs) were obtained from online databases and combined with environmental data to produce species distribution models using MaxEnt (species) or boosted regression trees (EECs). B) These models were clipped to LHSA region and combined with additional biological features in the spatial conservation prioritisation software, Zonation, to identify high priority areas for conservation. We identified the best 30% of the landscape (based on the spatial prioritisation) as high priority conservation areas after discussions with HCCREMS, DoE, and other stakeholders.

1.7. Stakeholder and expert engagement

This assessment has been undertaken in collaboration with a number of stakeholders within the LHSA region, with University of Melbourne researchers participating in over 40 stakeholder meetings associated with the LHSA since 2012 to discuss research methodologies and data, and to outline preliminary findings of the research. This engagement has helped us to make key decisions about which biodiversity features to include in the analyses, how those features should be weighted and which development scenarios to assess. Some of these decisions are highlighted in this report. Ongoing engagement with stakeholders has continued to produce useful feedback throughout this research process.

The Department of the Environment (DoE) has provided advice in setting the analytical framework of this assessment and identifying key outputs that will provide inputs to the LHSA. DoE also provided a number of biodiversity, vegetation, and planning layers and advice on their interpretation.

We have been in close consultation with the Hunter & Central Coast Regional Environmental Management Strategy (HCCREMS) team since 2012 to establish an understanding of the current status of biodiversity protection within the LHSA region and identify ongoing and emerging threats. They provided spatial data describing environmental and biodiversity patterns within the Greater Hunter region, as well as planning and land tenure data, and have been instrumental in the interpretation of these data.

Two expert retreats were organised by HCCREMS to discuss the research methodologies and data being used to assess conservation planning initiatives within the Greater Hunter region. The key focus for both workshops was to bring together academic experts in conservation planning from a number of Australian research institutions and representatives of key local government stakeholders to develop a modelling framework and ensure that the research outputs were tailored to provide the best possible inputs for the LHSA process. The workshops generated good discussion around the research methodology, the use of available input data and key outputs needed to better understand potential conservation opportunities within the Greater Hunter region.

In addition, two workshops were organised by HCCREMS to discuss aspects of the flora and fauna modelling, with participants including representatives from HCCREMS, OEH, local councils and biodiversity experts within the region. The purpose of these workshops was to finalise the species pool for inclusion in the analysis, assess the accuracy of input data for, and outputs from, preliminary SDMs and assign each species a weight based on its conservation importance within the region. These workshops also resulted in a number of participants providing additional spatial data for some species.

We met with representatives from the NSW Office of Environment & Heritage (OEH) and Department of Planning & Environment (DPE) in May 2014 to present preliminary findings from this research and discuss how these outputs might be used to inform decision making with regard to NSW planning strategies and the LHSA. In addition, we discussed potential options for development scenarios to assess within this research, including identifying the most likely candidates for urban expansion plans in the LHSA region.

This research has also been closely aligned with three other NERP projects within the LHSA region: Wildlife Corridors Planning led by Alex Lechner (NERP Landscape & Policy Hub, University of Tasmania, Lechner & Lefroy 2014); Mapping Community Values led by Chris Raymond (NERP Landscape & Policy Hub, University of South Australia), and Planning for Green Open Spaces led by Chris Ives (NERP Environmental Decisions Hub, RMIT University, Ives et al. 2014). These research projects all investigate aspects of biodiversity conservation and urban planning within the LHSA region.

In addition, aspects of this research have been presented to a broader audience at the Lower Hunter Regional Forum Seminar Series and several academic conferences, including the Best Practice Ecological Rehabilitation of Mined Lands Conference (Newcastle, NSW - 2013), the International Congress of Ecology (London, UK - 2013), EcoTas13 (Auckland, NZ - 2013), the Ecological Society of Australia conference (Alice Springs, NT – 2014) and the World Parks Congress (Sydney, NSW – 2014).

1.8. Previous conservation priorities in the Lower Hunter Region

Lower Hunter Valley has been the target of several nature and conservation assessments in the past. Numeral efforts have been made to map the distribution of native vegetation (Cockerill et al. 2013a) and threatened communities (Cockerill et al. 2013b), and the habitats of individual species of conservation interest (Eco Logical Australia 2013; Lloyd et al. 2013; Roderick et al. 2013). The outputs of many of these projects have been included to this work either directly as representative distribution maps of specific species and communities (see Chapter 3), or indirectly as environmental variables used to model the distributions of species and communities (Chapter 2).

Several assessments have also been taken to evaluate and identify important ecological corridors, both within and beyond the Lower Hunter. These include the Wildlife Corridors of State and Regional Significance (Scotts 2003), the Great Eastern Ranges Initiative (reviewed by Mackey et al. 2010) and a more recent, regional connectivity and corridor analysis funded by NERP (Lechner & Lefroy 2014). Promotion of landscape connectivity through establishment of corridors and other approaches aims to preserve and support ecological processes, such as dispersal, gene flow and recolonization of empty habitat patches, and therefore improve the long-term persistence of species and communities in the landscape. Functional connectivity can only be built upon existing locations of suitable habitat (Hodgson et al. 2009) and using species-specific information on connectivity needs, which is rarely available for many species. The main difference between this work and some of the previous connectivity and corridor work done in the region is, that whereas the corridor projects essentially aim to connect key habitats of key species and communities, this work aims to identify where in the landscape those key habitats are across multiple species and communities.

In 2009, the NSW Department of Environment, Climate Change and Water (DECC) published the Lower Hunter Regional Conservation Plan (DECCW 2009), identifying a suite of actions to meet the biodiversity commitments within the Lower Hunter Regional Strategy (Department of Planning 2006). These included the identification of candidate areas for the establishment of new reserves, as well as other areas of high conservation priority which could be protected through optional mechanisms, such as voluntary conservation initiative, offsetting and government biodiversity investments. The assessment was based on a suite of spatial layers, including information on native vegetation communities, old-growth forests, extensively cleared wilderness, wetlands and landscapes, key habitats of eight fauna assemblages and wildlife corridors of state and regional significance (Scotts 2003). These layers were compiled into a single Biodiversity Conservation Lands layer showing the local, regional and state significance of each location, and used together with biodiversity targets and reserve design principles agreed to by Australian states and territories and the Australian Government (commonly referred to as the JANIS criteria, Commonwealth of Australia 1997) to select areas of conservation priority. Identified areas of high priority included the Watagan Ranges-Port Stephens and Wallarah Peninsula Corridors and extensions/additions to Werakata, Karuah and Worimi Nature Reserves. Some of these areas have since then been formally protected.

The outputs of any spatial conservation planning assessment are dependent on the scale of the assessment and the input data that is used to populate the model, as well as the method by which priority areas are identified. This work differs most significantly from the one underpinning the Lower Hunter Regional Conservation Plan by using much larger, mostly species level input data on high quality habitats and known occurrences and by prioritizing areas based on local representation of biodiversity, using the principles of complementarity and irreplaceability. The Biodiversity Conservation Lands produced as part of the Regional Conservation Plan is mainly built upon vegetation patterns and proposed corridors, and the reserve design principles give high weight on feasibility of acquisition, favouring large continuous patches of habitat on public land holdings or major habitat linkages across the region. There are no ‘correct’ spatial conservation plans but each model is typically designed to answer a specific conservation question. As such, the Regional Conservation Plan is more directly tailored to support ecological processes of some species and communities in the Lower Hunter, avoiding likely conflicts between regional development and conservation. The prioritization presented in this report gives more detailed picture of biodiversity patterns in Lower Hunter and forms a basis for further biodiversity and conservation assessments, including the process of bringing together multiple planning needs in the region.

Chapter 2 Biodiversity features included in the analysis

This assessment includes data for a range of biodiversity features, including flora and fauna species, known species' habitats and ecological communities. This chapter describes the sources of these data and how they were processed prior to species distribution modelling (Chapter 3) or inclusion in the spatial prioritisation (Chapter 4).

2.1. Flora and fauna species

2.1.1. Species data: point occurrences and modelled distributions

All species listed under Commonwealth (EPBC Act 1999) or NSW legislation (Threatened Species Conservation Act 1995, National Parks and Wildlife Service Act 1974) were identified as potential biodiversity features to include in the analyses. Point occurrence data for all listed species within the Greater Hunter were downloaded from the ALA and BioNet, using the University of Melbourne data license. Additional point data for 101 species were provided by OEH and participants of the flora workshop.

To reduce biases due to potentially outdated and/or inaccurate spatial data, we undertook a process of filtering point occurrence records whereby species records were excluded if they were observed prior to 1 January 1990 to reduce uncertainties associated with spatial accuracy and subsequent changes in environmental data, particularly vegetation cover. We also excluded those records that had a spatial accuracy of greater than 100 m. This accuracy filtering excluded all records with denatured location coordinates of species classified as Category 2 Sensitive Species in the OEH's BioNet database. OEH provided spatially accurate records for some of these species to be included to the analyses. After the spatial accuracy filtering, the remaining data points for each species were then compared to a raster grid of the Greater Hunter with a 100 m grid resolution and all duplicate records within a given grid cell removed. Thus, the final data for each species represents the distribution of occurrence records across the Greater Hunter region since 1 January 1990 where duplicate records have been removed.

After data filtering, we had point occurrences for 712 species of amphibians, birds, mammals, plants and reptiles with at least one occurrence within the LHSA region. For 576 species with more than 20 occurrence points within the Greater Hunter we produced continuous distribution maps showing the likelihood of observing the species in any of the 100 m grid cells (Chapter 3). For the remaining 136 species with less than 20 occurrence points, we used the filtered occurrence records to indicate their known locations within the LHSA region. The full list of species included in the spatial prioritisation can be found in Appendix 3.

2.1.2. Additional species layers

Five additional data layers were provided by DoE for inclusion in the Zonation analyses. These data layers have been produced as part of other NERP projects and were considered important for the Lower Hunter Strategic Assessment. Prior to inclusion in Zonation, all additional layers were converted to rasters with the same extent and resolution (100 m) as the modelled species' data and clipped to the prioritisation area.

Distribution maps of Swift Parrot and Regent Honeyeater

The LHSA region has been shown to contain critically important winter foraging habitats for swift parrots (*Lathamus discolour*), and foraging and breeding sites for regent honeyeaters (*Anthochaera phrygia*) in winter and spring. Both species are listed as Endangered under the EPBC Act and as Critically Endangered/Endangered, respectively, under the NSW TSC Act. Habitat models for the swift parrot and regent honeyeater were produced by BirdLife Australia across the LHSA region (Roderick et al. 2013). These models were based on careful assessment and refinement of extant observation records combined with additional targeted surveys that allowed the potential distribution of the two relatively rare species to be modelled. The modelling was done using the same tools (MaxEnt) as presented in this report and utilised 15 environmental variables that described climatic, topographical and soil conditions across the LHSA region. Habitat suitability of the two species was predicted across the Lower Hunter region at a 100 m resolution. Details of the data collection and modelling are given in Roderick et al. (2013). We used these two species distribution models as the only distribution layers for these species as they provide the most comprehensive and up-to-date data available.

Important koala habitats for conservation

The LHSA contains important habitat for koala (*Phascolarctos cinereus*), listed as Vulnerable both nationally and in NSW (EPBC Act, NSW TSC Act). We produced an SDM for koala within the LHSA region using MaxEnt as described in Chapter 3. In addition, DoE provided a map of priority koala habitats for conservation generated by EcoLogical Australia (Eco Logical Australia 2013). This priority map is based on expert judgement and GIS modelling and identifies priority habitats for koala as a weighted score of vegetation type, soil fertility, patch size, proximity to water and roads, and the recorded presence of koala, projected across the LHSA region at a 25m resolution. It is good to distinguish between the differences in interpretation of the two koala maps: our SDM predicts the relatively likelihood of occurrence for koala at a given site based on the vegetation and environmental variables listed in Table 2. In contrast, by emphasising the importance of factors such as patch size and distance to roads, the priority map produced by EcoLogical Australia highlights areas of koala habitats that are still relatively intact and free from human disturbance, aspects that may be important when selecting sites for additional protection. However, in landscapes with intensive human land use, favouring relatively undisturbed areas increases the risk of trading-off the last remaining remnants of highly suitable habitat. Due to the differences in the preparation and interpretation of the two maps with respect to the importance of areas for koala protection, both layers were included in the prioritisation.

Foraging and roosting habitat of grey-headed flying fox

The grey-headed flying fox (*Pteropus poliocephalus*) is listed as an MNES species under the EPBC Act, and considered vulnerable across Australia (EPBC Act 1999) and within NSW (NSW TSC Act). The protection and management of this highly nomadic species is challenging as individuals follow temporal and spatial changes in their food resources across Eastern Australia and occupancy of camp sites fluctuates notably through time, with sites being occupied by up to tens of thousands of individuals present at any one time or temporarily abandoned. Due to the highly mobile and complex landscape use of the species and large temporal fluctuations in observations, statistical species distribution models (described in Chapter 3) might not comprehensively capture the importance of sites in terms of supporting long-term population dynamics. Therefore, in addition to our species distribution model, data layers of foraging and roosting areas of the grey-headed flying fox were included in the spatial prioritisation analysis.

The spatial data provided by DoE represented potential foraging habitat and known roosting camps based on analyses conducted by GeoLINK (Lloyd et al. 2013). Potential foraging habitat was based on a ranking scheme that considered flower, nectar and fruit productivity of different vegetation types, the density of important dietary species and the seasonality of available forage material. This information was combined to generate a foraging habitat score for each vegetation type within the Lower Hunter valley (Lloyd et al. 2013). Data were provided as polygons based on Map Units within the GHVMv4 (Sivertsen et al. 2011). Roosting campsites were provided as point location data for 20 camps across the LHSA where grey-headed flying foxes are known to occur. Each point was buffered by the estimated canopy availability of suitable vegetation surrounding each camp (Lloyd et al., 2013) before being converted to a raster.

2.2. Ecological Communities

2.2.1 Nationally-listed Ecological Communities

Ecological community data for communities listed under the EPBC Act were compiled by Parsons Brinckerhoff (Cockerhill et al 2013) and provided as polygons by DoE (Table 1). All nationally-listed ecological community layers were converted to individual raster grids for inclusion in the spatial prioritisation. The Hunter Valley Remnant Woodlands and Open Forest data includes both areas that have been specified in nomination and areas that have not been specified but which are consistent with the community definition. In this case grid cells that included specified areas were given higher value (1.0) in comparison to the unspecified ones (0.5) to reflect their higher importance within the region.

Table 1. Nationally-listed ecological communities included in the spatial prioritisation.

Community	**Commonwealth Status**
Listed under the EPBC Act 1999	
Littoral Rainforests and Coastal Vine thickets of Eastern Australia	Critically Endangered
Lowland Rainforests of Subtropical Australia	Critically Endangered
Nominated for listing under the EPBC Act 1999	
Subtropical and Temperate Coastal Saltmarsh	Vulnerable
Hinterland Sand Flats Forest and Woodland of the Sydney Basin Region	Waiting for decision
Hunter Valley Remnant Woodlands and Open Forests	Waiting for decision

2.2.2 State-listed Endangered Ecological Communities

Occurrence points for state-listed EECs within the Greater Hunter were extracted from the survey records used as input data for constructing the GHVMv4 (Sivertsen et al. 2011) based on the Map Unit codes. Because EECs are mutually-exclusive (i.e. two EECs cannot, by definition, occur in the same place), we treated these occurrences records as presence-absence data where the presence of one EEC indicated that all other EECs were absent. In addition, because these records were undertaken as part of a systematic survey, we considered them to be spatially accurate and no data filtering was undertaken.

For 14 EECs with more than 20 occurrence points within the Greater Hunter we produced continuous distribution maps showing the likelihood of observing the species in any of the 100 m grid cells (Chapter 3). For five EECs with less than 20 occurrences we used the occurrence records to indicate their known locations within the LHSA region. The full list of state-listed EECs included in the analyses can be found in Appendix 3.

Chapter 3 Modelling species potential distribution patterns

3.1 Modelling the distribution of threatened species

To identify areas important for conservation, it is necessary to understand how threatened species and other important biodiversity features are distributed across the landscape. Distribution data is typically available as occurrence records, where an observer has noted the location of an organism at a given point in time. However, incomplete sampling and difficulties in detecting species mean that these records often do not represent the entire habitat for a species. Therefore, prioritising sites for conservation based solely on known occurrence data is likely to be biased towards those sites that are well sampled or where common and easy to survey species are located, with the very real risk of missing important habitats (Rondinini et al. 2006).

Species distribution modelling provides a tool that can predict the likely distribution of a species based on known occurrence data and environmental conditions at these localities (Figure 2). The technique is well established within the ecological literature and provides a robust and transparent method for predicting the distribution of species from available data. Here we predict the distribution of 576 species and 14 EECs known to occur within the LHSA , for which there were sufficient data records to build models, using two species distribution modelling tools, MaxEnt (species; Phillips et al. 2006) and boosted regression trees (BRTs; Elith et al. 2006). The outputs from this modelling are then used as input data for a spatial conservation prioritisation to identify high priority conservation areas for the LHSA region (Chapter 4). For other biodiversity features, described in more detail in Chapter 2, we used the original point or polygon layers to represent their distribution in the spatial conservation prioritisation of LHSA region (Chapter 4).

3.2. Species distribution modelling

We used publically available species occurrence data in a species distribution modelling framework to characterise spatial patterns of threatened biodiversity within the LHSA region. The collection and pre-processing of these data are described fully in Chapter 2.

3.2.3. Sampling bias layers

Species distribution modelling techniques based on presence-only data assume that the landscape has been systematically or randomly sampled (Phillips et al. 2009) and failure to correct for geographic biases in the data can produce outputs that reflect the sampling effort rather than the true species distribution (Reddy & Dávalos 2003). One option for reducing biases is to manipulate the background data used in the modelling process by introducing a sampling bias layer that mimics the biases in the occurrence data (Phillips et al. 2009; Kramer-Schadt et al. 2013).

The spatial distribution of species observations within the Greater Hunter region is highly biased towards populated areas. Therefore, to reduce the influence of these observed biases in the species occurrence data, we generated sampling bias grids for five broad taxonomic groups of amphibians, birds, mammals, plants and reptiles. These taxon-specific bias grids were based on point data downloaded from the ALA and BioNet for all species observed within the Greater Hunter region. For each taxonomic group, we calculated a normalised kernel density layer from the available point data using a 10 km radius. We chose to use all species within a taxonomic group rather than just the listed species as it is likely that an observational technique that locates common species of a given taxa would also locate threatened species if they were present.

Because the sampling for EECs was conducted as part of a systematic survey, no bias layer was used in these models.

3.1.4. Environmental variables

A set of 18 ecologically-relevant environmental variables were selected as potential predictors of the distribution of threatened species and EECs within the Greater Hunter region (Table 2). These included variables describing the climate, vegetation, topography and soils that were available across the entire modelling region at 100 m resolution.

Several vegetation spatial datasets were available across the Greater Hunter region, with varying levels of accuracy. We took the best available datasets and merged these to provide a single layer that represented the best available data at the level of Keith Formations (Keith 2004) across the entire region. At the scale of the LHSA region, we used Keith Formation data from an updated version of the Lower Hunter vegetation mapping produced by Parsons Brinkerhoff (Cockerill et al. 2013a; updated by Mark Cameron, OEH, June 2014), while vegetation data outside the LHSA was obtained from the GHVMv4 spatial database (Sivertsen et al. 2011). In addition to the categorical Keith Formation layer (*final_vegetation*), we also generated a layer for three Keith Formations (dry sclerophyll forest, wet sclerophyll forest, rainforest) that represented the percentage cover of that vegetation community within a 2km radius of each pixel in the landscape (Table 2). The percentage cover estimates were restricted to these three Keith Formations as they have been assessed as having a high degree of accuracy (John Hunter, *Pers. Comm.*)

Table 2. Abbreviated names and definitions of mapped environmental data used as candidate predictor variables for inclusion in species distribution models. All environmental data were available in raster format with a resolution of 100 m.

Candidate variable	Definition (Source)	Units
mean_temp	Mean annual temperature (ANUCLIM)	degrees C
cold_temp	Mean temperature of the coldest period (ANUCLIM)	degrees C
hot_temp	Mean temperature of the hottest period (ANUCLIM)	degrees C
mean_rain	Mean annual rainfall (ANUCLIM)	mm
seasonal_rain	Mean annual temperature (ANUCLIM)	mm
mean_solar	Mean annual solar radiation (ANUCLIM)	$W/m^2/day$
Altitude	The altitude of a cell above sea level (25m DEM of Hunter Valley)	metres
Slope	The slope of a cell (derived from Altitude)	degrees
Eastness	The degree to which the aspect of a cell is east (east = 1, west = -1 – derived from Altitude)	index
Northness	The degree to which the aspect of a cell is north (north = 1, south = -1 – derived from Altitude)	index
rugg1000	Topographic ruggedness (standard deviation in altitude) in a 1000 m radius (derived from Altitude)	metres
terr1000	Relative terrain position in a 1000 m radius (derived from Altitude)	dimensionless
Wetness	Compound topographic index (derived from Altitude)	dimensionless
final_vegetation	Keith formation vegetation categories derived from the Parsons Brinkerhoff and Greater Hunter vegetation mapping (Sivertsen et al. 2011; Cockerill et al. 2013a)	categorical
Dry_sclerophyll_forests	The percentage of cells within a 2000m radius dominated by dry sclerophyll forest (derived from final_vegetation)	%
Rainforests	The percentage of cells within a 2000 m radius containing rainforest (derived from final_vegetation)	%
Wet_sclerophyll_forests	The percentage of cells within a 2000 m radius dominated by wet sclerophyll forest (derived from final_vegetation)	%
Soils	Digital Atlas of Australian Soils (CSIRO 2014)	categorical

ANUCLIM: Fenner School of Environment and Society, Australian National University
http://fennerschool.anu.edu.au/research/products/anuclim-vrsn-61

3.2. Species distribution modelling

3.2.1. Modelling species distributions using MaxEnt

All species distribution models were constructed using MaxEnt (Phillips et al. 2006, version 3.3.3k), a freely available software. MaxEnt uses presence-only occurrence data to predict the relative likelihood of observing a species in each pixel of the landscape, given the environmental conditions that exist there relative to the environmental conditions in pixels where the species is known to occur (Phillips & Dudík 2008).

