occur largely independently of, and would not be exacerbated by, the Proposal. Some, such as fire, are also likely to be influenced primarily by assumptions of fire management and fire response. Mining may facilitate establishment of the Cane Toad in the Pilbara bioregion through provision of artificial water sources; however, this would be addressed through risk assessment and management.

A separate IAR for the Proposal has been prepared and considers the outputs of this report in the context of the management frameworks that BHP Billiton Iron Ore has proposed to manage potential cumulative impacts identified in this CIA report. The IAR also discusses in further detail the potential for the Proposal to affect the Pilbara Olive Python's persistence and viability in the Pilbara bioregion.

9.8 THE IMPACT ASSESSMENT REPORT AND MNES PROGRAM

The strategic environmental assessment of the Proposal under the EPBC Act will be informed by two components: the IAR and the MNES Program. The CIA is one of a number of inputs to the IAR.

The IAR addresses in full the assessment requirements of the Terms of Reference under the Agreement, presents the findings of this CIA and other component studies and addresses the significance of potential impacts to relevant MNES when mitigation measures are taken into consideration.

The MNES Program sets out BHP Billiton Iron Ore's proposed approach to the application of the mitigation hierarchy to minimise impacts to relevant MNES to an acceptable level. The MNES Program details how BHP Billiton Iron Ore will embed application of the mitigation hierarchy during its internal project development, construction, operation and rehabilitation. The MNES Program outlines the requirement for implementation plans to address biodiversity, offsets, monitoring and reporting.

The purpose of the IAR and the MNES Program is to address the requirements of the Agreement. The CIA is a key component of the IAR and has been written to be considered as an appendix to the IAR.

10 References

* The references listed in this section include those cited in Appendix A and Appendix B of this document.

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Appendix A: Studies undertaken to support the CIA

Overview

The key study commissioned by BHP Billiton Iron Ore to support the assessment of potential cumulative impacts to MNES was species habitat modelling conducted by ELA (2015). The study utilised a considerable number of datasets from multiple sources and produced models that were used as base layers (in a Geographic Information System; GIS) to which datasets representing potential impacts were applied to quantify cumulative impacts. The ELA (2015) study is described in this appendix under óspecies habitat suitability modelsô

Other input came from a study undertaken by BHP Billiton Iron Ore (2015) to assess ecohydrological change potential and produce impact base layers and a spatial layer developed for grazing pressure by ELA specifically for use in the CIA. These studies are described in this appendix under óimpact studiesô In addition, the major input to the CIA was the disturbance footprint for existing and proposal BHP Billiton Iron Ore and third party operations. The disturbance footprint data are discussed in Section 2.5. These data formed the basis for development of the majority of potential impacts applied to MNES. Derivation of potential impacts to MNES is described in Section 2.4. Other studies commissioned by BHP Billiton Iron Ore to support the Proposal were a cumulative noise impact assessment and a cumulative dust impact assessment. These studies modelled and assessed the cumulative impacts of noise and dust from existing and proposal Billiton Iron Ore and third party operations in the Pilbara bioregion. While not considered in the CIA, the noise and dust studies will be used to inform BHP Billiton Iron Oreôs future management priorities and measures.

Species habitat suitability models

Introduction

The base layers used in the CIA were relative habitat suitability models developed by ELA (2015) for the Greater Bilby, Hamersley Lepidium, Northern Quoll, Pilbara Leaf-nosed Bat and Pilbara Olive Python, utilising over 2,700 species records from BHP Billiton Iron Ore and Parks and Wildlife, along with data for a range of topographic (elevation), terrain (ruggedness, position), climatic, hydrological, landscape, substrate and vegetation variable.

Base case habitat suitability models for MNES incorporated the best available data on species locations and environmental variables from a range of sources, including BHP Billiton Iron Ore and publicly-available records and databases. Species locations included records from several targeted surveys commissioned by BHP Billiton Iron Ore, as well as additional public records obtained through Parks and Wildlife. Species records were filtered by date, accuracy and spatial independence to ensure compatibility with the scale of modelling and of environmental background data. Data pertaining to environmental variables were obtained through BHP Billiton Iron Ore, Landgate, Geoscience Australia and the Bureau of Meteorology.

Overall, the species habitat models should be treated as indicative, highlighting those parts of the landscape where there is potentially a higher probability of species habitat being present. Further, it is noted that the models do not indicate the potential utilisation of these habitats by the species, nor the relative abundance of species. The models have been developed using available data collected in a landscape that has both mining and non-mining (e.g. grazing and feral animals) impacts present and do not represent a historical or current distribution of each MNES. This is considered to be a reasonable approach in the CIA. While there are some limitations with the models, they are considered valid for use in a range of applications. They are considered suitable for use in this Commonwealth CIA given the aims of the study, the analysis approach adopted and the regional focus.

Overview of modelling approach

ELA (2015) developed a predictive model of potential species óhabitat suitabilityôfor each MNES under consideration in the CIA. Given the limitations of obtaining a comprehensive inventory of species locations in such a large and remote area, the objective of the habitat suitability modelling was to provide a basis for assessment of potential cumulative impacts to each species by identifying locations most likely to be favoured by the species. Mining and other impacts within these regions would likely have greater consequence for species prevalence than in less favoured areas. The output from species habitat modelling was a predictive model surface across the Pilbara bioregion illustrating the relative probability of potential habitat for each target species (ELA 2015); this can be thought of as broadly analogous to óhabitat suitabilityô Use of the Pilbara bioregion was considered appropriate given the Proposal is wholly contained within this bioregion; however, it is noted that the distributions of the Greater Bilby and Northern Quoll extend beyond the bioregion and the CIA therefore may overstate the potential impacts to these species if considered across the speciesô entire range. Predicted relative probability of potential habitat is described further in the following section; the term óhabitat suitabilityô has generally been used in this document to describe the relative probability of potential habitat.

The habitat models were developed using statistical analysis software (S-Plus), a GIS program (ArcGIS), and purpose-built software (Generalised Regression Analysis and Spatial Prediction; óGRASPô; Lehmann et al 2002). GRASP utilises Generalised Additive Models (GAMs), which are based on regression techniques. The main advantages of this type of modelling include:

- Predictions are based directly on relationships between responses (i.e. species locations) and environmental variables. These predictions are subsequently used to produce a spatial distribution of preferred habitat. This contrasts to techniques such as kriging or other spatial interpolation that make predictions directly based on the point locations and thus can be heavily influenced by spatial bias.
- Regression-based statistical models facilitate improved interpretability by selecting variables based on appropriate statistical distributions.
- The non-parametric nature of GAMs facilitate improved fit to environmental gradients and more closely align with ecological theory.

Each model output was a GIS layer of predicted relative probability of potential habitat (óhabitat suitabilityô), which ranges from zero to 100 per cent for each cell (25 metres by 25 metres) in the model domain. Key information from the ELA (2015) report is provided in the following sections.

Consideration of alternative approaches

The use of species habitat models was considered the best available means to assess potential cumulative impacts to each of the MNES at a regional scale given the available data for the Pilbara bioregion. This approach was preferred over possible alternatives, such as an individual-, or population-based approach (whereby the impact to each species could be assessed based on known records as determined from on-ground investigations and surveys) because insufficient survey effort has been undertaken to enable an accurate estimate of key parameters for each species, such as distribution, population size, and population density, across all areas of the Pilbara bioregion. Alternative habitat based approaches include the use of species habitat mapped from on-ground investigations and surveys, or the use of other regional mapping as a surrogate for habitat, such as regional vegetation mapping undertaken by Beard (1975a, b), or regional land system mapping undertaken by the Western Australian Department of Agriculture and Food (DAFWA) and reported on by van Vreeswyk et al. (2004). The former approach is likely to be constrained by insufficient survey effort in the same way as individual-, or population-based approaches; the latter by the broad nature of the mapping and because individual vegetation units and land systems have not necessarily been differentiated using attributes pertinent to fauna habitat suitability. Of note is that vegetation units and land systems were included in the suite of environmental variables used to develop each habitat model.

With regard to the modelling approach implemented for the CIA, which utilised GAMs, the application and evaluation of statistical techniques for the spatial modelling of species habitat and species distribution has received much attention in contemporary scientific literature. Several authors have evaluated and compared the common approaches used within the field (e.g. Austin 2007, Elith et al. 2006, and Liu et al. 2013).

Logistic regression techniques have been widely used for several years while a number of emerging techniques have been applied more recently (Austin 2007; Elith et al. 2006). The commonly used techniques over recent years are briefly summarised below. Others, such as envelope-style methods (BIOCLIM) and distance-based methods (DOMAIN and LIVES) are not discussed in this review and have been documented as lacking the predictive power of the other approaches (Elith et al. 2006). Historically, many users applied Generalised linear models (GLMs; McCullagh and Nelder 1989) which are a generalisation of ordinary linear regression techniques and have been extensively used in the landscape ecology field (Guisan et al. 2006; Nicholls 1989, 1991; Rushton et al. 2004). They allow for a non-normal distribution of response variables and establishment of a relationship between a standard linear model and the response variable. They are based on the least squares method for maximum likelihood estimation.

GAMs (Hastie and Tibshirani 1990) are an extension of GLMs and have been widely applied. They are founded on the principles of GLMs and incorporate additive approaches whereby multiple statistical functions can be applied along with other statistical techniques and tests. Multivariate adaptive regression splines (MARS; Friedman 1991) are an alternative regression technique (Elith et al. 2006) and while in some ways similar to GAMs, they can incorporate stronger variable interactions and different model fitting mechanisms (non-linear).

More recently, machine-learning[6] approaches have been applied to ecological studies even though the statistical techniques are not new (Austin 2007 and Elith et al. 2006). Approaches include Maximum Entropy (MaxEnt; Phillips et al. 2006); Boosted regression trees (BRT; Friedman et al. 2000) and Random Forest (RF; Cutler et al. 2007). BRT and RF have a number of similarities, being based on regression trees (Elith et al. 2006; Liu et al. 2013). BRT is described by Elith et al. (2006) as óan additive regression model in which individual terms are simple trees, fitted in a forward, stage-wise fashionô RF is described by Liu et al. (2013) as being similar to BRT; however, the selection of predictors for each tree is random and the model focuses on the tree which obtains the best classification. In contrast, MaxEnt is described by Phillips et al. (2006) as predicting species distribution by finding the distribution of maximum entropy (closest to uniform).

In addition to the above approaches, a number of community based modelling approaches have been used (described by Austin 2007 and Elith et al. 2006) including MARS-COMM (a variant of MARS outlined above) and Generalised dissimilarity modelling (GDM; Ferrier et al. 2002). Essentially, these techniques rely on modelling approaches similar to the regression techniques outlined above, but are applied to a group of species (a community or assemblage) rather than to a single species. Elith et al. (2006) describe MARS-COMM as having the ability to ósimultaneously relate variation in the occurrence of all species to the environmental predictors in one analysis, and then estimate individual model coefficients for each speciesô

A summary of the common modelling approaches and application to the CIA is provided **Table A1**.

Austin (2007) documents how evaluation of differing modelling approaches is often not straightforward and puts the case for the strongest predictive models to be developed through appropriate consideration of:

- ecological theory (implicit, explicit and niche) and how it should influence the decisions made in development of the modelling/statistical approach;
- use of direct variables above indirect variables where available.

Austin (2007) concludes that ñthere is no standard for current best practice when modelling species environmental niche or geographical distributionò and ñthat ecological insight and statistical skill are more important than the precise methodology usedò

Lastly, Austin (2007) lists the following órules of thumbô

- Investigate the possibility of curvilinear relationships.
- State explicitly what ecological theory is being assumed or tested.
- Ensure that data resolution is consistent with theory and the predictors being used.
- Examine relationships between variables for environmental process interactions in order to derive more proximal predictors.

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[6] Machine learning is the process by which algorithms are constructed from data processing. The algorithms build models based on the input data and use these to make predictions, or decisions, rather than predefined instructions.

- Evaluate new methods with realistic artificial data (i.e. data consistent with current ecological understanding).
- Use more than one statistical method to build the predictive model.
- Do not depend solely on prediction success when evaluating species models.
- Investigate the model residuals for spatial and other patterns.
- Use independent data to test the models.

Elith et al. (2006) provide a review of contemporary species distribution modelling techniques and concludes that the ñnovel methodsò such as MaxEnt, GDM and BRT consistently outperformed more established methods, such as GLM, GAM and MARS. RF was not considered in that review; however, Liu et al. (2013) contend that RF has similar levels of model accuracy as BRT and has other potential benefits including computational improvements. Elith et al. (2006) conclude that ñthe good performance of the novel methods result from their ability to fit complex responses (often including interactions) and select a relevant set of variablesò. Despite the favourable reviews of recent and emerging techniques, a number of limitations restrict their application (**Table A1**). Further the potential benefit to prediction (increase in model success) was not considered significant above more traditional techniques such as GAM. GAM techniques are widely accepted within the industry, tried and tested, considered simpler to implement and interpret, and for these reasons was chosen as being a suitable approach for the CIA.

Table A1: Summary of species modelling approaches (adapted from Elith et al. 2006 and others)

Modelling approach	Description	Benefits	Drawbacks	Software requirements	Application to the CIA
GLM	Generalised Linear Modelling is a linear regression technique.	Widely documented use; handles erroneous data well.	Some limitations with statistical technique (such as the fitting of linear models).	S-Plus (statistical analysis software) and GRASP (purpose-built software; Generalised Regression Analysis and Spatial Prediction; Lehman et al 2002).	Limited. GAM and other approaches demonstrated to be superior.
GAM	Generalised Additive Modelling is an additive regression technique that uses non-parametric and smoothing functions in model development.	Extensively used in the landscape ecology discipline; Specialised software tools and descriptions are readily available. Functional flexibility allows potential for better fit of models to data.	Over-fitting/over-prediction suggested as a problem in some cases. Computationally more intensive than GLM. Common model methods do not incorporate variable interaction.	S-Plus and GRASP.	High. Established technique with good predictive power and readily available software and approach.
MARS	Multivariate Adaptive Regression Splines is an alternative regression technique.	Permits a non-parametric approach and includes variable interaction.	Potential benefits over more traditional regression techniques, such as GAM, are not clear.	R (a software environment for statistical computing and graphics) and Mixture and flexible discriminant analysis (mda) package within R.	Potential. However, potential benefit to prediction (increase in model success) not considered significant.
BRT	Boosted Regression Trees is a decision/classification tree technique.	Selects relevant variables well. Deals with noisy data and limited datasets satisfactorily. Can model variable interactions and fit complex functions. Thought to minimise problems	Computationally more intensive than GLM, GAM and MARS. Interpretation of results can be more complex.	R and Generalised Boosted Regression Models package within R.	High potential. However, software and approach would require further investigation to determine implementation practicalities for the CIA.

Modelling approach	Description	Benefits	Drawbacks	Software requirements	Application to the CIA
		with model over-fitting.			
MaxEnt	Maximum Entropy attempts to fit a distribution closest to uniform.	Purpose built to deal with presence-only datasets.	Licence excludes use for any commercial or for-profit purposes.	Stand-alone software.	None, given licence restriction.
RF	Random Forest is a machine-learning method with similarities to BRT. RF incorporates many decision trees, each with a separate sample of data and comprised of a different subset of predictors.	Thought to be thorough in the selection of prediction variables, fit complex functions and minimise problems with model over-fitting.	Computationally intensive. Interpretation of results can be more complex.	R and Salford Systems (purpose-built software).	High potential. However, software and approach would require further investigation to determine implementation practicalities for the CIA.
MARS-COMM	Same as for MARS, but incorporates community data. That is, it analyses the response of a group of species to inform response from individuals.	Can utilise data for other species or groups of species to assist modelling response of an individual.	Community modelling approach may not be appropriate for all species. More straightforward to implement than GDM.	As for MARS.	Possible.
GDM	Generalised dissimilarity models compute dissimilarity in species composition in relation to environmental characteristics (i.e. predictors).	Can utilise data for other species or groups of species to assist modelling response of an individual. More ecologically sophisticated than MARS-COMM.	Community modelling approach may not be appropriate for all species.	Specialised program not available.	None, given software restrictions.

Predicted relative probability of potential habitat

Development of the habitat models involved statistical analysis of relationships between records of species observations and spatial datasets that describe the environmental characteristics of the Pilbara bioregion. This process relied on the input data used (records of species observations and datasets describing environmental character) and the ability to identify statistically important relationships between them.

The broad steps of the model development were:

1. Review of species characteristics and data ï Review of the known distribution and characteristics of the species of interest.
2. Data audit ï Collation of all known environmental datasets and evaluation of their characteristics and potential for utilisation in the statistical modelling, and identification of data gaps and limitations.
3. Data preparation ï Preparation of the spatial data (environmental variables and species records) for modelling and interrogation of the data.
4. Statistical analysis ï Statistical analysis using GAM approaches.
5. Spatial models ï Generation of predictive spatial layers representing potential habitat and evaluation of the models generated.

REVIEW OF SPECIES CHARACTERISTICS AND DATA

The first step in model development involved review of the characteristics and habitat preferences of each target species using relevant literature and through discussions with ecologists with particular experience with, and expertise on the species. The review considered each speciesô habitat preferences, behaviour and movement, and distribution in the Pilbara bioregion, as well as an analysis of species record data and data accuracy.

Species presence records were collated for the bioregion from a number of readily available sources, primarily BHP Billiton Iron Oreôs internal database and the species database of Parks and Wildlife. Species data varied in source, survey type, age, observation type (direct vs. indirect) and record habitat type. In addition, the available presence data were likely to have a range of biases and limitations including variable survey methodology, lack of experimental design across the bioregion, seasonal variations in survey, and restricted spatial extent (where records from BHP Billiton Iron Oreôs internal database are generally restricted to BHP Billiton Iron Oreôs tenure).

DATA AUDIT

The second step in model development involved collation, generation, review and evaluation of all known and available environmental variables (spatial data layers) for their potential utilisation. This included a range of environmental variables covering hydrological, landscape, substrate, topographic, climatic and vegetation data. Once collated, the data were evaluated in terms of:

- coverage completeness;
- scale;
- attribution (type, completeness, relevance);
- accuracy;

- potential ecological relevance to the species of interest.

Key GIS data utilised are outlined in **Table A2**. They included:

- topographic data: digital elevation model, slope, and aspect;
- terrain data: topographic position, ruggedness, and topographic wetness index;
- climatic data: average maximum temperature, average minimum temperature, average annual rainfall;
- drainage data: watercourses and waterbodies;
- substrate data: geology, interpreted bedrock, and geological units;
- landscape data: land system types;
- vegetation data: pre-European vegetation, native vegetation extent, post-1988 vegetation, regional vegetation associations, Beard (1975a, b), and vegetation mapping;
- species data: species records;
- imagery: Landsat 25 metre resolution 2002 and 2003.

Data limitations

No critical data gaps were identified; however, the modelling approach could potentially be improved by the use of:

- complete coverage of geological mapping;
- soil type mapping;
- land surface mapping, particularly identification of rocky habitats;
- other data identifying characteristics of relevance to identified species preferences;
- future third party disturbance footprints.

Table A2: Environmental datasets used in the development of species habitat models by ELA (2015)

Layer*	Description	Details
Topographic data		
dem25m	Digital elevation model	Digital elevation model (30 m cell size) sourced from Geoscience Australia.
slope	Slope	Slope in degrees, derived from the DEM.
aspect	Aspect	Aspect in degrees, derived from the DEM. Areas of slope less than 2 coded as -1.
Terrain data		
top100	Topographic position 100 m	Derived from the DEM. Topographic position is the difference in elevation of a cell and the mean elevation of all cells within a defined neighbourhood (NSW NPWS 1994). Positive values indicate above average elevation, whereas negative values indicate below average elevation. A 100 m analysis neighbourhood was used to generate this layer.
top250	Topographic position 250 m	Derived from the DEM as for top100. A 250 m analysis neighbourhood was used to generate this layer.
top500	Topographic position 500 m	Derived from the DEM as for top100. A 500 m analysis neighbourhood was used to generate this layer.
top1000	Topographic position 1,000 m	Derived from the DEM as for top100. A 1,000 m analysis neighbourhood was used to generate this layer.
top2000	Topographic position 2,000 m	Derived from the DEM as for top100. A 2,000 m analysis neighbourhood was used to generate this layer.
rug100	Ruggedness 100 m	Derived from the DEM. Ruggedness is the value of the standard deviation of elevation values within a defined neighbourhood (NSW NPWS 1994). Higher values indicate more rugged terrain. A 100 m analysis neighbourhood was used to generate this layer.
rug250	Ruggedness 250 m	Derived from the DEM as for rug100. A 250 m analysis neighbourhood was used to generate this layer.
rug500	Ruggedness 500 m	Derived from the DEM as for rug100. A 500 m analysis neighbourhood was used to generate this layer.
rug1000	Ruggedness 1,000 m	Derived from the DEM as for rug100. A 1,000 m analysis neighbourhood was used to generate this layer.
rug2000	Ruggedness 2,000 m	Derived from the DEM as for rug100. A 2,000 m analysis neighbourhood was used to generate this layer.
wetness	Topographic wetness index	Derived from the DEM. The topographic wetness index describes wetness conditions with higher values indicating more saturated areas (Jenson and Domingue 1988).
Climate data		
tempmax	Average maximum temperature	Derived from 2.5 km scale data sourced from the Bureau of Meteorology describing average annual maximum temperature. Data were smoothed and resampled to a 25 m grid cell using a mean analysis on a neighbourhood of 2.5 km. Values were multiplied by 100 before converting to an integer to retain some complexity in

Layer*	Description	Details
		values.
tempmin	Average minimum temperature	Derived from 2.5 km scale data sourced from the Bureau of Meteorology describing average annual minimum temperature. Data were smoothed and resampled to a 25 m grid cell using a mean analysis on a neighbourhood of 2.5 km. Values were multiplied by 100 before converting to an integer to retain some complexity in values.
rainann	Average annual rainfall	Derived from 2.5 km scale data sourced from the Bureau of Meteorology describing average annual rainfall. Data were smoothed and resampled to a 25 m grid cell using a mean analysis on a neighbourhood of 2.5 km. Values were multiplied by 100 before converting to an integer to retain some complexity in values.
Drainage data		
strmall	Distance to streams (all)	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. Based on all mapped streams.
strmper	Distance to perennial streams	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the strmall layer encompassing only streams classified as perennial.
stmnonp	Distance to non-perennial streams	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the strmall layer encompassing only streams classified as non-perennial.
strmmaj	Distance to major streams	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the strmall layer encompassing only streams classified as major.
strmmin	Distance to minor streams	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the strmall layer encompassing only streams classified as minor.
hydpnts	Distance to hydrological points (all)	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. Features in the source data included springs, waterholes and waterpoints.
spring	Distance to springs	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the hydpnts layer encompassing only features classified as springs.
wtrhole	Distance to waterholes	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the hydpnts layer encompassing only features classified as waterholes.
wtrpnts	Distance to waterpoints	Euclidean distance to 250k watercourses based on hydrological datasets sourced from the Bureau of Meteorology. A subset of data used in the hydpnts layer encompassing only features classified as waterpoints.
damsall	Distance to dams	Euclidean distance to 250k man-made dams based on hydrological datasets sourced from the Bureau of Meteorology.
Landscape data		
Lndsyst	Landsystem	Index of land types from land system mapping by the Department of Agriculture and

Layer*	Description	Details
	types	Food Western Australia (DAFWA). Classes included: miscellaneous and undefined; alluvial plains; calcrete, silcrete and hardpan plains; hills and ranges; low hills and stony plains; mesas, breakaways and stony plains; river plains; salt lakes and fringes; and, sandplains and dunes.
Soil data		
Indsoil	Soil type	Index of broad soil types derived land system mapping by the DAFWA. Classes include: clay; deep loam; deep sand; gravel, stony or hardpan; loam; miscellaneous; salt lake; and, sand.
claypct	Soil clay percentage	Soil clay percentage in the top 30 cm of the soil profile. Derived from a 250 m cell raster developed as part of the Australian Soil Resource Information System.
Vegetation data		
vegstruc	Vegetation structure	Vegetation index layer derived from broad formations of the Shepherd et al. (2001) mapping. Based on attribution detailing broad vegetation community structure and classified into: undefined; forest/woodland; isolated/sparse shrubland; open chenopod/samphire shrubland; open forbland; open heath; open hummock grassland; open shrubland; and, tussock grassland.
vegflor	Vegetation floristic groups	Vegetation index layer derived from broad formations of the Shepherd et al. (2001) mapping. Based on attribution detailing vegetation community floristics and classified into: undefined; *Acacia* sparse/isolated shrubland; *Acacia* shrubland/woodland; tussock grassland; saltbush shrubland; mangroves; miscellaneous shrubland; *Eucalyptus* woodland; *Melaleuca* shrubland; open forbland; and, *Triodia* hummock grassland.

* Note: A number of the datasets collated were not utilised in the modelling procedure given attribute relevance, gaps in coverage or resolution issues. Datasets not utilised in the project (including geology and some of the drainage and vegetation datasets) are not included in this table.

DATA PREPARATION

The following steps outline the broad procedure used to prepare the environmental data:

1. Conversion to raster[7] dataset where source data were polygons. In these cases, the values of the source polygon data were classified into a discrete number of categories (approximately less than 10) prior to conversion to raster.
2. Development of indices (such as terrain and habitat indices).
3. Development of proximity layers.

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[7] Raster datasets display a representation of the real world surface as an array of equally sized cells arranged in rows and columns. They are composed of single or multiple bands. Each cell contains an attribute and coordinates. The coordinates are contained in the ordering of the matrix, unlike a vector structure which stores coordinates explicitly. Groups of cells that share the same value represent the same geographic feature. They are useful for storing data that vary continuously.

4. Standardisation of raster data to a consistent grid cell size (some of the raster data were resampled and smoothed prior to conversion).
5. Clipping of all data to the model extent.
6. Conversion of all values to integers.

Species records were filtered by ELA (2015) to derive a subset for inclusion in modelling which excluded potentially inaccurate records. Only records with stated positional accuracy of better than 100 m were included in the modelling subset (ELA 2015). Records were also evaluated on collection or observation date; records prior to 1980 were deemed to be at higher risk of poor accuracy (observation or positional) and were thus excluded from modelling. Other potential indicators of accuracy within the attribution, such as observer and survey, were also reviewed and, where appropriate, records were excluded from the modelling subset (ELA 2015). The number of species records used in the ELA (2015) modelling (subset) and the number excluded (reference) is detailed in **Table A3**.

The distribution and clustering of records was also reviewed to ensure spatial independence within the modelling subset. Coincident records of the same species were excluded and clusters of records occurring within 25 m were consolidated to limit the number of records occurring in close proximity to each other (ELA 2015)

Given that reliable absence data were not consistently available across the study area, pseudo-absence points were generated throughout the study area by ELA (2015). This approach is widespread for many similar studies where available data (including actual absences) have not been collected, or have not been collected using systematic methods across the entire study region (Wisz and Guisan 2009; Zaniewski et al. 2002; Chefaoui and Lobo 2008). This step essentially provides a background sample of the environmental characteristics found across the study region and is undertaken to inform the statistical modelling process such that statistical relationships can be identified (particularly for the presence data) and tested concerning the potential utilisation of all available habitat types. The number of pseudo-absence records used by ELA (2015) for each species is detailed in **Table A3**.