Models were built for those 576 species known to occur in the LHSA region and that had a minimum of 20 records within the Greater Hunter region, using taxa-specific sampling bias grids to account for potential biases in the point data (Kramer-Schadt et al. 2013). For the remaining 136 species with insufficient point records to build reliable models, we used the filtered data points to represent their distributions within the LHSA region (for more details, see Chapter 2). All modelling was undertaken at the scale of the Greater Hunter region, using raster grids with a grid cell resolution of 100 m. The larger spatial extent for modelling was used to increase the amount of available records for species and communities but also to better capture the full range of their natural environments and therefore improve the performance of the models (Hernandez et al. 2006). The larger region forms a logical administrative boundary within which environmental data were readily available. For each modelled feature, the predicted distribution produced at this larger scale was then clipped to the LHSA region and used in subsequent analyses (Figure 2; see Chapter 4 for more details).

Prior to building the final model, we undertook a process of variable selection by including all 18 environmental variables in preliminary MaxEnt models for each species and then examining the outputs to identify the most important variables across broad taxonomic groups (amphibians, birds, mammals, plants, reptiles). Where variables were known to be spatially correlated (collinearity > 0.8), we retained the variable that had the highest mean training gain (a measure of how well a variable describes the presence data) for all species within a taxonomic group. We then reran the models and iteratively removed those variables that contributed little information based on their permutation importance (less than 1% on average across all species within a taxonomic group based on jack-knife tests) (Williams et al. 2012).

Once the parameter set was finalised, we ran the models using a five-fold cross-validation procedure (Hastie et al. 2001). With this process, the dataset was randomly divided into five exclusive subsets and model performance calculated by successively removing each subset, refitting the model with the remaining data and predicting the omitted data. We assessed the mean area under the receiver operator curve (AUC) value of each modelled species to determine the model fit, that is, how well the models are able to predict a species' known occurrences. We retained those species for which the AUC value was greater than 0.7, which is generally considered to be a threshold of an informative model (Swets 1988). For these species, we then reran the models using the full dataset and predicted the relative likelihood of occurrence of each species across the Greater Hunter at a spatial resolution of 100 m.

To explore the spatial uncertainties in our species' SDMs, we used the individual predictions from the models generated using five-fold cross-validation for each species to calculate the coefficient of variation (CV) within each grid cell: that is, for each species we calculated the mean and standard deviation of the predicted value in each grid cell across the five individual predictions, and divided the standard deviation by the mean in each cell (producing the CV for each cell). When estimated for a single species, a CV value greater than one represents a cell where the standard deviation across the five predictions is greater than the mean of those predictions, indicating notable variation and therefore potentially high uncertainty in the predicted value in the particular grid cell. To summarise the spatial patterns in SDM uncertainty, the CV values in each cell were then averaged across all species to identify how the variation in predictive ability of the SDMs changes across the landscape.

3.2.2 Modelling EEC distributions using boosted regression trees

We used boosted regression trees (BRT) to model the potential distributions of 14 EECs within the LHSA region. This allowed us to utilise the absence points associated with the GHVMv4 survey data, where the presence of a given EEC at a location necessarily indicates the absence of all other EECs. BRT models are an advanced regression technique based on machine learning (Friedman 2002) and are being used increasingly to model the distributions of species (Elith et al. 2006). BRT models are capable of dealing with non-linear relationships between variables and can assess high-order interactions, making them particularly suited for ecological data (Elith et al. 2008). BRT models are also robust to the effects of outliers and irrelevant predictors (Leathwick et al. 2006).

We used BRT to analyse the relationship between the occurrence of each EEC and the environment. All analyses were carried out in R (version 3.1.1) using the 'dismo' library (Hijmans et al. 2013). The models were allowed to fit interactions, using a tree complexity of three and a learning rate of 0.003. We used ten-fold cross validation to determine the optimal number of trees for each model, giving the maximum predictive performance. BRT models have a tendency to over-fit the training data, so the performance of the model was assessed by making predictions at sites that were not used during model development. The probability of occurrence of each EEC was predicted across the Greater Hunter region at a spatial resolution of 100 m. Because EECs have legal definitions that restrict them to specific bioregions, we clipped all EEC model outputs to their listed bioregions.

3.2.3. Model selection

The predictive power of each model was evaluated using AUC values (Hanley & McNeil 1982), where models with an AUC value of 0.7 or greater were considered to be informative (Swets 1988). Model outputs for species or EECs with an AUC greater than 0.7 were clipped to the LHSA region for inclusion in the spatial prioritisation. Models for species or EECs with an AUC less than 0.7 were either excluded from subsequent analyses or replaced with their original point data if they were represented by less than 100 records.

3.3. Results

3.3.1. Model performance

In general, model performance for the 590 modelled biodiversity features (576 species and 14 EECs) was high, with mean AUC values greater than 0.82 for all taxonomic groups (Figure 3; Table 3). Seasonal rainfall, slope and local vegetation type were important drivers for all taxonomic groups. In addition, the percentage cover of dry and wet sclerophyll forest and rainforest within a 2000 m radius were important for all taxonomic groups. Using the iterative variable selection led to small changes in AUC values for all species, with no consistent trend. Twenty-six species were identified as being poorly modelled by MaxEnt based on a mean AUC value of less than 0.7 (Table 4). The majority were common bird species, such as the Australian magpie (*Cracticus tibicen*) and laughing kookaburra (*Dacelo novaeguineae*), with a high number of records across the Greater Hunter region. These species typically occupy a broad range of habitat types and are, therefore, difficult to model accurately. Those poorly modelled species with greater than 100 records (20 out of 26) were excluded from subsequent analyses. For the remaining six species with less than 100 records (Table 4), we converted the filtered occurrence data to presence-absence rasters. Removal or conversion of these poorly modelled species led to a final pool of 564 modelled biodiversity features (550 species and 14 EECs) and 147 point features (142 species and 5 EECs) for inclusion in the spatial prioritisation.

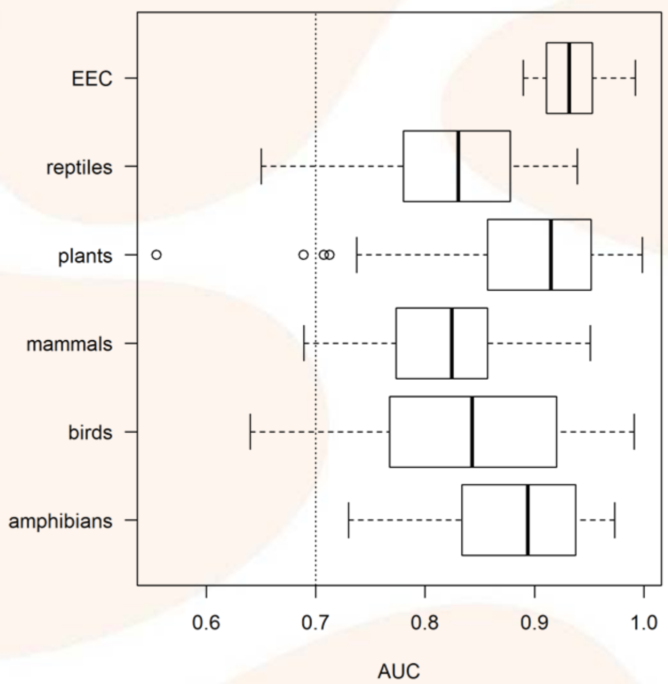


Figure 3. Boxplot of AUC values for 590 feature distributions modelled using MaxEnt (species) or boosted regression trees (EECs) summarised across the six broad taxonomic groups. AUC values greater than 0.7 are considered to be informative (Swets 1988). The black line within the boxes shows the median AUC values within groups. The whiskers give the full range of values and circles are individual features that differ significantly from the rest of the group. The boxes show how 50% of the values closest to median are distributed.

Table 3. AUC values and the relative importance of each environmental variable for 590 species distribution models summarised across taxonomic groups (mean ± standard error), along with the number of species per group. Variables with no data for a given taxa were not included in the model for that group. Variable descriptions are given in Table 2. Results are based on MaxEnt models for species, while EECs modelled using boosted regression trees. See Section 3.2 for further details. Outputs for individual species can be found in Appendix 1.

	Amphibians	**Birds**	**Mammals**	**Plants**	**Reptiles**	**EECs**
N	36	292	61	131	56	14
AUC	0.88 (0.01)	0.84 (0.01)	0.82 (0.01)	0.90 (0.01)	0.83 (0.01)	0.93 (0.01)
cold_temp	24.94 (3.39)	31.38 (1.37)	16.43 (1.94)	9.5 (1.18)	17 (2.22)	-
hot_temp	7.34 (1.36)	6.51 (0.51)	9.02 (1.38)	6.23 (0.89)	6.12 (1.04)	-
mean_rain	9.51 (1.86)	11.4 (0.91)	15.46 (2.34)	-	-	20.32 (3.81)
seasonal_rain	15.74 (1.73)	9.99 (0.54)	14.08 (1.44)	10.15 (1.05)	10.81 (1.23)	10.65 (2.45)
mean_solar	-	-	-	23.51 (1.81)	17.86 (2.23)	-
slope	14.11 (1.83)	10.33 (0.57)	12.8 (0.99)	4.6 (0.6)	10.96 (1.18)	5.91 (1.17)
rugg1000	3.43 (1.18)	-	-	-	-	6.72 (1.26)
terr1000	-	3.33 (0.27)	3.15 (0.57)	-	2.99 (0.33)	-
wetness	-	-	-	-	-	4.04 (1.03)
final_vegetation	4.76 (0.67)	3.97 (0.27)	8.46 (0.9)	6.94 (0.65)	10.06 (1.21)	9.51 (2.49)
Dry_sclerophyll_forests2000	5.38 (1.21)	8.95 (0.57)	6.35 (0.79)	7.03 (0.84)	10.06 (1.36)	7.7 (1.32)
Rainforests2000	3.79 (0.83)	3.52 (0.34)	3.26 (0.72)	3.35 (0.49)	2.58 (0.58)	4.82 (1.93)
Wet_sclerophyll_forests2000	8.99 (2.22)	10.63 (0.64)	8.33 (1.68)	5.7 (0.69)	8.56 (1.63)	3.16 (0.85)
soil	-	-	-	19.3 (1.34)	-	10.51 (1.49)

Table 4. List of 26 poorly modelled species with mean AUC values less than 0.7. These species were either excluded from subsequent analyses or included as point data if they had less than 100 records. Number of records refers to observations within the Greater Hunter region.

Species	Common Name	NSW Status	Number of records	Mean AUC (± se)	Decision
Birds					
Acanthiza pusilla	Brown Thornbill	P	4626	0.68 (0.01)	exclude
Alisterus scapularis	Australian King-Parrot	P	2244	0.68 (0.02)	exclude
Aquila audax	Wedge-tailed Eagle	P	1206	0.65 (0.02)	exclude
Artamus personatus	Masked Woodswallow	P	34	0.66 (0.09)	points
Cacatua galerita	Sulphur-crested Cockatoo	P	2256	0.69 (0.01)	exclude
Colluricincla harmonica	Grey Shrike-thrush	P	4255	0.67 (0.01)	exclude
Cormobates leucophaea	White-throated Treecreeper	P	4116	0.69 (0.01)	exclude
Corvus coronoides	Australian Raven	P	4501	0.70 (0.01)	exclude
Cracticus tibicen	Australian Magpie	P	5273	0.67 (0.01)	exclude
Dacelo novaeguineae	Laughing Kookaburra	P	5132	0.67 (0.01)	exclude
Eopsaltria australis	Eastern Yellow Robin	P	4385	0.69 (0.01)	exclude
Lichenostomus chrysops	Yellow-faced Honeyeater	P	5185	0.66 (0.01)	exclude
Malurus cyaneus	Superb Fairy-wren	P	4508	0.69 (0.01)	exclude
Ninox connivens	Barking Owl	V,P,3	22	0.64 (0.12)	points
Pachycephala pectoralis	Golden Whistler	P	4186	0.70 (0.01)	exclude
Pachycephala rufiventris	Rufous Whistler	P	2672	0.69 (0.01)	exclude
Pardalotus punctatus	Spotted Pardalote	P	4030	0.68 (0.01)	exclude
Philemon corniculatus	Noisy Friarbird	P	3678	0.67 (0.01)	exclude
Rhipidura albiscapa	Grey Fantail	P	6063	0.66 (0.01)	exclude
Strepera graculina	Pied Currawong	P	4849	0.64 (0.01)	exclude
Zosterops lateralis	Silvereye	P	3191	0.69 (0.01)	exclude
Mammals					
Tachyglossus aculeatus	Short-beaked Echidna	P	2350	0.69 (0.01)	exclude
Plants					
Diuris sulphurea	Tiger Orchid	P	40	0.69 (0.10)	points
Pterostylis obtusa	Blue-tongue Greenhood	P	29	0.55 (0.12)	points
Reptiles					
Lialis burtonis	Burton's Snake-lizard	P	63	0.66 (0.08)	points
Vermicella annulata	Bandy-bandy	P	62	0.65 (0.06)	points

3.3.2. Regional distribution patterns and uncertainty

We summed the predicted relative likelihood values in each grid cell across all species to give an indication of the overall regional biodiversity patterns based on the species included in this analysis (Figure 4a). In general, species were distributed unevenly across the region, with higher relative species richness closer to the coast. Maps of the predicted distributions for each of the modelled species are available upon request.

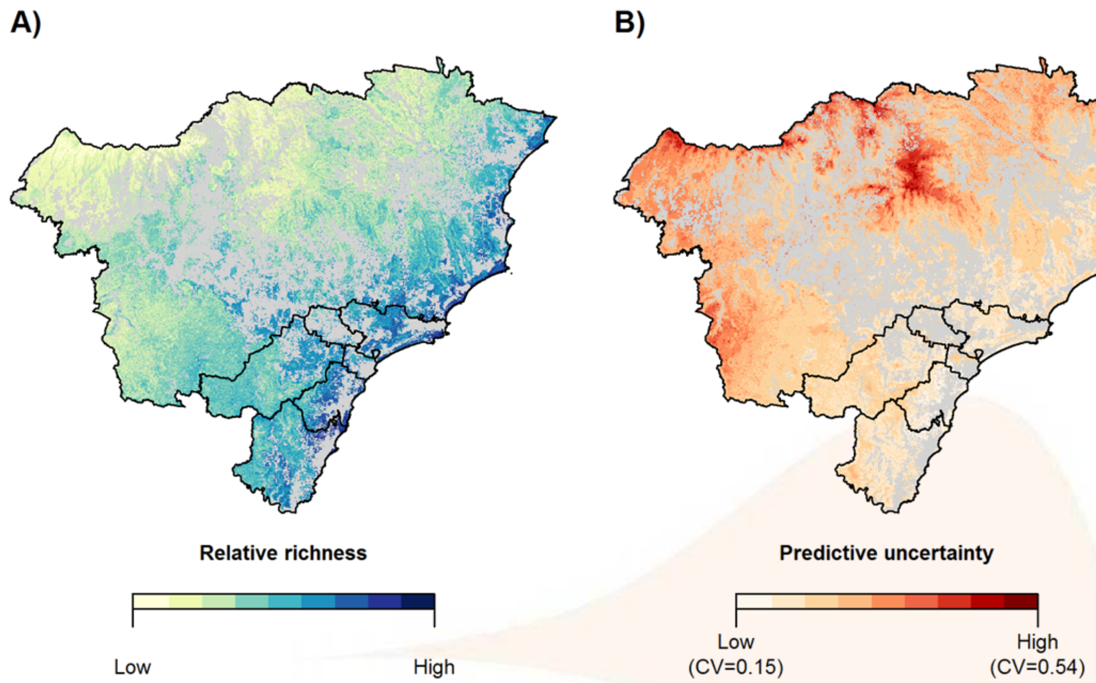


Figure 4. Spatial distribution patterns for species and EECs within the Greater Hunter region. A) Relative richness of species and EECs included in the analysis, calculated by summing the outputs of the 564 distribution models retained for inclusion in the spatial prioritisation. B) Mean predictive uncertainty across 550 modelled species distributions. These data were calculated by quantifying the coefficient of variation for each species' MaxEnt predictions based on five-fold cross validation and then averaging across all species (see Section 3.2.3). Grey represents areas within the Greater Hunter region that have been cleared of native vegetation.

The mean predictive uncertainty in the model predictions across the Greater Hunter region ranged from 0.15 – 0.54 (median: 0.26), with the highest values occurring around the Coolah Tops and the Barrington Tops National Parks (Figure 4b). After clipping the final models to the LHSA region, the mean spatial uncertainty across all species ranged from 0.15 – 0.39 (median: 0.21).

3.4. Discussion

3.4.1. Overview

The modelling framework described in this report to predict the distribution of threatened species within the LHSA region is well established amongst the conservation literature (e.g. Guisan & Zimmermann 2000; Phillips et al. 2006; Phillips & Dudík 2008; Williams et al. 2012). It provides a robust, transparent and repeatable method for predicting the relatively likelihood of species' occurrences across the landscape.

3.4.2. Limitations and sources of uncertainty

When using SDMs to inform decisions, it is necessary to consider the potential limitations and sources of uncertainty associated with the predictions (Guillera-Arroita et al. 2015). Uncertainty in species distribution modelling can arise from two major sources: poor quality input data or inappropriate model structures (Barry & Elith 2006). For example, inaccurate occurrence data may result from spatial biases in sampling, imperfect detection and/or misidentification of species, while appropriate environmental variables may not be available or mapped at a sufficiently-high resolution to be ecologically-relevant. Both issues can lead to models that may not reflect the true distribution of the species, with potential ramifications for the decision-making process. Also, the choice of modelling technique may influence model predictions. Here we chose to use two well-established methods (MaxEnt, BRT) to fully utilise the presence-only and presence-absence data available for species and EECs, respectively, and reduce any potential biases from model structure.

The occurrence data used in this analysis were obtained from two online databases that combine data from a range of sources, including systematic surveys, museum records and observations by the general public. While the records were cleaned for spatial accuracy to the best of our ability, we were unable to compensate for inaccuracies due to species misidentifications or taxonomic changes. Therefore, it is possible that some inaccurate records were included in the model construction.

Initial analyses identified a strong spatial bias in the occurrence data, with records concentrated close to the coast. For this reason, we included bias layers in the modelling approach to try and reduce the impact of this sampling bias when making predictions. Using a bias grid has previously been shown to help address issues related to sampling bias (Kramer-Schadt et al. 2013). However, the strong spatial bias in observation records is still evident in the species distribution models, showing higher levels of model uncertainty in the poorly surveyed areas of Northern and Eastern Greater Hunter (Figure 4). These gaps in survey data may also, to some degree, affect the estimated richness patterns in the region, although the overall pattern of increasing species richness towards coastal areas is generally well supported.

Species distribution models are reliant on the appropriate use of ecologically-relevant environmental data to make sensible predictions across the landscape and the availability of accurate data at an appropriate resolution can be problematic. We were able to include a range of environmental data describing characteristics of the climate, topography, soils and vegetation across the Greater Hunter region. Our modelling framework used a process whereby all species within a given taxonomic group were modelled using the same suite of environmental variables. While it would have ideally been better to fine-tune the models for each species individually, this was not possible due to time constraints and the large suite of species modelled. The high AUC values (Figure 3; Table 3) of most of our models indicate that, despite the somewhat generic variable selection process across taxonomic groups instead of individual species, our approach was successful in building distribution models that captured the known occurrences of species and notably increased our understanding of their distribution patterns within unsurveyed areas.

It is important to understand that there may be some mismatches between species' observed distributions and their predicted distribution when species are absent from a site identified as having suitable habitat. This common observation of environmentally-suitable but unoccupied sites often results from competitive exclusion by other species, a low dispersal ability that may prevent colonisation of otherwise suitable sites or historic factors that may have excluded species from a previously occupied site (Guisan & Zimmermann 2000). While these areas may not currently be occupied, they represent potentially suitable habitat for the species concerned and may still be important for conservation purposes.

While our analysis of spatial uncertainty in the predictions indicated some areas of higher uncertainty within the Greater Hunter region, these were located predominantly in the north-western areas outside the LHSA region (Figure 4). All modelled distributions were clipped to the LHSA region prior to further analysis, effectively removing these areas of higher spatial uncertainty in the predictions. Ideally, the predictions from SDMs should be validated to ensure that they accurately reflect the true distribution. There is a trade-off between using unvalidated SDM models and the time required to generate potentially hundreds of highly accurate SDMs. While it is important to recognise the potential uncertainties associated with the model predictions, SDMs contain more information than the original point data (Rondinini et al. 2006). The models retained for use in the spatial prioritisation all had a high predictive value and low spatial uncertainty in the predictions. Therefore, we feel confident that they represent the best available distribution data for inclusion in the spatial conservation prioritisation (Chapter 4; Hermoso et al. 2015). However, we recommend that sites highlighted by subsequent analyses as high priority for conservation or at risk from development be surveyed as part of the decision-making process.

Chapter 4 Spatial conservation prioritisation of the Lower Hunter Region

4.1. Prioritising areas for conservation – the algorithm

After mapping the spatial distribution of all included biodiversity values, our next step was to identify those areas across the LHSA region that are most important for comprehensively representing the regional biodiversity and which provide the best available habitat for the included features. This spatial prioritisation of sites within the LHSA region was carried out using the conservation prioritisation software Zonation v.4.0 (Moilanen et al. 2005, 2012). Zonation is a spatial tool that uses information about biodiversity features, their relative occurrences and biological needs to create a hierarchal ranking of sites across any given landscape (Figure 2b). The hierarchical ranking of the sites is created through a removal process, where the software starts by assuming that all sites (grid cells) in the landscape are protected. It then proceeds by progressively removing cells that cause the smallest marginal loss in conservation value (Figure 5). This is repeated until no cells are left, the least valuable grid cells being removed first and most valuable cells being retained until the very end. The cell removal order then produces a ranking, or priority value, for each cell. Priority areas for conservation can then be identified simply by taking any given amount of area with highest priority ranks, or by selecting the top fraction of ranked cells up to a given budget level. More details about the Zonation prioritisation algorithm can be found in Appendix 2.