Table A3: Species presence and pseudo-absence records used in the ELA (2015) modelling

Species	Species records used for modelling	Species records used for reference*	Pseudo-absence records used
Greater Bilby	21	50	3,280**
Hamersley Lepidium	616	709	2,685**
Northern Quoll	518	1,320	2,783**
Pilbara Leaf-nosed Bat	137	255	2,134
Pilbara Olive Python	75	168	3,226**
TOTAL	**1,367**	**2,502**	**N/A**

*Includes all records for the Pilbara IBRA compiled for the project including duplicates or others removed from the modelling set and all those included within the modelling set. ** Includes an additional 71 effective pseudo-absences generated from species presence records for the Mulgara, which was included during setup of species records for the first round of modelling but postponed until a second round of modelling (and updated with additional records at that time; ELA 2015).

STATISTICAL ANALYSIS

Following data preparation, input files were generated for statistical analysis in GRASP/S-Plus. Specialised statistical modelling software (GRASP) was used and has been purpose-built for such work by Lehmann et al. (2002a, b). This software was run as a module in the S-Plus statistical package to analyse the data and generate statistical models, and as an extension in ArcView GIS to derive the spatial representation of the models. Various tools and extensions were used in ArcGIS to develop and analyse the input data and evaluate and map the predictive model surfaces.

Broadly, a two-stage approach was used once species location and environmental data were prepared:

1. In the first stage, relationships between species locations and environmental variables were statistically investigated within S-Plus utilising GRASP to identify potential drivers for species distribution. GAMs were then generated utilising these identified relationships which were then statistically evaluated. The GRASP package permitted a variety of modelling options and parameters. Based on experience and recommendations within the program user guide and technical references, the following initial settings were employed by ELA (2015):
    a. Utilisation of randomly selected and spatially independent pseudo-absence points where actual absence records were unavailable or unreliable.
    b. Exploration of data (species against variables) utilising histograms and distribution plots to assist identification of ecologically relevant predictors.
    c. Generation of a correlation matrix to assist the identification of correlated variables.
    d. Utilisation of a step-wise, binomial modelling procedure that initially includes all potentially relevant environmental variables and then selects variables with strongest contribution and statistical relationships to predictors. Where appropriate, subsequent model runs utilised ôfullô models in which all selected variables were included in the model[8].
    e. Allocation of minimum contribution for predictors to five per cent and the maximum correlation between predictors to 75 per cent.
    f. Calculation of model contribution statistics and plots of models against predictor variables.
    g. Calculation of validation and cross-validation statistics to aid model evaluation.
    h. Generation of lookup tables for the statistical models for spatial development in GIS.
2. In the second stage, areas of potential habitat were modelled in geographic space based on the statistical models generated in the first stage and utilising the environmental variables identified of relevance to the species. A GIS grid (raster) data layer was produced, providing a representation of the spatial distribution of potential habitat for the species and the relative strength of the model prediction. Spatial evaluation of each model was also undertaken and models were re-run to test potential improvements to the model.

Following evaluation (spatial and statistical) of each model, consideration was given to whether the model provided a good representation of potential habitat based on what was gleaned from earlier steps

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[8] Full models are those where the models are based on the predictors selected by the operator as opposed to step-wise models which are generated by a process that tests the strength of inclusion (or exclusion) of each predictor and combination of predictors.

in the process and discussion with ecologists and other specialists. Where refinement was appropriate, the following options were considered:

1. Subsequent model iterations prepared within GRASP utilising different set/s of user-specified input variables or different model approaches.
2. Post processing of the model, such as by:
    a. introducing maximum or minimum levels for the predictive surface; or
    b. overlaying other spatial datasets to highlight or exclude parts of the landscape. An example of this may be to mask parts of the landscape where model predictions are at odds with prevailing ecological knowledge, or conversely to highlight specific parts of the modelled habitat.

These actions were not required for any of the models developed by ELA (2015).

SPATIAL MODELS

The spatial layers generated by ELA (2015), adapted for use in the CIA, are shown in **Figure 12** (Greater Bilby), **Figure 24** (Hamersley Lepidium), **Figure 36** (Northern Quoll), **Figure 48** (Pilbara Leaf-nosed Bat) and **Figure 64** (Pilbara Olive Python). The layers display habitat suitability ranks for each species based on the predicted relative probability of potential habitat modelled for each species by ELA (2015). The underlying relative probability is a zero to 100 per cent scale based on the conformance of in-situ conditions with preferred conditions identified in species response curves (the chances of presence or absence as a function of environmental gradients or classes; ELA 2015). For ease of interpretation in the CIA, habitat suitability was consolidated into the following four ranks:

- Habitat Rank 4: Highest probability of potential habitat (model value 70 to 100 per cent).
- Habitat Rank 3: Model value 30 to 70 per cent.
- Habitat Rank 2: Model value 10 to 30 per cent.
- Habitat Rank 1: Lowest probability of potential habitat (model value zero to 10 per cent).

All models produced were evaluated by assessing: (1) the predicted distribution of species habitat, (2) validation and cross-validation statistics, and (3) the contribution of the variables (or predictors) to final models. These are described below:

- Predicted habitat distribution ï The mapped prediction surface for each model produced was reviewed with regards to its alignment to recorded species locations, the landscape and habitat types against areas selected and knowledge of habitat preferences and species distribution.
- Validation and cross-validation statistics ï The correlation between the actual values and values predicted by each model using the receiver operating characteristic (ROC) test[9], and the graph

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[9] ROC analysis is a useful tool to evaluate the accuracy of a statistical model (e.g. logistic regression). An ROC curve is a plot of sensitivity on the y -xis against (1ï specificity) on the x axis. The 45° diagonal line connecting (0,0) to (1,1) is the ROC curve corresponding to random chance. The area under the ROC curve is an overall summary of model accuracy. The area under the

shape for validation and cross-validation were reviewed to determine the potential strength of each model. Models considered to be strong potential predictors of habitat had higher ROC values (greater than 0.5 indicates model is better than random) and a more perpendicular type graph shape.

- Variable Contribution ï the variables used in each model were reviewed for their contribution to the model (alone and within the preferred model) and their importance to the model overall (variable cannot be compensated by other variables if dropped from the model). The best models were determined based on the variableõs perceived relevance and importance to determining species distribution.

For each species, the modelling process was iterative, whereby each model run was evaluated by considering the evaluation steps outlined above, along with postulation of potential alternative approaches to trial, while reflecting on the knowledge of the characteristics of the species, landscapes and available data developed during earlier steps of the process. After undertaking a number of modelling attempts for each species with different combinations of input data and using different techniques, a detailed evaluation of the best model was undertaken using the above criteria and a critical review of the process and resultant outputs. Preferred models were also independently reviewed by ecologists with considerable experience with the subject species. Preferred models for each species are discussed further in the following sections.

Greater Bilby

During data exploration, potential relationships with species records were identified for environmental variables pertaining to elevation, slope, climate, as well as soil and landscape type. Different input combinations during model iterations often resulted in profound differences in the extent of predicted habitat. In particular, iterations that included vegetation datasets resulted in the extent of predicted habitat being constrained to a relatively small area in the central Pilbara. Step-wise model iterations favoured elevation over slope where both variables were included. Forced inclusion of both variables reduced the extent of predicted habitat to a smaller area than species presence records. The inclusion of proximity to hydrological features did not contribute significantly to models.

The preferred model was run as a step-wise model that selected maximum temperature, elevation, land system type and soil clay percentage (tempmax, dem25m, lndtype and claypct; **Table A2**). Distance to hydrological points and vegetation floristics were included as inputs, but not selected by the model. Validation statistics for the preferred model were very high (ROC 0.9 to 0.97); however, the model included the lowest number of species presence records (21), which is quite a low number and a likely limiting factor of predictive strength of the modelling process.

The extent of predicted habitat included existing species records and potential for expanded habitat beyond the range of these records. Given the relatively small number of records, this is likely a reasonable assertion. The broad extents of this layer were related to hotter temperatures and mid-level elevation. Localised differentiation in potential habitat probability in the model prediction surface coincided with moderate clay values, and land system types ôLow Hills and Stony Plainsô in the central

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curve equals 0.5 when the ROC curve corresponds to random chance, is greater than 0.5 when the model is better than random chance, and equals 1.0 for perfect accuracy.

and north-east parts of the Pilbara and ‘Alluvial Plains’ through the south-central and south-east parts. These variables relate to species habitat preferences and behaviour; this includes habitats that facilitate ability to burrow (claypct, lndtype) and restriction to desert environments (tempmax) (Section 3.2). The selection of the ‘Low Hills and Stony Plains’ land system type within some parts of the model can be reconciled with the Greater Bilby’s habitat preference for ease of burrowing as, in these areas, the surrounding land type was often of a rockier, rugged nature. Where sandier and looser substrate was available (such as around alluvial plains), the model predicted higher probability of habitat, which fits with knowledge of species habitat preferences (Section 3.2).

Hamersley Lepidium

Regional scale variables relating to elevation and climate exhibited potential relationships with species presence records during data exploration. Soil clay percentage and land system type (Hills and Ranges) also influenced predicted habitat; however, models performed best where only one of these variables was included.

The preferred model utilised elevation, land system type, annual rainfall, spring water points and annual average maximum temperature (dem25m, lndtype, annrain, spring, tempmax; **Table A2**). Validation statistics for the preferred model were the highest of all modelled species (ROC greater than 0.98). The spatial distribution of predicted habitat in the preferred model was strongly associated with the extent of known species presence records. Broad extents were associated with higher elevations and cooler temperatures. Some isolated patches of additional potential habitat were identified in the north-eastern and southern parts of the Pilbara. Finer patterns in predicted habitat were influenced by land system classes ‘Hills and Ranges’ and ‘Calcrete, Silcrete and Hardpan Plains’, as well as locally higher elevations.

Northern Quoll

Lower elevations, mid-level topographic position and moderate ruggedness over a localised area, and regional climate variables were identified as having a potential relationship to species presence during data exploration. Topographic position did not contribute significantly to explained deviance during model iterations and thus was discontinued in later iterations. Land system and vegetation structure were also identified during data exploration as having a potential relationship; however, during model iterations, it was identified that the land system predictor was able to account for explained deviance without including the vegetation layer.

The preferred model included variables associated with ruggedness, land system type, elevation and maximum temperature (rug250, lndtype, dem25m and tempmax; **Table A2**). Validation statistics were strong for this model (ROC 0.92 to 0.94). The spatial patterns of predicted potential habitat aligned well with species presence records in the northern and western Pilbara. At fine scales, the model predicted habitat in association with more rugged areas and in ‘Hills and Ranges’ land system types. This pattern broadly concurs with habitat of the species. In the southern Pilbara, it is likely that the model under-predicted potential habitat when evaluated against species presence records in this area.

It is noted that a handful of species records (approximately 10) were predicted at lower probabilities in the southern Pilbara. This observation was considered likely due to the heavy bias of records in the northern Pilbara (around 500 records) that likely had a much greater influence on the statistics than the small number in the southern Pilbara. On review of the percentage of species records within different probabilities of the model, the Northern Quoll model was considered an adequately-fitting model. Detailed review of the modelling steps and the preferred model chosen for the Northern Quoll determined that the best model possible had been reached given the available data and that the resultant model was appropriate for the species and the data. Further, the ecological evaluation for the model determined that it was a good match to expectations, specifically:

- The general trend for higher probability in the northern Pilbara was as expected.
- Areas in the extreme southern and south-eastern parts of the Pilbara are likely appropriate as low probability given:
    - Some of the Northern Quoll records in the central-southern Pilbara (e.g. Fortescue River, Paraburdoo, Tom Price and south of Hamersley Range) were considered sub-optimal habitat, or lower probability. The Northern Quoll has been recorded in these areas, but appears to be less frequently, or less reliably recorded (despite considerable survey effort).
    - In the southern and central areas of the Pilbara, the Northern Quoll appears to have a degree of short-term fluctuation in population that may be attributed to rainfall, or fire. This fluctuation has been observed during mine tenement surveys just north of the Fortescue Marsh at Bonney Downs Station following drought and fire (Bamford, M., pers. comm.). Similarly, survey results at Koodaideri, west of the Fortescue Marsh, indicate changes in Northern Quoll detectability over subsequent surveys (Dunlop, J., Parks and Wildlife, pers. comm.).
    - Following multiple years of good annual rainfall, the Northern Quoll is likely to re-populate these areas towards the southern portion of its Pilbara range, but the species can be locally absent, or very sparse and undetectable in these areas during droughts. Hence far fewer Northern Quolls have been recorded in these areas.

Given the aforementioned points, the probability of the Northern Quoll occurring at any given point in time in the southern-central Pilbara was considered low and this matches the preferred predictive model for the species.

Pilbara Leaf-nosed Bat

The species review and data exploration process identified that variables pertaining to the likelihood of cave formation were likely important in explaining the presence of species observations. Land system datasets that separated the broad land type óHills and Rangesôinto more detailed categories detailing differences in landform geology and geomorphology demonstrated that specific range types were more favourable for development of caves favoured by the species. In particular, sandstone/dolomite ridges and greenstone/chert ridges yielded species presences well above the background sample. Similarly, geology types known to contain suitable caves or where mine ores were prevalent also returned strong results, consistent with advice and literature on species preferences. Moderate to highly rugged country also showed species presences well above background levels and this was considered related to the cave habitat requirement of the species. Other variables exhibiting potential relationships included moderate soil clay content and close proximity to minor, non-perennial streams.

Initial step-wise models suggested many variables that satisfied the minimum thresholds for model inclusion, many of which were determined to not be the most ecologically relevant or to be surrogates for a variable more directly relevant to the species. Therefore, subsequent model runs were conducted using full models with the inclusion of variables with expected direct ecological relevance or that had returned strong relationships in the data exploration phase.

The inclusion of geology and land systems datasets in models resulted in considerable explanation of the deviance in species data; however, in earlier models, the additive statistical contribution of these datasets and subsequent expression in spatial distributions was distorted by the presence of proximity to stream datasets. The range of potential additive contributions for stream datasets was of a much higher order of magnitude (i.e. with increasing distance to streams, the relative potential for species reduced dramatically) resulting in weighting of this variable beyond its statistical fit to species data. The removal of this variable resulted in weighting of geology and land systems more commensurate to the statistical fit of these datasets.

Other datasets included in model iterations had generally small statistical contributions within the model as a whole; however, such inputs often had a significant local influence on the spatial distribution of predicted habitat. The relevance of such local inclusions and omissions were evaluated based on consistency to identified species preferences. The inclusion of clay content, for example, resulted in an expansion and ‘smoothing’ of predicted range in the central-eastern Pilbara; however, it also resulted in increased ‘noise’ in other flat areas away from cave-forming geology. Rainfall was identified as potentially the strongest climate variable during data exploration; however, the inclusion of this variable resulted in considerable noise around coastal areas such that minimum temperature was preferred for later model iterations.

Geology, land systems, temperature and ruggedness were included in the preferred model (bedrock, lsystbat, tempmin and rugg2000; **Table A2**). Spatially, the land systems and geology datasets controlled broad distribution patterns throughout the Pilbara. Local variation and finer changes to relative probability of habitat were influenced by the inclusion of a ruggedness input. The variation based on ruggedness likely reflects areas of river gorges within ranges or other steep cliffs where caves may be more likely. The inclusion of the temperature variable had a marked influence in the south-eastern Pilbara, where a contraction in predicted range was evident. Overall the model returned strong validation statistics (ROC 0.9).

Pilbara Olive Python

During initial data exploration, categorical datasets pertaining to land system class ‘Hills and Ranges’ and vegetation class ‘*Triodia* Hummock Grasslands’ were identified as potentially important influences in predicting potential habitat. The influence of these variables was confirmed during model iterations and these two layers, along with moderate scale ruggedness were dominant contributors to the preferred model. Potential relationships were also identified between species records and proximity to streams and some classes of hydrological points, as well as with areas of low slope values; however, these variables did not exert a strong influence during model trials. In contrast, broad elevation and terrain variables were moderately important predictors with little scope for replacement by other variables.

Validation statistics for the preferred model were good (ROC 0.82 to 0.88)., but slightly lower than for other species. Predicted potential habitat (of higher relative probability) was most heavily concentrated in the ranges in the southern and central Pilbara; however, potential habitat was also predicted in association with river plains in the northern Pilbara, and ranges and outcrops to the eastern Pilbara. Finer scale differentiation of predicted habitat was associated with land system types ‘Hills and Ranges’ and ‘River Plains’ and low to mid-level topographic position, particularly around rivers. The prediction of potential habitat across a large range and in a variety of environments was in accordance with existing species presence records, documented habitat preferences and perceived habitat distribution. The model also predicted potential habitat in the south-western and north-eastern Pilbara in areas where the species has not been recorded by the source datasets.

Existing species presence records were generally associated with moderate or higher probability values in the model; however, the model for this species had lower high-probability habitat than occurred for other species (**Table A4**). This is likely due to the nature of the species records and environmental data used to develop the model and is evidenced by the lower ROC value (**Table A5**). Despite the lower probabilities and ROC value, the relative pattern of distribution modelled is considered to generally be a good reflection of likely habitat.. This also aligns with habitat preferences identified in the earlier phase of the study.

Evaluation summary

A basic accuracy assessment was undertaken for each preferred species model. This reviewed the existing presence records for each species and the level of probability at which each was modelled. A summary of the results is provided in **Table A4** and it is noted that all species models predicted areas of high probabilities and further, a high proportion of the species records fell within areas modelled at higher probability for each species. The amount for each species is dependent on the strength of the relationship that the statistical process identified with the available data.

An evaluation summary of the selected model for each species is provided in **Table A5**. It outlines the environmental variables on which each model is based and provides a qualitative rating of model validation statistics, spatial and ecological evaluation and an overall assessment of model reliability. Designations of ógoodô for validation statistics or spatial evaluation indicate that the results were of the highest standard. Designations of ógood-moderateô and ómoderateô indicate lower performance or increasing departure from expected results. These classes, however, are still considered suitable results. Designations of low would reflect results unsuitable for further modelling; no species received this designation for any evaluation criteria (ELA 2015). An overall evaluation was assigned based on the combination of statistics and spatial evaluation.

Table A4: Predictive species habitat modelling accuracy assessment conducted by ELA (2015)

Species	Proportion of species records within 50% or greater model probability bands	Proportion of species records within 90-100% model probability band
Greater Bilby	100%	67%
Hamersley Lepidium	96%	75%
Northern Quoll	89%	45%
Pilbara Leaf-nosed Bat	83%	37%
Pilbara Olive Python	65%	18%

Model limitations

The models produced show areas of the landscape predicted to contain potential habitat for each of the subject species; however, as for all predictive models, the models generated were based on the data that were input into the process. These datasets and the process used to generate the predictive models have inherent limitations, including:

- Survey effort and therefore the records of species observations may have been biased to particular areas, which could have caused the model to only predict areas with the same environmental space as the area surveyed, and not predict other areas of potential habitat (or predict it with a weaker return). This potential limitation is particularly pertinent to development of the Northern Quoll habitat model. Presence records for the Northern Quoll were strongly clustered in the northern Pilbara. This may have contributed to potential underestimation of potential habitat by the preferred model in the southern Pilbara.

- Species presence data were limited for the Greater Bilby (21 records). This may have limited the predictive power of the procedure. In addition, the dataset for all species contained records with incomplete attribution. This limited the capacity to identify accuracy issues in those records and thus some erroneous records may be present and therefore may have negatively influenced the models.
- Some species presence data were affected by anthropogenic influences. Specifically, the Pilbara Leaf-nosed Bat is known to occupy natural caves as well as anthropogenic features such as mine shafts (Section 6.2). This influence likely complicated the predictive ability of the process and available data to explain distribution.
- Species absence data were not available for the study. To overcome the lack of this type of data, pseudo-absence data were used in the modelling, which are inherently less powerful and cannot inform the modelling to the same degree as the inclusion of actual absence data.
- Habitat fragmentation due to created patches from modelling techniques.
- Lack of scientific design of the surveys that collected the species data. Species presence/absence data from a scientifically robust regional survey program that surveyed the range of environments would be likely to produce more robust results.
- The modelling was undertaken across a large, data-poor area. Environmental datasets often available in other areas were not available for the study, or were available with incomplete coverage, or at a coarse scale. Of specific note was the lack of a dedicated soil dataset, providing detail around soil type, classification, surface texture and other pertinent attributes. Given the characteristics of some of the species, this may have limited the modelling procedure.
- The process relied on the ability to predict species habitat from the available environmental datasets. It is noted that the elevation dataset was used to predict four of the five modelled species; however, it is assumed that it is not elevation per se that is driving habitat distribution for these species. Rather, elevation may be a surrogate for a climatic or terrain relationship that cannot be explained as well as elevation based on other available variables.
- Being based on broad regional scale data (mostly 1:250,000 scale or greater), the models should not be utilised at a scale finer than this.
- Lack of information on other variables that may influence species distribution, such as introduced predators, competition or other anthropogenic influences and interactions.
- Highly specific species requirements limit the modelling procedure, such as for the Pilbara Leaf-nosed Bat, which is highly dependent on suitable roosting caves. The model predicted the landscape where suitable cave habitat and foraging habitat may exist (and this is considered appropriate); however, cannot predict the actual location and suitability of these features.
- Lack of consideration of temporal or seasonal variation.
- Lack of field validation of models.

In addition to the models being limited by available data, evaluation of models was constrained by information available on the specific habitat preferences of the modelled species. Model evaluation is (in part) based on the knowledge of species habitat preferences. Available information on the habitat preferences of the modelled species was limited to information on the broad vegetation types, floristic preferences and some substrate/land type information. The lack of coverage of finer scale datasets relating to these themes is noted as a limitation.

Overall, the models should be treated as indicative, highlighting those parts of the landscape where there is potentially a higher probability of species habitat being present. Further, it is noted that the models do not indicate the potential utilisation of these habitats by the species, nor the relative abundance of species. While there are some limitations with the models, they are considered valid for use in a range of applications, including the CIA. All the models generated were good or moderate-good predictions of potential habitat and met the aims and objective of the ELA (2015) study. Further, they are considered suitable for use in this Commonwealth CIA given the aims of the study and the analysis approach adopted.

Table A5: Summary of preferred model and model evaluation for each species

Species	Variables	Model validation	Spatial and ecological evaluation	Model reliability
Greater Bilby	lndtype, tempmax, dem25m, claypct (**Table A2**)	Contribution: lndtype, tempmax and dem25m have strong contributions. Statistics: Good to very good validation and cross-validation statistics (ROC 0.9-0.97).	Species records: Good: The model predicts high probability near species presence records and broad areas of potential habitat in the central and eastern Pilbara. Ecology: Good: Prediction is a good match to expected distribution and perceived core habitat areas. Relationship to spatial layers: Strongly associated with mid-level elevation (dem25m) and hotter temperatures (tempmax) in determining extents. Local differentiation associated with lndtype classes ôLow Hills and Plainsôand ôAlluvial Plainsô, and moderate clay values.	Good
Hamersley Lepidium	dem25m, lndtype, annrain, spring, tempmax (**Table A2**)	Contribution: lndtype and dem25m have strong contributions. Other variables have moderate contributions and replacement values. Statistics: Very good validation and cross-validation statistics (ROC 0.98).	Species records: Good: The model generally has strong association with the extents and finer scale distribution of species records. The exceptions to this are some small patches of predicted potential habitat in the north-eastern and southern parts of the Pilbara. Ecology: Good: The model is considered a good prediction of expected habitat areas. Relationship to spatial layers: Strongly associated with ranges in the southern Pilbara (dem25m). At a local level, lndtype class ôHills and Rangesôdiscern finer scale patterns.	Good
Northern Quoll	rug250, tempmax, dem25m, lndtype (**Table A2**)	Contribution: lndtype exerts strong contribution inside the model. Other variables have lower contribution inside the model but have less potential to be replaced. Statistics: Very good validation and cross-validation statistics (ROC 0.92 to 0.94).	Species records: Good-moderate: The model has a strong relationship to species records in northern and western lowland areas. Species distribution is potentially under-predicted in the southern Pilbara. Ecology: Good: The model generally strongly predicts habitat areas in the north and north-east Pilbara, which are considered core habitat for this species. Areas in the southern Pilbara are modelled as low probability and this fits with existing knowledge based on unpublished survey results. Therefore, these areas are considered sub-optimal habitat, occupied infrequently depending on broad scale weather patterns and fire. Relationship to spatial layers: Strongly associated with lowland areas (dem25m). At a	Good to Moderate

Species	Variables	Model validation	Spatial and ecological evaluation	Model reliability
			local level, areas of moderate to high ruggedness (rug250) discern finer scale patterns.	
Pilbara Leaf-nosed Bat	bedrock, lsystbat, tempmin, rugg2000 (**Table A2**)	Contribution: lsystbat and bedrock had the highest additive contributions within the model and least potential for replacement. Statistics: Good validation and cross-validation statistics (ROC 0.90).	Species records: Good: The model predicts high probability of potential habitat near existing species records, with very high probability predicted in the central-eastern Pilbara. The model is sensitive to areas with fewer observations and areas of more limited habitat. Examples include a broader predicted habitat than suggested by current species records within the Hamersley Ranges, as well as predicted habitat within mesas and breakaways in the eastern Pilbara. This is considered appropriate given that such areas represent potential cave-forming environments. Ecology: Good: Strong fit with knowledge of this species. Relationship to spatial layers: Strong relationship to lsystbat and bedrock, which set broad distribution patterns. Within these bounds, moderate to high ruggedness (rug2000) influences finer resolution changes, likely associated with gorge country and steep slopes. Temperature results in reduction of range in the south. The predictors utilised are considered appropriate for highlighting landscapes with potential for caves and suitable foraging areas.	Good
Pilbara Olive Python	dem25m, top2000, rug1000, lndtype, vegflor (**Table A2**)	Contribution: rug100, vegflor, lndtype have significant contribution to the model. Dem25m and top2000 have small-moderate contribution; however, the potential for top2000 to be replaced by other variables is low. Statistics: Good-moderate validation and cross-validation statistics (ROC 0.82 to 0.88).	Species records: Good-moderate: The model covers and expands on the extent of existing species records. At finer scales, species presence records are generally associated with mid-high probability cells within the model. Ecology: Moderate: The model predicts core habitat areas strongly, but potentially under-predicts other habitat areas of a widespread species. Relationship to spatial layers: Strong relationship to lndtype classes óHills and Rangesô and óRiver Plainsô Also associated with low to mid-level topographic position, particularly around rivers.	Good to Moderate

Impact studies

HYDROLOGICAL STUDIES

Background

BHP Billiton Iron Ore (2015) conducted an ecohydrological change assessment to assess the potential of existing and proposed mining operations within the Proposal area to change hydrological regimes and, in turn, affect key assets where connectivity exists between hydrological and ecological systems. Ecohydrology is the study of the interactions between water and ecosystems and, in contrast to traditional descriptive ecological methodologies, provides a process-level understanding of relationships between hydrological regimes and ecosystem structure and function. The BHP Billiton Iron Ore (2015) change assessment was undertaken as an initiative from BHP Billiton Iron Ore's Water Regional Management Strategy, which will be used to minimise the ecohydrological footprint of BHP Billiton Iron Ore's mining operations in the Pilbara bioregion. The ecohydrological change assessment will inform the strategic environmental assessment of the Proposal under the EPBC Act. The main elements of the BHP Billiton Iron Ore (2015) report with respect to the Commonwealth CIA are summarised in this section.

Objectives of the BHP Billiton Iron Ore (2015) assessment relevant to the Commonwealth CIA were to:

- provide an understanding of the existing hydrological regime (surface and groundwater), including relationships with ecosystem components and processes;
- understand the influence of proposed mining projects on water resources, including hydraulic connectivity with the regional groundwater system and the potential for reduction in surface water flow;
- evaluate the potential for ecohydrological change associated with proposed mining development in the study area. This includes consideration of BHP Billiton Iron Ore and third party mining projects, where information is available, in order to gain an appreciation of potential cumulative impacts.

Ecohydrological change assessment methodology

OVERVIEW

A multidisciplinary methodology was developed by BHP Billiton Iron Ore (2015) to assess the potential effects of hydrological regime change (surface and groundwater) on Pilbara landscapes, major ecosystem components and individual ecological assets. The methodology included the conceptualisation of landscape ecohydrological elements and processes in the form of ecohydrological units (EHUs). The BHP Billiton Iron Ore (2015) study area included all areas potentially subject to hydrological influence by the proposed mine and overburden storage area footprints of the Full Development Scenario.

BHP Billiton Iron Ore (2015) defined threatening processes associated with hydrological change and evaluated sensitivities to these various change processes associated with existing and proposed BHP Billiton Iron Ore mining operations (stressors). This occurred both on a regional level and for each ecohydrological receptor. This information was used to determine ecohydrological change potential before and after the application of mitigation measures. Ecohydrological change potential was evaluated by BHP Billiton Iron Ore (2015) as a function of hydrological change and the sensitivity of EHUs to hydrological change, using a combination of conceptual and GIS-based spatial analysis approaches.

BHP Billiton Iron Ore (2015) considered existing impacts, the potential impacts of the Full Development Scenario and the influence of third party mining operations, providing an indication of baseline and cumulative change potential.

ECOHYDROLOGICAL UNITS

The landscape water regime influences the nature and distribution of ecosystems in the inland Pilbara bioregion. The ecohydrological conceptualisation conducted by BHP Billiton Iron Ore (2015) provided a regional scale appreciation of landscape elements with similar ecological characteristics and water-related processes. It underpinned the identification of landscape elements with higher susceptibility to changes in the water regime.

The landscape comprising of BHP Billiton Iron Ore's existing and proposed mining operations was segregated by BHP Billiton Iron Ore (2015) into nine EHUs. EHUs 1 to 4 are upland source areas, transitional areas and channel zones (e.g. hills, drainage floors and channel systems). EHUs 5 to 9 are lowlands plains, channel systems and receiving areas (e.g. sandplains, channels, floodplains and ephemeral lakes). These EHUs are summarised as follows:

- EHU 1 - Upland source areas: hills, mountains, plateaux.
- EHU 2 - Upland source areas: dissected slopes and plains.
- EHU 3 - Upland transitional areas: drainage floors within EHUs 1 and 2 that accumulate surface flows from up-gradient.
- EHU 4 - Upland channel zones: channel systems of higher-order streams that are typically flanked by EHU 3 and dissect EHUs 1 and 2.
- EHU 5 - Lowland sandplains: level to gently-undulating surfaces with occasional linear dunes. Erratic drainage patterns but some tracts receive surface water flow from upland units.
- EHU 6 - Lowland alluvial plains: typically of low relief and featuring low-energy, dissipative drainage.
- EHU 7 - Lowland calcrete plains: generally bordering major drainage tracts and termini, typically with shallow soils and frequent calcrete exposures.
- EHU 8 - Lowland major channel systems and associated floodplains.
- EHU 9 - Lowland receiving areas: drainage termini in the form of ephemeral lakes, claypans and flats.

The EHUs were developed using several overlaying mapping layers in order to identify discernible units across the landscape. Information contributing to the development of the EHUs included:

- Pilbara land systems mapping (van Vreeswyk et al. 2004);
- a high-resolution, digital elevation model;
- interpretation of connectivity between surface and groundwater systems;

- major vegetation types based on consolidated vegetation mapping conducted by Onshore Environmental (2014) within BHP Billiton Iron Oreȇs tenements;
- inferred water use behaviour of major vegetation types based on Landsat Normalised Difference Vegetation Index data.

The EHUs provided a basis to identify and characterise the sensitivity of landscape elements to regional scale change in surface and groundwater regimes, including the potential for a landscape element to be affected by mining-related disturbance activities in other landscape elements. BHP Billiton Iron Ore (2015) assessed each EHU against specific criteria related to ecohydrological sensitivity to surface water and groundwater change, and rated each EHU as having a water sensitivity of low, moderate, or high based on the overall outcome for each hydrological process.

Sensitivity to surface water change

Each EHU was assessed by BHP Billiton Iron Ore (2015) against four specific criteria related to ecohydrological sensitivity to surface water change and rated as having a surface water sensitivity of Low, Moderate, or High based on the overall outcome (**Table A7**). The criteria were defined by BHP Billiton Iron Ore (2015) as follows:

- Landscape position with respect to patterns of drainage and the likelihood of receiving significant water inputs from up-gradient source areas. Landscape elements with a low rating receive minimal inflows from small catchment areas; while higher-rated areas tend to receive significant inflows from large, multifaceted catchment areas and multiple drainages.
- Contribution ratio of inflows (from other landscape elements) to incidental rainfall. Rainfall is the principal input to landscape elements with a low rating, whereas water inputs to high-rated areas are dominated by surface and in some cases groundwater inflows.
- Residence time of water within the landscape element, providing an indication of the duration that water is available for ecosystem use. Landscape elements with a low rating tend to have transiently available water that is rapidly lost from the system (e.g. by runoff or rapid evapotranspiration). High-rated areas have longer residence times associated with water capture, storage and release. This may contribute to habitat complexity enabling a greater diversity of water uses strategies within the ecosystem.
- The overall quantity of water available to ecosystems. Landscape elements with a low rating tend to include less-productive ecosystems that are highly constrained by water supply. High-rated areas have relatively abundant water (either persistently or episodically) and tend to host more diverse and productive ecosystems.

Table A7: Landscape-scale ecohydrological sensitivity to change in surface water regimes

Ecohydrological unit	Source area for inflows	Residence time within landscape	Quantity of water for ecosystems	Contribution ratio of streamflow to incidental rainfall	Sensitivity rating
1. Upland source areas: hills, mountains, plateaux	Low	Low	Low	Low	Low
2. Upland source areas: dissected	Low	Low	Low	Low	Low

Ecohydrological unit	Source area for inflows	Residence time within landscape	Quantity of water for ecosystems	Contribution ratio of streamflow to incidental rainfall	Sensitivity rating
slopes and plains					
3. Upland transitional areas: drainage floors within EHUs 1 and 2 that accumulate surface flows from up-gradient	Low-Moderate	Low-Moderate	Low-Moderate	Moderate-High	Moderate
4. Upland channel zones: channel systems of higher-order streams that are typically flanked by EHU 3 and dissect EHUs 1 and 2	Low-Moderate	Low-Moderate	Low-Moderate	Moderate-High	Moderate
5. Lowland sandplains: level to gently-undulating surfaces with occasional linear dunes. Erratic drainage patterns but some tracts receive surface water flow from upland units	Low	Moderate	Low-Moderate	Low	Low
6. Lowland alluvial plains: typically of low relief and featuring low-energy, dissipative drainage	Low	Moderate	Low-Moderate	Low	Low
7. Lowland calcrete plains: generally bordering major drainage tracts and termini, typically with shallow soils and frequent calcrete exposures	Low	Moderate	Low-Moderate	Low	Low
8. Lowland major channel systems and associated floodplains	High	Moderate-High	High	High	High
9. Lowland receiving areas: drainage termini in the form of ephemeral lakes, claypans and flats	Moderate-High	High	High	High	High

Sensitivity to groundwater change

Each EHU was assessed by BHP Billiton Iron Ore (2015) with respect to depth to watertable and rated for groundwater sensitivity as Low, Moderate or High (**Table A8**). Depth to watertable was used to determine the sensitivity ratings, based on potential connectivity between groundwater-dependent vegetation and groundwater resources as follows:

- Areas with a deep watertable (greater than 30 metres below ground level [bgl]) were considered to be not utilised by groundwater-dependent vegetation and therefore to have a Low sensitivity.
- Areas with a watertable between 10 and 30 metres bgl were considered to potentially provide some opportunistic/facultative connectivity between the watertable and overlying vegetation and therefore to have a Moderate sensitivity.

- Areas with a watertable less than 10 metres bgl were considered likely to provide connectivity between the watertable and overlying vegetation, with the overlying vegetation being somewhat groundwater-dependent; these areas were therefore considered to have a High sensitivity.

Table A8: Landscape-scale ecohydrological sensitivity to change in groundwater regimes

Ecohydrological unit	Depth to watertable (metres below ground level)	Sensitivity rating
1. Upland source areas: hills, mountains, plateaux	> 30	Low
2. Upland source areas: dissected slopes and plains	> 30	Low
3. Upland transitional areas: drainage floors within EHUs 1 and 2 that accumulate surface flows from up-gradient	> 30	Low
4. Upland channel zones: channel systems of higher-order streams that are typically flanked by EHU 3 and dissect EHUs 1 and 2	> 30	Low
5. Lowland sandplains: level to gently-undulating surfaces with occasional linear dunes. Erratic drainage patterns but some tracts receive surface water flow from upland units	10-30	Moderate
6. Lowland alluvial plains: typically of low relief and featuring low-energy, dissipative drainage	10-30	Moderate
7. Lowland calcrete plains: generally bordering major drainage tracts and termini, typically with shallow soils and frequent calcrete exposures	< 10	High
8. Lowland major channel systems and associated floodplains	< 10	High
9. Lowland receiving areas: drainage termini in the form of ephemeral lakes, claypans and flats	< 10	High

STRESSES AND THREATENING PROCESSES

The existing and proposed mining operations of the Proposal will result in modified surface water and groundwater regimes, which have the potential to result in ecohydrological change at the landscape and ecohydrological receptor scale. These mining areas were considered by BHP Billiton Iron Ore (2015) to be stressors for the purposes of the change assessment. Third party operations were also considered as stressors to evaluate the potential for ecohydrological change from cumulative operations. Threatening processes that were considered by BHP Billiton Iron Ore (2015) and that were of key relevance to the Commonwealth CIA were groundwater drawdown and reduced surface water availability. These processes were also considered in the context of surplus water management (BHP Billiton Iron Ore 2015).

Existing and proposed BHP Billiton Iron Ore mining operations

Existing BHP Billiton Iron Ore operations considered by BHP Billiton Iron Ore (2015) were the Mining Area C, Eastern Ridge, North Flank, Shovellana, Whaleback, Wheelara and Yandi mining operations and their associated rail infrastructure.

For proposed BHP Billiton Iron Ore operations, the BHP Billiton Iron Ore (2015) study area was partitioned into four regions based on catchment extents:

- Central Pilbara: The expansion of Mining Area C and new mining operations in the Jinidi, South Flank, Mudlark, Tandanya, South Parmelia and Gurinbiddy mining areas.
- Eastern Pilbara: Mining development initially focused in the Eastern Ridge, Homestead and Shovelanna mining areas, before expanding to include the Jimblebar, Ophthalmia, Prairie Downs and Western Ridge mining areas.
- Fortescue Marsh: Marillana, Coondiner and Mindy mining areas in the southern Fortescue River Valley, and at a later stage the Roy Hill mining area north-west of Fortescue Marsh.
- Marillana Creek: Initial focus on the existing Yandi operation before expanding into the Munjina, Upper Marillana, Ministers North and Tandanya (also in the Central Pilbara) mining areas.

Existing and proposed third party mining operations

Existing third party mines operating in the BHP Billiton Iron Ore (2015) study area were:

- Brockman Syncline 4, Hope Downs 1, Hope Downs 4, Marandoo, Mt Tom Price, Paraburdoo, Paraburdoo - Eastern Range, West Angelas, Western Turner Syncline Section 10 and Yandicoogina (Rio Tinto Iron Ore).
- Cloudbreak and Christmas Creek (Fortescue Metals Group).
- Philôs Creek (Mineral Resources Limited).

A number of third party operations are proposed in the BHP Billiton Iron Ore (2015) study area, as follows:

- Rio Tinto Iron Ore expansions and new operations: Hope Downs 1, Hope Downs 4 and West Angelas, Yandicoogina (Pocket - Billiards South) and Koodaideri.
- Other operators: Davidson Creek Hub (Atlas Iron), Marillana Project (Brockman Resources), Nyidinghu and Mindy Mindy (Fortescue Metals Group); Iron Valley (Mineral Resources Limited), Roy Hill (Hancock Prospecting Pty Ltd [Hancock Prospecting]) and Yandicoogina South (Nexus Minerals Ltd).

Groundwater drawdown

Groundwater drawdown is the decline or reduction in the watertable, or groundwater levels, related to abstraction for orebody dewatering or water supply. Potential environmental impacts associated with groundwater drawdown include vegetation health decline, vegetation assemblage change, and the loss or modification of aquatic and subterranean habitats. Considerations when evaluating potential impacts to environmental factors include the nature of hydrological regime change (in particular where different to the natural range in watertable fluctuation) and the responsiveness of ecosystems to this change (BHP Billiton Iron Ore 2015).

The groundwater drawdown footprint was defined by BHP Billiton Iron Ore (2015) to include areas where groundwater levels were predicted to decline by greater than one metre relative to the óno disturbanceô baseline. The significance of potential change was evaluated by BHP Billiton Iron Ore (2015) as a function of EHU type sensitivity, depth to groundwater and groundwater salinity being classified as insignificant, low, moderate or high (**Figure A1**).

Reduced surface water availability

The diversion of water drainage around mining operations is necessary for the protection of mine infrastructure and human safety. These diversions involve modifications to natural flow regimes. Open pit mining also reduces the size of catchment drainage source areas and other mine infrastructure can also affect landscape drainage by directing flows into culverts and creating drainage shadows. Potential environmental impacts associated with modified surface water availability include decline in vegetation health, vegetation assemblage change (including the spread of weeds) and the loss or modification of aquatic habitats. Key considerations for the evaluation of potential impacts to environmental factors are the nature of hydrological regime change, and the responsiveness and resilience of ecosystems to this change (BHP Billiton Iron Ore 2015).

Reduction in surface water availability was evaluated by BHP Billiton Iron Ore (2015) in terms of catchment area reduction determined through a GIS spatial analysis and EHU type sensitivity being classified as insignificant, low, moderate or high (**Figure A2**).

Surplus water management

Dewatering rates sufficient to enable resource extraction are predicted to exceed operational water demands for a number of the Proposal mining operations. The disposal of surplus dewatering volumes can be managed by return to the environment or transfer to operational uses elsewhere. Potential environmental impacts associated with surplus water disposal options include modified drainage flow regimes, increased water availability for riparian vegetation, weed dispersal and water quality changes in stygofauna habitat. Key considerations for the evaluation of potential impacts consist of the response of the ecosystem to altered water regimes and elevated water levels (BHP Billiton Iron Ore 2015).

Indicative water balances were developed by BHP Billiton Iron Ore (2015) for each of the mining regions in the study area to determine areas with a water deficit (water negative) or surplus water (water positive) over the development timeframe. Ecohydrological change potential was considered to exist in regions where a period of significant water surplus (greater than approximately two gigalitres per year) was forecast.

Output

The following maps produced by BHP Billiton Iron Ore (2015) are of key importance to the CIA:

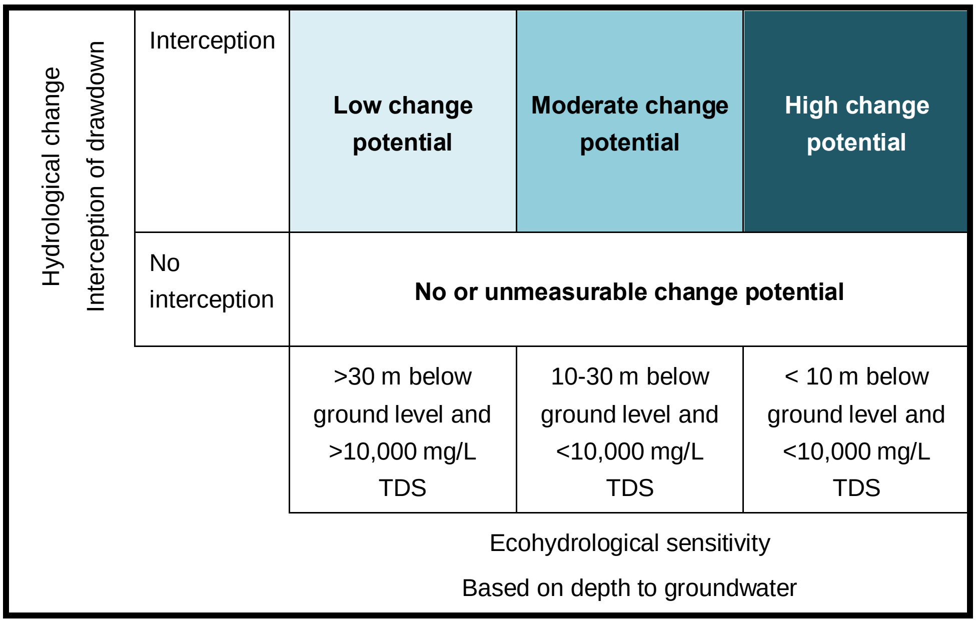
- Surface water change potential predicted from existing BHP Billiton Iron Ore and third party iron ore mines (CIA Scenario 1; **Figure A3**).
- Cumulative surface water change potential predicted from existing iron ore mines and reasonably foreseeable future third party iron ore mines (CIA Scenario 2; **Figure A4**).
- Cumulative surface water change potential predicted from existing iron ore mines, reasonably foreseeable future third party iron ore mines and the Full Development Scenario (CIA Scenario 3; **Figure A5**).
- Groundwater change potential predicted from existing BHP Billiton Iron Ore and third party iron ore mines (CIA Scenario 1; **Figure A6**).
- Cumulative groundwater change potential predicted from existing iron ore mines and reasonably foreseeable future third party iron ore mines (CIA Scenario 2; **Figure A7**).

- Cumulative groundwater change potential predicted from existing iron ore mines, reasonably foreseeable future third party iron ore mines and the Full Development Scenario (CIA Scenario 3; **Figure A8**).

Limitations

Key uncertainties and limitations associated with the ecohydrological change potential study were noted by BHP Billiton Iron Ore (2015) as:

- Limited calibration of model based on field monitoring.
- Simplification of real world processes may cause reduced accuracy.
- Thresholds of significant change for runoff are difficult to determine due to a limited amount of data.

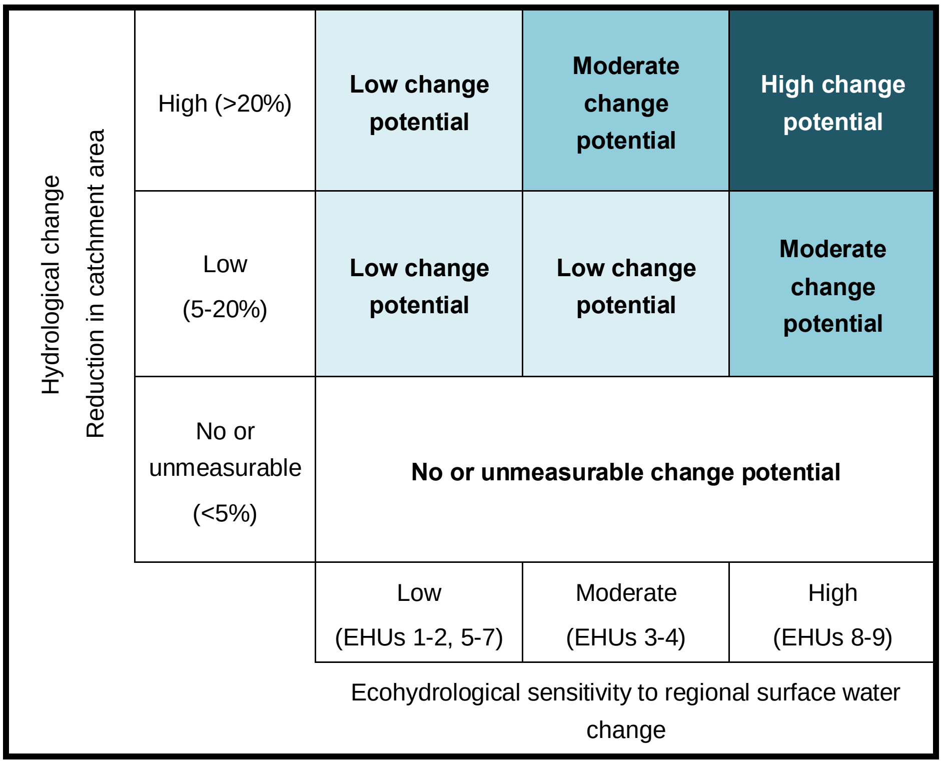


Hydrological change
Interception of drawdown

	>30 m below ground level and >10,000 mg/L TDS	10-30 m below ground level and <10,000 mg/L TDS	< 10 m below ground level and <10,000 mg/L TDS
Interception	**Low change potential**	**Moderate change potential**	**High change potential**
No interception	**No or unmeasurable change potential**		

Ecohydrological sensitivity
Based on depth to groundwater

Figure A1: **Groundwater change potential matrix**

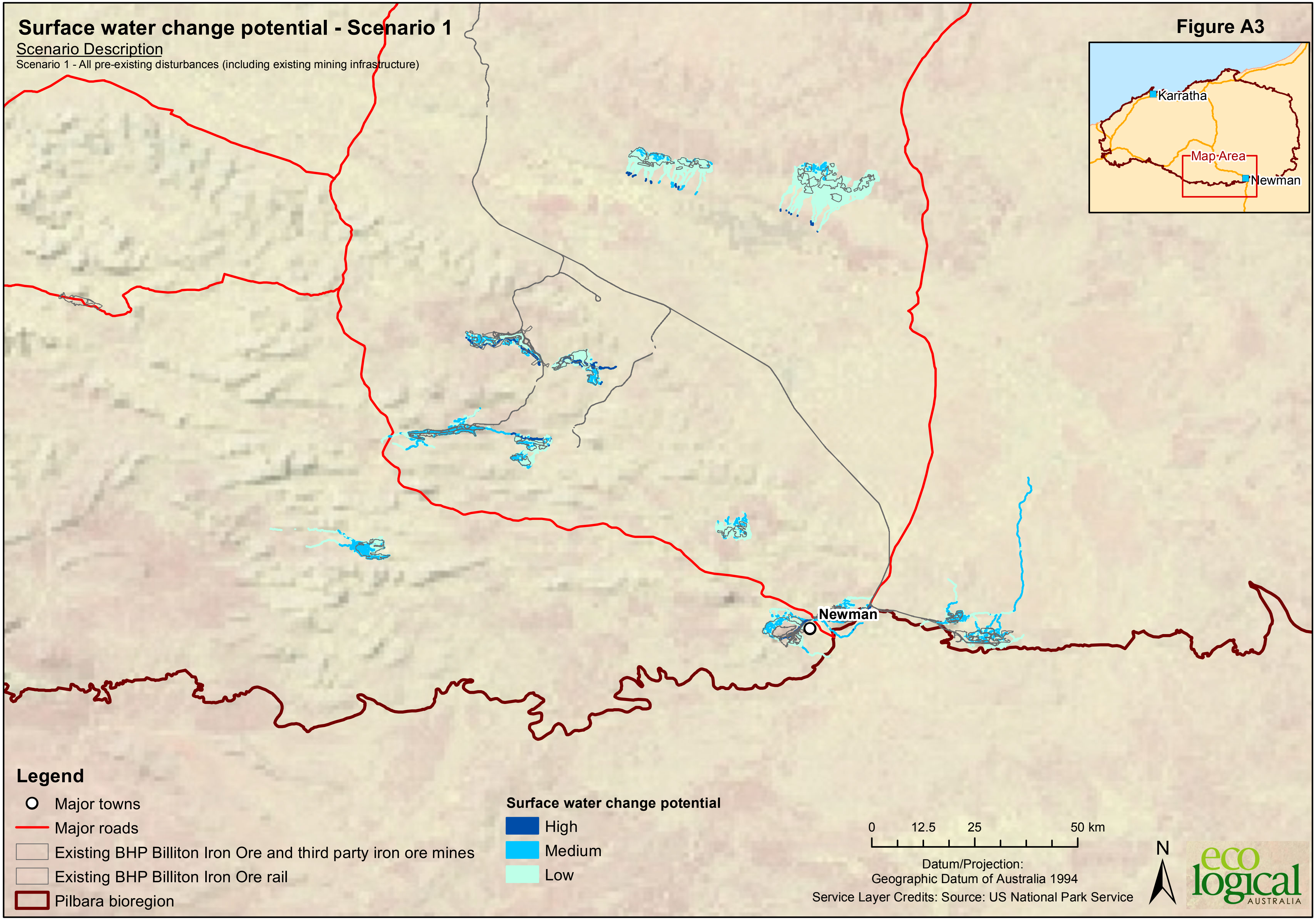


Hydrological change
Reduction in catchment area

	Low (EHUs 1-2, 5-7)	Moderate (EHUs 3-4)	High (EHUs 8-9)
High (>20%)	**Low change potential**	**Moderate change potential**	**High change potential**
Low (5-20%)	**Low change potential**	**Low change potential**	**Moderate change potential**
No or unmeasurable (<5%)	**No or unmeasurable change potential**		

Ecohydrological sensitivity to regional surface water change

Figure A2: **Surface water change potential matrix**



Surface water change potential - Scenario 1

Figure A3

Scenario Description

Scenario 1 - All pre-existing disturbances (including existing mining infrastructure)

Datum/Projection:
Geographic Datum of Australia 1994

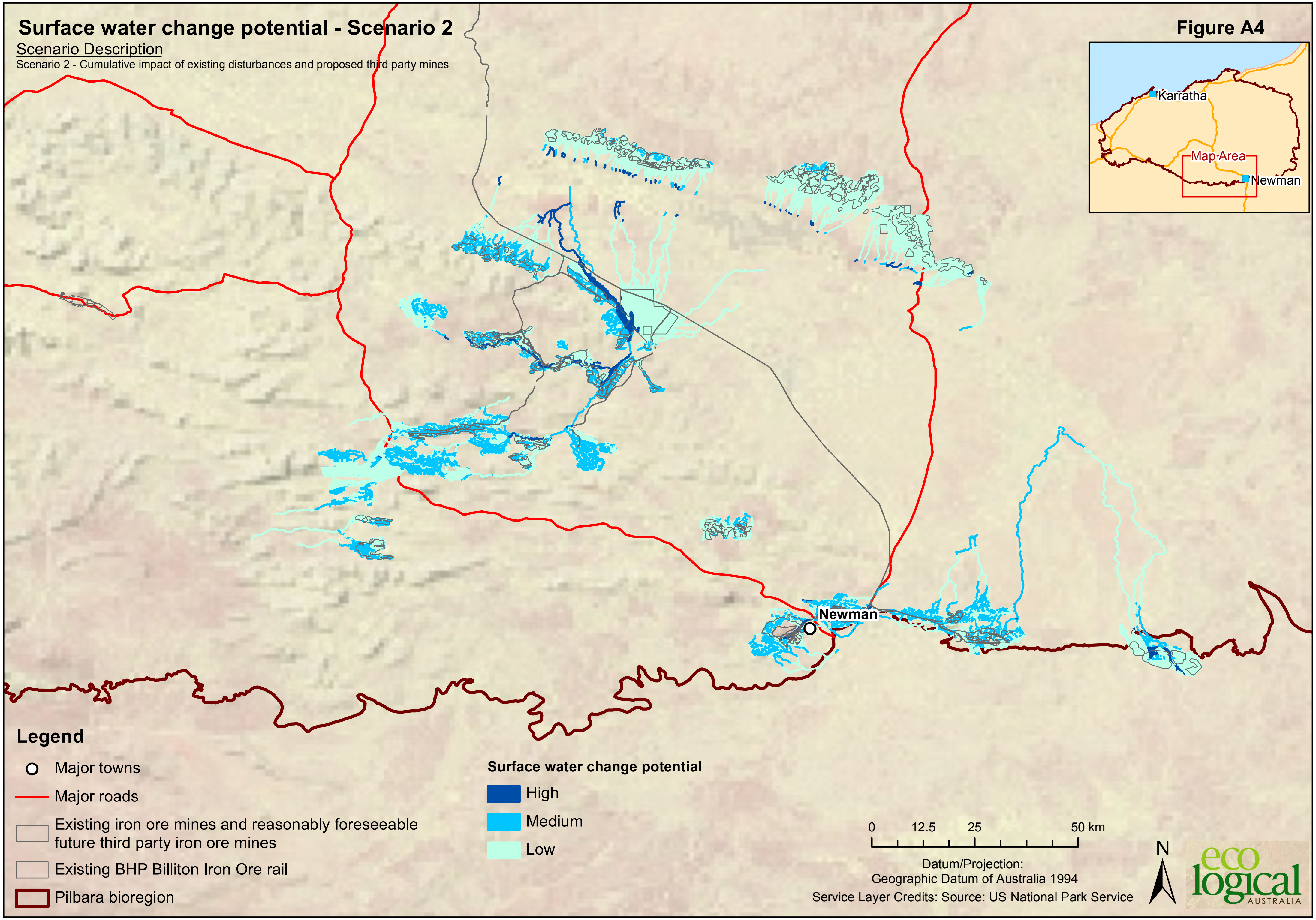
Service Layer Credits: Source: US National Park Service