The conservation prioritisation produced by Zonation is primarily based on local habitat quality and presence of biodiversity features in each grid cell. The spatial distribution of different features drives the prioritisation in the sense that the program seeks to find a set of sites that represents the entire regional biodiversity as comprehensively as possible (see Section 1.3). In the case of this assessment, local habitat quality is reflected by the relative likelihood of observing the species in a given cell, as predicted by the species-specific distribution models, assuming higher values to indicate a better suitability and therefore quality of habitat. For features with point occurrence or polygon data no discrimination of habitat quality between the locations can be made unless such information is specifically provided. The program can in addition account for other ecological factors such as connectivity of sites. However, for the analyses presented in this draft report we did not include connectivity considerations as it was not possible to acquire the detailed information on dispersal capability and/or connectivity needs of the considered features within the time frame. The top priority sites identified in this analysis therefore represent areas which are assumed to be of high local habitat quality and where representation of the included features is maximised.

BOX 1: Creating a spatial prioritization in Zonation

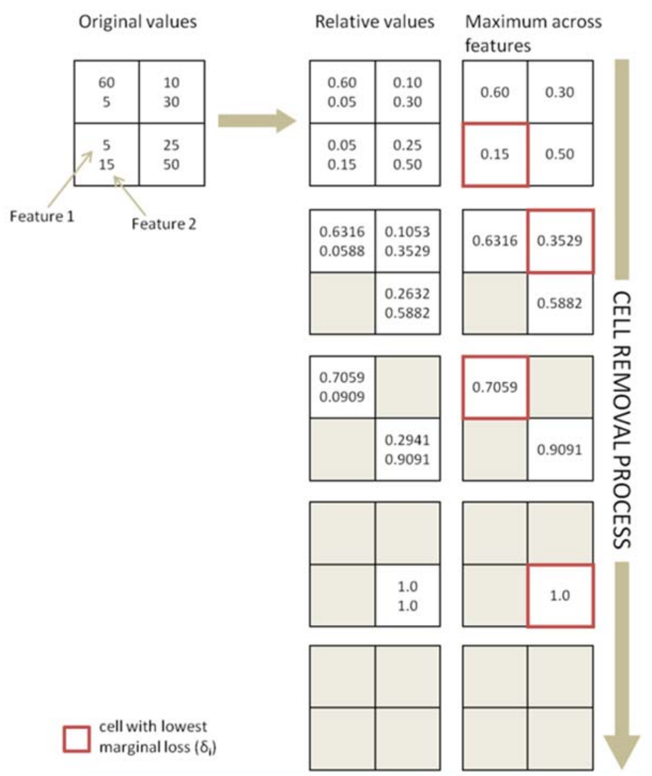


Figure 5. Illustration of how spatial prioritisation is created by the Zonation software, using a simple example of two features (Features 1 and 2) and four grid cells.

Zonation can use data of any type, for example, probabilities of occurrences, known presences and absences, numbers of individuals, populations, breeding sites, etc. For the purpose of this illustration let us assume that the original data values are numbers of individuals of both features in each grid cell, both features having a total 100 individuals within the study area. The program starts by transforming the original values into relative values. For example, the 5 individuals of Feature 1 in the low-left grid cell represent 5% (0.05) of the entire population of Feature 1 within the study region, and 15 individuals of Feature 2 represent 15% (0.15) of Feature 2 population. The program then starts to remove cells based on the maximum relative values across the two features in each cell. The cell that has the smallest maximum value will be removed at each step, as this causes the smallest marginal loss across both features. At each step the relative values are updated for the remaining cells, so that the more a feature has lost in previous steps, the more valuable the remaining occurrences become. The program then proceeds to remove cells until no cells are left in the landscape. The removal produces a ranking where relatively less valuable grid cells across both features are removed first and the most valuable grid cells are retained as long as possible. Because the program converts the original values to relative values, different data types such as modelled distributions and point occurrences can be analysed in together. However, it is important to understand the subtle differences in the way the different data types drive the prioritization process and how the results can be interpreted for each data type. In practice, when the analysed spatial data is very large such as in the case of Lower Hunter (>280,000 grid cells), the relative value of any single point occurrence is likely to be much higher than a corresponding single value within a continuous modelled distribution surface. From this follows that the relatively few locations of species represented with point occurrences or polygon data are likely to have high relative values and therefore will be retained till the very end of the prioritization process.

We used Zonation to build an understanding of how conservation priorities within the LHSA region are distributed, but also to assess how they are currently protected and what the anticipated impacts of proposed future development to these priorities are. In the first phase the prioritisation was done without considerations of land tenure or future development plans. Hence, the conservation value of a given grid cell was based purely on the biodiversity features within that cell, irrespective of whether that cell is currently protected or not, or if it is proposed to be developed under any of the development scenarios. To analyse the latter two aspects we used a built-in feature of the Zonation software called *replacement cost analysis* (Cabeza & Moilanen 2006). The feature allows artificial alteration of the cell removal order in the prioritisation process to account for the fact that some areas might be ear-marked for development whereas others are already protected by existing reserve networks. This process constrains Zonation to remove grid cells from certain areas first (e.g. planned development areas) or to retain cells until the very end (e.g. existing protected areas) regardless of their conservation value. This produces a constrained solution that can be compared with the unconstrained solution to quantify the impact of including or excluding sites to/from the top fraction.

We used the replacement cost feature in two ways (Table 5): first, we forced in protected areas of the PPSA region (Figure 6) to analyse how much of the distributions of features are currently secured under different levels of protection and what conservation potential there is left in the currently unprotected areas (Section 4.5.3). Second, for each of the assessed development scenario we forced out sites marked for future development and quantified the potential losses these would cause to features in terms of lost distribution area. The assessment of development impacts is described in more detail in Chapter 5.

Table 5. General description of the spatial analyses done using the spatial prioritization software Zonation (version 4.0). See Chapters 4 and 5 for further details.

Spatial analysis	Methodological description	Purpose	Described in more detail in
Priorities for conservation *Unweighted* *Weighted*	Unconstrained prioritisation	To identify areas of high conservation value across all included biodiversity features. In the unweighted analysis all features are treated as equally important. In the weighted analysis features are weighted according to their Commonwealth and state threat-listing and other characteristics (see section 4.3 for details).	Chapter 4

Current protection	Constrained prioritisation where protected areas are forced in to the top priorities	To analyse how well features are currently protected by the different types of protected areas and what conservation potential remains in the unprotected areas.	Chapter 4
Development impacts *Urban* *Infrastructure* *Agriculture* *Cumulative impact* *Mining*	Constrained prioritisation where for each of the development scenario areas proposed for development are forced out from the top priorities	To estimate the potential losses to biodiversity if the areas proposed for development were entirely cleared.	Chapter 5

4.2. Features used in the prioritisation

To map the spatial configuration of conservation priorities in the LHSA region we used spatial data for 721 biodiversity features (Table 6), described in detail in Chapter 2. For each biodiversity feature we used an individual map showing their distribution within the LHSA region as input data for the spatial prioritisation. This included modelled distributions (described in Chapter 3) for 564 biodiversity features (550 species and 14 EECs), and point occurrence data for an additional 147 biodiversity features (142 species and 5 EECs) for which good distribution models could not be built due to low number of observation records or poor model performance. In addition, we used polygon data for five Commonwealth-listed EECs and five additional raster layers for regent honeyeater, swift parrot, koala and grey-headed flying fox as described in Section 2.1.2. Of all biodiversity features included in the prioritisation, 91 were listed as MNES (Table 6). The selection of species and other biodiversity features for this analysis was done in collaboration with DoE and HCCREMS, together with participants of the flora and fauna workshops. All maps of biodiversity features were clipped with a mask to restrict the prioritisation to areas of remnant native vegetation. This *prioritisation footprint* covered ~280,149 ha or 65% of the LHSA region and is described in Section 1.5.

4.3. Weighting of features

In conservation prioritisation, species and other biodiversity features are rarely seen as equally important for conservation (Margules & Pressey 2000). For example, there might be greater interest in protecting a critically endangered species that is endemic to the study region in comparison to a non-threatened species that is common and occurs across a large range. These differences in conservation importance can be incorporated to spatial conservation planning through the use of weights which guide the algorithms to give higher priority to areas with species of greater importance. There are no general rules for how species and other features should be weighted relative to each other. Weighting schemes are always case-specific and reflect the subjective values of managers, decision-makers and the wider society. However, DoE recently produced a decision framework for guiding the weighting of MNES in Strategic Assessments (Miller 2004, unpublished) based on their respective national threat-category and level of endemism to the region of interest.

For the fauna and flora species, as well as for the EECs in the LHSA region, a weighting scheme was developed in two separate workshops organised by HCCREMS in July 2013 (fauna) and May 2014 (flora and EECs). Expert panels invited by HCCREMS used information on factors such as Commonwealth and State threat listings, and migratory behaviour, to set weights for each species or EEC (Table 7). These weights were used in the spatial prioritisation of the LHSA region to give higher priority to areas with occurrences and/or high habitat suitability of features with higher weights. Final weightings for individual species and EECs are given in Appendix 3. We did not explore other combinations of weights as part of this project but we report the result of both unweighted and weighted solutions to illustrate how the selected weights impact the prioritisation process.

Table 6. Taxonomic breakdown of the 721 biodiversity features included in the Zonation spatial prioritisation. MNES features are listed under the EPBC Act, while Commonwealth-listed species may be listed under the EPBC Act or the migratory bird agreements with China, Japan or the Republic of Korea (CAMBA, JAMBA, ROKAMBA). NSW-listed features are listed as threatened under the NSW Threatened Species Conservation Act. Note the species and communities may be listed under multiple legislation or listed in NSW as protected but not threatened. Therefore, the total number of features included in the prioritisation for each taxonomic group is not necessarily the sum of the listed features for that group. The complete feature lists can be found in Appendix 3.

Taxa	Total	MNES	Commonwealth-listed	NSW-listed
Amphibians	40	3	3	6
Birds	316	51	51	50
Mammals	64	7	7	23
Plants	212	24	24	43
Reptiles	62	0	0	2
EECs	24	6	6	17
Other habitat features	3	-	-	-
Total	721	91	91	141

It is worthwhile noting that as the Zonation algorithm uses values of the relative representation of features to create the priority ranking of the landscape, higher value is inherently given to sites that contain occurrences of narrowly distributed species. This follows the logic that any one occurrence of a narrowly distributed species is more important than an occurrence of a common species. Higher weights for narrowly distributed species might, therefore, have minimal additional benefits to how well these species are represented in the top priority sites. Weights can, however, be effectively used to distinguish between true rare endemics and species that are rare only within the study region but common outside it. To fully explore the impact of weighting on the resulting priorities it is essential to compare it to an otherwise identical but unweighted solution.

Table 7. Base criteria used to weight biodiversity features within the LHSA region based on their perceived conservation importance. Weightings were derived by participants of the flora and fauna workshops. Note that species and communities may be listed under multiple legislation. Whenever a feature had multiple threat listings, the highest weight was used.

Fauna	Flora & EECs	Weight
Critically endangered	Commonwealth-listed	7
Endangered	Critically endangered	6
Endangered population	Endangered	5
Vulnerable	Vulnerable	4
Migratory A	Endemic	3
Key Spp - important in region or might become threatened Migratory B	Nominated or possible for listing	2
Other	Other	1

4.4. Protected Areas

The spatial prioritisation of the LHSA region was compared to the existing protected area network to assess how well the conservation priorities are currently protected and what conservation potential there remains within unprotected areas. Based on discussions with DoE and HCCREMS, we identified all relevant protected areas to be included in the analysis and divided them into three categories that were assumed to represent different levels of tenure security (Table 8; see Appendix 4 for details of the spatial layers used):

LEVEL 1 protected areas have the highest level of protection and include nature reserves, national parks, regional parks, state conservation areas and aboriginal areas. These protected areas together cover approximately 84,613 ha (19.7%) of the LHSA region and contain 27.9% (78,239 ha) of the region's remnant native vegetation (Table 8).

LEVEL 2 protected areas include flora reserves and protected areas within state forests, Ramsar wetlands and two environments listed under State Environmental Planning Policy (coastal protection - SEPP14 & littoral rainforest - SEPP26). In addition, they include Commonwealth-listed heritage sites and indigenous protected areas. Note that Williamstown RAAF Airport was excluded from the Level 2 protected areas, even though it is listed as historic Commonwealth Heritage site. Salt Ash (military target practicing area) and the indigenous Commonwealth Heritage sites around the Airport were included based on their known biodiversity value (Eco Logical Australia 2012) and because there are low chances of these areas being developed any time in the near future. Level 2 protected areas cover approximately 14,635 ha (3.4%) of the LHSA region and contain 4.5 % (12,500 ha) of the region's remnant native vegetation (Table 8).

LEVEL 3 protected areas are regions that have a low level of formal protection for conservation purposes but are typically thought of as having some conservation value. These include wildlife refuges, registered property agreements and Commonwealth lands. These areas cover almost 2,570 ha (0.6%) of the LHSA region and contain 0.7% (2,023 ha) of the region's remnant vegetation (Table 8).

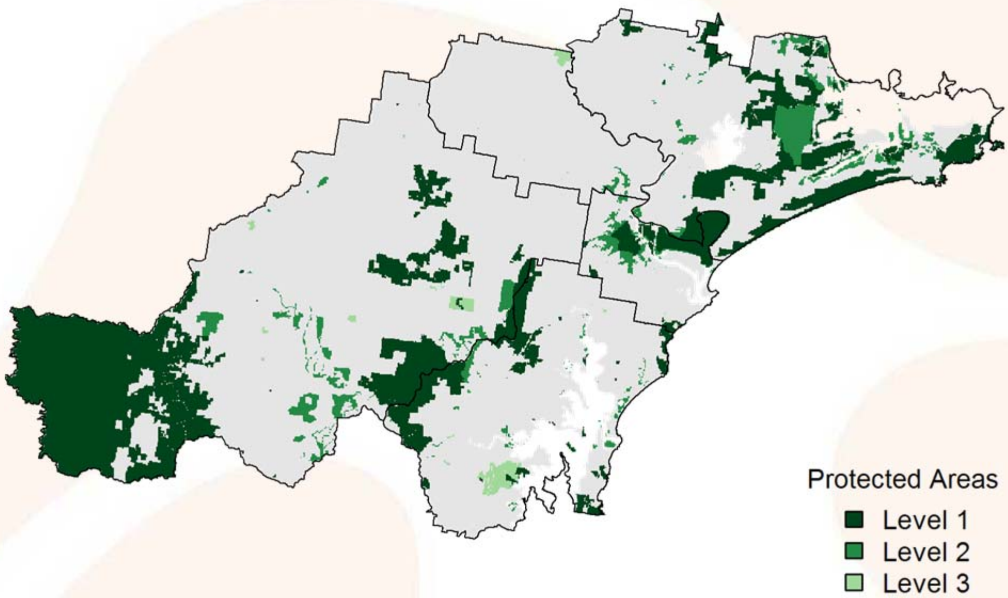


Figure 6. Current protected areas within the LHSA region. Protected areas have been grouped into three broad categories based on the strength of the legislative protection, with darker regions representing higher security.

Together these three levels of protected areas cover 23.7% (101,800 ha) of the LHSA region and 33.1% (92,762 ha) of the region's remnant vegetation (Figure 6; Table 8). For each protected area category we calculated the general overlap with the high priority conservation areas identified by the weighted spatial prioritisation of the LHSA region (Section 4.5.1; Figure 7b). We also assessed how well each of the protected area categories represents the regional biodiversity by calculating the average and minimum proportion of features' LHSA distributions that are captured by protected areas at each level of protection.

Table 8. The protected areas within the LHSA region, showing the area (ha) and proportion (%) of the LHSA region that is currently protected under each level of protection considered. We also show the area and proportion of native vegetation that is protected under each level of protection.

Protected Areas	**LHSA region**		**Native vegetation**	
	ha	%	ha	%
Level 1	84,613	19.7	78,239	27.9
Level 2	14,635	3.4	12,500	4.5
Level 3	2,570	0.6	2,023	0.7
Total	101,818	23.7	92,762	33.1

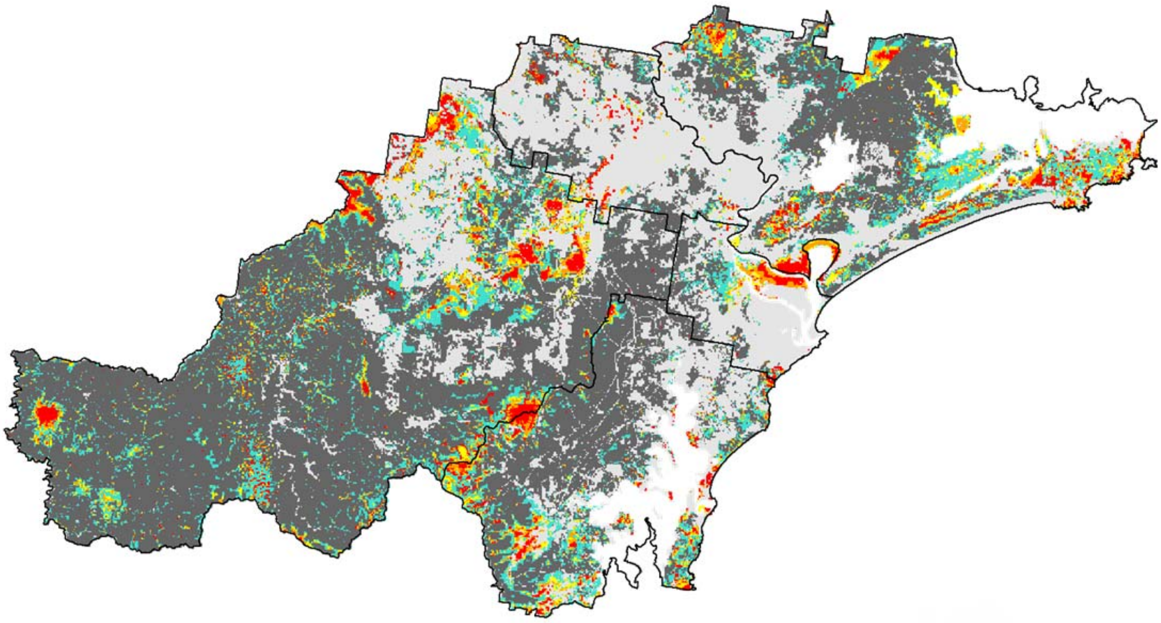
4.5. Results

4.5.1. Conservation priorities within the LHSA region

The unweighted spatial prioritisation of the LHSA region highlighted a number of highly important areas distributed across the region (Figure 7a). Concentrations of high priority conservation areas, which belong to the best 30% of the LHSA in terms of representing regional biodiversity (red to cyan areas in Figure 7), in the localities of North Rothbury, Polkolbin, Abermain, Sawyers Gully, Pelaw Main (near Kurri Kurri), Yengo National Park, Watagans National Park, Heaton State Forest, Anna Bay, Koragang, and Tomago. (Figure 7a). Several smaller areas of high conservation priorities are distributed in other parts of the LHSA region.

Adding species weights resulted in a slight change in the spatial arrangement of the high priority conservation areas (Figure 7b). The most notable changes occurred across the northern boundary of Port Stephens near Dunns Creek and Wallaroo State Forest where sites identified as high priority conservation areas in the unweighted prioritisation were not included in the weighted prioritisation. These changes are largely driven by the low weights given to a number of orchid species in these

a) Unweighted



b) Weighted

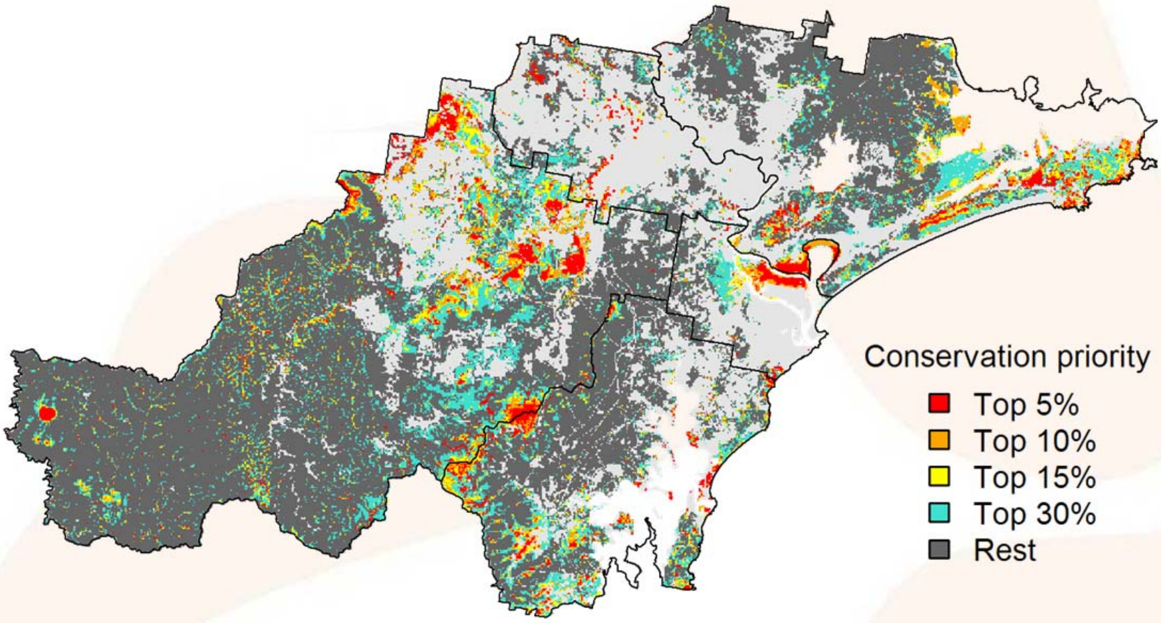


Figure 7. Conservation priorities within LHSA region when all biodiversity features are a) treated equally and no weighting is used and b) when biodiversity features are weighted differently. Note that the priority categories are cumulative: whereas the top 5% of Lower Hunter's conservation priorities are shown in red, the top 10% includes both red and orange areas. The best 15% includes red, orange and yellow areas, and so on. These priorities are based on representation of features only, with factors such as connectivity are ignored. Light grey represents areas that have already been cleared of native vegetation.