Surface water change potential - Scenario 2

Figure A4

Scenario Description

Scenario 2 - Cumulative impact of existing disturbances and proposed third party mines



Legend

○ Major towns

— Major roads

☐ Existing iron ore mines and reasonably foreseeable future third party iron ore mines

☐ Existing BHP Billiton Iron Ore rail

☐ Pilbara bioregion

Surface water change potential

■ High

■ Medium

■ Low

Datum/Projection:
Geographic Datum of Australia 1994

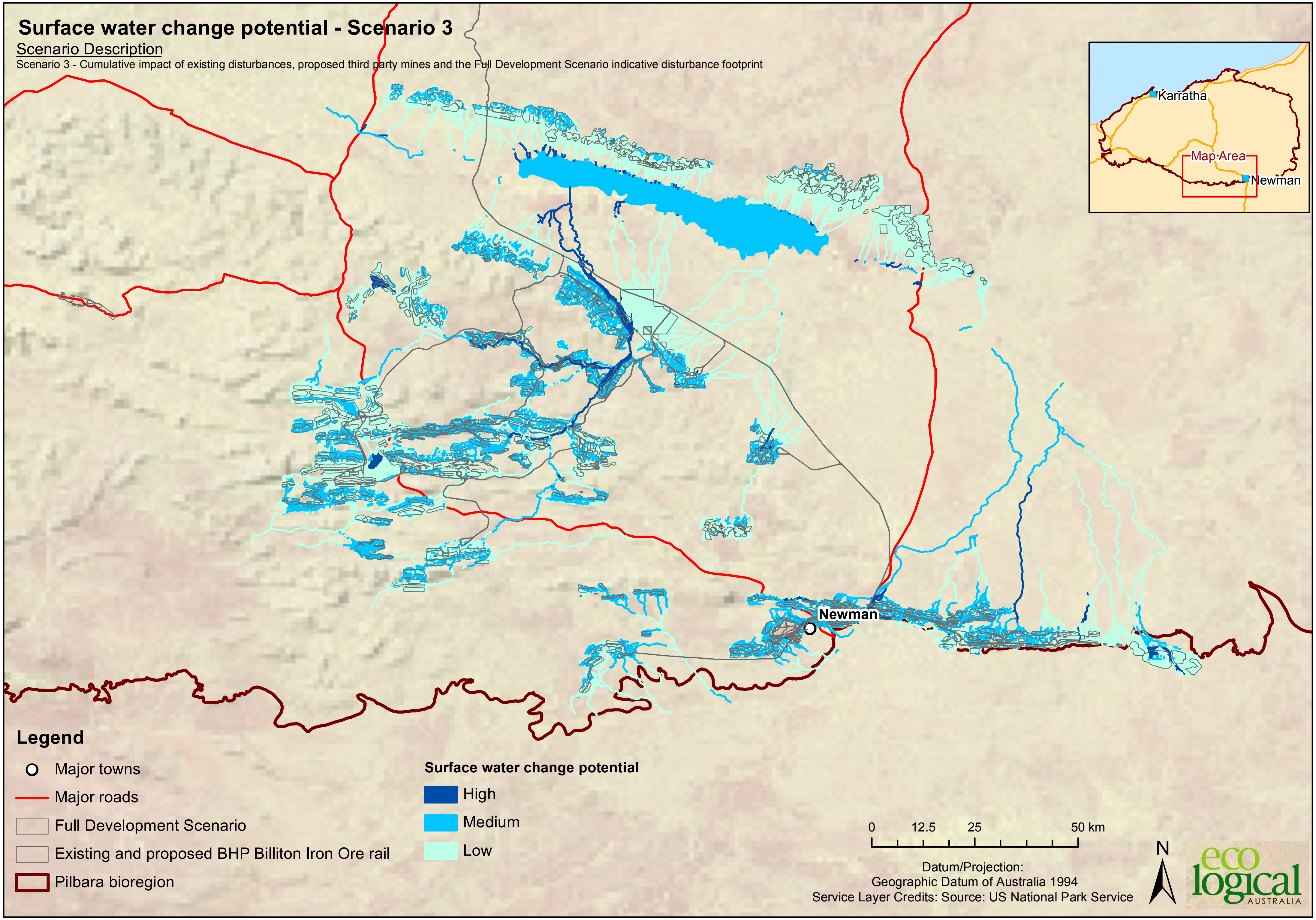
Service Layer Credits: Source: US National Park Service

ecological AUSTRALIA

Surface water change potential - Scenario 3

Scenario Description

Scenario 3 - Cumulative impact of existing disturbances, proposed third party mines and the Full Development Scenario indicative disturbance footprint



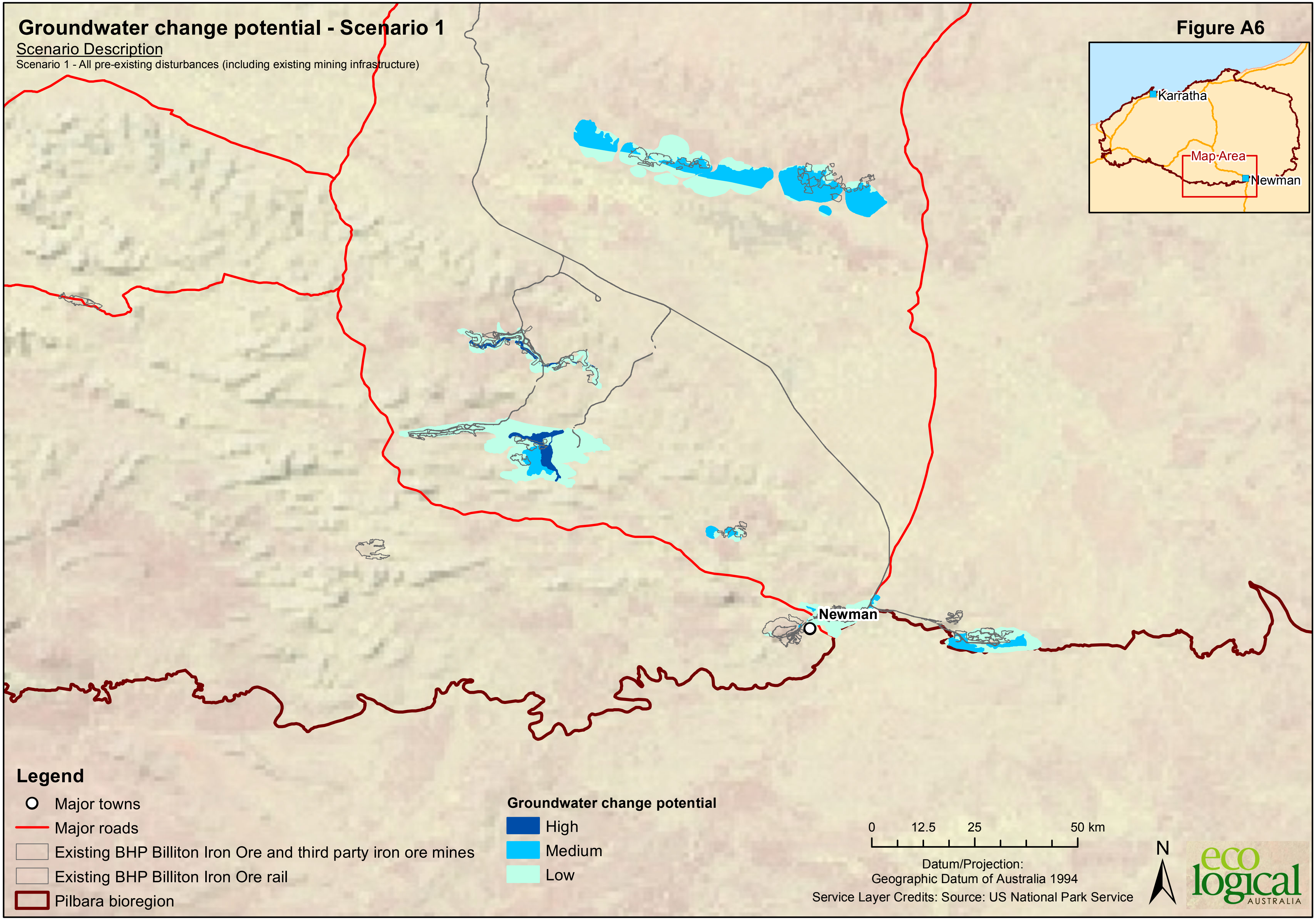
Datum/Projection:
Geographic Datum of Australia 1994
Service Layer Credits: Source: US National Park Service

Groundwater change potential - Scenario 1

Figure A6

Scenario Description

Scenario 1 - All pre-existing disturbances (including existing mining infrastructure)



Datum/Projection:
Geographic Datum of Australia 1994

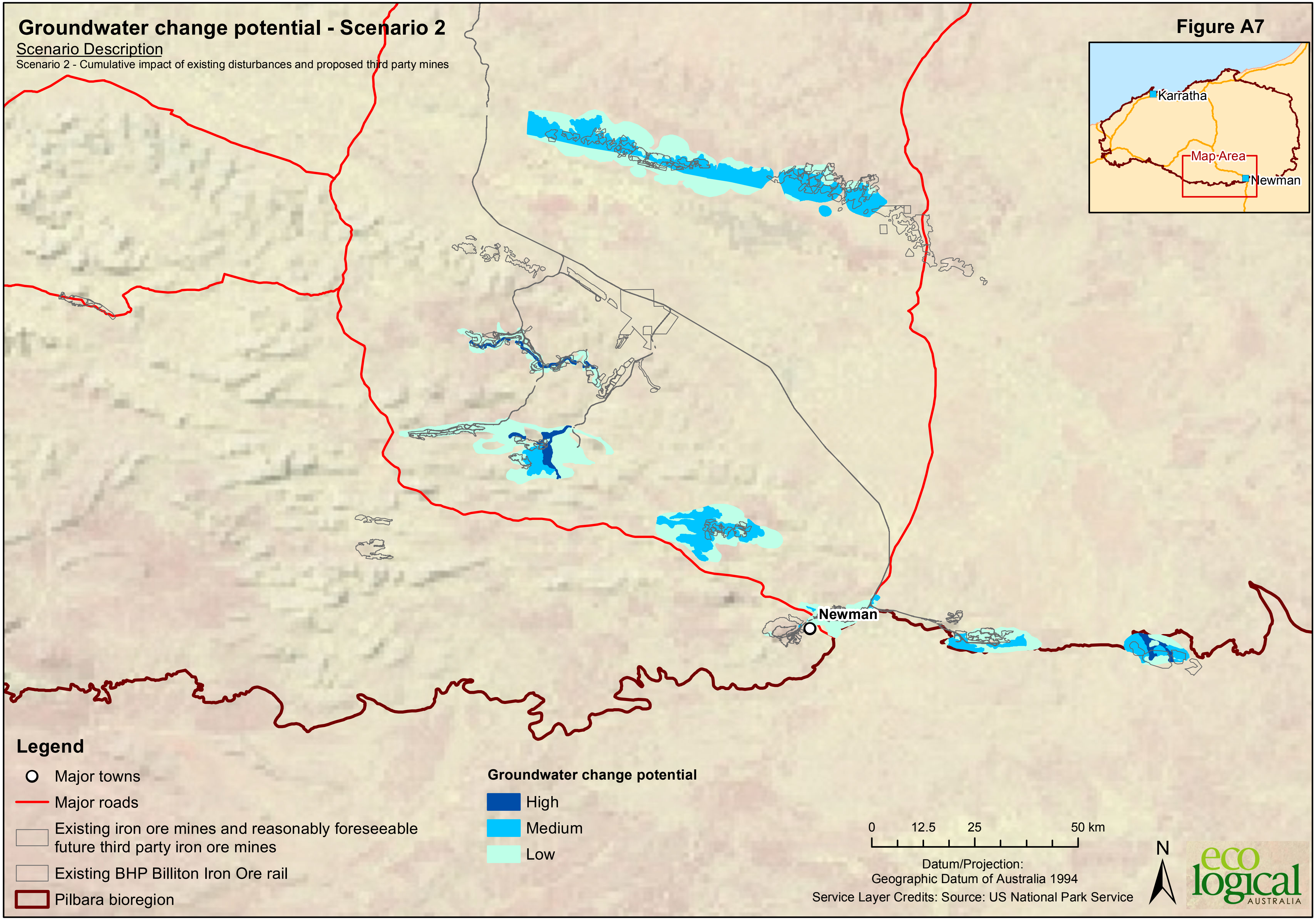
Service Layer Credits: Source: US National Park Service

Groundwater change potential - Scenario 2

Figure A7

Scenario Description

Scenario 2 - Cumulative impact of existing disturbances and proposed third party mines



Datum/Projection:
Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

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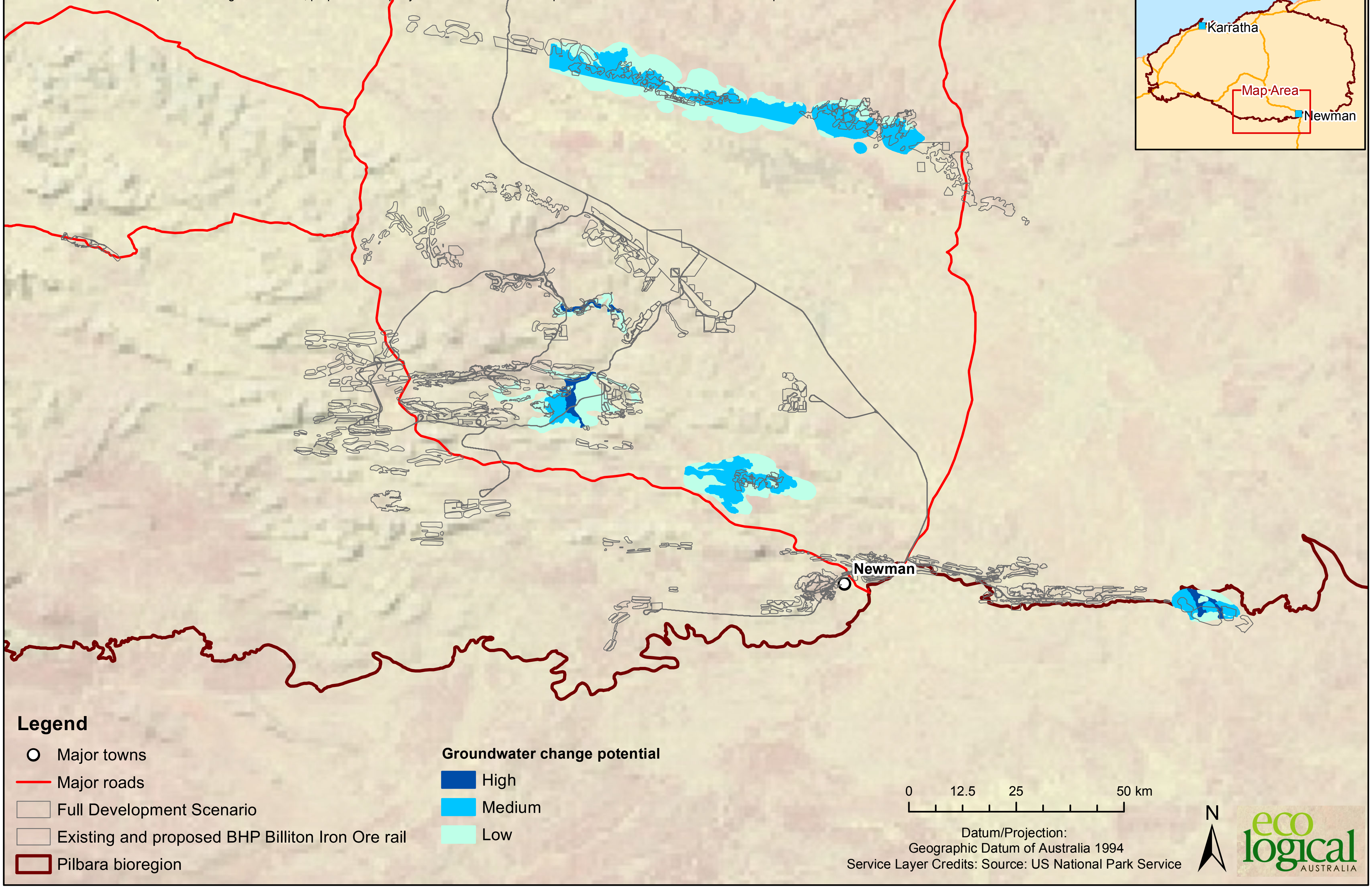
Groundwater change potential - Scenario 3

Scenario Description

Scenario 3 - Cumulative impact of existing disturbances, proposed third party mines and the Full Development Scenario indicative disturbance footprint



GRAZING PRESSURE

The impact of grazing was applied to the Greater Bilby (Section 3.3.2), Northern Quoll (Section 5.3.2) and Pilbara Olive Python (Section 7.3.2) from a spatial layer for grazing pressure developed for the Pilbara bioregion by ELA. The grazing pressure layer categorised areas as either zero, low, medium or high grazing pressure (**Figure A9**). The approach to the development of the layer broadly considered land system data (which contain a ‘Pastoral Potential’ spatial attribute; land systems are characterised according to vegetation types, substrate and landscape characteristics; van Vreeswyk et al. 2004) and distance to water. Development of the layer was also informed by local knowledge through review by Pilbara pastoral station managers. This review determined that slope, which was identified in preliminary data exploration as a potential factor (e.g. Cruz et al. 1998), does not significantly influence grazing pressure in the Pilbara as most cattle in the Pilbara will graze on any slope if there is green fodder available and that, while flat deltas are often more productive for fodder, this is reflected in the land system layer. Slope was therefore not considered in the final grazing pressure layer, which was endorsed by the Pilbara pastoral station managers.

Table A9 outlines the data used and scoring system implemented to categorise areas in terms of potential grazing pressure. Data for ‘Pastoral Potential’ were available within the Department of Agriculture and Food Western Australia (DAFWA) land systems layer, in which each land system has a Pastoral Potential of either Very high, High, Medium high, Medium, Low, Very low, or Other (**Figure A10**). Data for ‘Distance to Water’ were derived from the 1:250,000 topographic map series covering pastoral bores, waterholes, springs, water points (pools and soaks), watercourses and lakes (**Figure A11**).

The following key information was used to inform the ‘Distance to Water’ scoring system (**Table A9**):

- A typical pattern is noted throughout the literature of vegetation cover decreasing as water is approached in areas where grazing has occurred (e.g. Bastin et al. 1993a, b).
- Meat and Livestock Australia (2012) state that cattle are known to walk up to 10 kilometres from water; however, the majority of grazing occurs within two kilometres of water.
- Pickup et al. (1998) state that most grazing activity (in central Australia) occurs within four to six kilometres of water.
- In favourable conditions, cattle typically graze within three to four kilometres of water; in drier conditions, grazing may extend to 10 kilometres (Howes and McAlpine 2008).
- A zone of extreme degradation up to around 50 metres away from the water source was noted by James et al. (1999).
- Degradation near bores can vary depending on how developed a pastoral station is. If open ranging is practised (i.e. fewer bores are established), then cattle will travel further to ephemeral creeks and river deltas to graze following significant rainfall, which allows areas around bores to regenerate. Pastoral stations that are ‘fully developed’ (i.e. where bores are arranged to ensure that cattle are within five to six kilometres of a bore) will be subject to more severe degradation because there is no chance to regenerate. Cattle will not travel more than six kilometres from a bore to find water, except during severe drought (various, Pilbara pastoral station manager workshop, pers. comm., 2013).
- Degradation near rivers varies between permanent and ephemeral water features. Areas near ephemeral water features are generally less degraded as they can regenerate outside of the summer period of maximum rainfall. Areas near permanent water features are grazed continuously

and are therefore prone to greater degradation (various, Pilbara pastoral station manager workshop, pers. comm., 2013).

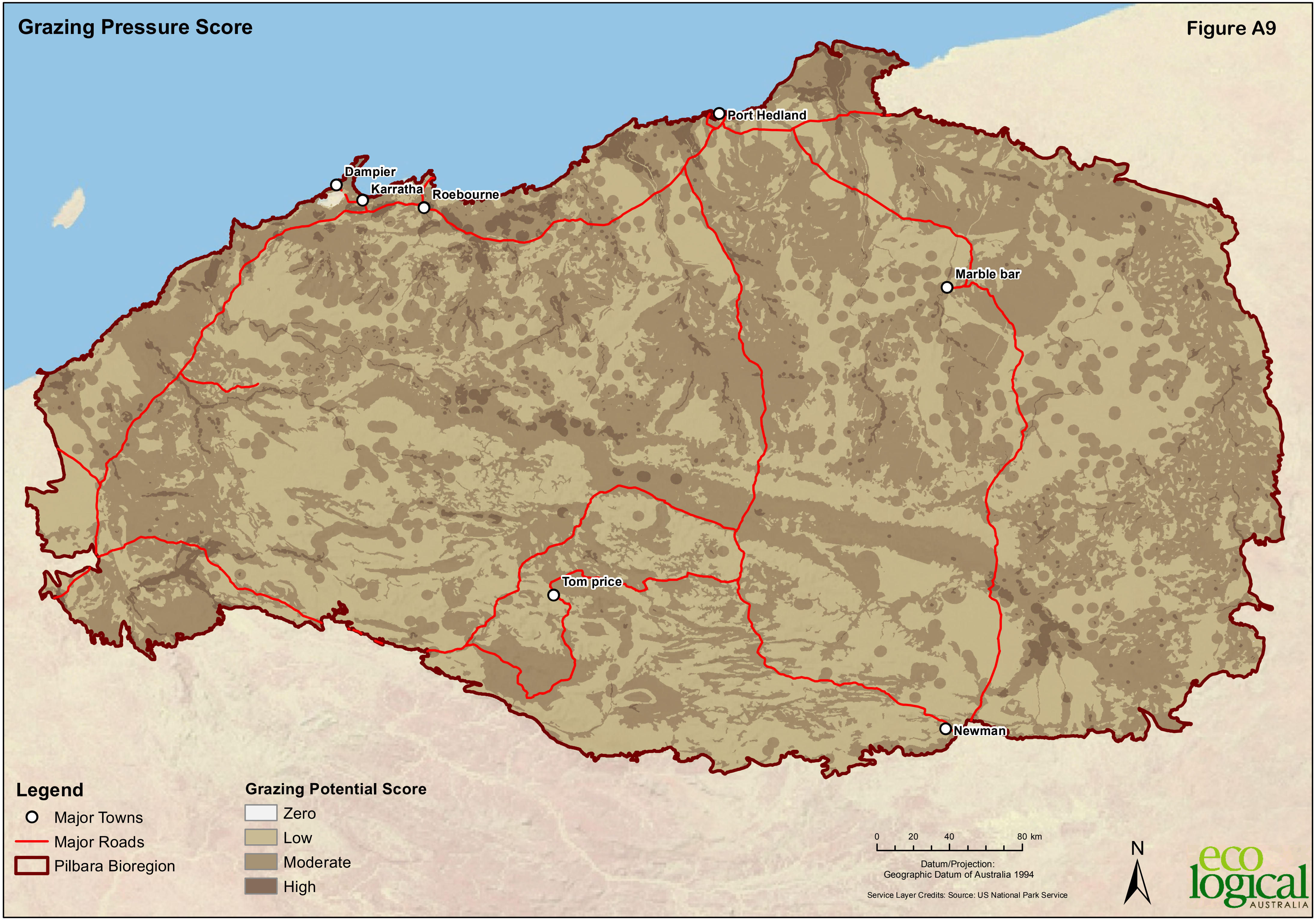
The sum of the normalised scores for Pastoral Potential and Distance to Water were used to determine the grazing pressure of an area as either Zero, Low, Medium or High (**Table A9**).

Table A9: Source data layers and scoring system for development of the grazing pressure spatial layer

Attribute and source layer/s	Pastoral potential/ distance to water feature		Score	Normalised score	Combined score (sum)	Grazing pressure
Pastoral Potential (DAFWA land systems layer)	Very high		6	6	12	High
	High		5	5	10	High
	Medium high		4	4	8	Moderate
	Medium		3	3	6	Moderate
	Low		2	2	4	Low
	Very low		1	1	2	Low
	Other		0	0	0	Zero
Distance to water feature derived from data from the Topographic map series (1:250,000) covering: Pastoral Bores; Waterholes; Springs; Water points (pools and soaks); Watercourses (lines and areas); and Lakes (mostly waterholes).	Bore or permanent water feature	0-1 km	3	6	9	High
		1-3 km	2	4	6	Moderate
		3-6 km	1	2	3	Low
		>6 km	0	0	0	Zero
	Ephemeral water feature	0-1 km	3	3	6	Moderate
		1-3 km	2	2	4	Low
		3-6 km	1	1	2	Low
		>6 km	0	0	0	Zero

Grazing Pressure Score

Figure A9



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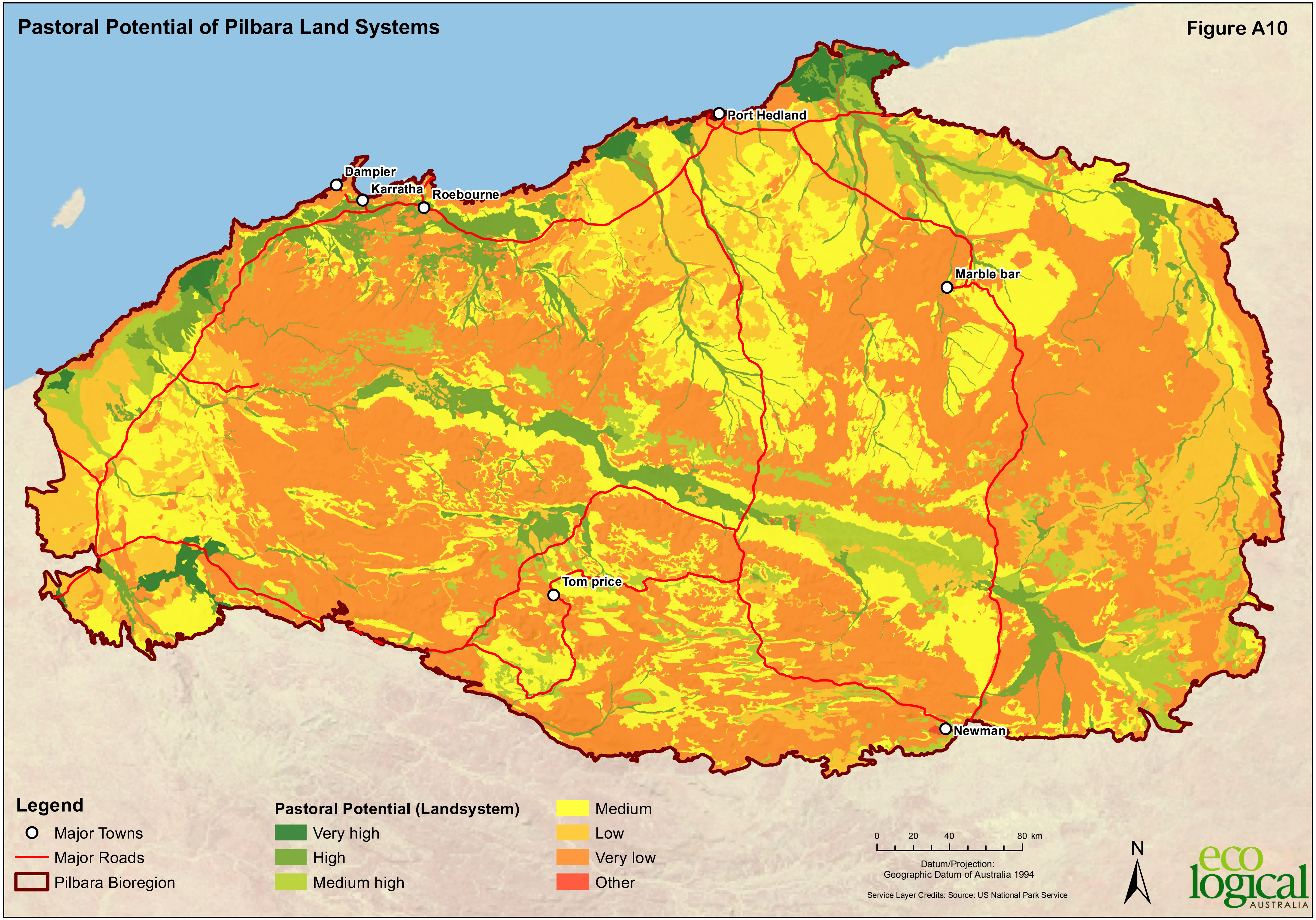
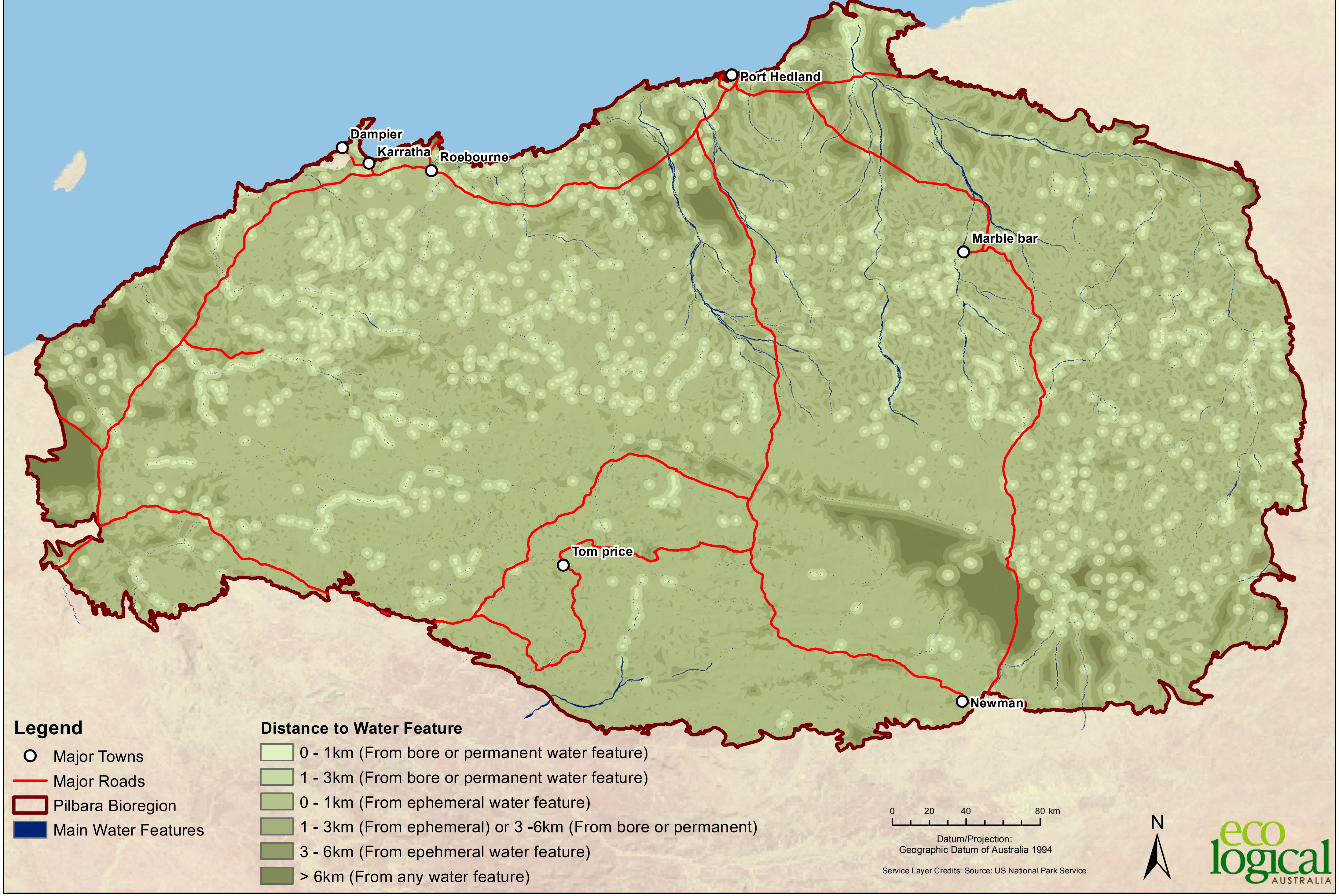
Pastoral Potential of Pilbara Land Systems

Figure A10



Distance to Water Features

Figure A11



Appendix B: Literature review ï cumulative environmental effects

OVERVIEW

This appendix introduces and defines the concept of cumulative environmental effects and discusses the main ways these effects can occur. CIA is then discussed as a process by which to assess and report on the impacts of cumulative environmental effects. A typology of CIA approaches is presented that divides approaches into those that extend traditional, usually project-specific environmental impact assessment (EIA) methods over broader spatial and temporal scales, and those that are more strategic and objective-based.

BACKGROUND

Cumulative environmental effects refer generally to the phenomenon of temporal and spatial accumulation of change in environmental systems in an additive or interactive manner (Spaling and Smit 1993). Shoemaker (1994) defines cumulative environmental change as ña change in the environment resulting from multiple initiatives of the past, present and reasonably foreseeable future, which combine in an additive, amplifying or discontinuous mannerò. Franks et al. (2010) describe cumulative effects as ñsuccessive, incremental and combined impacts of one, or more, activities on society, the economy or environmentò.

Sources of environmental effects range from simple additions to complex interactions of stressors, and are not necessarily brought about by only one activity or cause. For instance, change in vegetation cover across a region may be attributable to several different types of industries interacting in time and space, rather than a single development (Sadar 1994). Sources of environmental effects also include natural variability and anthropogenic climate change.

In the context of the mining industry, cumulative environmental effects can be summarised into four categories:

1. Space crowding is defined by Rees (1995) as ña system being perturbed by several similar agents or activities, or by different activities producing a similar effect, in an area too small to assimilate the combined impacts.ò Nibbling is an incremental form of space crowding according to Court et al. (1994) and is the gradual disturbance and/or loss of land and habitat.
2. Time crowding is defined as impacts so close in time that the impacts of one are not dissipated before the next occurs (CEARC 1986).
3. Interactive effects can be additive or synergistic, reflecting the interactive nature of ecosystems. Additive is the simple linear addition of effects, whereas synergism (or ócompoundingô) is when two or more agents have a greater effect combined than the sum of the individual agents. Antagonistic effects can also occur, where the combined impact of more than one agent is less than the sum of the individual impacts (Canter and Kamanth 1995), but are unlikely in the mining industry.
4. Indirect effects are secondary impacts arising as a result of the direct effect. For example, removal of vegetation can lead to various indirect effects, such as proliferation of feral animals or weeds, fragmentation, and degradation of habitat (DEST 1995).

Time lags and space lags are sometimes evident in the environmental impacts of the mining industry, where the environmental impact arising from an action may be realised years, or even decades after the action occurs (e.g. groundwater contamination). Space lags occur when the action and effect are spatially separate (e.g. downstream contamination of a waterway from a chemical spill).

Each of these effects is summarised at **Table B16** and **Table B17**. Triggers and thresholds are also noted in **Table B16** and are pertinent to describe environmental trigger points and ecosystem resilience. Resilience is the amount of change a system can undergo (its capacity to absorb disturbance) and remain within the same regime that essentially retains the same function, structure and feedbacks (Walker and Salt 2006). Parsons et al. (2009) suggest that resilience may be considered from an engineering perspective, where resilience is the speed of return to a steady state and is focused on efficiency of function, or from an ecological perspective, where resilience is the magnitude of disturbance that a system can absorb before the system is restructured in another state with different controlling variables and processes and is focused on maintenance of function.

Assessing ecosystem resilience and determining thresholds and triggers for management requires understanding of the potential alternate states in the system, the processes required to change those states, and the variation within the states (Parsons et al. 2009). Developing an understanding of the cumulative direct and indirect effects of mining, and their time and space lags is critical to determining triggers and thresholds for change in ecosystem condition, and therefore adaptive management. Adaptive management is a learning-based approach that, to be successful, should be strategic, adaptive and participatory (Parsons et al. 2009). Parsons et al. (2009) outlines the key components of a successful adaptive management approach as:

- Set a vision for the desired state of a system that meets the needs of all stakeholders. The desired state has social, technical, environmental, economic and political dimensions.
- Translate the vision into a hierarchy of objectives.
- Define acceptable levels of change (thresholds) for the system and monitor how the system performs in relation to the desired state and thresholds.
- Implement corrective management actions if one or more defined thresholds are approached or exceeded.
- Constantly review knowledge of the system and incorporate into the adaptive management process, including through updated thresholds and management options.

In terms of CIA of the mining industry, two of four pathways identified by Spaling and Smit (1993) are important:

- Multiple actions that induce environmental change in an additive but non-synergistic manner (e.g. multiple greenhouse gases that all contribute to global warming).
- Multiple actions with synergistic interaction. As previously stated, synergism occurs when the total effect of an interaction between two or more processes is greater than the sum of the effects of each individual process (e.g. the combination of sulphur oxides and nitrogen oxides to form smog).

It is important to note that these pathways are not mutually exclusive in time and space as several pathways may function simultaneously, or thresholds and time lags in one pathway may activate another in a complex environmental system (Cocklin et al. 1992; Spaling and Smit 1993).

Table B16: Sources of environmental change and their impacts (Sadar 1994)

Issue type	Main characteristics	Examples
Space crowding	High density of impacts to a single environmental medium.	Habitat loss/fragmentation in grasslands.
Time crowding	Frequent and repetitive impacts to a single environmental medium.	Wastes sequentially discharged into creeks, rivers and wetlands.
Compounding effects	Synergistic effects due to multiple sources on a single environmental medium.	Downstream effects of several projects in a single watershed.
Indirect	Secondary and tertiary impacts resulting from a primary activity.	Roads to resources which open up wilderness areas.
Time lag	Long delays in experiencing impacts.	Carcinogenic effects.
Space lag	Impacts resulting some distance from their sources.	Gaseous emissions into the atmosphere.
Triggers and thresholds	Impacts to biological systems that fundamentally change system behaviour.	Effects in changes in woodland age on woodland fauna.

Table B17: Indirect effects resulting from vegetation loss

Direct effect	Indirect effects
Vegetation loss	Fragmentation of communities, leads to isolation of gene pools and long-term loss of population viability, increased edge effects and weeds/feral encroachment.
	Decrease in energy fixation with impacts to soil, vegetation and fauna.
	Loss of diversity over the long-term.
	Loss of varied age structure and reduced habitat niches.
	Change in infiltration rates with impacts to water table levels and soil erosion.
	Salt intrusion in coastal environments where dunal vegetation serves to fix salt levels in geographic space allowing for succession plant communities in land.
	Weed invasion with potential to gradually take over the whole ecosystem beyond the original impact site.
	Carbon emissions from direct release of greenhouse gases on clearing and subsequent lower carbon fixation rates from less regrowth.
	Increased wind erosion from destabilised exposed soil.
	Domestic and feral animal invasion often associated with human settlements in cleared areas.
	Altered fire regimes that may lead to reduced reproduction of native flora species.

CUMULATIVE IMPACT ASSESSMENT

CIA recognises that although individual actions may have an insignificant effect by themselves, the aggregated or collective action of these effects may be significant (Elliott and Thomas 2009). CIA is the process of identifying and classifying environmental effects and pathways, in order to avoid, wherever possible, the potential triggers or sources that lead to cumulative environmental effects (Harriman and Noble 2008).

CIA is often regarded as an information-generating procedure with the aim of analysing and assessing the cumulative effects associated with past, present or proposed human activities (Spaling and Smit 1993). The process is linked through information flow to planning and decision making. In this vein, CIA is viewed as an extension of the scientific component of Environmental Impact Assessment (EIA). Less commonly, CIA has been used to determine an order of preference among a set of resource allocation choices based on social norms that act as decision rules to compare and rank alternative choices, and trade-off environmental, social and economic objectives in order to define alternative future scenarios. This application of CIA is comparable in some respects to multi-criteria evaluation and planning (Voogd 1983).

Prediction of cumulative effects involves identifying the total effects on a resource arising from different components of the plan or project (intra-plan or intra-project effects); and the total effects of the plan or project in combination with those of other human activities, and human-induced effects such as climate change (inter-plan or inter-project effects) (Therivel and Ross 2007). The main steps of CIA are (adapted from Therivel and Ross 2007):

1. Identify the affected receptors (also described as valued ecosystem components, receivers or resources) and define the extent of the assessment, including in relation to spatial and temporal scales.
2. Determine what past, present and future human activities have affected or will affect these receptors, and what has led to these activities (context).
3. Predict the effects on the receptors of the project/plan in combination with the effects of other human activities, and determine the significance of the effects.
4. Suggest how to manage the cumulative effects.

Scale issues must be addressed early in the CIA process. The selection of spatial and temporal boundaries for the assessment is difficult and there is no right or wrong approach (Karstens et al. 2007), although the scale chosen in a study dictates the types of problems to be addressed, the solutions to be found, and the impacts to be evaluated (Lebel 2004). Another particular scale problem lies in the scoping of relative effects. For instance, if a species is rare at a regional level but locally abundant, should that species still be ‘scoped in’ for CIA at the local level? The selection of scale in an assessment may be intentionally or unintentionally political as it may favour some factors (Lebel 2004).

In comparison to EIA, CIA has been rarely carried out in Australia, partly as a result of a lack of legislative requirement for it, but also because of the complexity associated with prediction of synergistic and interactive impacts. Often, the only consideration given to cumulative effects concerns those that are easy to identify and are generally additive (Cooper and Canter 1997). Complex and expensive models of the interactions between various agents or stressors are often required in order to gain a comprehensive picture of the cumulative effects associated with an activity.

Academics and practitioners interviewed by Gunn and Noble (2012) identified three ways to aggregate effects of individual projects to form a regional assessment of cumulative effects. The first was to simply óadd upô individual effects such that a range of individual effects on a particular valued ecosystem component are evaluated and summarised into trend information. This approach was considered too simplistic and reflected similar thinking to that used in EIA, where each project is treated individually. The second approach was to build an assessment framework around what are perceived as ócumulative effects issuesô in a region. In this approach there is no investigation into the causes and pathways to change contributing to those issues. As such, there is little scope for preventing adverse cumulative effects from occurring in the first place. The third and final approach was to assess the nature and quality of a specific suite of valued ecosystem components that are ócumulative by definitionô (e.g. habitat fragmentation or water quality). The focus of this approach is on components that are indicative of ecosystem health or somehow indicative of cumulative regional change. Rather than break down the individual stressors and then add up the individual effects, this approach adopted ósurface disturbanceô as a proxy for cumulative effects in evaluating past trends in human stress on the regional environment and the implications of future land use scenarios.

Harriman and Noble (2008) present a typology of regional approaches to CIA based on multiple characteristics, functions and expectations. They divide regional approaches into those that emphasise assessment of cumulative effects of individual and multiple development projects by extending EIA methodologies over broader spatial and temporal scales, and those that are strategic environmental assessment (SEA)-driven, where emphasis is placed on the CIA of initiatives, plans and opportunities by adopting an objective-based approach to assessment and decision making. **Table B18** summarises the characteristics of strategic and non-strategic approaches to CIA. No approach is better or worse than any other; they all suit different purposes. The SEA-driven approaches are more complicated than the EIA-driven approaches, but, where they can be carried out effectively, can identify potential cumulative effects of potential industries before they occur, and identify the need for policies to deal with these potential effects before they occur.

Table B18: Characteristics of strategic and non-strategic approaches to CIA (Harriman and Noble 2008)

Aspect	EIA-driven approaches		SEA-driven approaches	
	Type I	Type II	Type III	Type IV
Description	CIA performed within the context of a single project.	CIA of multiple projects or multi-component activities.	CIA of plans or programs for a particular resource or industrial sector.	CIA of multiple plans or programs, across sectors.
Regulatory characteristics	Single proponent.	Single to multiple proponents.	Single industry sector, or government agency responsible for resource sector.	Regional planning or administrative authority governing body.
Trigger	Cumulative effects of project actions on specified valued ecosystem components (VECs) in the project locations.	Cumulative and additive effects of multiple projects on a region or regional VECs.	Cumulative effects of proposed or existing sector-based plans or development initiatives.	Cumulative environmental change or regional land use planning initiatives.

Aspect	EIA-driven approaches		SEA-driven approaches	
	Type I	Type II	Type III	Type IV
Types of alternatives considered	Proceed or not proceed; technical design and engineering considerations.	Alternative development projects; spatial or temporal configurations.	Multiple sector-based alternatives driven by sectorôs development vision.	Multiple region-based alternatives or scenarios driven by broader regional, sustainability, or policy-oriented goals or objectives.
Scoping factors				
Scope	Restrictive, inward-focused, limited to the stressors and impacts that stem from a single project (non-strategic).	Ambitious, outward-focused, taking into account combined stressors and impacts of multiple projects (non-strategic).	Restrictive, inward-focused, limited to the stressors and effects of policies, plans or programs of a particular sector (strategic).	Ambitious, outward-focused, taking into account the stressors and effects of the combined policies, plans or programs of multiple sectors (strategic).
Temporal bounds	Project life cycle defined by project or proponent, considering also past environmental change.	Past, present and reasonably foreseeable future developments in the projectôs region.	Past, present and reasonably foreseeable sector activities, plans and programs as defined by the sectorôs activities (e.g. oil and gas licensing).	Past, present, and longer term futures of regional environments and economies as defined by a regional authority, sustainable development plan, or similar strategy.
Spatial bounds	Site-specific, focused on direct on-site and off-site project impacts with continuous dispersion over space. Defined by the single project or project proponent.	Often population- or ecosystem-based. Defined by multiple projects within an administrative or physical region.	Boundaries of sector initiatives (e.g. forest harvest area) or by sector claims (e.g. oil and gas licensing and exploration claim).	The planning region under consideration as defined by natural features or by regional authority ï possibly multi-jurisdictional.
Cumulative effects considerations				
Typical sources and pathways of cumulative effects	Individual, predicted project actions combined with past and future environmental change.	Multiple projects or activities, individually contributing and interacting, and combined with past and reasonably foreseeable impacts of project development.	Activities of a single sector, often of a similar type and interacting with other similar sectoral activities, plans, policies, or developments.	Activities of multiple sectors, often diverse and interacting with other regional activities, plans, policies, or developments.

Aspect	**EIA-driven approaches**		**SEA-driven approaches**	
	Type I	**Type II**	**Type III**	**Type IV**
Typical CIA questions	What are the likely additive or incremental impacts of the proposed activity? What are the key stressors?	Are residual effects of many single projects significant? Are the synergistic effects of multiple initiatives or actions overloading natural or social carrying capacity? What is the effects based contribution of multiple projects?	What are the potential cumulative impacts of each sector alternative? What is the preferred sector-based option given desired outcomes? What are the opportunities and constraints on development?	What are the preferred regional environmental conditions or objectives? What are the potential cumulative impacts of each regional use alternative? What are the opportunities or constraints to current and future developments?
CIA planning and management				
Planning orientation	Individual project planning and evaluation. EIA and regulatory approval (reactive planning).	Incremental project planning; regional development and evaluation. EIA and regional development (reactive planning).	Large role in industry and sector planning. Plan formulation and initiative prioritisation (proactive planning).	Larger role, related to multi-sectoral planning. Contributing to regional development or environmental management (proactive planning).
Cumulative impact management	Mitigation, monitoring and management of significant individual, project-based impacts. Individual proponent responsibility, usually private sector.	Mitigation, monitoring and management of significant individual, project-based impacts. Multiple proponent responsibility.	Enhance positive impacts, avoidance of negative impacts. Select preferred sector-based development strategy. Risk reduction to the sector and sector environment. Regulate future development.	Enhance positive impacts, avoidance of negative impacts. Select preferred land use alternatives. Focus on risk reduction to regional environment, and regulating future sector activities and development.
Role of CIA in the EIA process	CIA is treated as one of several layers of information in impact prediction and decision making; embedded in single project assessment and approvals process.	CIA is performed to contribute to a larger regional impact understanding that informs decisions about the predicted and acceptable levels of change or impacts due to multiple project developments on regional VECs; assessment remains inherently project-driven.	CIA used to inform strategic decisions about the cumulative effects of alternative sector-based development initiatives; CIA is one aspect of a larger sector-based SEA process to inform downstream project activities.	CIA may be performed on its own, as an integral part of basis or basis for a regional SEA process; it defines regional thresholds and sets the context for acceptable sector activities.

Cumulative impact assessment case studies and guides

This section summarises the approach taken and outcomes of a number of CIA case studies and recent guides to undertaking CIA. A synopsis is presented that summarises the common themes across the case studies and guides, highlights any key points of difference, and outlines the possible advantages and disadvantages of the various approaches. Based on this, a rationale for the approach used in this CIA is provided.

CASE STUDIES

Namoi Catchment water study (Schlumberger Water Services 2012)

The Namoi Catchment in north-western NSW has been identified as an area with significant reserves of economically extractable coal and coal seam gas (CSG). The region also contains highly productive agricultural land. The region's water resources (surface and ground water) currently support human populations and extensive agricultural irrigation. In response to public concerns the NSW government commissioned an independent study on the potential impacts of coal mining and CSG extraction on the water resources in the catchment.

The project consisted of several phases including detailed project scoping, model conceptualisation, numerical model development, sensitivity analysis, scenario predictions and uncertainty analysis. Water modelling was undertaken using separate but linked surface water and ground water models.

Surface water modelling was undertaken using the lumped parameter LASCAM model. Runoff and recharge were modelled at the sub-catchment scale (99 sub-catchments) using a daily time step. Model performance was calibrated against gauged surface flow data.

Groundwater modelling was undertaken using the MODFLOW 2000 model. This model was developed as a set of 1 km by 1 km grids (cells) with 20 vertical layers representing geological strata.

Numerical groundwater quality modelling was found to be problematic as there was a paucity of quality input data available. This resulted in a high level of uncertainty such that numerical simulation of the movement of solutes with groundwater could not be accurately achieved. Therefore, qualitative measures were developed and employed, focusing on salinity, in relation to changes in groundwater flow and ground water levels. Surface water data were more abundant. However, the main mechanism for surface water quality impact was assessed from flooding or release events and given the uncertainty associated, these events were not simulated.

The model was used to simulate seven mining scenarios including a no mining base case. Each of the other six scenarios contained fixed development locations with development from currently approved or operational mines to extensive and widespread development. Each scenario was run for a 90 year period and the likely regional impacts reported.

The project was targeted at the strategic or regional level. The results were not designed to be used at the site scale and in particular not be used for site level impact assessment (e.g. is a certain spring affected). The strategic level modelling focused on regional change in ground water levels, stream water balances, ground water transfer between formations and catchment scale rainfall/runoff processes. Impacts were prioritised into those deemed to have the greatest impact.

Namoi cumulative risk assessment tool (Eco Logical Australia 2011, 2012)

The Namoi Cumulative Risk Assessment Tool (NCRAT) is a spatial tool that quantifies the relative risk of cumulative impacts across ten natural resource assets in the Namoi Catchment in northern New South Wales (NSW) (land use, soils, carbon, surface water, groundwater, vegetation extent, vegetation type, vegetation condition (intactness), vegetation connectivity and threatened species). NCRAT is ArcGIS compatible and interfaces with ArcGIS Version 10. It was designed to report the cumulative risk of any mining scenario constituting a combination of one or more mines including open cut coal mines, longwall coal mines and coal seam gas operations. NCRAT was designed to:

- Analyse the cumulative impact of a scenario (input by the user) across a number of asset sensitivity surfaces.
- Call on respective risk tables that associate sensitivity and likeliness/magnitude with risk.
- Produce a risk report that includes maps, area statistics, single and cumulative risk diagrams, and statements about specific assets affected.

The following assumptions apply to NCRAT:

- It is designed to establish the level of impact and risk at the strategic landscape scale, but is not designed for site or project scale risk assessment.
- It considers relative not absolute risk, thus is most useful for comparing risk between scenarios.
- It considers unmitigated risk to establish a level of baseline risk, where initiatives such as biodiversity offsets and water buyback are assumed not to have been undertaken (Version 2 of NCRAT, currently being developed, will incorporate opportunities for risk mitigation).
- It is sector-specific in that it considers cumulative risk of the coal mining and CSG sectors only.

A number of new spatial layers have been developed for the NCRAT project; specifically landscape corridors, local links, local catchments, vegetation intactness and threatened species models.

The major innovative feature of NCRAT is that it re-derives each surface (receptor) following the addition of each mine or new scenario. This facilitates assessment and reporting of non-linear (compound) cumulative impact over time; because the impact of the mine ónôaffects the level of impact of mine ón+1ô In contrast, most contemporary models report the linear (additive) cumulative impact, where all mines are assigned to the receptor simultaneously (rather than sequentially). In terms of ecological impacts (e.g. effects on MNES), additive approaches may not adequately define iterative impacts to connectivity, fragmentation and effective habitat.