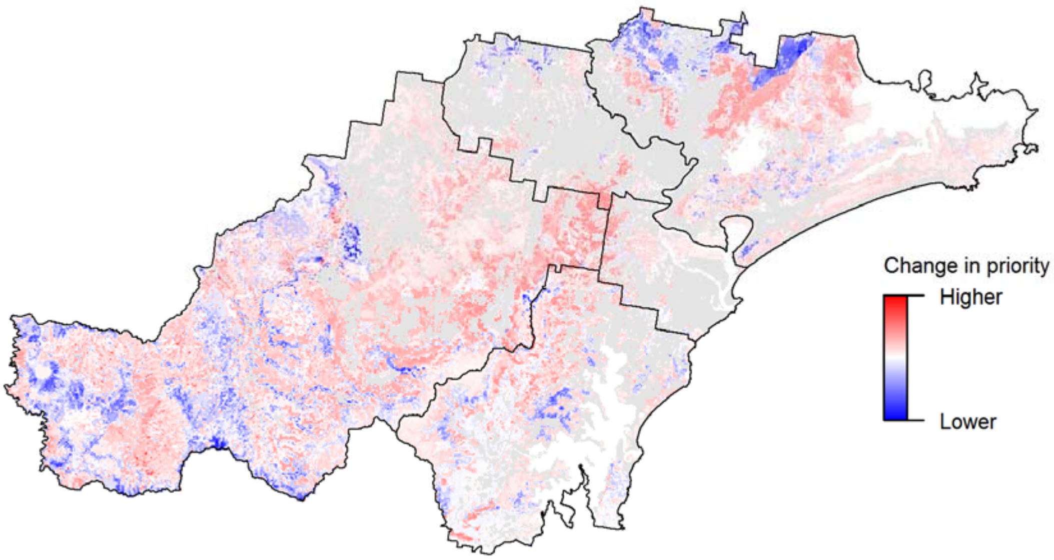


Figure 8. Difference in priority rankings between the unweighted and weighted solutions (Figure 7). Red colours indicate areas where conservation priority increased after features are weighted (described in Section 4.3). Blue colours show areas which had higher priority in the unweighted solutions but where priority reduced after incorporating weights. The intensity of the colour reflects the magnitude of the change. White areas have identical priority in both solutions.

areas that are protected but not listed as threatened in NSW (hence given the lowest possible weight of one – see Section 4.3 for details). These species included the orange blossom orchid (*Sarcochilus falcatus*), leopard orchid (*Dendrobium gracilicaule*), tall wasp orchid (*Chiloglottis trilabra*), Austral Lady's Tresses (*Spiranthes australis*), and king greenhood orchid (*Pterostylis baptistii*). In contrast, there is an expansion of high priority conservation areas under the weighted prioritisation in Cessnock and Maitland, particularly near Quorrobolong and Farley respectively. The weighted spatial conservation prioritisation (Figure 7b) was chosen by participants in an expert retreat held in September 2014 as the most representative of conservation priorities within the LHSA region. Therefore, this weighting scheme has been used for all subsequent analyses and is referred to as the *weighted prioritisation* hereafter. In this report, following discussions from the same stakeholder workshop, we consider *high priority conservation areas* to be those cells that are in the top 30% of the weighted spatial prioritisation.

In addition to the larger more continuous patches, several of the highest priority sites are located in the small fragments, particularly in Maitland and Cessnock. In general, small habitat patches tended to have higher priority ranks across the region than larger patches (Figure 9), with this pattern largely driven by small habitat fragments that often represent the last known occurrences of some of the features considered in this analysis. As connectivity was not accounted for in this analysis, the small fragments were not penalised for their small size and isolation. Half of the high priority conservation areas of the LHSA region are within the area of Cessnock LGA, which can be expected because of the relatively large size of the LGA (Figure 10). Interestingly, the majority of these areas are located in the more fragmented northern areas of the LGA and, to lesser extent, within the largely protected southern and eastern areas. On the other hand the two smallest LGAs in the LHSA region, Maitland and Newcastle, contain more high priority conservation areas than what could be expected based on their relative sizes. Newcastle LGA makes a particularly important contribution to regional conservation priorities, having 1.78 times more priority conservation areas than would be expected based on the amount of native vegetation remaining within the LGA. 53.5% of Newcastle's remaining native vegetation is identified within the high priority conservation areas of the LHSA region, with these habitats largely concentrated in the coastal habitats on Kooragang Island and around Fullerton Cove (Figure 10). Maitland LGA also contains a notable proportion of the high priority conservation areas based on the amount of native vegetation remaining within the LGA, with 37.3% of the remnant vegetation within this LGA identified within the high priority conservation areas of the LHSA region. These habitats are largely distributed in small, isolated fragments across the LGA (Figure 10). Both Maitland and Newcastle LGAs are characterised by high levels of native vegetation clearing, with approximately 72.6% and 67.4% of their landscape cleared of native vegetation, respectively.

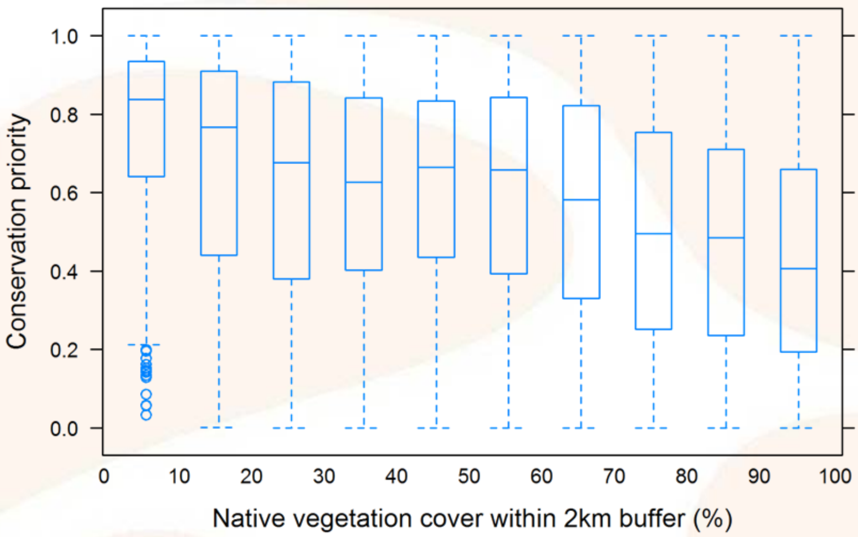


Figure 9. The distribution of conservation priority ranks with respect to relative patch size within the LHSA region. We used the proportion of native vegetation within a 2km radius of a given pixel e as a surrogate for patch size, with smaller values representing small and more isolated patches. The horizontal line within boxes shows the median conservation priority of grid cells within each patch size group. The whiskers give the full range of values and open circles are individual outlier pixels that differ significantly from the rest of the group. The boxes show how 50% of the values closest to median are distributed.

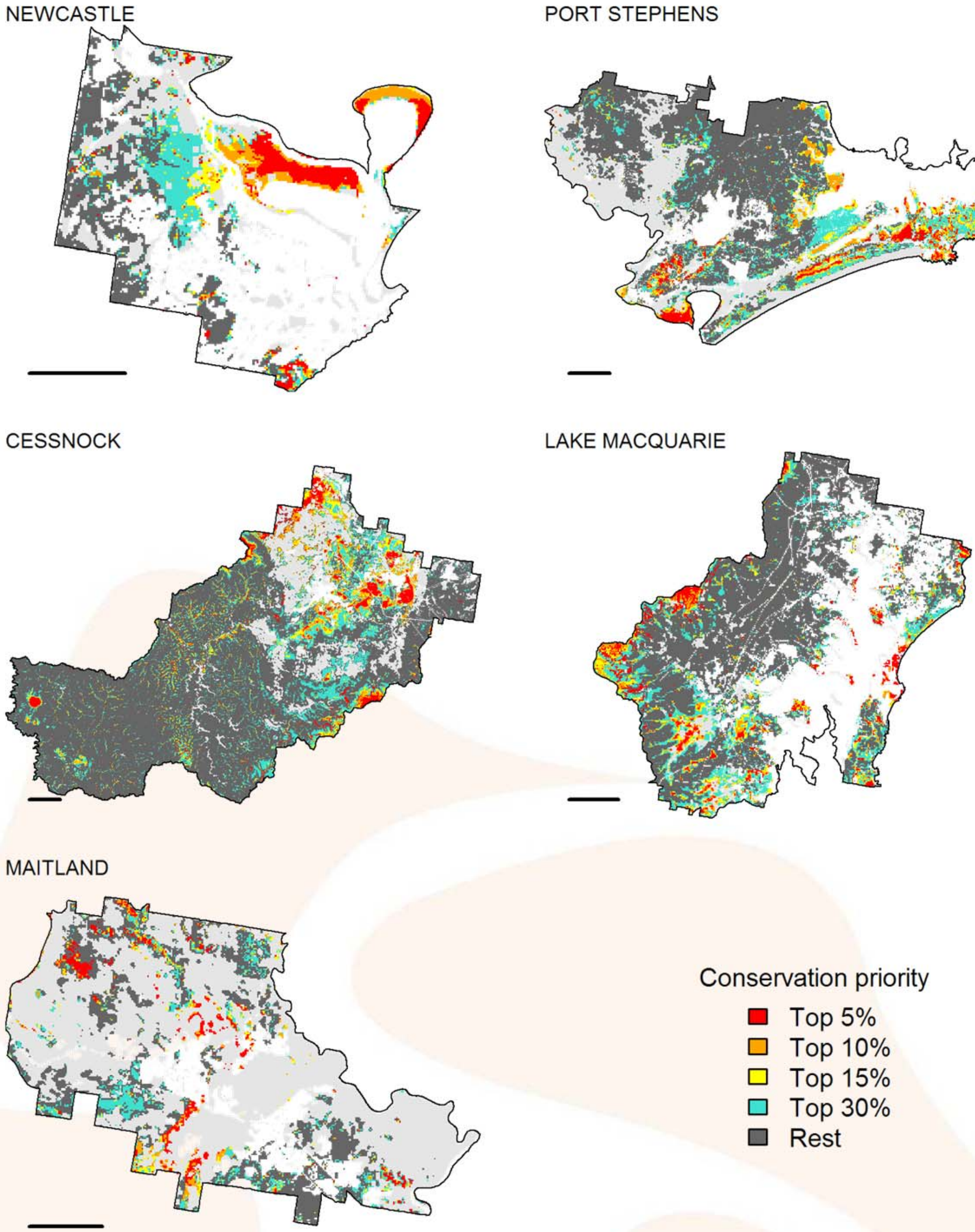


Figure 10. Regional conservation priorities (shown in Figure 7B) within each of the LGAs in the LHSA region. Scale bars represent distances of 5km, while light grey represents areas that have already been cleared of native vegetation.

Table 9. The proportion of total area and high priority conservation areas covered by LGAs in the LHSA region. The ratios show how much of top priorities are within each LGA relative to their size (Total area) and the relative amount of native vegetation they contain (Native vegetation). Ratio values greater than 1.0 represent LGAs that have a higher proportion of high priority conservation areas or native vegetation than expected based on their size, while ratio values less than 1.0 represent LGAs that have a lower proportion of high priority conservation areas or native vegetation than expected.

LGA	**Area (ha)**		**Proportion of LHSA (%)**			**Ratio of high priority conservation areas to**	
	Total area	Native vegetation	Total area	Native vegetation	High priority conservation areas	Total area	Native vegetation
Newcastle	21,497	11,021	5.0	2.5	4.5	0.89	1.78
Port Stephens	97,344	75,944	22.6	19.2	22.8	1.01	1.19
Cessnock	196,474	190,199	45.7	58.3	50.4	1.10	0.86
Lake Macquarie	75,715	51,776	17.6	16.2	17.6	1.00	1.08
Maitland	39,239	34,357	9.1	3.8	4.8	0.52	1.24

4.5.2. Representation of features within the top priority sites

All biodiversity features considered in this analysis are represented within the high priority conservation areas shown in Figure 11. On average, these sites cover 50.1% of the LHSA distributions of all included biodiversity features and 67.9% of MNES feature distributions within the LHSA region. Figure 12 shows the proportion of features' LHSA distribution captured by the different levels of the top priority conservation areas. Prioritising sites based on their irreplaceability and complementarity allows highly area-efficient representation of regional biodiversity. All biodiversity features included in this assessment can be represented within just 5% of the area of the LHSA region with extant native vegetation (shown in red in Figure 11). These sites alone cover on average 26.4% of the LHSA distributions of all included biodiversity features and 42.1% of the MNES LHSA distributions, and represent some of the most critical sites for biodiversity protection within the LHSA region. Due to their generally higher weighting, MNES features are better represented in all high priority conservation areas in comparison to non-MNES features (Figure 12). Feature-specific values for the proportion of each features' LHSA distribution included within the high priority conservation areas can be found in Appendix 5.

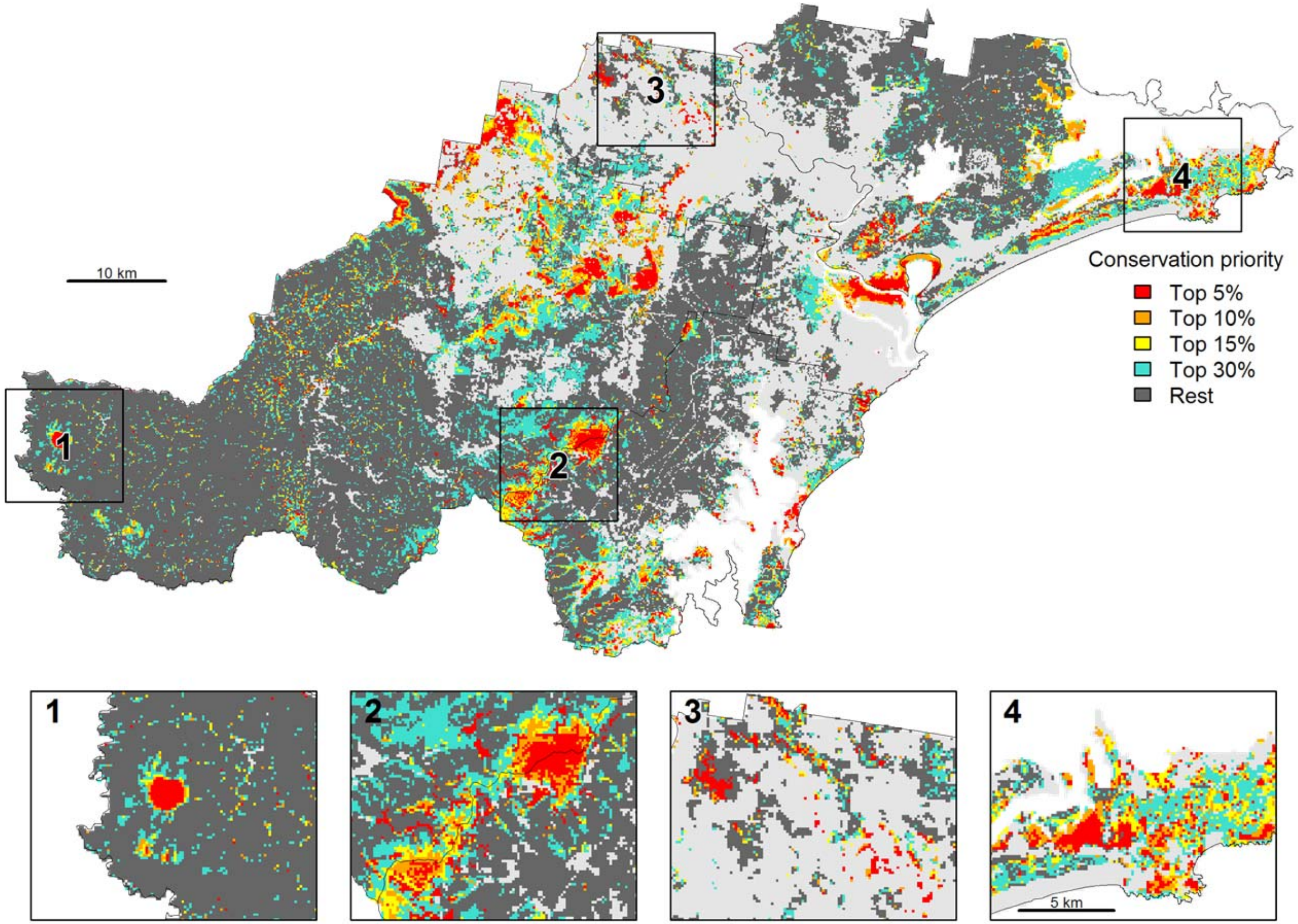


Figure 11. The high priority conservation areas identified within the LHSA region based on the best 30% of the weighted spatial prioritisation (Figure 7b). The inset boxes highlight example areas of priority sites across the LHSA region, with important threatened biodiversity features in these areas identified in Table 10. Light grey represents areas that have already been cleared of native vegetation. Inset boxes: 1) Yengo National Park; 2) Watagans National Park and Heaton State Forest; 3) Luskintyre and Martinvale; 4) Anna Bay and One Mile.

Table 10. Example of some of the important threatened biodiversity features present in the boxes identified in Figure 11. Note that this is not an exhaustive list of all features present at the identified regions and that the distributions of features listed in this table do not necessarily align with the distributions of the priority areas within the boxes.

Scientific Name	Common Name	MNES	NSW Status	EPBC Status	Data type
Box 1: Yengo National Park					
Eucalyptus fracta	Broken Back Ironbark		V		SDM
Olearia cordata		TRUE	V	V	points
Persoonia hirsuta	Hairy Geebung	TRUE	E1,3	E	points
Box 2: Watagans National Park and Heaton State Forest					
Aepyprymnus rufescens	Rufous Bettong		V		SDM
Hoplocephalus stephensii	Stephens' Banded Snake		V		SDM
Kerivoula papuensis	Golden-tipped Bat		V		SDM
Litoria littlejohni	Littlejohn's Tree Frog	TRUE	V	V	points
Lowland rainforest in NSW North Coast and Sydney Basin bioregion			E		SDM
Macropus parma	Parma Wallaby		V		SDM
Nominated EC Lowland		TRUE		CE	polygon
Petroica phoenicea	Flame Robin		V		SDM
Potorous tridactylus	Long-nosed Potoroo	TRUE	V	V	SDM
Ptilinopus magnificus	Wompoo Fruit-Dove		V		SDM
Senna acclinis	Rainforest Cassia		E1		SDM
Thylogale stigmatica	Red-legged Pademelon		V		SDM
Tyto tenebricosa	Sooty Owl		V,3		SDM
Box 3: Luskintyre and Martinvale					
Eucalyptus camaldulensis	Eucalyptus camaldulensis population in the Hunter catchment		E2		SDM
White box yellow box Blakely's red gum woodland			E		points
Box 4: Anna Bay and One Mile					
Charadrius mongolus	Lesser Sand-plover	TRUE	V	C,J,K	SDM
Crinia tinnula	Wallum Froglet		V		SDM
Haematopus fuliginosus	Sooty Oystercatcher		V		SDM
Haematopus longirostris	Pied Oystercatcher		E1		SDM
Pandion cristatus	Eastern Osprey		V,3		SDM
Prostanthera densa	Villous Mint-bush	TRUE	V	V	points
Sternula albifrons	Little Tern	TRUE	E1	C,J,K	SDM
Tyto longimembris	Eastern Grass Owl		V,3		SDM
Xenus cinereus	Terek Sandpiper	TRUE	V	C,J,K	SDM
Coastal saltmarsh in the NSW North Coast, Sydney basin and South East Corner bioregion			E		points
Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregion			E		SDM
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregion			E		SDM
Swamp sclerophyll forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregion			E		SDM
Grey-Headed Flying Fox roosting habitat					other
Nominated EC Littoral		TRUE		CE	polygon
Nominated EC Saltmarsh		TRUE		V	polygon

There is notable variation in how well biodiversity features are represented by the high priority conservation areas (Figure 12), these differences being largely explained by features' respective weight in the prioritisation process (Section 4.3) and their relative rarity within the LHSA region (Figure 13). Across the 721 biodiversity features included in the analysis, 152 have all of their LHSA distribution contained within the high priority conservation areas, including 34 MNES features and 43 features listed as threatened (Table 11). Some 35 features have less than 25% of their current LHSA distribution within the priority areas, including two MNES species (Figure 11; Giant Burrowing Frog, *Heleioporus australiacus*; Brush-tailed Rock-wallaby, *Petrogale penicillata*). For each of these species, we used a modelled species distribution as input data to map their potential suitable habitat within the LHSA region. All features either had relatively low weights in the prioritisation due to their mainly low to moderate threat listing (e.g., Common Maidenhair, *Adiantum atroviride* and Sydney Boronia, *Boronia ledifolia*) or relatively large distributions across the LHSA region. A good example of this is the spotted quail thrush (*Cinclosoma punctatum*), which has 22.6% of its LHSA distribution within the high priority conservation areas but whose suitable habitat covers approximately 40% of the LHSA region (Figure 13).

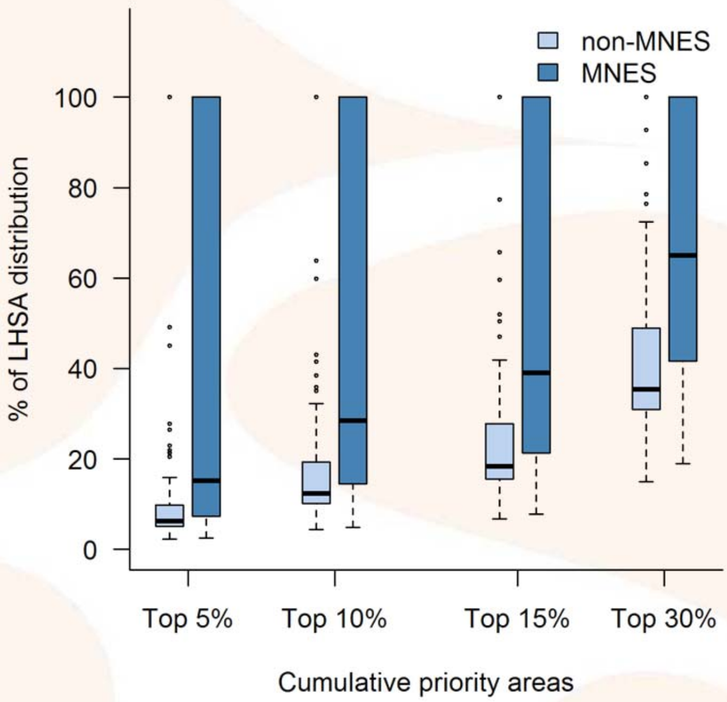


Figure 12. The proportion of MNES and non-MNES biodiversity feature distributions within the LHSA region that are captured by the high priority conservation areas identified in the weighted spatial prioritisation (Figure 11). The black horizontal line shows the median coverage within each group. The whiskers give the full range of values and dots are individual outlier features that differ significantly from the rest of the group. The boxes show how 50% of the values closest to median are distributed.

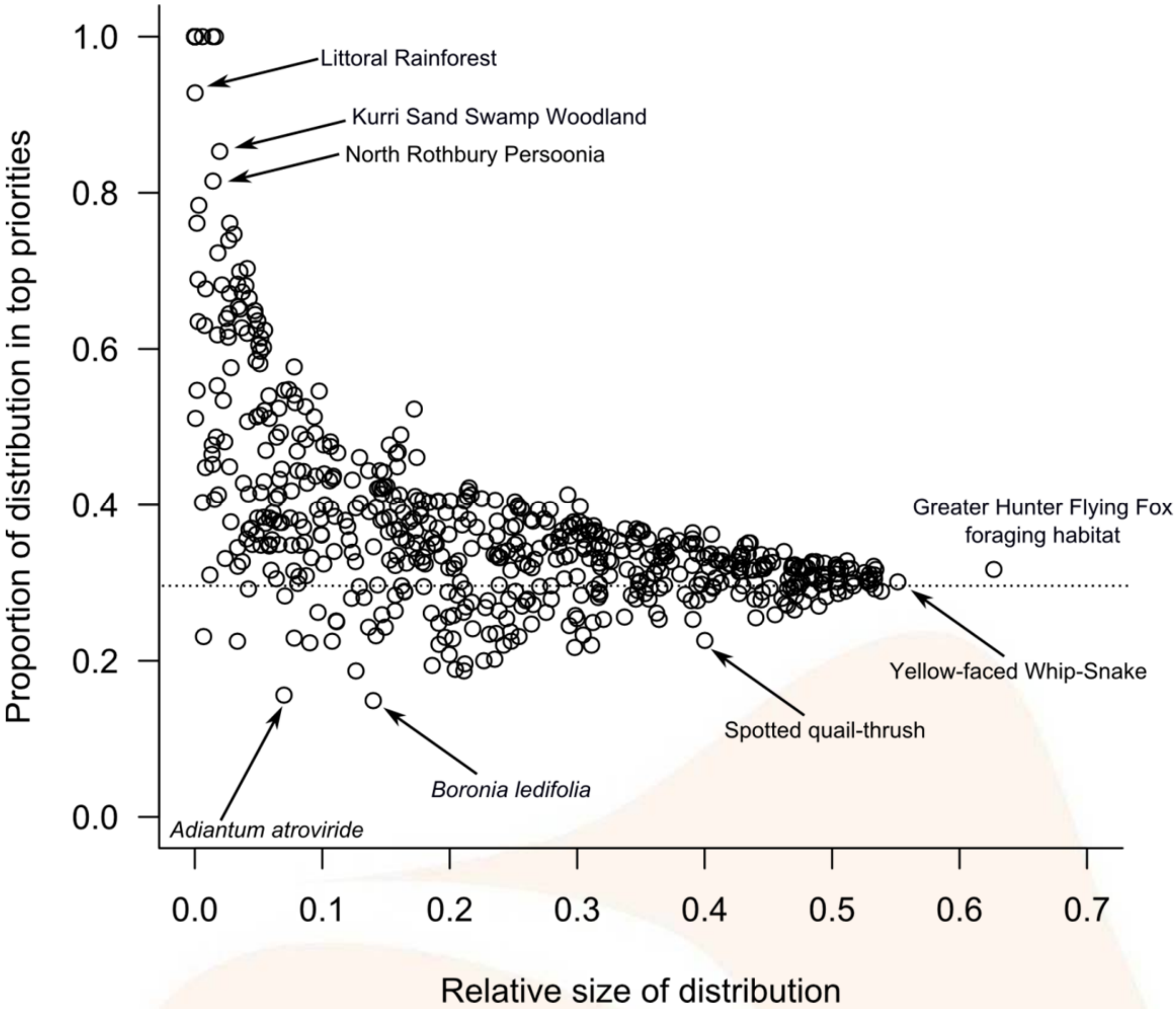


Figure 13. The proportion of each biodiversity features' distribution that is captured within the high priority conservation areas (the best 30% of the landscape for biodiversity; Figure 7b and Figure 11) plotted against the relative size of its distribution within the LHSA region, where each point represents a single biodiversity feature. Threatened biodiversity features with all of their distributions within the high priority conservation areas are listed in Table 11. Features with narrower distributions tend to have a higher proportion of their distribution within the high priority conservation areas. The dotted line represents the proportion of habitat that you would expect to be included within the top 30% of the priority for a feature that is present everywhere in the landscape. Relative distribution sizes for features represented by points and polygons were calculated as the number of cells where a feature was present divided by the number of cells in the prioritisation footprint. In contrast, the relative distribution of modelled species is the sum of the model prediction in each cell divided by the number of cells in the prioritisation footprint.

Table 11. Threatened biodiversity features which have all of their distribution captured within the high priority conservation areas identified by the weighted spatial prioritisation.

Scientific Name	**Common Name**	**MNES**	**NSW status**	**EPBC status**
Arthropteris palisotii	Lesser Creeping Fern		E1,3	
Botaurus poiciloptilus	Australasian Bittern	TRUE	E1	E
Callitris endlicheri	Black Cypress Pine, Woronora Plateau population		E2	
Callocephalon fimbriatum	Gang-gang Cockatoo		V,3	
Chamaesyce psammogeton	Sand Spurge		E1	
Charadrius leschenaultii	Greater Sand-plover	TRUE	V	C,J,K
Darwinia peduncularis			V	
Dasyornis brachypterus	Eastern Bristlebird	TRUE	E1	E
Dillwynia tenuifolia	Dillwynia tenuifolia, Kemps Creek		E2,V	
Epacris purpurascens var. purpurascens			V	
Eucalyptus castrensis	Singleton Mallee		E1	
Eucalyptus nicholii	Narrow-leaved Black Peppermint	TRUE	V	V
Eucalyptus pumila	Pokolbin Mallee	TRUE	V	V
Grevillea shiressii		TRUE	V	V
Leionema lamprophyllum subsp. obovatum	Leionema lamprophyllum subsp. obovatum population in the Hunter Catchment		E2,2	
Limicola falcinellus	Broad-billed Sandpiper	TRUE	V	C,J,K
Litoria littlejohni	Littlejohn's Tree Frog	TRUE	V	V
Muehlenbeckia costata	Scrambling Lignum		V	
Neoastelia spectabilis	Silver Sword Lily	TRUE	V	V
Neophema pulchella	Turquoise Parrot		V,3	
Nettapus coromandelianus	Cotton Pygmy-Goose		E1	
Ninox connivens	Barking Owl		V,3	
Olearia cordata		TRUE	V	V
Persicaria elatior	Tall Knotweed	TRUE	V	V
Persoonia hirsuta	Hairy Geebung	TRUE	E1,3	E
Planigale maculata	Common Planigale		V	
Prostanthera cineolifera	Singleton Mint Bush	TRUE	V	V
Prostanthera densa	Villous Mint-bush	TRUE	V	V
Pultenaea maritima	Coast Headland Pea		V	
Rostratula australis	Australian Painted Snipe	TRUE	E1	V
Rulingia prostrata	Dwarf Kerrawang	TRUE	E1	E
Turnix maculosus	Red-backed Button-quail		V	
Velleia perfoliata		TRUE	V	V
Coastal saltmarsh in the NSW North Coast Sydney Basin and South East Corner bioregion			E	
Quorrobolong scribbly gum woodland in the Sydney Basin bioregion			E	
Urtica incisa, Adiantum aethiopicum, Dichondra repens, Doodia aspera, Adiantum formosum, Nyssanthes diffusa			E	
White box yellow box Blakely's red gum woodland			E	
White gum moist forest in the NSW North Coast bioregion			E	
Grey-Headed Flying Fox roosting habitat				
Nominated EC Hinterland		TRUE		FPAL
Nominated EC Littoral		TRUE		CE
Nominated EC Lowland		TRUE		CE
Nominated EC Saltmarsh		TRUE		V

4.5.3. Representativeness of the existing reserve network: gaps and opportunities

The current protected area network covers 33.1% of the remaining native vegetation within the LHSA region. Of this, 27.9% is within Level 1 protected areas, while Level 2 and Level 3 protected areas each cover 4.5% and 0.7% of the remaining native vegetation, respectively (Table 12). On average 34.9% of all biodiversity features' LHSA distributions fall inside currently protected areas, with MNES features generally better represented in Level 1 and Level 2 protected areas than non-MNES features (Figure 14; Table 12). Due to their significantly larger size, the Level 1 protected areas cover the largest proportion of biodiversity features' LHSA distributions, providing protection to 28.5% of features' distributions on average. Level 2 and 3 protected areas cover notably smaller areas in the LHSA region and consequently protect smaller proportion of the distribution of features included in this assessment (Table 12), although they do play significant roles in protecting some species in the LHSA region (e.g., individual outliers in Figure 14). There are 67 features (7 MNES) that are currently not represented by any protected areas, and 79 features (11 MNES) that are not protected within the legislatively most secure Level 1 protected areas (Table 12; Table 13). Feature-specific values for the proportion of each features' LHSA distribution currently protected in each of the protected area categories can be found in Appendix 5.

Although almost a quarter of the LHSA region is currently protected, there is considerable scope for improving the representativeness and effectiveness of the regional reserve network for the biodiversity features selected for this assessment. Of the high priority conservation areas identified in the weighted spatial prioritisation (Figure 11), approximately 29.2% falls within currently protected areas (Figure 15). The remaining 70% of these sites are distributed across the LHSA region with concentrations of unprotected high priority areas around Kurri Kurri, and North Rothbury in Cessnock; Heatherbrae, Tomago and Anna Bay in Port Stephens; and, Mandalong in the Lake Macquarie area. These areas are crucial for the preservation of biodiversity in the LHSA region and could form a starting point for further conservation actions.

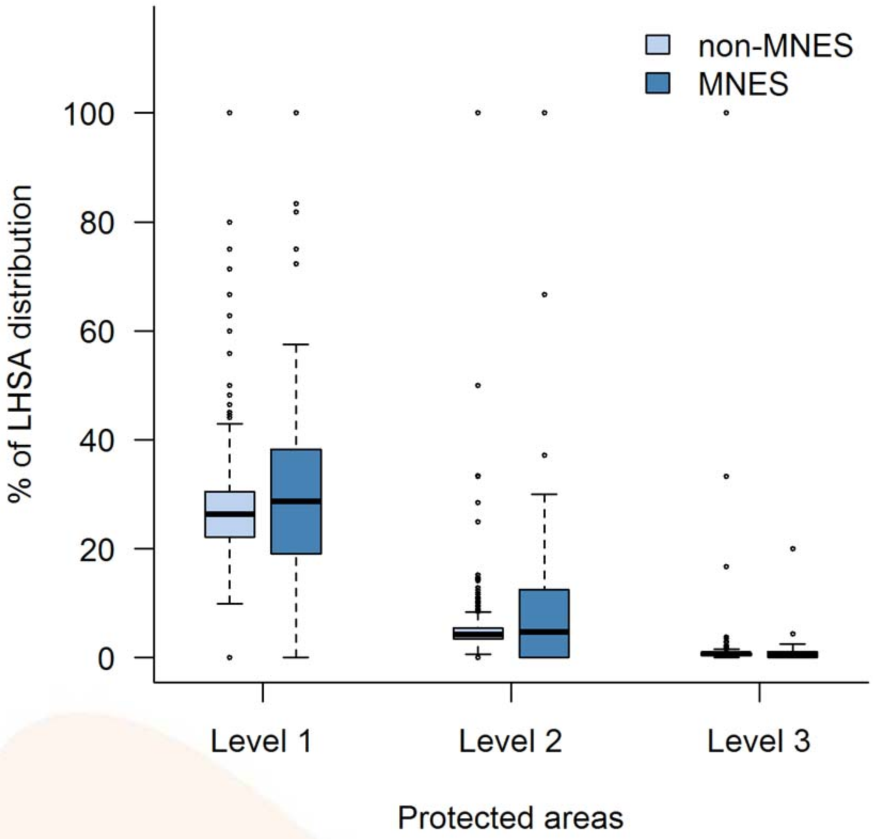


Figure 14. The proportion of MNES and non-MNES biodiversity features' distributions with the LHSA region that are covered by the three levels of protected areas. The black horizontal line shows the median coverage within each group. The whiskers give the full range of values and dots are individual outlier features that differ significantly from the rest of the group. The boxes show how 50% of the values closest to median are distributed.

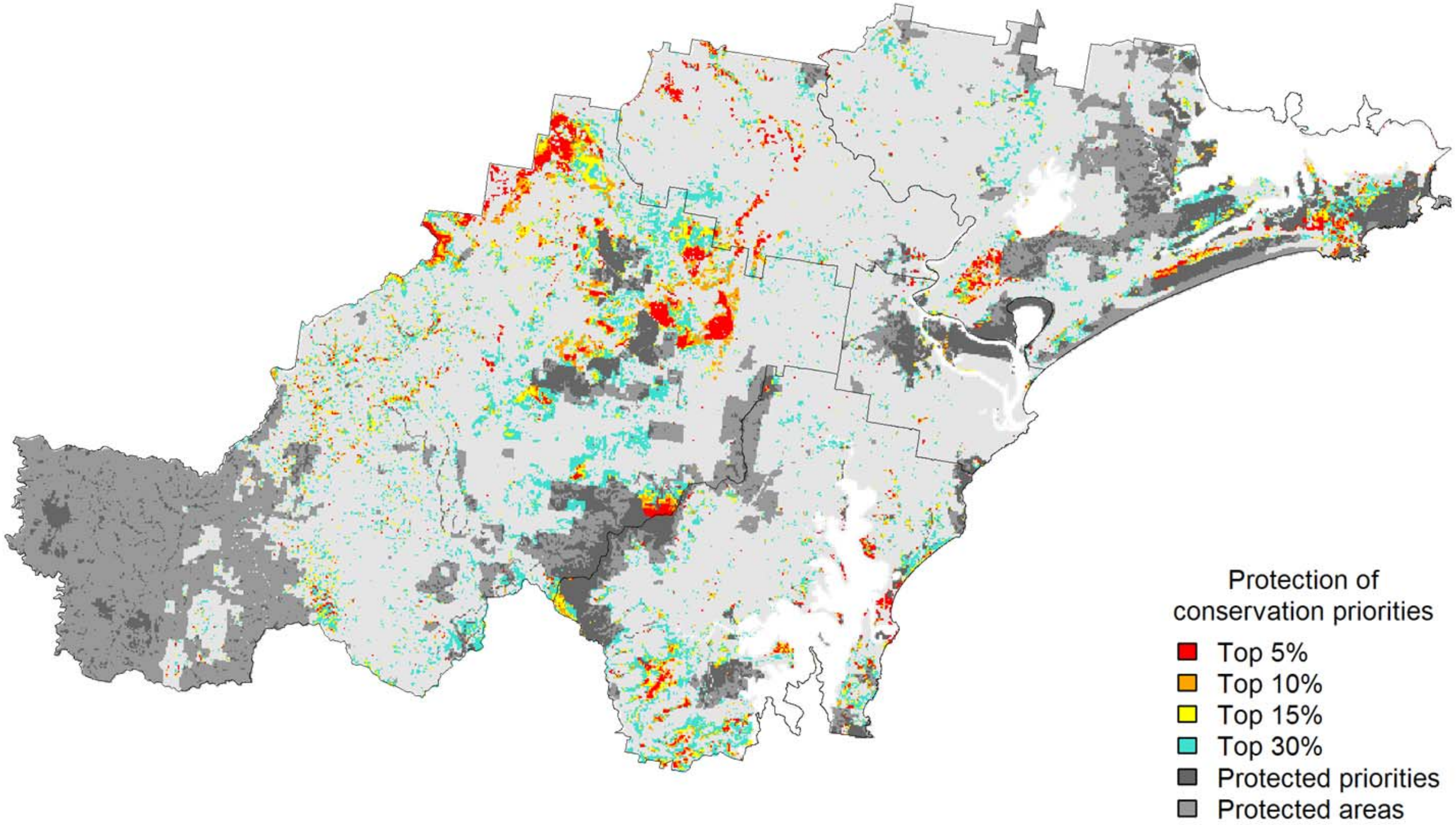


Figure 15. The high priority conservation areas (the best 30% of the weighted prioritisation) within the LHSA region overlaid on the current protected area network. High priority conservation areas that are currently protected are shown in dark grey, while the areas coloured red to cyan represent high conservation priority areas (based on the biodiversity features included in this analysis) that have no formal protection. Regions in light grey show areas of the current protected network that are not within the high priority conservation areas identified in this analysis.

Table 12. Representation of biodiversity features within the current protected area network in the LHSA region. The first columns show, for each protected area level, the proportion of the native vegetation (prioritisation footprint) and the proportion of the high (top 30%) priority conservation areas identified by the weighted prioritisation (Figure 9) that is contained within each of these areas. The mean representation gives the average proportion of features' LHSA distributions that is protected by each protected area level. Numbers in square brackets refer to corresponding values for MNES features only. The following four columns show the *cumulative* proportion of native vegetation and high priority conservation areas protected across the levels of protected areas, the cumulative average representation of features, and the number of features that do not have any occurrences within the protected area network or have greater than 75% of their LHSA distributions protected. For example, protected areas in Level 1 and 2 categories together cover 32.4% of the native vegetation within LHSA region. On average they protect 34.0% of the LHSA distributions of all considered features but there are 70 features (7 MNES) that do not have any parts of their LHSA distribution covered by these protected areas. The last column shows how much of features' LHSA distributions (average and minimum) could potentially be represented if a similar amount of area was protected with site selection based on the weighted prioritisation (Figure 9). Results for individual biodiversity features are provided in Appendix 5.

Protected Area	**% of native vegetation**	**% of high priority conservation areas**	**Mean representation**	**Cumulative**					
				% of native vegetation	% of high priority conservation areas	Mean representation	Features not protected	Features with >75% protected	Mean (min) Zonation representation
Level1	27.9	29.2	28.5 [36.7]	27.9	29.2	28.5 [36.7]	79 [11]	39	48.3 (13.6)
Level2	4.5	6.5	5.5 [10.0]	32.4	35.8	34.0 [46.7]	70 [7]	48	52.1 (16.5)
Level3	0.7	1.0	0.9 [0.9]	33.1	36.8	34.9 [47.6]	67 [7]	49	52.7 (16.9)

Table 13. Threatened biodiversity features that do not have protection under the different levels of protected areas within LHSA region. An additional 54 non-threatened biodiversity features included in this analysis do not have protection in at least one of the protected area levels assessed. Results for individual species can be found in Appendix 5.

Scientific name	**Common name**	**MNES**	**Threat status**		**No protection within**		
			NSW	EPBC	Level 1	Level 2	Level 3
Anas querquedula	Garganey	TRUE		C,J,K	X		
Arthroteris palisotii	Lesser Creeping Fern		E1,3		X	X	X
Botaurus poicilotilus	Australasian Bittern	TRUE	E1	E	X	X	X
Callitris endlicheri	Black Cyress Pine, Woronora plateau population		E2		X	X	X
Callocephalon fimbriatum	Gang-gang Cockatoo		V,3		X	X	X
Chamaesyce psammogeton	Sand Surge		E1		X	X	X
Darwinia peduncularis			V		X	X	X
Dasyornis brachypterus	Eastern Bristlebird	TRUE	E1	E	X	X	X
Dillwynia tenuifolia	Dillwynia tenuifolia, Kem's Creek		E2,V		X	X	X
Epacris pururascens var. pururascens			V		X	X	X
Eucalyptus castrensis	Singleton Mallee		E1		X	X	X
Eucalyptus nicholii	Narrow-leaved Black Peppermint	TRUE	V	V	X	X	X
Eucalyptus pumila	Pokolbin Mallee	TRUE	V	V	X		
Grevillea shiressii		TRUE	V	V	X	X	X
Hirundo rustica	Barn Swallow	TRUE		C,J,K	X		
Litoria littlejohni	Littlejohn's Tree Frog	TRUE	V	V	X	X	X
Neoastelia spectabilis	Silver Sword Lily	TRUE	V	V	X	X	X
Neophema pulchella	Turquoise Parrot		V,3		X	X	X
Nettapus coromandelianus	Cotton Pygmy-Goose		E1		X	X	X
Ninox connivens	Barking Owl		V,3		X	X	X
Persicaria elatior	Tall Knotweed	TRUE	V	V	X		
Prostanthera cineolifera	Singleton Mint Bush	TRUE	V	V	X	X	X
Quorrobolong scribbly gum woodland in the Sydney Basin bioregion			E		X	X	
Turnix maculosus	Red-backed Button-quail		V		X	X	X
Urtica incisa, Adiantum aethioicum, Dichondra repens, Doodia aspera, Adiantum formosum, Nyssanthes diffusa			E		X	X	X

4.6. Discussion

The spatial prioritisation highlighted a number of areas within the LHSA region that have high biodiversity value, particularly in Maitland and Newcastle LGAs. Many of these areas are small remnant patches of vegetation that constitute the last remaining occurrences of a number of biodiversity features, and are crucial for halting the loss of biodiversity within the LHSA region. Comparison of the high priority conservation areas identified by Zonation and the current protected area network revealed that approximately 29% of the identified conservation priority areas are currently protected to some degree, leaving 70% of these sites without any protection. These include several critical areas around North Rothbury, Abermain, Heatherbrae, throughout Maitland LGA and along the shores of Lake Macquarie, that belong to the most critical 5% conservation priorities in terms of representing the full range of the LHSA regions' biodiversity. The comparison also revealed that, although 33% of the LHSA region has some level of protection, there are significant gaps in the representation of biodiversity features within these areas. For example, 67 biodiversity features, including seven MNES features, currently have no protection within the LHSA region. Therefore, there is notable conservation potential outside the current protected area network and significant improvements in the level of biodiversity protection could be achieved with relatively small expansions of the protected areas by strategically targeting sites that host currently underrepresented species.

In addition, our analysis highlighted that 85% of the current protected area network within the LHSA region has strong legal mechanisms for protection (Level 1 protected areas: nature reserves, national parks, regional parks, state conservation areas and aboriginal areas). The remaining areas are either contained within protected areas inside State Forests or heritage sites (Level 2) or sites with low or voluntary mechanisms for protection not necessarily assigned for conservation purposes (Level 3: wildlife refuges, registered property agreements and Commonwealth lands). While Level 2 and 3 protected areas are quite small in size, they currently protect biodiversity features that are not represented in the most secure protected areas. Therefore, significant conservation gains could be made by strengthening the level of protection in these sites, particularly where they are under threat from future development.