The emphasis of NCRAT is provision of a risk report, informed by magnitude and likelihood of impact across a number of asset classes. In summary, a mining scenario is initiated by defining the type and spatial footprint of the first mine and intersecting it with each original sensitivity layer. The output sensitivity is reported against its appropriate risk matrix to derive a risk statement for each asset, for mine 1. Delineation of additional mines (optional) requires that the original asset and associated sensitivity layers are updated as temporary layers (enabling a synergistic analysis of ócumulativeô impacts). These updated sensitivity layers are reported against equivalent risk matrices to derive a risk statement for each asset, for each additional mine. Risk statements for individual mines are combined into a final risk statement for the scenario.

Abbot Point Cumulative Impact Assessment (Eco Logical Australia and Open Lines 2012)

The Abbot Point CIA considered the potential direct, indirect and facilitated impacts arising from the proposed expansion of coal export facilities at the Port of Abbot Point in north Queensland. At the time of the assessment, the Port was the subject of a number of proposals for expansion by four key proponents ï Adani, BHP Billiton, GVK Hancock and North Queensland Bulk Ports (NQBP); with the expectation that future proposals for further development at the Port be realised.

The Abbot Point CIA considered past and present conditions in terms of their influence on the environmental baseline. The project assessed the future impact of all proposed infrastructure (three terminals, dredging and common user infrastructure) in combination, i.e. the cumulative effects of all proposed development. Within this, impacts were considered to be direct (e.g. vegetation clearing), indirect (e.g. degrading of water quality), or facilitated (e.g. increased shipping). That is, the focus was on questions such as ñwhat is the cumulative direct impact of vegetation clearance for all proposed developments?ò

The overarching objectives of the Abbot Point CIA were to:

- Understand the cumulative impacts of known projects operating and proposed at Abbot Point.
- Establish a baseline of current conditions, from which cumulative impact increases can be measured.
- Determine individual (project specific) and joint (port wide) management and mitigation actions required to avoid, minimise and manage environmental impacts.
- Develop a framework for joint mitigation of port wide cumulative impacts and, if necessary, offsets to address residual impacts such that there will be a ómaintain or improveô outcome for MNES and other environmental values.
- Allow timely assessment and approval processes to continue for the individual proponents.
- Provide a CIA and management framework that are scalable and can be built upon and incorporated into future development proposals.
- Use project-by-project assessment mechanisms to deliver these outcomes.

The CIA focused primarily on federally protected matters with the following key issues:

- Greater Barrier Reef World Heritage Area.
- Marine and terrestrial threatened and migratory species and communities.
- Caley Valley Wetland and its internationally important migratory shorebird community.
- Impacts relating to an increase in shipping activity through the reef.

The spatial scope was defined as the boundaries of the Abbot Point SDA in the terrestrial environment, as well as the nearshore areas surrounding the Port of Abbot Point. The CIA assessed all potential impacts associated with any proposed projects with a current port and/or land allocation at Abbot Point. These comprised the proposals of Terminal 0, Terminal 2 and Terminal 3 and their associated dredging, rail within the Abbot Point SDA, common user infrastructure required to enable the projects, and facilitated shipping within the Great Barrier Reef.

The assessment accounted for potential future development within the boundaries of the Abbot Point SDA by developing a common set of baseline information, conservation objectives and an ongoing management framework intended to be adopted as part of any new proposal. The assessment and outcomes were specifically designed to enable future (currently unknown) port precinct projects to be incorporated and assessed in a similar manner, utilising the work already undertaken to enable regulators and the public to examine future projects in the context of existing baselines and ongoing, coordinated management.

The assessment approach and methodology were developed as a function of the objectives and scope of the CIA.

The approach began with an understanding of the environmental values relevant to the assessment, drawing on existing data for the region and scientific literature. To help with this, a specialised team of four experts from the fields of marine biodiversity, shorebird ecology and world heritage were engaged in the project. A set of conservation objectives for all relevant values were defined as a result of this and these objectives were used to frame the assessment and outcomes.

Understanding and defining impacts was the next phase of the assessment. The cumulative nature of impacts was considered in three ways:

1. The cumulative effects of all proposed port activities for each type of impact. For example, when considering construction noise, the total construction noise levels associated with developing all components of the port (Terminal 0 + Terminal 2 + Terminal 3 + railways, etc.) was considered.
2. The cumulative effects on an environmental receptor of all applicable impacts occurring in conjunction across the Abbot Point project area. This was referred to in the assessment as ádditiveô cumulative impacts. For example, the combined effects on migratory shorebirds of construction noise impacts + degradation of habitats through disturbance.
3. The reactions between different types of impacts occurring concurrently and interacting to produce a different outcome.

An understanding of the type, nature and extent of potential impacts was informed by two key sources of information: data and reports prepared as part of environmental assessment and approval processes for individual projects within the Abbot Point project area; and a suite of 16 technical studies specifically commissioned for the purposes of the CIA to determine, and where possible quantify, the combined effects of each type of impact.

The assessment then brought together this understanding of the existing environmental values with the expected cumulative impacts across the port. It led to a range of recommended avoidance, mitigation, management and offsets measures to address potential cumulative impacts and to deliver the conservation objectives.

The CIA process resulted in three key outcomes:

1. Identification of port wide conservation objectives to maintain or enhance the environmental values at Abbot Point. The objectives focus on the key values such as migratory shorebirds and World Heritage, as well as the broader marine, wetland and terrestrial values of the area.

2. A proposed Joint Environmental Management Framework (JEMF) that will provide for coordinated and adaptive management of the Port in order to achieve the conservation objectives.
3. A set of best practice shipping requirements relating to Abbot Point that recognise the sensitivity of the marine environment of the Great Barrier Reef World Heritage Area.

These outcomes and the overall analysis in the CIA confirmed that ongoing development of the Port can occur in a manner that can sustain biodiversity values and deliver the conservation objectives. The experts supported this and considered that the CIA process as a whole represents a robust and appropriate approach to considering the potential cumulative impacts of proposed expansions at the Port of Abbot Point.

Lower Athabasca regional plan 2012 (LARP 2012)

The Alberta Government (a Canadian provincial agency) has developed the Lower Athabasca Regional Plan (LARP) to guide sustainable development for the next 50 years. The LARP identifies strategic directions for the next ten years and sets the regulatory framework to consider economic development, ecosystems and the environment and human development via a cumulative effects management system.

The LARP covers a region of 93,212 km2 in the north-eastern corner of Alberta, Canada. Oil sands in the region represent 95% of Canadaôs known oil reserves. Oils sands production is expected to double by 2020. While oil sands represent the major economic potential for the region, there are also metal and mineral mines, quarries, forestry agricultural production and hydro-electricity generation. The LARP seeks to optimise economic development potential while identifying and preserving critical environmental functions and human needs.

The LARP consists of management frameworks to manage long-term cumulative effects of development at a regional scale, considering all development aspects. While the LARP does not provide a detailed approach to cumulative impact modelling it does set out the requirement to assess future development against (current) baseline conditions and all land use elements. The LARP also established goals for key ecosystem values related to groundwater, surface water and air quality. However, for each of these critical elements the LARP described requirements for:

- Establishing baseline conditions.
- Providing a consistent approach to understanding potential effects.
- Establishing a monitoring network with a management framework.

A critical element of the LARP is the development of environmental and economic triggers and limits based on established science or ôbestô expert opinion. Limits and triggers were established as part of management frameworks for air quality, surface water quality and groundwater quality. Air quality triggers and limits were based on accepted Alberta ambient air quality objectives; surface water quality triggers and limits on statistical deviation from historical ambient concentrations; and groundwater quality (interim) triggers and limits on baseline concentrations, regional knowledge and professional judgment or provincially accepted groundwater quality guidelines where applicable. Limits in the frameworks were intended as boundaries in the system that should not be exceeded. Triggers were to function as warning signals to allow for ongoing evaluation, adjustment and innovation.

Mountaintop mining in the Appalachian Mountains (USA) (Lindberg et al. 2011)

A study of the cumulative impacts of mountaintop mining on water quality in the American central Appalachian Mountains found the proportion of major and trace elements increased at a rate directly proportional to the upstream extent of mining. Lindberg et al. (2011) measured water quality at 23 locations upstream and downstream of mining operations in the Mud River and its tributaries, then correlated their results with the extent of watershed upstream, the percentage of watershed mined upstream, and the number of active US Environmental Protection Agency permitted active mine discharge outlets upstream. They determined the suite of stream solutes attributable to mining discharge significantly increased in concentration between the upstream and downstream sites, and these consistent increases were highly correlated with the cumulative amount of upstream mining disturbance. Their study also found that two mine sites rehabilitated almost two decades prior to the study were also contributing contaminants to receiving waters.

Lindberg et al. (2011) concluded observed increases in conductivity and selenium concentration was directly attributable to the aerial extent of surface coal mining occurring in the watershed. They suggested further study to inform the placement and treatment of rock spoil during all phases of mining and reclamation.

Lindberg et al. (2011) used a straightforward experimental design and data analysis techniques for their study, to demonstrate the relationship between the area of mining in a watershed, and the cumulative impacts of multiple mine discharges on water quality. Despite the obvious differences between streams in the United States and Australia, the relationship between area affected by mining activities and the cumulative impacts to stream water quality would likely hold true in an Australian context. The study offers empirical evidence of the relationship between mining operations and cumulative impacts to water quality, and is an example of an appropriate experimental design and analysis technique for field studies investigating the relationship between mining and effects on water quality.

Managing land use in north-eastern Alberta (USA) (Schneider et al. 2003)

A case study on forest management in north-eastern Alberta (Canada) provides an example of the potential usefulness of landscape-simulation modelling for forecasting the cumulative impacts of multiple uses in a catchment. Schneider et al. (2003) asked key stakeholders in the energy and forestry industries to weigh current management options in terms of their long-term effects on forest resources, in order to balance conservation and economic objectives. The simulation model used was ALCES®. They modelled the current regulatory framework and typical industrial practices on a suite of ecological and economic indicators over a 100 year period, then compared the outcomes with modelled alternative management scenarios which incorporated varying levels of ôbest practiceôactions. Their simulations suggested that if current practices continue the cumulative activities of the energy and forestry industries in the study area would result in significant loss of forest resources from the landscape, and declines in caribou habitat. They were able to demonstrate that implementing best practice activities resulted in improvements (compared to the simulated current practices) in ecological outcomes, while maintaining sustainable economic benefits.

The ALCES (A Landscape Cumulative Effects Simulator) model is a decision support system. It was developed to track industrial footprints and ecological processes under alternative management scenarios. It relies on qualitative data and quantitative assumptions relating to future industrial activities, natural disturbances and regeneration trajectories for each disturbance type. It will deal with different disturbance activities in the same location (such as installing a gas pipeline alongside a road), and a range of additional natural and human-made disturbances in the model runs. A key advantage is that it was designed to model the cumulative landscape-level effects of small, localised disturbances.

The model has been widely applied and critiqued in the United States and Canada, and consequently much modified and refined since the first version became available in the mid-1990s (Carlson et al. 2010). It is a stock and flow model built using the STELLA modelling platform. Using an annual time step (although monthly time steps can be used for the meteorology module) the model modifies the area and length of up to 20 land cover and 15 anthropogenic footprint types in response to natural disturbances, succession, landscape conversion, reclamation of footprints, and creation of new footprints associated with simulated land use trajectories (Carlson et al. 2010). The relationships between simulated industrial changes in the landscape and environmental and socio-economic indicators are then assessed by a linear program algorithm.

A core criticism of the model is that it is spatially stratified. This means the model is much faster to run than spatially explicit models, but it will not specifically track the geographic location of features of interest in the landscape (Carlson et al. 2010). That is, it will describe a change in a resource, but not where in the landscape the change is occurring.

Cumulative impact assessment of wind farms on Tasmanian Wedge-tailed Eagles (Smales and Muir 2005)

The project aimed to predict the potential cumulative impact of collision risk posed by a number of Tasmanian wind farms across the Tasmanian Wedge-tailed Eagle *Aquila audax fleayi* distribution, and to provide an estimate of the number of turbines or area of turbines at which predicted collision rates will likely to compromise the Tasmanian Wedge-tailed Eagle population (Smales and Muir 2005). Smales and Muir (2005) used a deterministic risk assessment model which incorporated consideration of a combination of variables tailored to wind farms and Tasmanian Wedge-tailed Eagle behaviour and ecology. The model estimated individual site risk, the chance of a bird surviving a site, and the chance of visiting a site, then determined cumulative effect of N sites (Smales and Muir 2005).

The probability model is presented at the end of the paper in full, and is straightforward to calculate. It relies on ecological data for the species being available (e.g. numbers of movements of a certain type per year, total population size, mortality rates, home range), and spatial data such as the area of the site and the area of the region of interest. It would work well for single impact and single species assessments where the requisite level of ecological information is available. It was not designed to handle multiple species or impacts.

Fitzroy River Basin water quality cumulative impact assessment (DERM 2009)

The Queensland Department of Environment and Resource Management (DERM) undertook a study on the cumulative impacts of mining activities on water quality in the Fitzroy River Basin after concerns were raised over the quality and quantity of mine water discharges released between February and September 2008.

DERM (2009) interrogated water quality monitoring data for the previous five years and other relevant information and data on approved discharges sourced from coal mines holding environmental approvals in the Fitzroy River Basin. They grouped the data (and mines) according to their location, dividing the catchment into eight sub-catchments, and focused their analyses on electrical conductivity. The analysis considered the volume, frequency and duration of discharges from each mine during 2008, and their permissible electrical conductivity discharge limit. The potential for local and cumulative impacts was assessed using electrical conductivity monitoring data at the most downstream receiving monitoring point in each waterway.

Each mine was allocated a cumulative risk rating (very low, low, medium, high, very high) based on their potential for producing cumulative impacts. The risk assessment cross-referenced the permissible electrical conductivity (based on Queensland Water Quality Guideline figures) with the frequency and volume of mine discharges, to determine their potential to adversely affect environmental values and water quality objectives for the Fitzroy River. Environmental values of particular interest were crop irrigation, potential use for drinking water, and protection of aquatic ecosystems (DERM 2009).

Using this technique DERM (2009) was able to identify mines which had a high or very high risk of contributing to cumulative impacts. They also offered recommendations related to the type and location of monitoring conducted by mines to better contribute to landscape-scale monitoring efforts, and suggested the ANZECC/ARMCANZ toxicant trigger values for aquatic ecosystems are applied, rather than those for irrigation or stock watering.

DERM (2009) used a risk assessment approach for one water quality parameter to determine cumulative impacts. Although adequate for their purpose, this approach would quickly become cumbersome as various ecological, socio-economic and industry activity variables were added. However, the approach could be adapted for use in developing response curves, which could then be used in a more sophisticated model (e.g. a decision support system).

In terms of demonstrating the relationship between mining activities and cumulative impacts, the study was able to categorise specific mines according to their capacity to contribute to cumulative impacts to water quality, and therefore aquatic ecosystem condition. The study identified the geographic proximity of mines and their discharge regimes are influential in determining the scale and magnitude of cumulative impacts.

Review of cumulative impact assessment techniques (Franks et al. 2010)

Franks et al. (2010) reviewed management and assessment approaches that seek to address the cumulative impacts of coal mining activities, drawing on examples from three different coal resource provinces (the Bowen Basin, Hunter Valley and Gunnedah Basin). They presented a conceptual model to describe the relationship between mining actions and receiving environments, described the planning approvals process for assessing cumulative impacts including consideration of the relevant state and Commonwealth legislation, and offered examples of attempts to manage cumulative impacts arising from mining activities.

The reviewed approaches to managing cumulative impacts were:

- Strategic and regional planning ï state government initiatives to improve coordination and planning (e.g. Queensland Government Coal Infrastructure Taskforce, NSW Government reform to define the Department of Planning as the pre-eminent planning body for New South Wales, industry facilitated community strategic planning groups such as the Clermont Preferred Futures group).
- Information exchange, networking and forums ï informal and formal networks to exchange of ideas and advice (e.g. Muswellbrook Mine Managers Forum, Queensland Mining Rehabilitation Group).

- Pooling of resources to support initiatives and programs ï multiple mining operations may focus and coordinate investment to target community and environment needs to generate the best value for each spend through pooling resources. For example, the Upper Hunter River Rehabilitation Initiative was a five year program which trialled river rehabilitation methods in a 10 km reach of the Hunter River. The research was funded by government, university research groups, the local catchment management authority, and local coal mine operations.
- Multi-stakeholder and regional monitoring ï these are programs designed to monitor issues of high stakeholder concern over a broader geographic scale than the location of a single or even multiple clustered operations. Examples are the Hunter River Salinity Trading Scheme, and the Upper Hunter Air Quality Monitoring Network. These programs are a collaborative effort by state and local government, industry, and the community, conducted at a geographic and temporal scale considered sufficient to capture the cumulative effects of mining in the target systems.

Franks et al. (2010) determined that there is scope to improve CIA through careful analysis of the different ways impacts aggregate and interact, collation and forecasting of information on announced and future projects, and collaborative research. They suggested Governments could also play a greater role in improving CIA, through provision of strategic assessments, and explicit links between regional and land use planning and the environmental impact assessment process.

Franks et al. (2010) offer good examples of attempts to manage and assess cumulative impacts, but aside from mentioning the information exchange, networking and forums are common and straightforward, and that the more advanced approaches (coordination and planning, and multi-stakeholder monitoring) are more challenging to implement, they do not assess the success or otherwise of the attempts. Some of the examples are from programs completed or initiated in the 2000s, so there should be some data or other information available to inform discussion of their success (or otherwise) and, therefore, to determine which approach or combination of approaches is recommended.

An exploratory study of coal mining cumulative impacts in the Muswellbrook area of NSW (Brereton et al. 2008)

This project was a cross-company collaboration that focused on the challenges involved in dealing with cumulative, or multi-mine, impacts at the local level. The project built on an earlier Australian Coal Association Research Program (ACARP) funded project conducted in 2004, undertaken by the Centre for Social Responsibility in Mining (CSRM) that aimed to enhance the capacity of individual mines to monitor and manage their impacts to local communities.

The study location was Muswellbrook, a town of approximately 10,200 people in the Upper Hunter Valley of New South Wales.

Key objectives of the study, as endorsed by the industry steering committee for the project, were to:

- Develop a framework for assessing, monitoring and reporting the cumulative social, environmental and economic impacts (both positive and negative) of coal mining on regional areas where multiple mines operated.
- Undertake a trial of the framework in an area where there were multiple mines.
- Identify methods and indicators that can be applied to other regions of Australia where multi-site impacts are a salient issue.

A research plan methodology was adopted to ascertain the perceived main cumulative impacts of mining on the Muswellbrook area. Stage 1 was a scoping phase which included a review of research literature on cumulative impacts. This was followed by interviews with stakeholders such as residents, and key people involved in industry and local government.

Stage 2 was a project reference group workshop. Attendees were invited to the workshop on the basis that they had extensive knowledge of the social, economic and/or environmental wellbeing and condition of the Muswellbrook and Hunter Valley area; were considered specialists in their fields, and/or represented regulatory organisations involved in planning, monitoring or assessing the impacts of coal mining on communities.

The participants in the workshop reviewed the information collated up to that time, provided advice on other available information, and provided suggestions on how various impacts should be measured and managed. The main cumulative impacts identified by the community reference group were:

- Perceived decrease in health and wellbeing ï physical and psychological.
- Decreasing sense of place.
- Loss of vegetation/biodiversity.
- Increased coal-related transportation and traffic.
- Increased noise ï operational.
- Improved community infrastructure.
- Water quality ï especially post-mine.
- Economic distortion due to over-reliance on mining.
- Land loss.

Complaints data from mine complaint registers was also obtained and analysed as part of Stage 2.

Stage 3 involved the analysis, synthesis and presentation of the information collected in Stages 1 and 2 into a report. A key recommendation of the report was a revised approach for assessing the cumulative impacts of mining in regional communities:

- Stage 1 ï compilation of background literature, exploration of ABS social and economic data, environmental data and mine data, and a Project Reference Group meeting.
- Stage 2 ï quantification and description of cumulative impacts and community engagement.
- Stage 3 ï the second meeting of the Project Reference Group to review and analyse the data and community feedback.
- Stage 4 ï reporting and compiling the action agenda.

The key differences between the method used, and the revised approach are a delayed community engagement process after background data analysis has been undertaken and there has been an initial meeting of the project reference group. Also, a provision is made for a second expert workshop, after data collection and analysis have been completed.

A test of the usefulness of GIS for cumulative effects assessment (Parker et al. 1993)

This paper presents the outcomes of testing the usefulness of a Geographic Information System (GIS) in assessment of cumulative impacts via a case study in New Zealand.

GIS has the capability of handling large quantities of spatial data (e.g. spatial overlaps and proximities) which allows for the assessment of spatial distribution and effects. It can also be used to display changes in the environment over time. According to Parker et al. (1993) a GIS can be used to:

- Present and update survey data on natural and human environments, thus providing a context for considering proposed or likely developments, from a regional perspective.
- Analyse spatial relationships between natural and human aspects of the environment.
- Analyse and present spatial changes over time (e.g. population, distribution/density changes, land use changes, loss of native forest).
- Present and analyse future scenarios (e.g. ówhat ifô analyses).

Data from the Meremere Ecological District in New Zealand were used to illustrate the contribution different methodologies could make to CIA. Data layers depicting the natural environment (air quality, water quality, fauna, floral etc.), physical environmental characteristics (geology, soils, hydrology, climate), human environment and human activities were included in the analyses. Parker et al. (1993) assessed the cumulative impacts of:

- A single activity on a single attribute ï agriculture on wetlands.
- Multiple activities on a single attribute ï all land uses on wetlands.
- Multiple activities on multiple attributes ï transportation, thermal electricity generation, recreation and coal mining on North Island fernbird habitat and remnant kahikatea.

Parker et al. (1993) concluded that although GIS is useful in the assessment of cumulative impacts, there are some drawbacks to its use. It can integrate information from a variety of sources and analyse spatial relationships. However, GIS cannot reveal why such impacts occur and how to address them. These questions can only be answered through consulting scientific studies or expert opinion.

Although GIS can integrate data from different sources, scales and times, Parker et al. (1993) asked whether it is appropriate to combine information from one year with information from another and to draw conclusions as to their spatial relationships if they have not occurred at the same place or time.

However, the use of GIS is a useful method in the assessment of CIA in conjunction with other methods which can complement GIS such as network analysis, matrices and the use of expert opinion.

Cumulative environmental effects of the Cross River tram (Tricker 2007)

This study identified links between SEA and EIA, using the Cross River Tram in London as an illustrative case study.

The approach consisted of interviews, documentary reviews, and detailed recording of the data collected. Tricker (2007) used a problem tree to map the links between actions and impacts, and initial temporal and spatial boundaries. The assessment boundaries were changed throughout the study as more data and evidence became available. A matrix was then used to record the possible impacts to the various environmental components.

An environmental network analysis method was used to analyse cumulative impacts of the Cross River Tram. Environmental network analyses are a common method for assessing the interactions between causes of impact, and between types of impact.

The conceptual framework for Trickerôs (2007) approach can be distilled into four steps:

1. Characterisation of future, present, and past baselines, including description of indirect impacts as well as direct project impacts. Valued environmental components and sites likely to experience impacts identified on an area-by-area basis. Collection of data using a matrix.
2. Descriptive summary of alteration effects across all impact sites in terms of access, encroachment, and induced-growth.
3. Identification of impacts to individual valued environmental components, including direct impacts from project components as well as indirect impacts of alterations.
4. Analysis of causeï effect pathways between project components/ indirect causes of impacts and the overall valued ecological component, using a network (or causal chain) analysis.

Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources (Barrett et al. 2013)

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development has been established under the *Environment Protection and Biodiversity Conservation Amendment (Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development) Act 2012* to provide advice to the Federal Environment Minister on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC to develop its advice so that it is based on best available science and independent expert knowledge. BAs involve scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion, with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources. The central purpose of BAs is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of CSG and coal mining development.

It is not possible to define a prescriptive process that would produce a BA for any given bioregion when followed step by step, due to the differences in data, geology, hydrogeology and ecology across bioregions, as well as differing CSG and coal resource development pathways. Instead of a prescriptive process Barrett et al. (2013) specify an overarching principle to the generation of BAs. Where departures from this principle occur (due to deficiencies in data, information and models), these are recorded, judgments exercised on what can be achieved, and an explicit record made of the confidence in the scientific advice produced from the BA.

The BA methodology guides the analysis of potential direct, indirect and cumulative impacts to receptors that can be assessed at a regional scale. It is not a development-specific environmental impact assessment but does result in BAs that can inform development-specific assessment. The BA methodology is conducted in five components:

- Contextual information: Component 1 presents the context and background against which qualitative and quantitative assessments of impact and risk of CSG and coal mining development are generated.
- Model-data analysis: Component 2 evaluates and synthesises information from data and models to develop a quantitative description of the hydrologic relationship between coal seam depressurisation and dewatering and associated impacts to anthropogenic or ecological receptors.
- Impact analysis: Component 3 reports and records the direct, indirect and cumulative impacts and associated uncertainties of impacts of CSG and coal mining development to receptors within assets and their associated uncertainties.
- Risk analysis: Component 4 provides a scientific assessment of the likelihood of impacts to receptors contained within assets based on the propagation of uncertainties from models and data.
- Outcome synthesis: Component 5 delivers a synthesis of outcomes used by the IESC to support scientific advice on impacts and risk of CSG and coal mining development to water resources.

A BA is conducted within a specified area termed a ôbioregionô. The bioregion itself contains identified key water-dependent óassetsô within which are located óreceptorsô. A water-dependent asset is an entity, such as a Ramsar or state significant wetland, within a bioregion with characteristics having value and which can be linked directly or indirectly to a dependency on water quantity or quality. Receptors are discrete, identifiable attributes, such as a particular rare or threatened species, within assets that are measurably affected by a change in water quantity or quality resulting from CSG or coal mining development. It is through receptors that the impacts of CSG and coal mining development are defined within a BA. These impacts include changes in baseline variables, flow regimes, hydraulic conditions, surface water ï groundwater connections, inundation patterns and effects of salt or salinity. Other impacts such as ecotoxicology, human health or water quality impacts from heavy metal contamination or impacts of hydraulic fracturing fluids are under consideration in other research and studies (such as the ôNational Assessment of Chemicals associated with coal seam gas extractionö) and will be able to be linked to the BAs.

From these impacts to receptors, positive or negative effects of CSG and coal mining development on the values of assets can be determined. While a BA provides advice on the receptors and assets, it does not analyse the economic or social impacts and risks of CSG and coal mining development. The information from a BA will provide a regional context for decision makersô advice. However, it is not a development-specific environmental impacts assessment. At the same time, BAs will undoubtedly inform development-specific assessments.

Consideration of Cumulative Impacts in EPA Review of NEPA Documents (U.S. EPA 1999)

The purpose of this guidance is to assist United States Environmental Protection Agency (U.S. EPA) reviewers of National Environmental Policy Act (NEPA) documents in providing accurate, realistic and consistent comments on the assessment of cumulative impacts. While there is no ócookbookô method of assessing cumulative impacts, the guidance offers information on what issues to look for in the analysis, what practical considerations should be kept in mind when reviewing the analysis, and what should be said in U.S. EPA comments concerning the adequacy of the analysis.