It is worth noting that the paradigm of conservation reserve design often favours large patches of habitat over small fragments as they are considered to be more robust to demographic and environmental perturbations that may influence population persistence (Tilman et al. 1994; Cabeza & Moilanen 2001). Although the ecological theory behind the paradigm is scientifically correct, it does not take into account that highly fragmented landscapes with relatively recent land clearance often have high conservation value as they contain biodiversity features that have been otherwise largely lost from the surrounding landscape. In this assessment, we identified that many of the remnant habitat patches, particularly in Maitland, have high conservation value. The nature of the landscape in this region also means that these fragments are likely to be at risk of future development and should therefore be carefully evaluated when further development decision are made. In this assessment we did not include connectivity as one of the aspects to be prioritised when evaluating the conservation priority of the sites, which further increases the value of the small fragments in the prioritisation process – prioritising sites based on connectivity often tends to place higher priority on large intact areas whereas smaller fragments drop out from the priorities. Although consideration of landscape connectivity is unarguably important, too heavy an emphasis on connectivity comes with the risk of missing critically important occurrences of rare species in their last habitat fragments. It should be kept in mind that connectivity builds upon representation (Hodgson et al. 2009) – there is nothing to connect if the last occurrences are lost.

The high priority conservation areas identified in this analysis could be considered as a starting point for developing a successful conservation plan in the LHSA region. However, as the prioritisation is based on representation and local habitat quality, further work beyond the analysis of this assessment are needed. Once species occurrences in the remaining highest quality habitat are secured, one needs to further assess which areas are needed to maintain the ecological functions that are crucial for species long-term persistence. This requires more detailed analyses of population dynamics to identify the areas and structures that need to be maintained in the landscape.

4.6.1. Limitations and sources of uncertainty

The areas identified as conservation priorities in this assessment are dependent on the input data used and it is important to recognise that a different set of biodiversity features is likely to result in a different prioritisation solution. Given the large number and taxonomic breath of the features used in this analysis, the sites identified are likely to encompass a wide range of habitat types and requirements. However, it should be noted that invertebrates and fungi are not represented at all in this assessment nor did we consider the freshwater or marine environments. Delineating an appropriate biodiversity feature pool to include in a regional conservation planning analysis is not a trivial task. In this work we sourced and cleaned a large dataset of biodiversity features. We decided which of the features to include, and how to weight their relative conservation importance, using expert knowledge available during the project. Another factor affecting the distribution of high priority conservation areas is the scale of the assessment. The identified high priority conservation areas in this assessment are important at the scale of the LHSA region. However, the relative importance of these sites is likely to change if the assessment was undertaken at a larger or smaller scale.

It also follows that the outputs from the spatial prioritisation are only as good as the input data. Poor quality data (i.e. inaccurate distribution models and inaccurate point data) or missing data may result in the identification of conservation priorities that do not align with the real world. In addition, inaccuracies in the conversion of data layers from polygon to raster, such as vegetation cover or land use type, may also affect the spatial prioritisation. For example, we used the most recent available vegetation mapping for the LHSA region to restrict the prioritisation area to patches of native remnant vegetation. Any spatial inaccuracies in this layer or subsequent clearing of native vegetation may mean that our prioritisation area does not accurately reflect the areas considered to be important on the ground.

We have used the proportion of a features' LHSA distribution that is protected as our metric for assessing the potential value of a scenario and we typically report the mean and minimum proportion of distributions across all biodiversity features. However, these estimates are not entirely equal across all input data types, with the values for species with modelled distributions calculated as the sum of predicted likelihoods within the area of interest, while values for point and polygon data represent the true proportion of cells within the area of interest. Whereas this does not diminish the value or interpretation of the analysis outputs, it is important to understand the subtle difference between the different data types.

Chapter 5 Identification and assessment of potential development risks

We assessed five development scenarios to explore the potential impacts of development on the high priority conservation areas identified in Chapter 4 and individual biodiversity features within the LHSA region. We also identified the area of vegetation within the prioritisation footprint that is likely to be at risk of clearing and the degree to which the scenarios overlap with the current protected area network. These data can be used to identify potential conflicts between development and biodiversity conservation, and to assess the relative impacts of each development scenario. Areas of conflict highlighted in this chapter should be further investigated to quantify potential development impacts in more detail and to assess whether further avoidance and/or mitigation measures could be used to reduce potential biodiversity losses.

5.1. Development scenarios

The development scenarios were identified through engagement and discussions with DoE, HCCREMS, OEH and DPE. These scenarios investigate urban, rural, infrastructure and agricultural development that is likely, or could potentially take place in the LHSA region, and is anticipated to lead to extensive clearing of native vegetation. We also estimated the cumulative impact if all of these development activities were to be undertaken in the LHSA region. In addition, we included a hypothetical scenario to investigate the potential conflicts between mining and biodiversity in the LHSA region using information on existing mining titles and applications.

We briefly describe each of the scenarios below, with additional information about the spatial layers used to create each scenario in Appendix 6. In all scenarios we have assumed that the development footprint will be completely cleared, leading to the loss of all extant native vegetation and occurrences of features within the footprint areas. We have also assumed that areas within the current protected area network that overlap with the development footprints will be cleared. We acknowledge that, while these assumptions were necessary for technical reasons, they may in some instances be unrealistic. For this reason, some of the results presented in this chapter are likely to be coarse estimations of the potential impacts.

Scenario 1: Urban development

In this scenario the potential future losses to biodiversity from urban expansion were investigated using three footprints that loosely describe a progressive outward expansion in built-up areas for urban, rural and infrastructure development in the LHSA region (Figure 16).

The first footprint includes areas ***currently zoned*** to allow development that, if undertaken, is likely to clear all remnant patches of native vegetation within the zoned area. A set of land zoning categories to be included to this footprint were identified in collaboration with HCCREMS, DoE and DPE (Table 14). The footprint layer was created from land use zones of the consolidated Local Environmental Plans (LEPs) for Cessnock, Lake Macquarie, Newcastle, Maitland and Port Stephens, and three State Environmental Planning Policy (SEPP) land use zones for Port of Newcastle, Tomago Industrial area and Huntlee. These layers were provided by DPE and their zoning information is correct as of 15th of February 2015. After consultations with HCCREMS and Port Stephens Planning and Building, three groups of SP2 Special Purpose and Defence areas in Salt Ash, around the Williamtown RAAF Airport and on the eastern side of Nelson Bay Road were removed from this footprint.

Table 14. Local Environmental Plan (LEP) codes identified to describe land use that has a high likelihood of extensive native vegetation clearance in the targeted site.

Land zone code	**Type**	**Description**
B1	Business Zones	Neighbourhood Centre
B2	Business Zones	Local Centre
B3	Business Zones	Commercial Core
B4	Business Zones	Mixed Use
B5	Business Zones	Business Development
B6	Business Zones	Enterprise Corridor
B7	Business Zones	Business Park
B8	Business Zones	Metropolitan Centre
IN1	Industrial Zones	General Industrial
IN2	Industrial Zones	Light Industrial
IN3	Industrial Zones	Heavy Industrial
IN4	Industrial Zones	Working Waterfront
R1	Residential Zones	General Residential
R2	Residential Zones	Low Density Residential
R3	Residential Zones	Medium Density Residential
R4	Residential Zones	High Density Residential
SP2	Special Purpose Zones	Infrastructure

1.Urban development

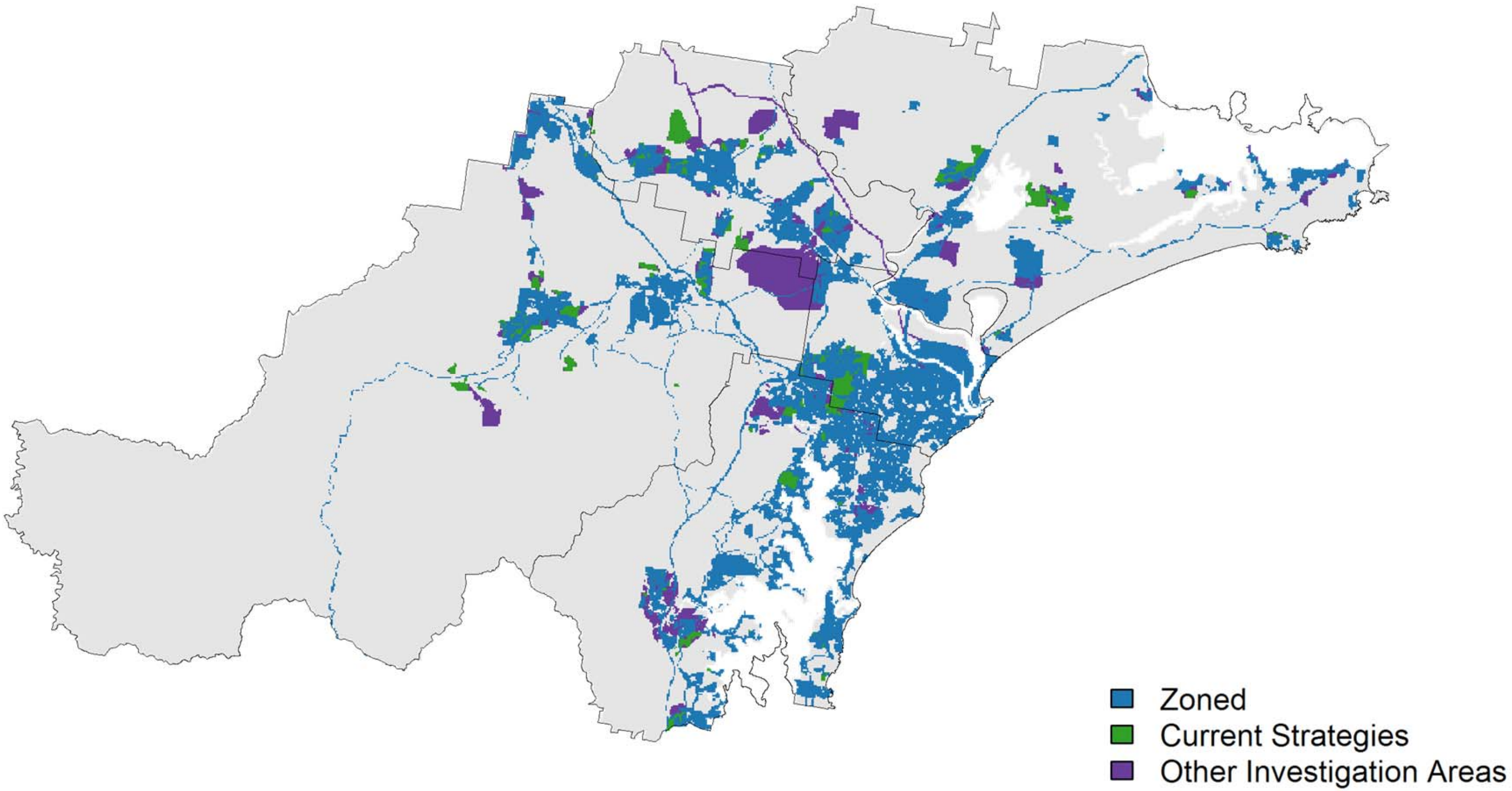


Figure 16. Map of the Urban Development scenario, showing the non-overlapping areas of the three progressive footprints used in this scenario. Zoned = Currently zoned areas for development; Current strategies = Investigation areas within current strategy for urban expansion; Other investigation areas = Additional investigation areas that are identified in the Lower Hunter Council's local strategies.

The Salt Ash Air Weapons Range is mostly in a natural state and has been identified in previous assessments as one of the biodiversity hotspots in Port Stephens LGA (e.g. Eco Logical Australia 2012). It has been classified as Commonwealth Heritage site and was, therefore, included in the regional Protected Areas layer (Section 4.4). The area is still used for target practices by the military but is in minimal use (Wonona Christian, Senior Strategic Planner, Port Stephens Council, and Mary Greenwood, HCCREMS, pers. comm.). The SP2 Special Purpose Zone around the Williamtown RAAF Airport and SP2 Defence area on the eastern side of Nelson Bay Road were excluded as they act as buffer areas for the airport and are unlikely to go through any large development or land clearing actions. The sites included in this footprint cover an approximate area of 49,940 ha and are mostly concentrated around the city of Newcastle, along A43 highway in Maitland LGA, in Kurri Kurri and Cessnock, and around the shores of Lake Macquarie (Figure 16).

The second footprint layer included areas within the ***current strategies*** that were identified as potential target sites for urban and economic development in the 2006 Lower Hunter Regional Strategy (Department of Planning 2006) as well as in Council-endorsed strategies. These areas have since been investigated further through state and local governments, and some of them have already been re-zoned and, therefore, overlap with the areas identified in the first footprint. The unzoned areas are currently under further investigation to establish whether they will be zoned for development and/or if any refinements to these areas are needed. We used the 'URA Option 1 and 2' layer provided by OEH for this footprint. Those areas within the footprint that do not overlap with lands currently zoned for development cover additional 5,000 ha and are located close to main roads and existing settlements, such as Rutherford and Medowie, and in Cameron Park (Figure 16; Table 15).

The third footprint within the urban scenario includes ***other investigation areas*** that are identified in the Lower Hunter Council's local strategies (Figure 16). This footprint layer includes development proposals at various stages, such as urban releases, growth areas and urban settlement strategies, some of which overlap both with currently zoned areas and current strategies areas. These areas are scattered across the fringes of urban and rural development in the Lower Hunter, including a larger freight hub development area proposed between Ashtonfield and Black Hill. The non-overlapping area of this footprint layer covers an additional 12,250 ha, which together with the two other footprints form the urban development scenario.

The total footprint of this scenario is approximately 67,200 ha covering 16.7% of the LHSA region (Table 15). We note that, while the areas included in this footprint are from ongoing planning projects at various stages, it is unrealistic to assume that all areas within the urban footprint will eventually be developed. For example, there are interdependencies within these layers, especially within the current strategies and other investigation areas, which may change the likelihood of some areas being developed in the future. We reiterate that this scenario does not represent an actual regional development plan for the LHSA region but has been specifically designed to address the main objectives of this study.

Scenario2: Hunter Expressway

The second development scenario investigated the explicit impacts of the Hunter Expressway on biodiversity in the LHSA region. The Hunter Expressway project aimed to improve travel times for motorists between Newcastle and the Upper Hunter and to reduce traffic on previously problematic key routes across the broader network, such as the New England Highway. It involved the construction of a four lane freeway link between the M1 Pacific Motorway near Seahampton and the New England Highway, west of Branxton, and was one of the biggest road infrastructure projects built in the Hunter Valley. The Hunter Expressway opened to traffic on 22 March 2014. Here we estimated the potential losses in biodiversity features' distributions caused by the building of the highway.

This scenario was included in the analysis primarily to maintain comparability with other NERP research outputs (Lechner & Lefroy 2014). We note that representing linear structures in raster format comes with unavoidable technical shortfalls and, as such, they are not ideal development footprints to be tested using the approach presented in this report. To create a raster based footprint for a linear structure such as roads and highways, we assumed that all grid cells overlapping the built highway were cleared of native vegetation. Due to data conversion constraints, this roughly equals a 100 m wide strip along the highway, which is a coarse representation of the actual footprint (Figure 17).

Scenario 3: Important Agricultural Lands

In this scenario we explored the impacts of potential agricultural development using the Important Agricultural Lands data (Hunter Councils 2013) that maps the most suitable areas for different forms of agriculture in the LHSA region. For each agricultural land use type, these areas are defined as ”land that is capable of sustained use for agricultural activity, with appropriate management practices, and which has the potential to contribute substantially to the ongoing productivity and adaptability of agriculture in the region". From this layer we identified areas of high value for intensive agricultural activity, including Broad Acre Agriculture, Cultivated Turf and Viticulture, which typically lead to onsite removal of vegetation and intensive land use. These sites were assumed to represent potential expansion of intensive agriculture in the LHSA region, likely to result in further clearance of native vegetation within the LHSA region. The areas identified in this footprint cover approximately 44,800 ha and are mostly concentrated on the lowland areas of Maitland, North Cessnock and West Port Stephens (Figure 17; Table 15).

Scenario 4: Cumulative impact of all urban, rural, infrastructure and agriculture development

The fourth scenario is a combination of the first three scenarios and investigates the cumulative impacts of urban, rural, infrastructure and agriculture development within the LHSA region (Figure 17). This footprint uses the same assumptions described for scenarios 1-3. The combined area of this footprint is approximately 106,900 ha and 26.6% of the LHSA region.

Scenario 5: Current mining titles and applications

The final scenario explored the potential conflicts between the mining industry and biodiversity conservation by mapping overlaps between the high priority conservation areas and existing mining titles and title applications for coal within the LHSA region. This additional scenario was included in this assessment to also maintain levels of comparability with other NERP research outputs that have investigated similar scenarios within the LHSA region (Lechner & Lefroy 2014). This footprint is based on the locations of current titles and title applications obtained from the online database MinView (NSW Resources & Energy 2014). As there is little public spatial information about future mining sites in the LHSA region, we used the titles and title applications as an indication of interest for mining activities within the LHSA region. The area covered by these sites is 93,600 ha, or 23.3% of the LHSA region (Figure 17; Table 15). We note that it is highly unlikely that all the sites within this footprint would be mined at any stage, and therefore this scenario serves the purpose of highlighting potential conflicts between biodiversity conservation and mining activities. These conflicts should be explored further if mining activities are to be carried out at these sites.

Table 15. The development scenarios within the LHSA region, showing the area (ha) and proportion of the LHSA region that will be developed under the proposed footprints. We also show the maximum area and proportion of native vegetation that would likely be cleared if all habitats within proposed areas of each footprint are developed.

Scenario	**Total development footprint**		**Native vegetation at risk of being cleared**	
	ha	% of LHSA region	ha	% of LHSA native vegetation
1. Urban Development	67,209	16.7	23,815	8.5
Zoned	49,938	12.4	13,952	5.0
Current strategies	5,028	1.3	2,898	1.0
Other investigation areas	12,243	3.1	6,965	2.5
2. Hunter Expressway	511	0.1	326	0.1
3. Important Agricultural Lands	44,786	11.2	16,670	6.0
4. Cumulative Development	106,866	26.6	37,992	13.6
5. Mining titles	93,587	23.3	71,053	25.4

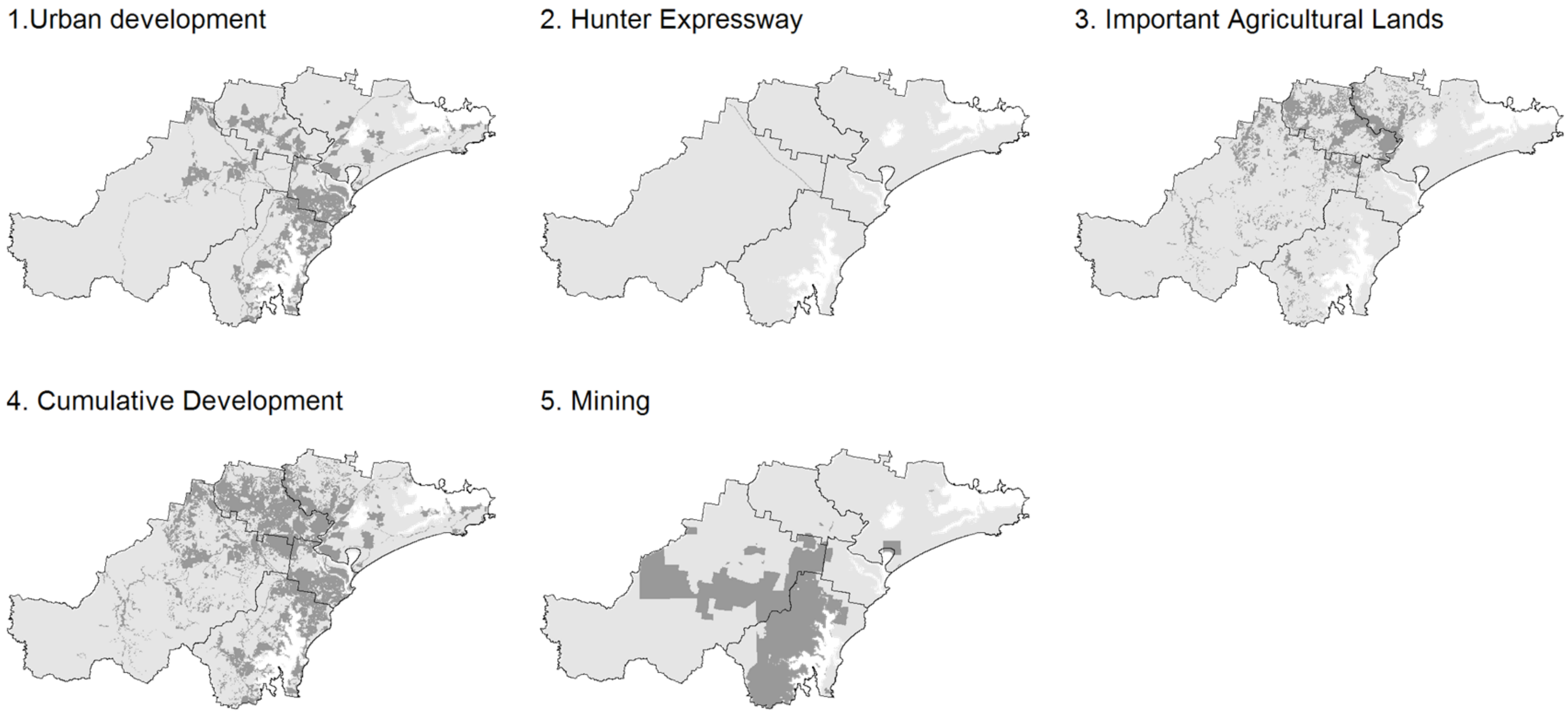


Figure 17. Development scenarios assessed in this report. Light grey area shows the distribution of remnant native vegetation within Lower Hunter Region. Dark grey areas show sites that were assumed to be fully developed in each scenario. The cumulative scenario (scenario 4) combines scenarios 1 - 3.