Several key areas of information should be considered by U.S. EPA reviewers in determining whether the cumulative impacts assessment in a NEPA document is adequate. These areas are described below, and expand on the approach presented in the Council on Environmental Quality’s (CEQs) ‘Considering Cumulative Effects under the National Environmental Policy Act’ handbook:

- Resources and ecosystem components: In reviewing CIA, U.S. EPA reviewers should focus on the specific resources and ecological components that can be affected by the incremental effects of the proposed action and other actions in the same geographic area.
- Geographic boundaries and time period: U.S. EPA reviewers should determine whether the NEPA analysis has used geographic and time boundaries large enough to include all potentially significant effects on the resource of concern. The NEPA document should delineate appropriate geographic areas including natural ecological boundaries, whenever possible, and should evaluate the time period of the project’s effects.
- Past, present and reasonably foreseeable future actions: The adequacy of CIA depends on how well the analysis considers impacts that are due to past, present, and reasonably foreseeable actions. U.S. EPA reviewers should determine whether the CIA adequately considered:
    - Whether the environment has been degraded, and if so, to what extent.
    - Whether ongoing activities in the area are causing impacts.
    - The trends for activities and impacts in the area.
- Describing the condition of the environment: The NEPA analysis should establish the magnitude and significance of cumulative impacts by comparing the environment in its naturally occurring state with the expected impacts of the proposed action when combined with impacts of other actions. Use of a ‘benchmark’ or ‘baseline’ for purposes of comparing conditions is an essential part of any environmental analysis.
- Using thresholds to assess resource degradation: In the context of U.S. EPA reviews, quantitative thresholds can be used to determine if the cumulative impacts of an action will be significant and if the resource will be degraded to unacceptable levels.

Memorandum: Guidance on the consideration of past actions in cumulative effects analysis (Council on Environmental Quality 2005)

In this Memorandum, the Council on Environmental Quality provides guidance on the extent to which agencies of the U.S. Federal government are required to analyse the environmental effects of past actions when they describe the cumulative environmental effect of a proposed action.

The environmental analysis required under NEPA is forward-looking, in that it focuses on the potential impacts of the proposed action that an agency is considering. Thus, review of past actions is required to the extent that this review informs agency decision making regarding the proposed action, which can occur in two ways:

1. The effects of past actions may warrant consideration in the analysis of the cumulative effects of a proposal for agency action. In determining what information is necessary for a CIA, agencies should use scoping to focus on the extent to which information is ‘relevant to reasonably foreseeable significant adverse impacts’. Based on scoping, agencies have discretion to determine whether, and to what extent, information about the specific nature, design, or present effects of a past action is useful for the agency’s analysis of the effects of a proposal for agency action and its reasonable alternatives. Generally, agencies can conduct an adequate CIA by focusing on the current aggregate effects of past actions without delving into the historical details of individual past actions.

2. Experience with, and information about, past direct and indirect effects of individual past actions may also be useful in illuminating or predicting the direct and indirect effects of a proposed action. Agencies should clearly distinguish analysis of direct and indirect effects based on information about past actions from a CIA of past actions.

Considering cumulative effects under the National Environmental Policy Act (Council on Environmental Quality (1997)

This handbook provides a framework for advancing environmental impact analysis by addressing cumulative effects in either an environmental assessment (EA) or environmental impact statement (EIS). The handbook presents practical methods for addressing coincident effects (adverse or beneficial) on specific resources, ecosystems and human communities of all related activities, not just the proposed project or alternatives that initiate the assessment process. The handbook provides informal guidance and is not exhaustive or definitive; it should assist practitioners in developing their own study-specific approaches.

The handbook defines eight general principles of CIA:

1. Cumulative effects are caused by the aggregate of past, present, and reasonably foreseeable future actions.
2. Cumulative effects are the total effect, including both direct and indirect effects, on a given resource, ecosystem, and human community of all actions taken, no matter who (federal, non-federal or private) has taken the actions.
3. Cumulative effects need to be analysed in terms of the specific resource, ecosystem, and human community being affected.
4. It is not practical to analyse the cumulative effects of an action on the universe; the list of environmental effects must focus on those that are truly meaningful.
5. Cumulative effects on a given resource, ecosystem and human community are rarely aligned with political or administrative boundaries.
6. Cumulative effects may result from the accumulation of similar effects or the synergistic interaction of different effects.
7. Cumulative effects may last for many years beyond the life of the action that caused the effects.
8. Each affected resource, ecosystem, and human community must be analysed in terms of its capacity to accommodate additional effects, based on its own time and space parameters.

The handbook identifies seven primary methods for developing the conceptual causal model for a CIA as:

- Questionnaires, interviews and panels to gather information about the wide range of actions and effects needed for a CIA.
- Checklists to identify potential cumulative effects by reviewing important human activities and potentially affected resources.
- Matrices to determine the cumulative effects on resources, ecosystems and human communities by combining individual effects from different actions.

- Networks and system diagrams to trace the multiple, subsidiary effects of various actions that accumulate upon resources, ecosystems, and human communities.
- Modelling to quantify the cause and effect relationships leading to cumulative effects.
- Trends analysis to assess the status of resources, ecosystems, and human communities over time and identify cumulative effects problems, establish appropriate environmental baselines, or project future cumulative effects.
- Overlay mapping and GIS to incorporate locational information into cumulative effects analysis and help set the boundaries of the analysis, analyse landscape parameters, and identify areas where effects will be the greatest.

Recent trends in cumulative impact case law (Smith 2005)

This document presents the results of an analysis conducted for the purpose of examining recent trends in case law in the U.S. regarding CIA. An examination of rulings from the Ninth Circuit Court of Appeals for the period 1995-2004 revealed that cumulative impacts litigation is increasing, with 20% of the cases decided in the year 2004 alone.

As for how the CIA in the agency NEPA documents held up under judicial scrutiny in the Ninth Circuit Court, the record is decidedly in the plaintiffsô favour. Challengers were successful in their claims of inadequate analysis in 60% of the cases decided in the ten year analysis period. The most common reason plaintiffs used to challenge an agencyôs CIA was that there was not an adequate analysis of all past, present and reasonably foreseeable future actions.

The results of the overall analysis revealed some key lessons for practitioners desiring to improve their CIA and to increase the likelihood that they will withstand a legal challenge should one arise:

- Lesson 1: Consider cumulative impacts for each resource analysed, and carefully search out, document and analyse all past, present and foreseeable future actions.
- Lesson 2: Do not make unsubstantiated claims about cumulative impacts.
- Lesson 3: The CIA does not need to be óperfectô to survive a legal challenge.
- Lesson 4: Do not tie your CIA to either a programmatic NEPA document that does not contain site-specific analysis or to a non-NEPA document.

In summary, a simple recipe for preparing a legally adequate CIA emerges clearly from this analysis:

- Ensure cumulative impacts are considered for all relevant resources.
- Ensure all relevant past, present and reasonable foreseeable future actions which may affect the resources analysed are identified and assessed.
- Ensure that analysis includes facts, data and rationale to back up the conclusions made about cumulative impacts.

PRACTICE GUIDES FOR CONDUCTING A CIA

Cumulative impact: a good practice guide for the Australian Coal Mining Industry (Franks et al. 2010)

The Australian Coal Association Research Program funded this project, which acknowledged that there are increasing expectations for regulation mandating CIA in NSW and Queensland. The report notes that Federal Court rulings have interpreted the EPBC Act to include cumulative impacts, and this is anticipated to be included in the reform of the EPBC Act. The Guide also provides a business case why CIA is in the interests of mining entities. Franks et al. (2010) suggest that managing cumulative impacts can level the playing field for individual players. In addition, voluntary assessment with supporting stakeholder consultation may avoid lengthy approvals process.

Cumulative impacts are defined as successive, incremental or combined impacts that can be positive and negative. The Guide identifies that cumulative impacts can arise from a single operation in addition to current activities, multiple mining (and processing) operations, or interactions of mining impacts with other land use impacts. Cumulative impacts can leave the receptor more sensitive to future impacts particularly as impacts reach a ótipping pointôfor that system. There may also be a reverse cumulative impact from mine closures, particularly on social aspects of the receiving environment.

The Guide stresses the importance of understanding impact pathways, cause and effect relationships, as well as source and sink impacts. The Guide advocates a system approach to understanding the totality of impacts to a receiving environment. The influence of external factors on the receiving environment and the historical trend in the study area provides context for interpreting impact assessment results.

Modelling requires geographic, time and systems boundaries to be explicitly defined and calibrated. Franks et al. (2010) cite a framework for the cumulative impacts of mining operations on groundwater systems, currently in development by Sinclair Knight Merz and the Sustainable Minerals Institute, University of Queensland.

CIA will inherently contain uncertainty. Data aggregation must remain meaningful to the scale of interpretation depending on the system and issue. It is also likely that CIA will identify knowledge gaps that may be resourced by cooperative data projects or monitoring programs. Franks et al. (2010) are strong advocates of strategic regional assessments as they may identify issues and potential resolution to issues at an early stage of project development (or prior to exploration) and can establish regional datasets for ongoing monitoring and compliance assessment. The Regional Forest Agreements are cited as an example of resource development planning in Australia. The authors state that resource limitations are rarely an impasse to CIA. Data sharing of monitoring data can be useful for resource intensive modelling. A Canadian example is provided from Alberta, Canada, where the Oil Sands Developers Group have in-house data collection and analysis systems with assistance from consultants where required. Data are reported publically in an anonymous and aggregated form to overcome any commercial sensitivity of new mining proposals.

The Guide provides a generic process to CIA summarised into eight steps (**Table B19**).

Table B19: Generic approach to CIA (Franks et al. 2010)

Step	Tasks
1. Determine key impacts of concern to stakeholders.	Establish the focus and boundaries of the assessment.
2. Define the system to be understood.	Delineate the study area, profile baseline systems including existing impacts.
3. Determine how impacts are accumulating.	Drill down into how impacts may aggregate in time and space.
4. Determine what actions are contributing to the generation of impacts and by whom.	Forecasting, modelling and scenario analysis. The use of scenarios is identified as a tool to anticipate change under different plausible future situations.
5. Review available strategies.	Identify management options to avoid or mitigate potential impacts. This can include information sharing and new data collection strategies to inform future impact assessments.
6. Consider whether collaborations are necessary to pursue strategies.	Iteratively build a cooperative study team. This team may facilitate information exchange and inform key stakeholders of issues arising.
7. Monitor priority receptors and agree on thresholds and indicators with stakeholders.	Monitoring and evaluation loops.
8. Report and communicate to stakeholders.	Discuss the findings with stakeholders.

Guidance for preparers of Cumulative Impact Analysis (California Department of Transport 2005)

The California Department of Transportation (2005) provides eight steps to serve as guidelines for identifying and assessing cumulative impacts for an Environmental Assessment:

- Identify resources (e.g. wetland, water quality, and threatened species) that may be directly or indirectly affected.
- Define the geographic extent of the (e.g. drainage basin or sub-basin or range, sub-range; or population distribution for a species.
- Describe the current health of the resource, recent trends which have affected the resource e.g. changes resulting from flood or fire and the historical context (key historical patterns) of the resource.
- Identify direct and indirect impacts of the project.
- Identify other reasonably foreseeable actions or projects that affect each resource.
- Assess the cumulative impact of the proposed project in combination with other actions/projects.
- Report the results along with any limitations faced.
- Assess the need for mitigation for direct, indirect, or cumulative impacts.

European commission guidelines for the assessment of indirect and cumulative impacts as well as impact interactions (Hyder 1999)

These are guidelines prepared for the European Commission which consider the assessment of indirect and cumulative impacts as well as their interactions with each other.

The general principles of scoping can be applied to the assessment of cumulative impacts and will help identify the potential impacts considered to be significant and which of those will require further assessment. Data collection should focus on determining the current and future status of the environmental resource, historical trends and existing regulatory standards and development plans.

The following is a list of general scoping principles which can be applied to the assessment of cumulative impacts:

- Setting geographical and time frame boundaries for the assessment.
- Consideration should be given to historical or potential future impacts which may affect the assessment.
- Collecting the baseline data.
- Assessing the impacts.
- Consideration of alternatives.

The guidelines provide information on eight methods and tools which were selected from case studies and literature research which can be used to assess cumulative impacts. A combination of these techniques can be used, or certain methods can be adopted at different stages of the EIA process.

These generally fall into two groups:

1. Scoping and Impact Identification Techniques - these identify how and where an indirect or cumulative impact or impact interaction would occur. Examples include network and system analysis, consultation and questionnaires, checklists and spatial analysis. Spatial analysis, in particular GIS, is suited to large scale or complex projects and for projects where analysis or modelling is required. However, it can be expensive to buy and run a GIS package and there is also a need for skilled staff to operate the system.
2. Evaluation techniques - these quantify and predict the magnitude and significance of impacts based on their context and intensity. Examples include evaluation techniques, modelling and carrying capacity analysis. Modelling is an analytical tool which enables the quantification of impacts which can affect the environment by simulating environmental conditions, e.g. air quality, water quality, noise modelling. Developing a new model is generally demanding in terms of cost, expertise, time and possibly data so they are best suited to larger and more complex projects.

Hyder (1999) recommended assessing cumulative impacts early in a project, citing matrix development and expert opinion as useful methods for scoping and evaluating projects.

Framework for assessing potential local and cumulative effects of mining on groundwater resources (Howe 2011)

The National Water Commission (NWC) recognised the need for groundwater use by mining operations to be managed rigorously and consistently. The National Water Commission engaged Sinclair Knight

Merz and the Sustainable Minerals Institute to develop a framework for assessing the potential local and cumulative effects of mining on groundwater resources and to develop tools to help predict and assess these effects.

A number of objectives were proposed for the project, which were met through a series of reports, guidelines and risk management based tools. A key output was the development of the mining risk framework which is supported by the risk management based tools as indicated by Howe (2011) below.

- Groundwater and Resource Information for Development Database (GRIDD): A GIS-based tool to categorise mining and water resources at a 100 kilometre by 100 kilometre grid scale.
- Multi-Mine Water Accounts Tool: A software tool to enable integrated management and accounting of water resources across multiple mines sites. This supports the sustainable and efficient use of water resources by the mining industry. The Multi-Mine Water Accounts Tool:
    - Builds on the water accounting framework developed for the Australian minerals industry, through the Minerals Council of Australia.
    - Includes a method to assess the potential for worked water sharing across a group of mines operating within a region.
    - Includes a ówhat ifô scenario engine to allow simulations of potential expansions or new mines, to support water resource planning.
- Cumulative Impact Assessment Tool (CIAT): A software tool for assessing risk in relation to the impact that mining proposals may have on the condition of existing groundwater, and the interaction between different groundwater users (a link to the tool is provided, but a login and password is required).

SYNOPSIS

The case studies reviewed were from Australia, North America and Europe. A number of different approaches were applied, but there were tasks common to most studies. These were:

- An initial literature review and data gathering phase.
- Defining the system of interest.
- Use of conceptual models (that include thresholds and triggers).
- Development of risk assessment matrices to qualify risks.
- Numerical modelling, often with GIS support.
- Scenario testing against a base case.

Few studies incorporated expert advice and key stakeholder consultation, or monitoring, feedback and adaptive management. On a technical level, few authors offered details on the actual mechanism for calculating additive and synergistic impacts; the decision making process for thresholds and triggers, or a conclusion as to whether the approach implemented was successful.

The practice guides each offered a recommended approach for conducting CIA. Analysis of the tasks in each practice guide revealed the following consolidated approach (adapted from Hyder 1999, CDT 2005, Franks et al. 2010, and Howe 2011):

1. Determine key impacts of concern to stakeholders and sensitive receivers ï this involves consultation with the local and regional community, government, industry, and experts. Some guides advocated the use of a specialist workgroup comprised of stakeholder representatives.
2. Define the system of interest ï identify resources that may be directly and indirectly affected (e.g. air quality, water quality, native vegetation, etc.), and define the geographic extent of the study area (e.g. catchment or sub-catchment, population distribution for a species).
3. Collect baseline data ï describe the current health of the resource, recent trends that have affected the resource, thresholds and triggers.
4. Determine how the impacts are accumulating ï via conceptual models, expert advice, and/or modelling.
5. Determine what actions are contributing to the impacts and by whom ï identify the direct and indirect impacts of the project in terms of their location, frequency, timing, duration, magnitude and potential interactions.
6. Review available strategies ï consider alternatives, identify other reasonably foreseeable actions or projects, and assess the cumulative impact of the proposed project in combination with other actions/projects.
7. Consider whether collaborations are necessary to pursue strategies ï there are opportunities for industry groups to collaborate to share the cost and outcomes of CIA, and to improve strategic planning.
8. Monitor sensitive receivers and agree on thresholds and indicators with stakeholders ï this task is informed by stakeholder consultation, and incorporates scientific understanding and expert advice to identify thresholds for adaptive management.
9. Report and communicate to stakeholders ï maintain transparent communication with stakeholders, reporting the results of the assessment, monitoring and any limitations encountered. Also assess the need for mitigation of direct, indirect or cumulative impacts.

A key difference in the studies was the modelling technique applied. The various approaches reviewed each customised a modelling technique to suit their specific goals. This included purchasing specialised software (e.g. ALCES®), creating a tailored probability model, using correlation and regression analyses, and building software that incorporates a GIS component and relies on impact matrices, where required. The spatial approach used in this CIA to apply potential impacts to the Greater Bilby, Hamersley Lepidium, Northern Quoll, Pilbara Leaf-nosed Bat and Pilbara Olive Python is consistent with the recommended approach outlined above. One of the main advantages of the approach is identification of the spatial distribution of potential impacts and the likely interaction (through multiplication and spatial overlay). This is suitable for large scale assessments such as for the Proposal. The main limitations of the approach are outlined in Section 8.1.3 and relate to the distance or area thresholds specified for each potential impact and the magnitude/value of the potential impact applied for each distance or area category, not to the approach per se. In this regard, it is noted that the levels of potential impact were set based on the best available literature, data and specialist expertise and knowledge (including peer review).

Appendix C: Sensitivity analysis

Background

The Commonwealth CIA involved development and GIS application of a range of potential impacts related to mining operations and infrastructure development. Levels of potential impact were assigned based on the expected spatial extent of the impact at differing intensities, as well as conceptualisation of the relative susceptibility of species to the impact. Assignment of levels of potential impact was based on a conceptual model that detailed relative levels of threat to each target species based on expert understanding and scientific literature. Quantifying potential impact involves considerable subjective judgment in determining the magnitude and spatial extent of impacts, which can represent a source of uncertainty within the modelling process. A sensitivity analysis was undertaken to test the robustness of assignment of levels of potential impact and determine the degree to which minor changes in levels of impact affected results.

Approach

The approach to the sensitivity analysis was as follows:

1. Selection of species and impact scenario. A single species (Pilbara Olive Python) was used and one impact scenario (Scenario 1 ï existing impacts) was tested to enable greater focus on testing a range of alternative levels of impact.
2. Generation of a ôSensitivity Base Caseô for the Pilbara Olive Python, which represents the application of the chosen impact scenario (Scenario 1) to the target speciesô base case habitat model using the same levels of potential impact for Scenario 1 as the standard Commonwealth CIA analysis (as per the Rev1 Commonwealth CIA report), but for only a subset of the potential impacts to simplify the analysis. In additional to removal of habitat within the disturbance footprint, the Sensitivity Base Case considered fragmentation of habitat and predation. These were tested within the sensitivity analysis as these were expected to have the most potential to affect results due to large areas of potential impact. The modifier for habitat loss was also included to facilitate improved and sensible comparison to impact areas calculated in the core analysis undertaken within the CIA (by ensuring that known mining losses are accounted for).
3. Generation of three alternative outcomes for Scenario 1, using different levels of potential impact to those used in the Sensitivity Base Case as per (a), (b) and (c) below, noting that values for 0% and 100% impact were unchanged in each of the alternatives to preserve the range of scoring.
    a. Alternative 1 - Uniform increase of 10% impact (i.e. 20% impact to 30% impact and 50% impact to 60% impact).
    b. Alternative 2 - Uniform increase of 20% impact (i.e. 20% impact to 40% impact and 50% impact to 70% impact).
    c. Alternative 3 ï Increased spread between levels (i.e. 20% impact to 30% impact and 50% impact to 70% impact for fragmentation of habitat; 20% impact to 50% impact for predation).
4. Calculation of the degree of change from the Sensitivity Base Case to Alternatives 1, 2 and 3.

The values used in the sensitivity analysis for the Sensitivity Base Case and Alternatives 1, 2 and 3 are provided in **Table C1**.

Table C1: Values used in the sensitivity analysis for the Sensitivity Base Case and Alternatives 1-3

Impact		Level of potential impact to Pilbara Olive Python habitat suitability			
		Sensitivity Base Case	Alternative 1	Alternative 2	Alternative 3
Removal of habitat	Clearing footprint	100%	100%	100%	100%
Fragmentation of habitat	>450 ha	0%	0%	0%	0%
	200-450 ha	20%	30%	40%	30%
	100-200 ha	50%	60%	70%	70%
	<100 ha	100%	100%	100%	100%
Predation	>2 km	0%	0%	0%	0%
	0-2 km	20%	30%	40%	50%

Results

Figure C1 illustrates the distribution of habitat ranks within the Sensitivity Base Case. The distributions of changed habitat ranks are illustrated in **Figure C2** to **Figure C4**. The marginal change from the Sensitivity Base Case to Alternatives 1-3 is provided in **Figure C5** to **Figure C7**.

The area of each habitat rank in the Sensitivity Base Case and Alternatives 1-3 is provided in **Table C2**, along with the per cent change between each alternative and the Sensitivity Base Case. The area of each habitat rank was generally within 4% of the area of the Sensitivity Base Case. The only exception was the area of Habitat Rank 3 in Alternative 3, which decreased by 7% in comparison to the Sensitivity Base Case. This represents a decrease of approximately only 1% relative to the total area of the Pilbara bioregion. That is, Habitat Rank 3 extends across 15.99% of the Pilbara bioregion in the Sensitivity Base Case and 14.83% of the bioregion in Alternative 3; a difference of 1.16%.

The area that increased or decreased by zero, one, two or three habitat ranks as a result of each alternative is provided in **Table C3**. The maximum change in habitat rank for each alternative was one rank. In all alternative scenarios, greater than 96.9% of the Pilbara bioregion remained unchanged with respect to habitat rank.

Table C2: Area of each habitat rank in the Sensitivity Base Case and Alternatives 1-3

Habitat Rank	Area (ha) [% change compared to Sensitivity Base Case]			
	Sensitivity Base Case	Alternative 1	Alternative 2	Alternative 3
1	10,786,084	10,880,918 [+0.9%]	10,956,991 [+1.6%]	11,066,474 [+2.6%]
2	3,131,353	3,102,433	3,101,982	3,089,947

Habitat Rank	Area (ha) [% change compared to Sensitivity Base Case]			
	Sensitivity Base Case	Alternative 1	Alternative 2	Alternative 3
		[-0.9%]	[-0.9%]	[-1.3%]
3	2,843,581	2,810,750 [-1.2%]	2,735,127 [-3.8%]	2,637,679 [-7.2%]
4	1,024,123	991,041 [-3.2%]	991,041 [-3.2%]	991,041 [-3.2%]

Table C3: Area of habitat that increased or decreased by one, two or three ranks, or that did not change between the Sensitivity Base Case and Alternatives 1-3

Change in Habitat Rank	Area (ha) of potential change [% of Pilbara bioregion]		
	Sensitivity Base Case to Alternative 1	Sensitivity Base Case to Alternative 1	Sensitivity Base Case to Alternative 1
+3	0 [0%]	0 [0%]	0 [0%]
+2	0 [0%]	0 [0%]	0 [0%]
+1	0 [0%]	0 [0%]	0 [0%]
0	17,591,310 [98.9%]	17,439,613 [98.1%]	17,232,683 [96.9%]
-1	193,831 [1.1%]	345,528 [1.9%]	552,458 [3.1%]
-2	0 [0%]	0 [0%]	0 [0%]
-3	0 [0%]	0 [0%]	0 [0%]

Conclusion

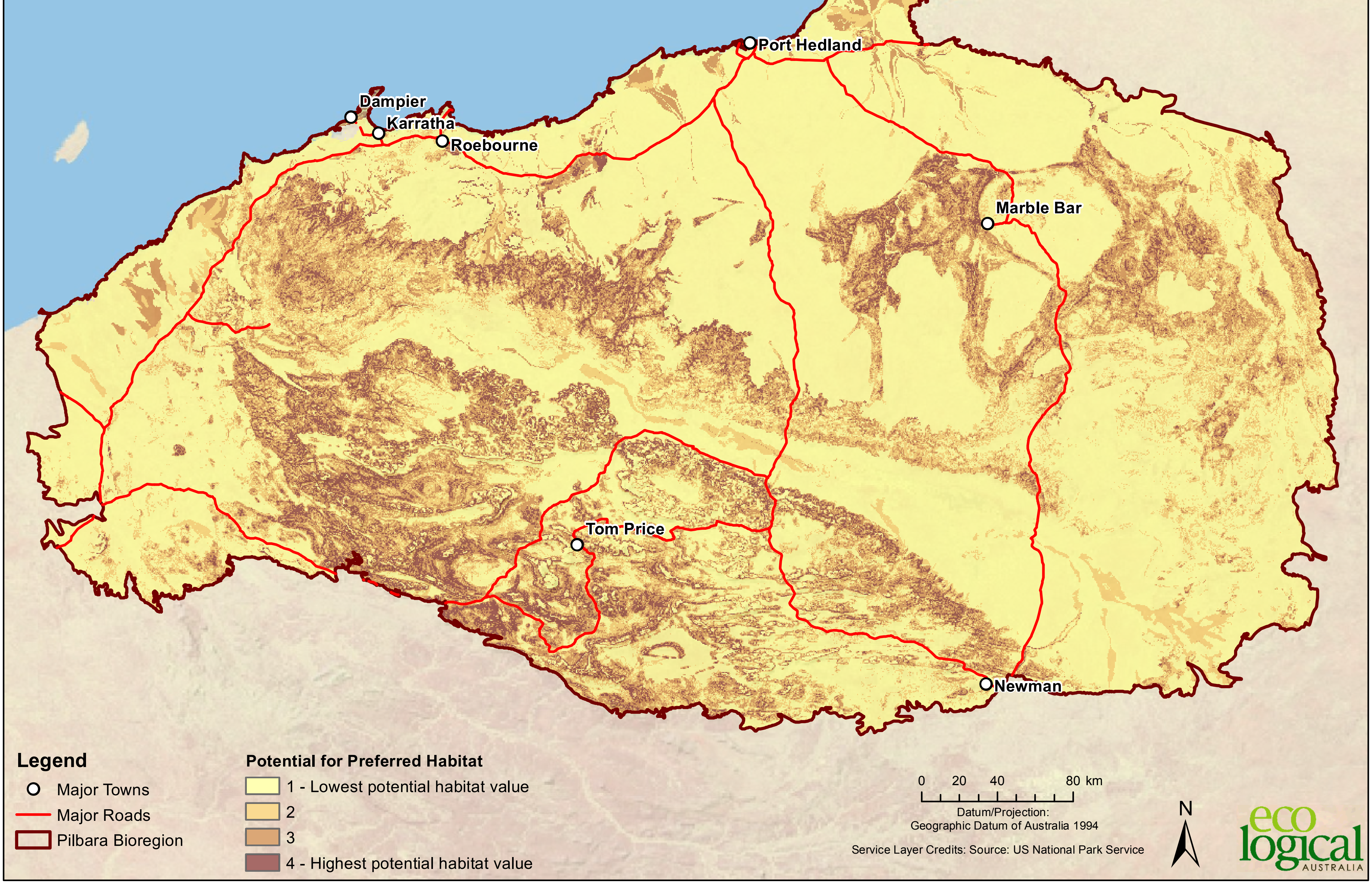
This sensitivity analysis tested whether increasing the level of potential impact by 10% or 20%, or increasing the spread between mid-range levels of potential impact (i.e. excluding the 0% impact and 100% impact values) resulted in a significantly different outcome. The results presented indicate that the selection of alternative levels of potential impact had a negligible effect on results compared to the levels used in the standard CIA analysis. Therefore, the CIA approach in designating levels of potential impacts is considered to be robust and fit for purpose, with minor variations in levels of potential impact unlikely to significantly affect the outcome.