5.2. Analysis setup for assessing impacts of development

We used the replacement cost feature (described in Section 4.1) of Zonation to assess the anticipated impacts of the five different development scenarios in the LHSA region. Here the spatial prioritisation described in earlier chapters was repeated, but this time assuming that the proposed development areas will be entirely cleared and any biodiversity features within them will be lost. This is achieved by setting the program to remove grid cells from the proposed development areas first, and only after that, continue prioritising areas outside the proposed development sites. The impact is then measured as proportion of feature distributions lost when all development areas have been removed.

5.3. Results

In this section we describe the potential impacts of the development scenarios within the LHSA region. For each scenario we report the following impacts:

- the maximum amount of remnant vegetation that would be cleared,
- the overlap of development with high conservation priority areas,
- the average proportion of biodiversity features' LHSA distribution that is at risk to be lost if all the development areas are entirely cleared, and
- the biodiversity features most affected and to what degree.

A summary of these results can be found in Table 16, with sections providing specific details about each scenario below. We reiterate here that all impacts on features are with respect to their distributions within the LHSA region. We do not consider the impacts of development outside of LHSA region nor do we report the impacts with respect to a feature's global distribution. We also underline that the reported impacts are based on the assumption that all native vegetation within the development sites is lost, which is likely to be an overestimation of the true impacts.

Scenario 1: Urban development

The entire urban development footprint is estimated to clear up to 8.5% (23,800 ha) of native vegetation within the LHSA region (Table 15). Developing these sites would also clear up to 11% of the high priority conservation areas, with significant conflict areas likely to occur near Branxton (Huntlee/Sweetwater), Abermain and Weston (General Industrial zone in Cessnock LEP), Heatherbrae and around Tomago (Table 16; Figure 18). At these sites, the development footprint overlaps significantly with areas that have been identified as top 5% priorities within the LHSA region (Chapter 4). In addition, there are many more scattered high priority conservation areas that overlap with the potential development areas in this scenario, such as Morriset and Catherine Hill Bay-Swansea stretch around Lake Macquarie, and areas north-west from Bolwarra and Bolwarra Heights in Maitland. This scenario is also likely to clear up to 1.8% of the currently protected areas in the LHSA region: these include 1% of the Level 1 areas, and 4.7% and 12% of the less secure Levels 2 and 3 protected areas, respectively (Table 16).

On average, developing all areas within the urban footprint is estimated to lead to the loss of up to 12.7% of the LHSA distributions of biodiversity features (Table 17). However, there is notable variation between features. Some 18 of the analysed features may be at risk of losing all of their known LHSA occurrences if the areas in the urban development scenario are entirely cleared, including the state-listed endangered sand spurge (*Chamaesyce psammogeton*) and cotton pygmy-goose (*Nettapus coromandelianus*), and the naturalised population of the MNES *Grevillea shiressii*, which is endemic to NSW (Table 17). Another ten features are at risk of losing at least 50% of their current LHSA distribution under this scenario, of which toothed helmet orchid (*Corybas pruinosus*) and honey Caladenia (*Caladenia testacea*) have 75% and 80% of their known occurrences overlapping with the development footprint.

The largest impact within the urban footprint arises from currently zoned areas and is further increased as the footprint is expanded to areas within current strategies and to other investigation areas. The potential development of all land within the ***zoned*** areas would clear up to 7,818 ha of vegetation and could lead to the potential disappearance of 12 biodiversity features. Approximately 7% of the high priority conservation areas would be lost if these sites were entirely cleared, including some of the most critical sites near Huntlee, Kurri Kurri, Tomago and Kooragang wetlands which belong to the best 5% of the LHSA region in terms of their biodiversity value. Expanding the urban footprint to areas within the ***current strategies*** is likely to increase the urban environment in the LHSA region only by 1.3%, and clear a relatively small additional area of up to 2,898 ha of native vegetation. However, the potential impacts of these expansions are notable, with another four features potentially being at risk of losing their current known occurrences within the LHSA region if these sites are entirely developed. For the *Acianthella amplexicaulis* orchid the proportion of known occurrences likely to be lost increases from 50% to 100% when the current strategies are added to the footprint. Another two orchid species, the honey Caladenia and bird's mouth orchid, would be at risk of losing more than 50% of their known LHSA occurrences after these expansions. Adding the remaining ***other investigation areas*** would lead to an additional clearing of up to 6,965 ha of native vegetation. These potential additions may put two more features, the endangered sand spurge (*Chamaesyce psammogeton*) and Australian pratincole (*Stiltia isabella*), at risk of losing all their known occurrences in the LHSA region.

Scenario 2: Hunter Expressway

Based on the analysis approach used in this assessment, the building of Hunter Expressway was estimated to clear up to 0.1% (326 ha) of the native vegetation within the LHSA region (Table 15). Due to its small footprint size, this development scenario has by far the smallest biodiversity impact across the analysed scenarios: the building of the highway was estimated to result in the mean loss of up to 0.18% of features' LHSA distributions, with no major impacts on the representation of any of the analysed features (Table 16). However, it should be noted that, despite the potentially small onsite impact of this scenario, the Hunter Expressway runs across two large areas identified as highly important for biodiversity: Branxton/Huntlee and Kurri Kurri. Other impacts not included in this assessment, such as noise pollution and dispersal barriers, are typical issues associated with linear infrastructure and should be assessed using appropriate methods to establish a comprehensive understanding of the impacts (e.g., Tulloch et al. 2015). The impacts of this scenario on the regional connectivity between habitat patches have been assessed by Lechner and Lefroy (2014).

Table 16. Predicted impact of each development scenario on the current distributions of features in the LHSA region, assuming that all native vegetation within the development sites are cleared. The first two columns show the mean and maximum losses of feature distributions within the LHSA region under each development scenario based on the modelled data or occurrence records used for each feature. The values in brackets give the mean impact to MNES species alone. The table also highlights the number of features that may lose between 50-100% of their known LHSA distribution under each scenario, as well as the proportion of high priority conservation areas and currently protected areas likely to be cleared. Feature-specific estimates of distribution loss can be found in Appendix 7.

Scenario	**Loss of LHSA distributions (%)**		**Number of features lost**	**Number of features losing at least**			**Priority conservation areas cleared (%)**			**Current protected areas cleared (%)**			
	Mean	Max		90%	75%	50%	Top 5%	Top 10%	Top 30%	Level 1	Level 2	Level 3	Total
1. Urban development													
Zoned	8.2 [8.4]	100	12	0	1	6	10.1	8.9	6.9	0.8	3.1	7.2	1.3
Zoned + Current strategies	9.8 [9.4]	100	16	0	2	6	10.7	10.0	8.2	0.8	3.8	10.6	1.5
Zoned+ Current strategies + Other investigation areas	12.7 [11.7]	100	18	0	2	8	12.9	12.3	11.0	1.0	4.7	12.0	1.8
2. Hunter Expressway	0.18 [0.18]	1.5	0	0	0	0	0.3	0.3	0.2	0.0	0.0	0.0	0.0
3. Important Agricultural Lands	5.6 [5.2]	100	2	0	1	3	8.4	7.6	6.7	0.0	1.6	7.4	0.4
4. Cumulative development	17.1 [16.0]	100	19	0	3	10	18.7	18.1	16.7	1.1	6.1	19.1	2.2
5. Mining	24.9 [24.0]	100	22	0	1	7	16.4	17.2	21.2	7.5	14.5	76.4	10.3

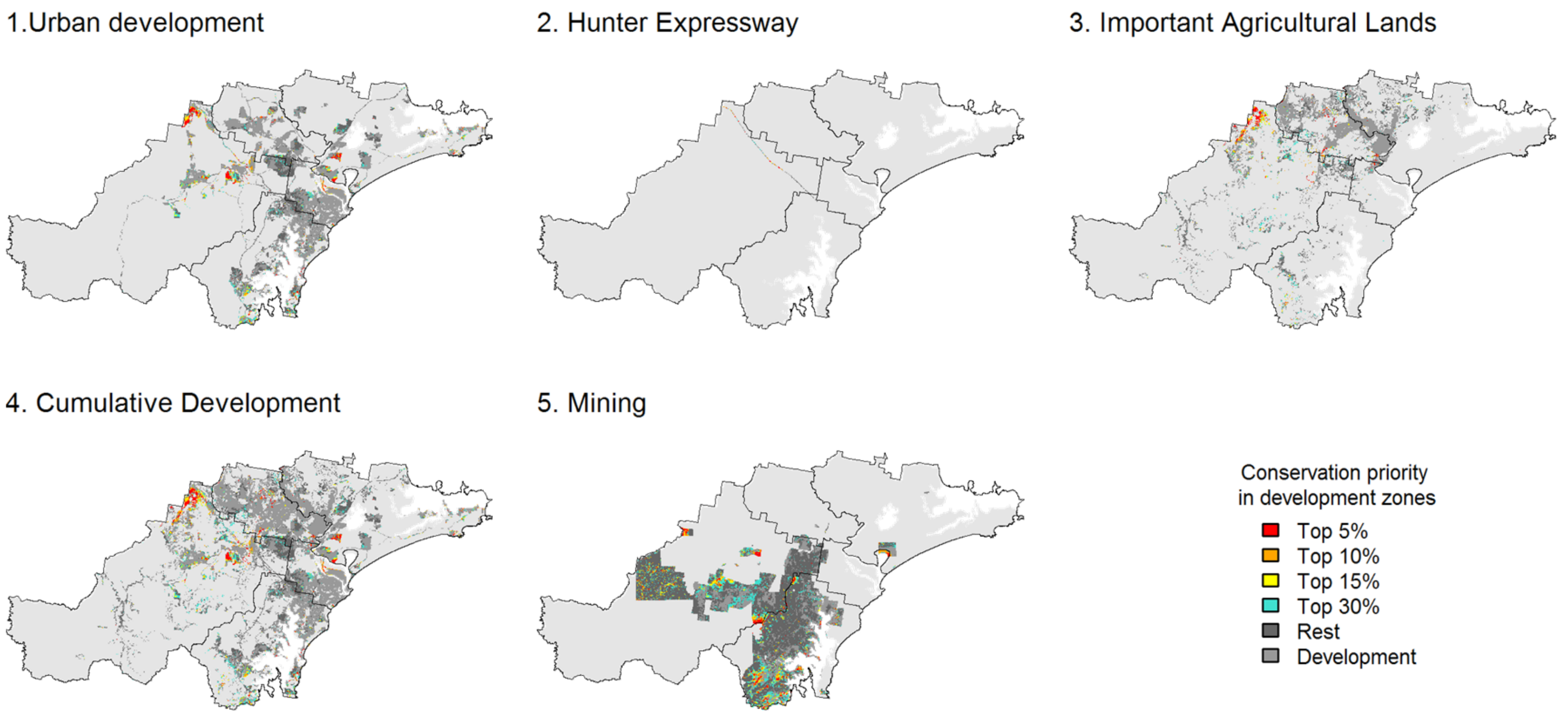


Figure 18. Overlap of each of the assessed development footprints with identified high priority conservation areas as described in Chapter 4. Areas with remaining native vegetation that overlap with the development footprint but which are not identified as priority sites for conservation are shown in dark grey. Areas in light grey show locations within the footprint where native vegetation has already been cleared.

Table 17. List of most critically impacted features in the Urban Development scenario, when all footprints in the urban scenario are considered. The data column represents the data type that was included in the prioritisation for each feature.

	Taxa	Family	MNES	NSW status	EPBC status	Data
Features at risk of losing entire LHSA distribution						
Acianthella amplexicaulis	plants	*Orchidaceae*		P		Points
Garganey (Anas querquedula)	birds	*Anatidae*	TRUE	P	C,J,K	Points
Red-winged Parrot (Aprosmictus erythropterus)	birds	*Psittacidae*		P		Points
Gang-gang Cockatoo (Callocephalon fimbriatum)	birds	*Cacatuidae*		V,P,3		Points
Sand Spurge (Chamaesyce psammogeton)	plants	*Euphorbiaceae*		E1,P		Points
Small Snake Orchid (Diuris chryseopsis)	plants	*Orchidaceae*		P		Points
Diuris dendrobioides	plants	*Orchidaceae*		P		Points
Grevillea shiressii	plants	*Proteaceae*	TRUE	V,P	V	Points
Nepean Conebush (Isopogon dawsonii)	plants	*Proteaceae*		P		Points
Australian Little Bittern (Ixobrychus dubius)	birds	*Ardeidae*		P		Points
Cotton Pygmy-Goose (Nettapus coromandelianus)	birds	*Anatidae*		E1,P		Points
Conesticks (Petrophile canescens)	plants	*Proteaceae*		P		Points
Petrophile sessilis	plants	*Proteaceae*		P		Points
Pterostylis revolute	plants	*Orchidaceae*		P		Points
Brown-snouted Blind Snake (Ramphotyphlops wiedii)	reptiles	*Typhlopidae*		P		Points
Australian Pratincole (Stiltia Isabella)	birds	*Glareolidae*		P		Points
Tiny Sun Orchid (Thelymitra carnea)	plants	*Orchidaceae*		P		Points
Tall Sun Orchid (Thelymitra media var. media)	plants	*Orchidaceae*		P		Points
Features at risk of losing at least 75% of LHSA distribution						
Honey Caladenia (Caladenia testacea)	plants	*Orchidaceae*		P		Points
Toothed Helmet Orchid (Corybas pruinosus)	plants	*Orchidaceae*		P		Points
Features at risk of losing at least 50% of LHSA distribution						
Oriental Plover (Charadrius veredus)	birds	*Charadriidae*	TRUE	P	J,K	Points
Small Tongue Orchid (Cryptostylis leptochila)	plants	*Orchidaceae*		P		Points
Climbing Orchid (Erythrorchis cassythoides)	plants	*Orchidaceae*		P		Points
White-throated Honeyeater (Melithreptus albogularis)	birds	*Meliphagidae*		P		Points

	Taxa	Family	MNES	NSW status	EPBC status	Data
Yellow Wagtail (Motacilla flava)	birds	*Motacillidae*	TRUE	P	C,J,K	Points
Bird's-mouth Orchid (Orthoceras strictum)	plants	*Orchidaceae*		P		Points
Tall Leek Orchid (Prasophyllum elatum)	plants	*Orchidaceae*		P		Points
Blue-tongue Greenhood (Pterostylis obtusa)	plants	*Orchidaceae*		P		Points

Scenario 3: Important Agricultural Lands

The Important Agricultural Lands scenario is expected clear up to 6.0% (16,670 ha) of native vegetation within the LHSA region (Table 15). Approximately 7% of the identified high priority conservation areas overlap with the potential development locations of this scenario (Table 16). The most suitable areas for agricultural development also overlap with 7.4% of the least secure Level 3 protected areas, while there is no overlap with the most secure Level 1 protected areas and only a small overlap of 0.6% with the Level 2 protected areas. Spatially, the impacts are concentrated around existing agricultural lands, with significant conflict areas overlapping with the top 5% conservation priorities around North Rothbury, East Maitland, Sawyers Gully, Woodberry, and along the Hunter River in Maitland Vale and Oakhampton (Figure 18). On average, biodiversity features are anticipated to lose up to 5.6% of their current LHSA distributions under this scenario (Table 16). Two threatened bird species, the cotton pygmy-goose and red-backed button-quail, are predicted to be most heavily impacted and may be at risk of losing their entire LHSA distribution. Four additional features may lose more than 50% of their known LHSA occurrences if all of the sites identified in this scenario are cleared. Of these, the endangered EEC White box-yellow box-Blakely's red gum-woodland may lose up to 77.8% of its currently known locations (Table 18).

Table 18. List of most critically impacted features in the Important Agricultural Lands scenario. The data column represents the data type that was included in the prioritisation for each feature.

	Taxa	Family	MNES	NSW status	EPBC status	Data
Features at risk of losing entire LHSA distribution						
Cotton Pygmy-Goose (Nettapus coromandelianus)	birds	*Anatidae*		E1,P		Points
Red-backed Button-quail (Turnix maculosus)	birds	*Turnicidae*		V,P		Points
Features at risk of losing at least 75% of LHSA distribution						
White box yellow box Blakely's red gum woodland EEC				E		Points

	Taxa	Family	MNES	NSW status	EPBC status	Data
Features at risk of losing at least 50% of LHSA distribution						
White-browed Treecreeper (Climacteris affinis)	birds	*Climacteridae*		P		Points
Ground Cuckoo-shrike (Coracina maxima)	birds	*Campephagidae*		P		Points
Diuris dendrobioides	plants	*Orchidaceae*		P		Points

Scenario 4: Cumulative impact of all urban, rural, infrastructure and agriculture development

The cumulative development scenario, combining the first three scenarios, could lead to the loss of up to 13.6% (37,992ha) of the native vegetation within the LHSA region (Table 15). Developing all areas within this footprint would clear up to 16.7% of high priority conservation areas, including nearly 20% of most critical top 5% conservation priorities. The main conflict sites of the footprint are located around Branxton-Rothbury, Kurri Kurri, Heatherbrae-Tomago and Southern Lake Macquarie (Figure 18). Clearing these sites is also likely to result in a potential 2.2% loss of the current protected area network in the LHSA region, with 19.1% of Level 3 protected areas overlapping with the potential development sites, and 1.1% and 6.1% of Level 1 and 2 protected areas, respectively (Table 16). The cumulative impact of these developments is, on average, predicted to result in up to 17.1% reduction in feature's current LHSA distributions. Some 19 features may lose all of their know occurrences within the LHSA region, including four state-listed species and two MNES species. An additional 13 features may lose at least 50% of their known LHSA occurrences. Of these, the honey Caladenia (*Caladenia testacea*), toothed helmet orchid (*Corybas pruin*) and the endangered EEC White box-yellow box-Blakely's red gum-woodland may be at risk of losing 75% or more of their current distributions (Table 19).

Table 19. List of most critically impacted features in the cumulative development impact scenario, including all potential impacts arising from urban, rural, infrastructure and agriculture development. The data column represents the data type that was included in the prioritisation for each feature.

	Taxa	Family	MNES	NSW status	EPBC status	Data
Features at risk of losing entire LHSA distribution						
Acianthella amplexicaulis	plants	*Orchidaceae*		P		Points
Garganey (Anas querquedula)	birds	*Anatidae*	TRUE	P	C,J,K	Points
Red-winged Parrot (Aprosmictus erythropterus)	birds	*Psittacidae*		P		Points
Gang-gang Cockatoo	birds	*Cacatuidae*		V,P,3		Points

	Taxa	Family	MNES	NSW status	EPBC status	Data
(Callocephalon fimbriatum)						
Sand Spurge (Chamaesyce psammogeton)	plants	*Euphorbiaceae*		E1,P		Points
Small Snake Orchid (Diuris chryseopsis)	plants	*Orchidaceae*		P		Points
Diuris dendrobioides	plants	*Orchidaceae*		P		Points
Grevillea shiressii	plants	*Proteaceae*	TRUE	V,P	V	Points
Nepean Conebush (Isopogon dawsonii)	plants	*Proteaceae*		P		Points
Australian Little Bittern (Ixobrychus dubius)	birds	*Ardeidae*		P		Points
Cotton Pygmy-Goose (Nettapus coromandelianus)	birds	*Anatidae*		E1,P		Points
Conesticks (Petrophile canescens)	plants	*Proteaceae*		P		Points
Petrophile sessilis	plants	*Proteaceae*		P		Points
Pterostylis revolute	plants	*Orchidaceae*		P		Points
Brown-snouted Blind Snake (Ramphotyphlops wiedii)	reptiles	*Typhlopidae*		P		Points
Australian Pratincole (Stiltia Isabella)	birds	*Glareolidae*		P		Points
Tiny Sun Orchid (Thelymitra carnea)	plants	*Orchidaceae*		P		Points
Tall Sun Orchid (Thelymitra media var. media)	plants	*Orchidaceae*		P		Points
Red-backed Button-quail (Turnix maculosus)	birds	*Turnicidae*		V,P		Points
Features at risk of losing at least 75% of LHSA distribution						
Honey Caladenia (Caladenia testacea)	plants	*Orchidaceae*		P		Points
Toothed Helmet Orchid (Corybas pruinosus)	plants	*Orchidaceae*		P		Points
White box yellow box Blakely's red gum woodland EEC				E		Points
Features at risk of losing at least 50% of LHSA distribution						
Oriental Plover (Charadrius veredus)	birds	*Charadriidae*	TRUE	P	J,K	Points
White-browed Treecreeper (Climacteris affinis)	birds	*Climacteridae*		P		Points
Ground Cuckoo-shrike (Coracina maxima)	birds	*Campephagidae*		P		Points
Small Tongue Orchid (Cryptostylis leptochila)	plants	*Orchidaceae*		P		Points
Climbing Orchid (Erythrorchis cassythoides)	plants	*Orchidaceae*		P		Points
White-throated Honeyeater (Melithreptus albogularis)	birds	*Meliphagidae*		P		Points
Yellow Wagtail (Motacilla flava)	birds	*Motacillidae*	TRUE	P	C,J,K	Points
Bird's-mouth Orchid (Orthoceras strictum)	plants	*Orchidaceae*		P		Points

	Taxa	Family	MNES	NSW status	EPBC status	Data
Tall Leek Orchid (Prasophyllum elatum)	plants	*Orchidaceae*		P		Points
Blue-tongue Greenhood (Pterostylis obtusa)	plants	*Orchidaceae*		P		Points

Scenario 5: Current mining titles and applications

The hypothetical clearing of the remaining 71,053 ha of native vegetation within the current mining titles and applications would result in an average loss of up to 24.9% of features' current LHSA distributions (Table 15; Table 16). While the examined footprint is the least realistic of the assessed scenarios, it does provide some useful insights of potential future conflicts between the interests of the mining industry and biodiversity conservation within the LHSA region. The current and applied mining titles encompass several areas identified as high priorities for conservation (Figure 18). These include areas near and around Martinsville, Mandalong, Morisset, Abermain, Mount Sugarloaf and Pokolbin. The total overlap with high priority conservation areas and current and applied mining titles in the LHSA region is 21.2%. These titles also overlap by 7.5%, 14.5% and 76.4% with Levels 1, 2 and 3 protected areas. If all the areas within these titles was cleared, up to 22 features would be at risk of losing all their known occurrences, including two MNES features, the eastern bristlebird (*Dasyornis brachypterus*) and narrow-leaved black peppermint (*Eucalyptus nicholii*), and the state-listed lesser creeping fern (*Arthropteris palisotii*), gang-gang cockatoo (*Callocephalon fimbriatum*) and common planigale (*Planigale maculate*). Another eight features would be at risk of losing more than 50% of their current distribution, among these the vulnerable MNES biconvex paperbark (*Melaleuca biconvex*), the endangered Woronora Plateau population of the black cypress pine (*Callitris endlicheri*), and two state listed EECs (Table 20).

Table 20. List of most critically impacted features in the Mining scenario, assuming that all remaining native vegetation within current mining titles and applications is cleared. The data column represents the data type that was included in the prioritisation for each feature.

	Taxa	Family	MNES	NSW status	EPBC status	Data
Features at risk of losing entire LHSA distribution						
Southern Whiteface (Aphelocephala leucopsis)	birds	*Acanthizidae*		P		Points
Lesser Creeping Fern (Arthropteris palisotii)	plants	*Davalliaceae*		E1,P,3		Points
Brown Tree Snake (Boiga irregularis)	reptiles	*Colubridae*		P		Points
Musky Caladenia	plants	*Orchidaceae*		P		Points

	Taxa	Family	MNES	NSW status	EPBC status	Data
(Caladenia gracilis)						
Gang-gang Cockatoo (Callocephalon fimbriatum)	birds	*Cacatuidae*		V,P,3		Points
Gnat Orchid (Cyrtostylis reniformis)	plants	*Orchidaceae*		P		Points
Eastern Bristlebird (Dasyornis brachypterus)	birds	*Dasyornithidae*	TRUE	E1,P	E	Points
Leaden Delma (Delma plebeian)	reptiles	*Pygopodidae*		P		Points
Purple Donkey Orchid (Diuris punctata)	plants	*Orchidaceae*		P		Points
Black Rock Skink (Egernia saxatilis)	reptiles	*Scincidae*		P		Points
Crimson Chat (Epthianura tricolor)	birds	*Meliphagidae*		P		Points
Narrow-leaved Black Peppermint (Eucalyptus nicholii)	plants	*Myrtaceae*	TRUE	V,P	V	Points
Genoplesium acuminatum	plants	*Orchidaceae*		P		Points
Genoplesium ruppii	plants	*Orchidaceae*		P		Points
Diamond Dove (Geopelia cuneata)	birds	*Columbidae*		P		Points
Nepean Conebush (Isopogon dawsonii)	plants	*Proteaceae*		P		Points
Pacific Gull (Larus pacificus)	birds	*Laridae*		P		Points
Conesticks (Petrophile canescens)	plants	*Proteaceae*		P		Points
Petrophile sessilis	plants	*Proteaceae*		P		Points
Common Planigale (Planigale maculate)	mammal	*Dasyuridae*		V,P		Points
Small Butterfly Orchid (Sarcochilus spathulatus)	plants	*Orchidaceae*		P		Points
Beautiful Firetail (Stagonopleura bella)	birds	*Estrildidae*		P		Points
Features at risk of losing at least 75% of LHSA distribution						
Quorrobolong scribbly gum woodland in the Sydney basin bioregion EEC				E		Points
Features at risk of losing at least 50% of LHSA distribution						
Black Cypress Pine, Woronora Plateau population (Callitris endlicheri)	plants	*Cupressaceae*		E2		Points
Biconvex Paperbark (Melaleuca biconvex)	plants	*Myrtaceae*	TRUE	V,P	V	SDM
White-throated Honeyeater (Melithreptus albogularis)	birds	*Meliphagidae*		P		Points
Bird's-mouth Orchid (Orthoceras strictum)	plants	*Orchidaceae*		P		Points
Pterostylis chaetophora	plants	*Orchidaceae*		P		Points
Thelymitra peniculata	plants	*Orchidaceae*		P		Points

Taxa	Family	MNES	NSW status	EPBC status	Data
Coastal saltmarsh in the NSW north coast Sydney basin and South East corner bioregion EEC			E		Points

5.4. Discussion

5.4.1. Overview: Impacts of potential development on biodiversity in the LHSA region

The general biodiversity impacts of all development scenarios are given in Table 16, with the predicted impacts for individual features provided in Appendix 7. The impact of each development footprint varies both in the extent of habitat likely to be cleared and the potential loss of biodiversity feature distributions. For example, while together the zoned and current strategies areas in the urban scenario are likely to clear a similar amount of native vegetation as the important agricultural lands footprint (up to 16,850 ha and 16,670 ha, respectively; Table 15), the potential biodiversity impacts of the urban development are estimated to be notably larger (average loss of 9.8% of distributions and 17 features at risk of disappearing in the combined zoned and current strategies footprint vs. 5.6% and 3 features in the important agricultural lands footprint; Table 16). In general, we did not find MNES to be more highly or less impacted by the potential development in any of the scenarios (Table 16).

Assessment of the development scenarios highlighted several potential conflicts between future urban, infrastructure and agricultural development and biodiversity protection in the LHSA region. While the majority of the assessed scenarios showed relatively little conflict with the existing protected area network in the LHSA region, they had notable overlaps with several of the currently unprotected high priority areas for conservation (Figure 18; Table 16). Significant conflicts, where potential development overlaps with areas identified as within the most important 5% of the entire region, were found especially around Branxton-Rothbury (including Huntlee), Kurri Kurri, Rutherforth-Largs, Tomago-Heatherbrae and the fringes of southern Lake Macquarie (Figure 19; Appendix 8). Without further mitigation actions the development of these sites would likely lead to the notable reduction of regional biodiversity and the local loss of features that are difficult or impossible to find elsewhere within the LHSA region.

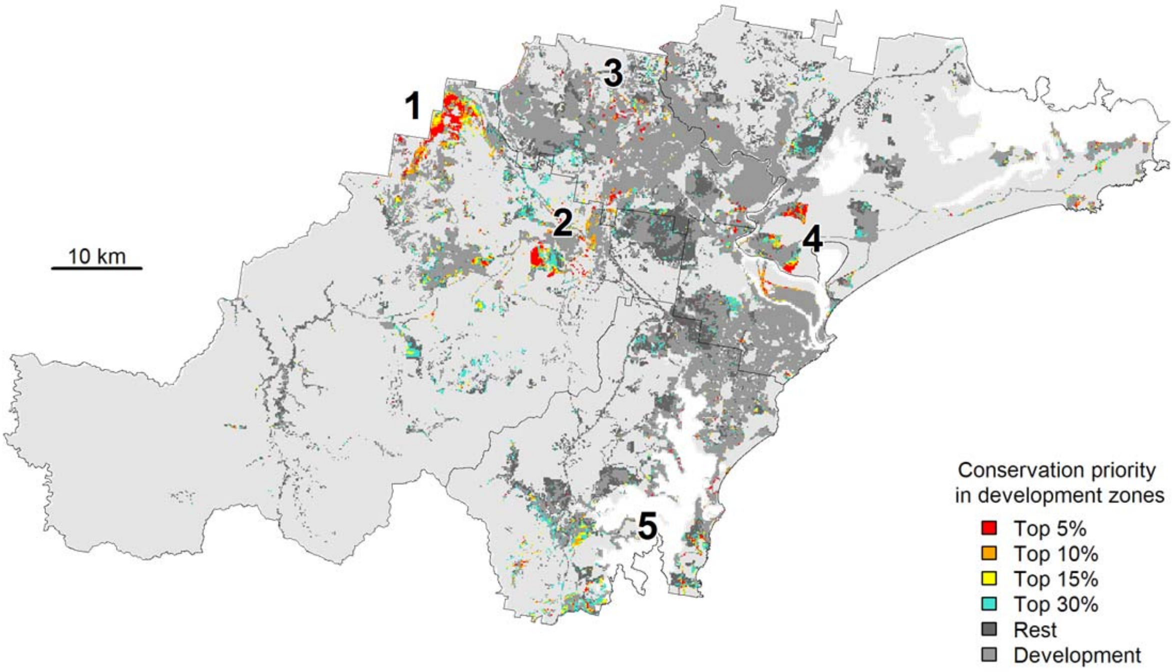


Figure 19. The conservation value of areas within the LHSA region at risk of being developed under the Cumulative Development scenario. The high priority conservation areas (coloured red to cyan) represent sites of high conservation value based on the best 30% of the LHSA region for the 721 biodiversity features included in this assessment. 1) Branxton-Rothbury (including Huntlee), 2) Kurri Kurri, 3) Rutherforth-Largs, 4) Tomago-Heatherbrae and 5) Southern Lake Macquarie. Development in these locations should be avoided if possible to avoid significant biodiversity losses. Areas in dark grey (Rest) have lower conservation value and represent areas where development is likely to have a lower overall impact on biodiversity features included in this assessment, although individual species may still be affected. Light grey represents areas within the development footprint that are already cleared of native vegetation.

The hypothetical mining scenario also revealed potential future conflicts in the LHSA region between the mining industry and protection of regional biodiversity. The identified conflict sites differed in most parts from the other scenarios, being concentrated on the mostly undeveloped regions of Lake Macquarie and Cessnock LGAs (Figure 18). We re-iterate that it is highly unlikely that all the sites included in the footprint of this scenario will be developed. Nevertheless, it is worthwhile noting that this scenario had the highest overlap with currently protected areas within the LHSA region (Table 16), potentially threatening not only the persistence of species and communities within the conflict sites but also some of the already achieved conservation efforts within the LHSA region. The Level 3 protected areas, of which over 76% overlap with current and applied mining titles, are likely to be at particular risk of degazetting due to their relatively weak legislative status.

With the exception of the Hunter Expressway, all development scenarios risk losing ll know occurrences of a number of biodiversity features, assuming that all native vegetation within the scenario footprints was cleared (Table 17; Table 18; Table 19; Table 20). A majority of these features are bird or plant species, with orchids forming the single biggest taxonomic group within the identified highly impacted features. We note that many of these features are very rare within the LHSA region but, particularly in the case of non-threatened species, may be near the limit of their geographical range and, therefore, be more common outside the assessment area. Some of the bird species, such as gargany (*Anas querquedula*) and Cotton Pygmy Goose (*Nettapus coromandelianus*) are vagrant visitors to New South Wales, and as such do not necessarily constitute high conservation priority. A majority of the highly impacted species and communities are also represented by point occurrences, and for some of them the points do not correctly reflect their true distribution within the study region. Nevertheless, as these shortfalls are constant across the scenarios, the number of highly impacted features provides a measure to compare the relative impacts of different development activities, and highlights species and communities that, irrespective of their threat status, are at risk of disappearing from the LHSA region.

Overlaying the priority ranking of the LHSA region on each of the development footprints (Figure 18; Appendix 8) provides an opportunity to identify those areas where development is likely to result in the loss of high priority conservation areas. Development should be avoided in these sites where possible to prevent the loss of key biodiversity features and habitats. If avoidance is not possible, mitigation actions should be undertaken. In contrast, the weighted prioritisation map (Figure 7b) can be used to identify areas of the landscape with a low conservation priority that may be better suited for development activities (Bekessy et al. 2012). Combining such information with planning tools can help to identify areas for development that minimise the impact to biodiversity while meeting planning requirements (Pettit et al. 2015).

5.4.2. Limitations and sources of uncertainty

The exact impact values for each scenario should be interpreted with caution as they are based on the assumption that all areas marked for development will be entirely cleared. This may not necessarily be a realistic assumption, especially for the mining titles and areas of rural residential development. It is nevertheless likely that these land use types will have significant local impacts to biodiversity. Further inaccuracies can arise from data conversions, where line and polygon shapes are forced into raster grid formats which are necessary for this type of analysis. These can create inaccurate overlaps between biodiversity features distributions and development scenarios, both in terms of false overlaps and false non-overlaps. These types of errors in spatial data conversions are typical and unfortunately non-trivial to solve. The outputs of these assessments nevertheless provide useful insights on the relative potential conflicts between development options and conservation that can be investigated further with more detailed analyses. We also note that we did not assess the likely indirect impacts of development, such as dispersal barriers, noise and pollution nearby impact sites and increased fragmentation of the landscape, which can further negatively affect biodiversity features and the persistence of populations in the landscape. This means that despite the potential coarseness and errors in the footprint estimates, our approach is very likely to be a conservative underestimate of the full scale ecological impacts of the assessed development plans.

We also reiterate that the outputs from the spatial prioritisation are only as good as the input data. Poor quality data (i.e., inaccurate distribution models and inaccurate point data) or missing data may result in the identification of potential biodiversity losses that does not align with the real world. In some cases, particularly for some of the included plant species, the data filtering process (described in Section 2.1.1) may have also removed old records of occurrences that are still extant today. For example, biodiversity features that are under-represented in the assessment (e.g., have fewer occurrence records than real world occurrences) may appear to be more heavily impacted by development than might be realistic. Conversely, the impacts of development on potentially over-represented biodiversity features (e.g., models that overpredict the extent of a feature's distribution) may be underestimated. While these potential biases are unavoidable in the absence of perfect knowledge about biodiversity distributions, we provide a relative assessment of the potential impacts of development based on the available data. The purpose of this study is to highlight and quantify the potential conflicts between development and conservation across the entire region. Further investigation into the identified conflict areas should be carried out to provide detailed accurate impact assessments.

Chapter 6 Synthesis and future directions

6.1 Summary

Using our proposed framework for regional-scale strategic impact assessments, we were able to identify high priority areas for conservation within the LHSA region based on the distribution of 721 biodiversity features (including 91 MNES and 141 state-listed features). We identified potential conflicts between these high priority conservation areas and potential development within the LHSA region, quantifying the anticipated losses to biodiversity and individual biodiversity features if that development goes ahead. In this final chapter, we synthesise the main findings and discuss some of the limitations of the assessment. We also highlight some recommendations to guide the LHSA and identify options for future work.

6.1.1. Conservation priorities and current protection of biodiversity in the LHSA region

The spatial prioritisation identified large areas within the LHSA region that are highly important for the conservation for the biodiversity features included in this assessment. These high priority conservation areas (considered here to be the best 30% of the LHSA region with native vegetation) are distributed across the entire region, with important areas located around, North Rothbury, Pelaw Main (near Kurri Kurri), Heaton State Forest, Watagans National Park, Kooragan Island, Tomago, and Anna Bay (Figure 7B). In many cases, particularly in Maitland LGA, these high priority conservation areas are small fragments of native vegetation that may contain the last known occurrences of some the biodiversity features included in this assessment. Cessnock, the largest LGA in the LHSA region, contains half the identified high priority conservation areas (Table 9). However, the majority of the high priority conservation areas are located in the more fragmented northern areas of the LGA and, to lesser extent, within the largely protected southern and eastern areas (Figure 10). In the two smallest LGAs, Newcastle and Maitland, the majority of native vegetation has already been cleared, but the remaining areas hold notable conservation value with approximately 50% and 40%, respectively, of the two LGA's vegetated areas identified as high priorities for conservation (Table 9).

All 721 biodiversity features included in this assessment are represented within the high priority conservation areas, with, on average, half of their LHSA distributions captured within these areas (68% of the distributions of MNES features)(Figure 12 and Figure 13). In addition, 152 biodiversity features (34 MNES) have their entire LHSA distributions within the high priority conservation areas (Table 11). The assessment highlighted that, while 33% of the remnant native vegetation within the LHSA region is currently protected, 63.2%% of the high priority conservation areas are currently unprotected , and another 7.6% is protected by only the intermediate or low security protected areas (Figure 15; Table 12). In contrast, several of the unprotected areas are threatened by potential future development. While many biodiversity features are represented within the current protected area network, there are 80 features (12 MNES) that do not occur with the most secure protected areas and 67 features (7 MNES) that are not protected at all (Figure 14; Table 13). The currently unprotected high priority conservation areas (Figure 15), therefore, provide notable conservation potential and significant improvements in the level of biodiversity protection in the LHSA region could be achieved with relatively small expansions of the protected areas strategically targeted to sites with currently underrepresented species and communities. Special attention is required to maintain the biodiversity values of the small vegetation fragments identified as high priority for conservation. It is likely that conservation actions beyond land tenure changes are required, including active management and restoration of lost habitats to secure the long-term persistence of the rarest species and communities within these fragments.

6.1.2. Impacts of potential development on biodiversity in the LHSA region

In our assessment we investigated the potential impacts of five development scenarios (Figure 17). Of these, four looked at realised, likely and potential urban, infrastructure and agriculture development within the LHSA region and one compared the overlap of existing and applied mining titles and biodiversity values within the region. We re-iterate here that, although the spatial data used in these scenarios were in some parts provided by NSW DPE, the assessed scenarios do not necessarily represent actual plans for future development but rather were developed to help understand where potential future conflicts between development and biodiversity conservation may occur.

Our results highlighted several conflict areas where potential future development is likely to overlap with the identified high priority conservation areas and where notable biodiversity losses can be expected if the development proceeds to clear native vegetation (Figure 18). These sites are mostly concentrated along the urban and rural fringes and along main roads in the LHSA region, with larger areas of conflicts identified in Huntlee, North Rothbury, Pelaw Main (near Kurri Kurri), Tomago, Heatherbrae and around the fringes of Lake Macquarie. Many of these sites belong to the most important 5% of the LHSA region in terms of their biodiversity value and without further mitigation actions, the development of these sites would likely lead to the loss of features that are difficult or impossible to find elsewhere within the region. The majority of the assessed development scenarios pose little threat to current protected areas in the LHSA region but the overlap between unprotected high priority areas and proposed and potential development in LHSA is notable (up to

21% depending on the scenario)(Table 16). The cumulative development scenario that combined all urban, infrastructure and agricultural development was estimated to result in the clearance of up to 38,000 ha of native vegetation and the average loss of up to 17% of biodiversity features' LHSA distributions. Nearly all development scenarios were highlighted as potentially clearing the last known occurrences of some biodiversity features within the LHSA region, with likely implications for their persistence within the region. More detailed assessment of these conflict sites is needed to fully understand the potential risks of biodiversity losses that would follow from developing these sites and to assess most suitable mitigation actions.

Comparison of mining titles and high priority conservation areas also revealed potential future conflicts between the mining industry and biodiversity conservation in the LHSA region. The current and applied mining titles cover 23% of the LHSA region, concentrated on the mostly undeveloped regions of Lake Macquarie and Cessnock LGAs (Figure 18). This scenario differed from the other scenarios, not only in the spatial extent and distribution of the footprint, but also due to the relatively high overlap with existing protected areas (Table 16). Ten percent of the existing protected area network in the LHSA region falls within these mining titles, with the legislatively less-secure Level 3 protected areas overlapping by 76% with the mining scenario footprint. If mining becomes more active within these areas, not only will biodiversity features be at risk of being lost, but also the legacy of past conservation efforts.

6.2. Discussion and future directions

In this assessment we have shown how systematic spatial prioritisation methods provide a coherent approach to dealing with many data layers describing biodiversity features and potential development scenarios in a way that cannot be achieved by the human brain within a deliberative process. Consequently, the results presented in this report represent potentially extremely valuable inputs to the deliberative process that significantly reduces the cognitive burden on those involved. We have undertaken a transparent and repeatable analysis of the biodiversity values of the region and the likely impacts of several development scenarios, using peer-reviewed methods with a long history of use in conservation planning. The analysis presented in this study can be repeated for any combination of biodiversity features and development scenarios, or if needed, conducted on different scale. Nonetheless, we reinforce that what is provided here is not a 'solution' to a decision problem, but an input. We have not attempted to balance costs, constraints, social preferences and the myriad of other considerations that necessarily go into complex land management and planning decisions.

A significant part of this assessment has been the mapping and modelling of the distributions of 566 species and communities within the LHSA region. While modelled distributions always have their limitations, we note that the species distribution models produced in this project had high to very high predictive performance. Therefore, we feel confident that they provide significant improvement to our understanding of biodiversity patterns within the LHSA region, and represent the best available distribution data for inclusion in the spatial conservation prioritisation. However, as a general rule, we recommend that sites highlighted by subsequent analyses as high priority for conservation and at risk from development, and areas thought to be of high conservation value that were not identified as such in our analysis be surveyed as part of the decision-making process.

Development proposals that are likely to result in the loss of biodiversity features or severely decrease their current distribution size should be analysed in further detail to understand where mitigation actions could provide substantial conservation benefit. In order to avoid further loss in local biodiversity, known locations of highly threatened species should be excluded from development. We also recommend that proposed development areas overlapping with the high priority conservation areas should be targeted for further surveys to validate the anticipated losses and to further guide appropriate actions for solving these conflicts. Areas included in the top 5% and 10% priorities are particularly difficult, or impossible, to replace with sites elsewhere in the LHSA region and should, therefore, be the core focus of any further assessments.

We re-iterate that the conservation priorities identified in this assessment are based on local habitat quality and representation of the species and communities included in the spatial prioritisation. These areas have not been selected from the perspective of ecological processes and, therefore, the outputs of the spatial prioritisation do not provide any information about the adequacy of the solution to ensure the long term persistence of biodiversity features within the landscape. Such evaluations require more detailed information on species demographics and movement, which is rarely available for large number of species. While consideration of potential connectivity requirements between habitat patches and the potential impacts of similar development scenarios in the LHSA region has been assessed by Lechner and Lefroy (2014), these were done based on average dispersal distances across a range of species and therefore, may not be representative of connectivity requirements for individual biodiversity features. However, maintaining healthy ecosystems starts by securing the presence of their biodiversity components, followed by actions aimed to preserve or improve the underlining intra- and interspecific dynamics. For a small subset of well-studied species it may be possible to develop spatially-explicit metapopulation models to evaluate their likely long-term persistence under different development scenarios. This could be an appropriate next step to help decision makers understand the potential implications of the proposed development and the additional conservation investments needed to secure critical long-term ecological processes. Such models should ideally also consider threatening processes outside the LHSA that may influence the persistence of the species of interest. Although it was not possible to include ecological processes in this assessment, the prioritisation provides valuable information on the critical habitat needed to halt further biodiversity loss in the LHSA. The priority maps could also be used to guide future biodiversity mapping exercises, particularly in areas that are currently poorly surveyed, as the underlining species distribution models have the potential to reveal locations of previously unknown local populations or important habitats (Guisan & Thuiller 2005).

We note that many small habitat patches were identified as having high conservation value. Many small, isolated fragments of vegetation on the river valleys of Lower Hunter that have been identified as high priority conservation areas because they contain the last remaining occurrences of biodiversity features that are not found elsewhere in the landscape − essentially they are irreplaceable. Given the paucity of evidence supporting the notion that these patches are unviable simply because they are small, we strongly recommend considering these patches irreplaceable until it can be shown that the conservation values they contain can be better secured elsewhere.

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