Pilbara Olive Python Preferred Habitat - Sensitivity Base Case

Figure C1

Description

Base Case - Utilises modifiers for habitat loss, predation and fragmentation using the same modifier values as used for Scenario 1 in the core analysis.



Datum/Projection:
Geographic Datum of Australia 1994

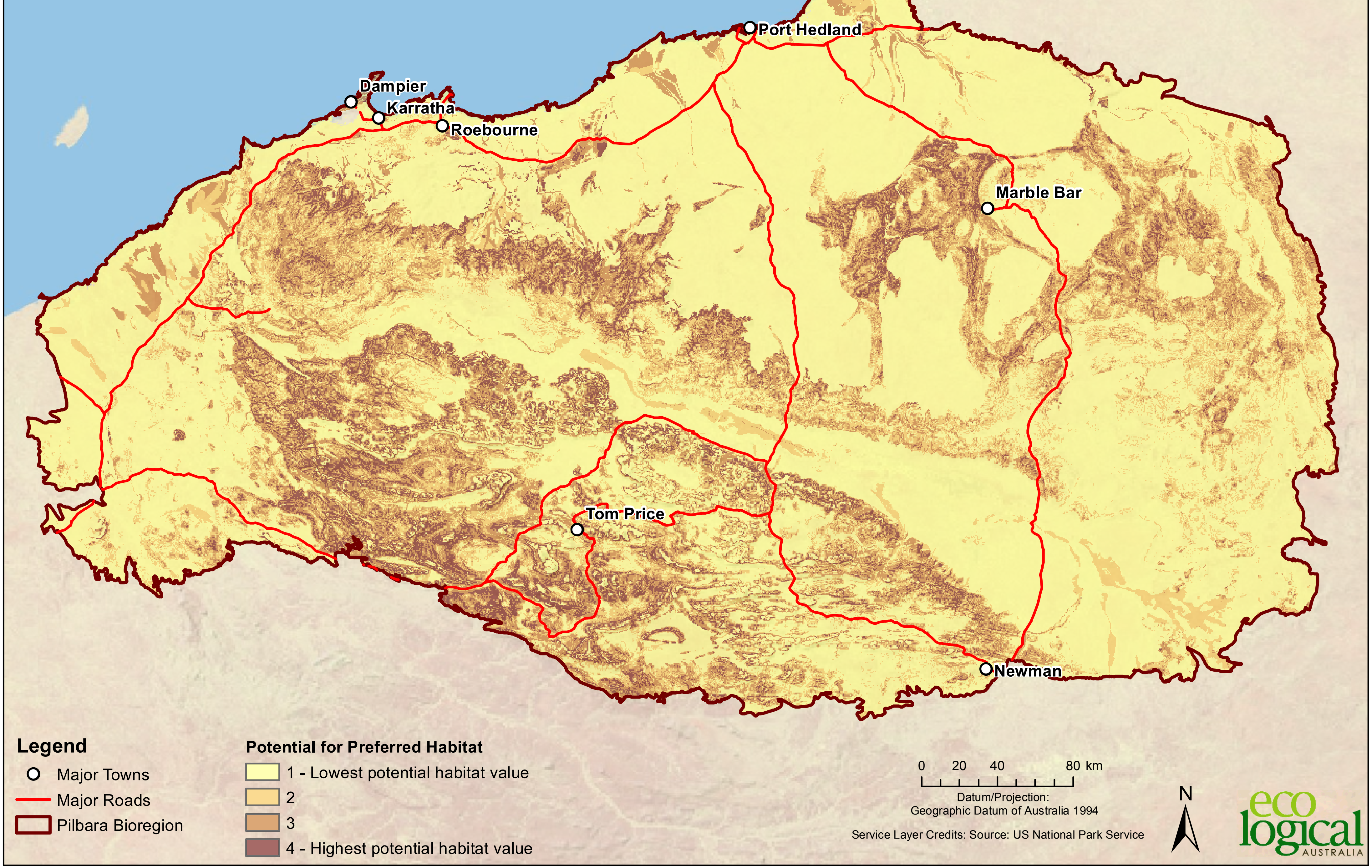
Service Layer Credits: Source: US National Park Service

Pilbara Olive Python Preferred Habitat - Sensitivity Alternative 1

Figure C2

Description

Alternative 1 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where mid-range scores are reduced by 0.1 from the core analysis



Datum/Projection:
Geographic Datum of Australia 1994

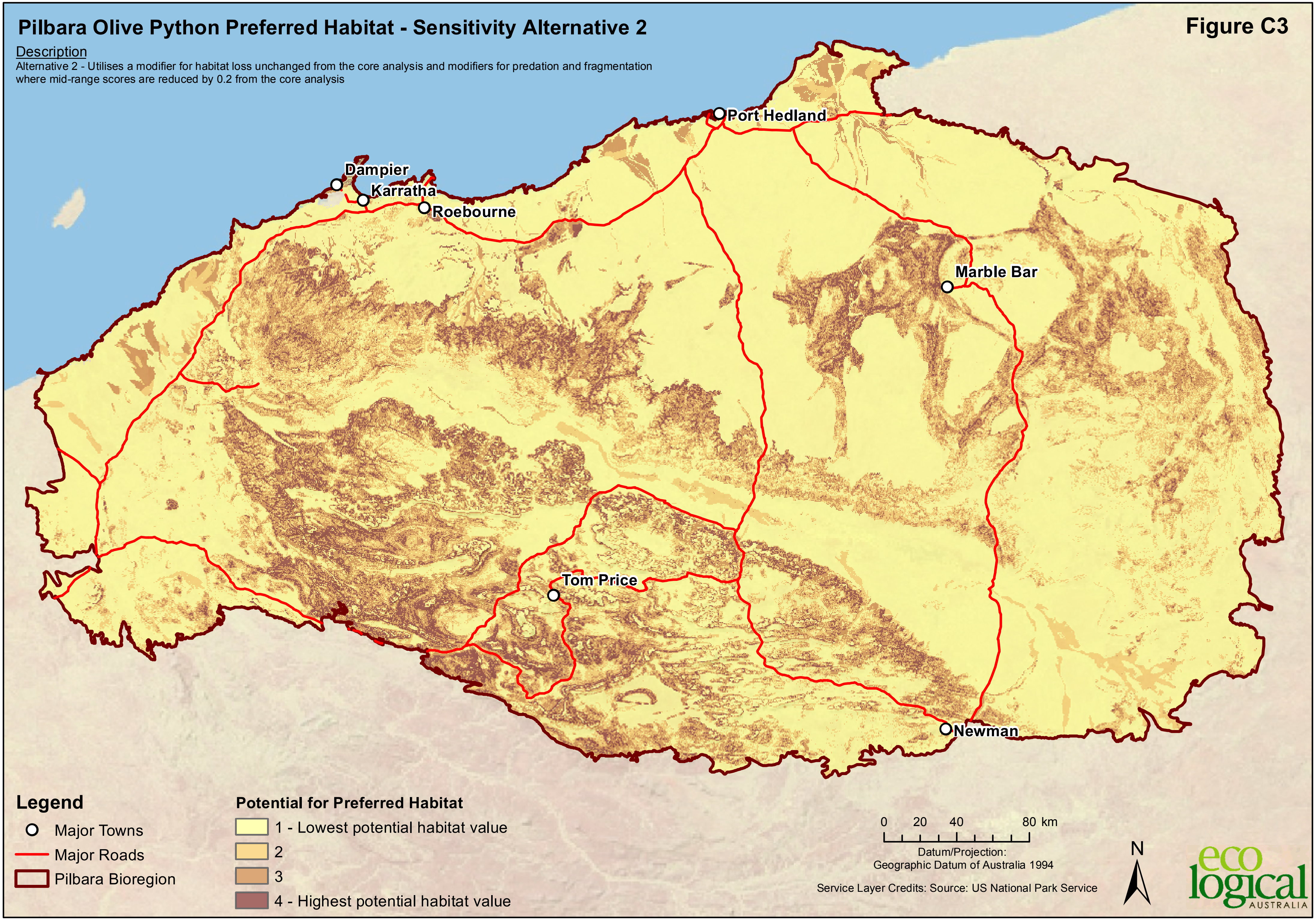
Service Layer Credits: Source: US National Park Service

Pilbara Olive Python Preferred Habitat - Sensitivity Alternative 2

Figure C3

Description

Alternative 2 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where mid-range scores are reduced by 0.2 from the core analysis



Datum/Projection:
Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

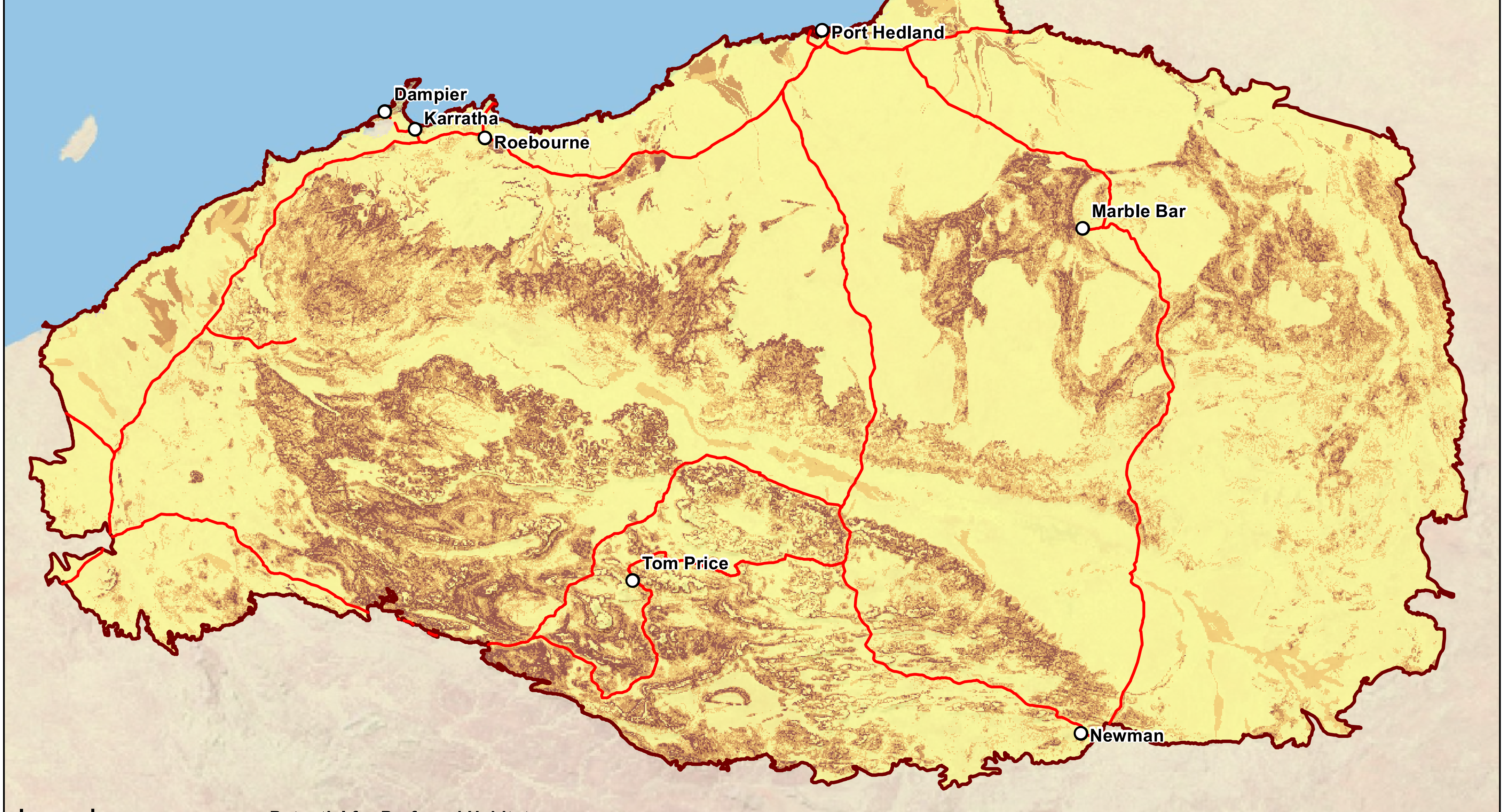
eco logical AUSTRALIA

Pilbara Olive Python Preferred Habitat - Sensitivity Alternative 3

Figure C4

Description

Alternative 3 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where the range between class thresholds are increased by 0.1 from the core analysis



Legend

- ○ Major Towns
- Major Roads
- Pilbara Bioregion

Potential for Preferred Habitat

- 1 - Lowest potential habitat value
- 2
- 3
- 4 - Highest potential habitat value

Datum/Projection:
Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

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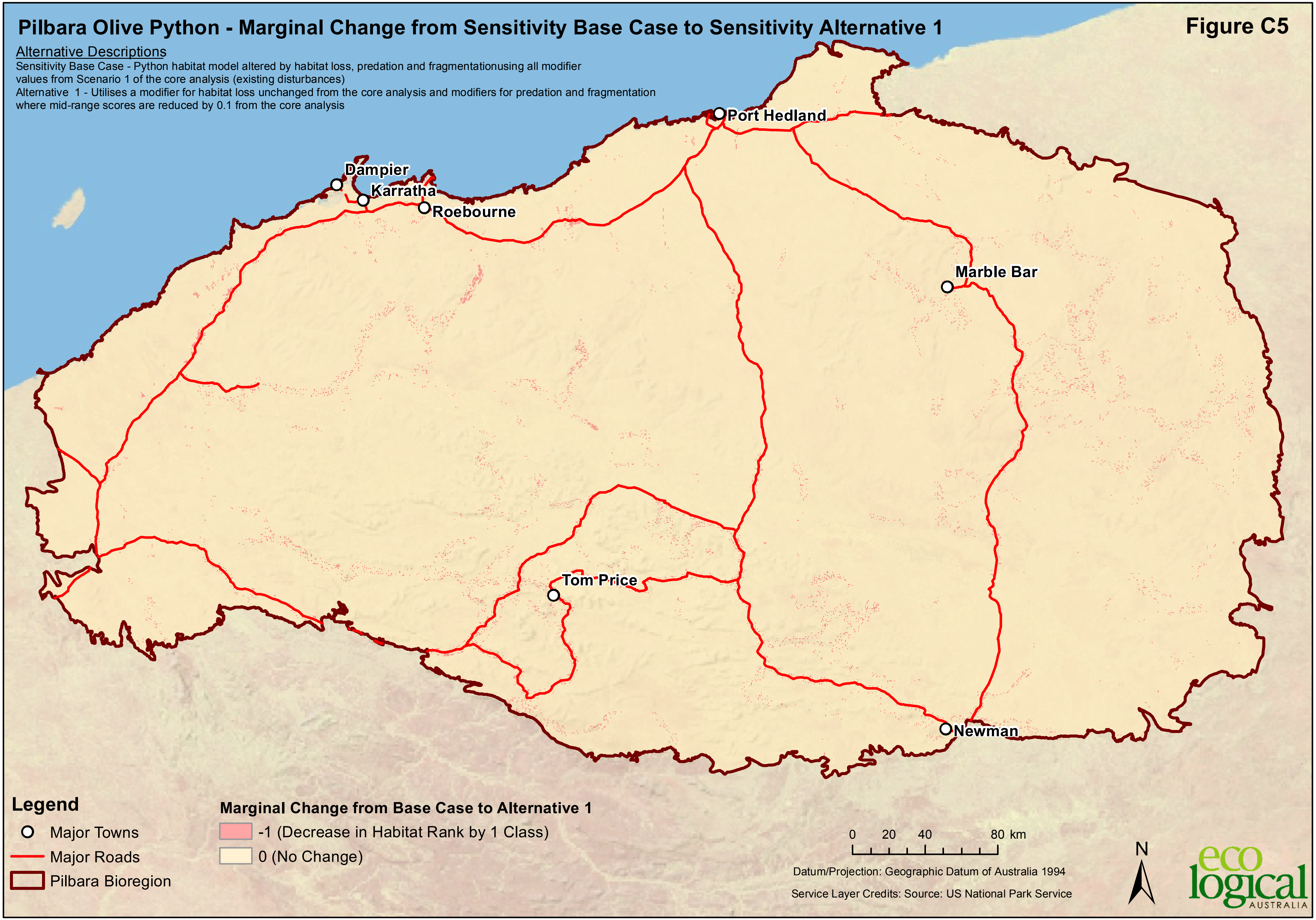
Pilbara Olive Python - Marginal Change from Sensitivity Base Case to Sensitivity Alternative 1

Figure C5

Alternative Descriptions

Sensitivity Base Case - Python habitat model altered by habitat loss, predation and fragmentationusing all modifier values from Scenario 1 of the core analysis (existing disturbances)

Alternative 1 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where mid-range scores are reduced by 0.1 from the core analysis



Legend

- ○ Major Towns
- — Major Roads
- ▭ Pilbara Bioregion

Marginal Change from Base Case to Alternative 1

- 🟥 -1 (Decrease in Habitat Rank by 1 Class)
- ▭ 0 (No Change)

Datum/Projection: Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

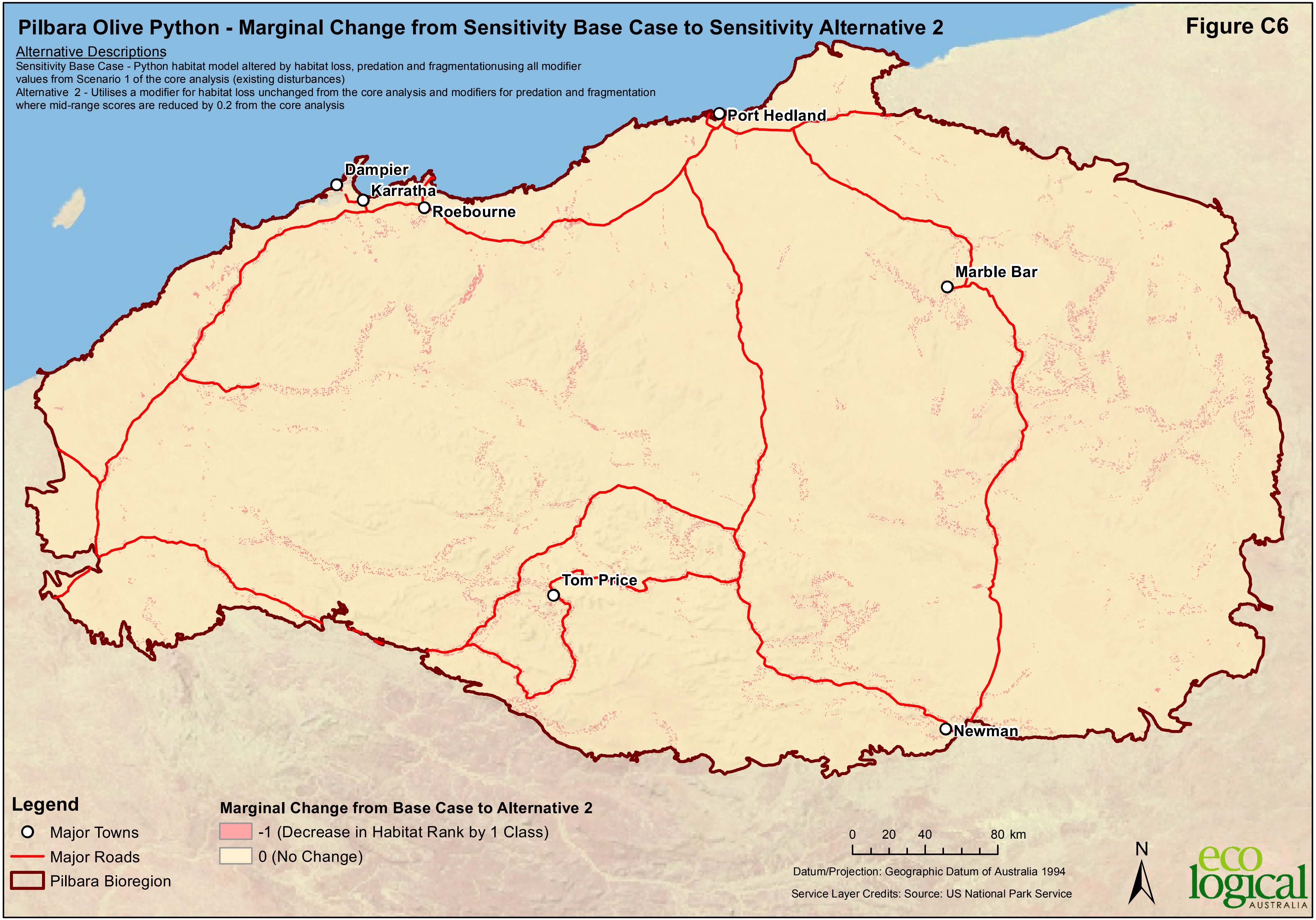
Pilbara Olive Python - Marginal Change from Sensitivity Base Case to Sensitivity Alternative 2

Figure C6

Alternative Descriptions

Sensitivity Base Case - Python habitat model altered by habitat loss, predation and fragmentationusing all modifier values from Scenario 1 of the core analysis (existing disturbances)

Alternative 2 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where mid-range scores are reduced by 0.2 from the core analysis



Datum/Projection: Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

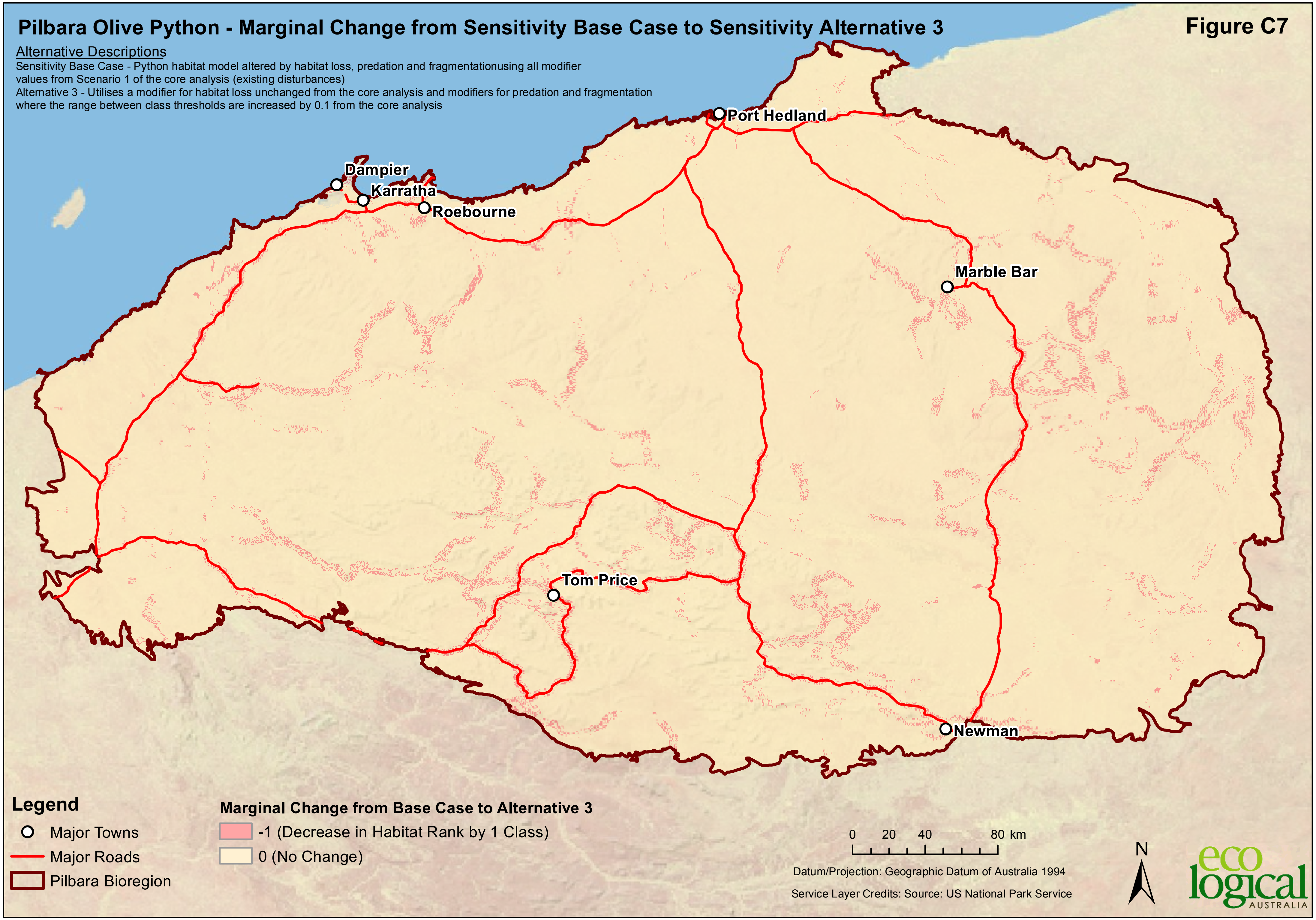
Pilbara Olive Python - Marginal Change from Sensitivity Base Case to Sensitivity Alternative 3

Figure C7

Alternative Descriptions

Sensitivity Base Case - Python habitat model altered by habitat loss, predation and fragmentationusing all modifier values from Scenario 1 of the core analysis (existing disturbances)

Alternative 3 - Utilises a modifier for habitat loss unchanged from the core analysis and modifiers for predation and fragmentation where the range between class thresholds are increased by 0.1 from the core analysis



Legend

- ○ Major Towns
- Major Roads
- Pilbara Bioregion

Marginal Change from Base Case to Alternative 3

- 🟥 -1 (Decrease in Habitat Rank by 1 Class)
- ▭ 0 (No Change)

Datum/Projection: Geographic Datum of Australia 1994

Service Layer Credits: Source: US National Park Service

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Appendix D: MNES viability summary

The following table provides a summary of peer reviewer species matter expertsô assessment of the cumulative impact of the Proposal to the viability of the five relevant MNES considered in the CIA.

Species matter expert	MNES	Peer reviewer assessment of viability
Rick Southgate	Greater Bilby	The cumulative impact likely to occur with the expansion of mining has been difficult to access based on the assessment conducted. This will remain the case until a more robust indication of distribution and extent of habitat suitability can be defined and the description of the threat layer is better resolved. It is likely the direct cumulative impact of BHPBIO mining operations on the viability of the bilby population in the Pilbara bioregion from pits and OSA, infrastructure, railway will be minor relative to the indirect cumulative impacts. The major impacts will likely occur indirectly through cattle management on the pastoral leases held by BHPBIO, the development of infrastructure to support pastoralism (more development of bores, roads etc directly possibly supported by BHPBIO or indirectly from royalties to regions) and altered fire regimes resulting from mining operations and pastoralism. Expansion of this pattern will likely cause greater habitat degradation and increase overall predation pressure. Agriculture that may develop from dewatering and associated weed spread may also play a part. Weeds spread much further away from roads than 500 m (as suggested by the modelling assumptions), as occurs particularly down drainage lines. (Southgate, R., pers. comm., 2015)
Eddie van Etten	Hamersley Lepidium	The most important question here is: is the threat of extinction greater with planned future mining? Although there is a likely loss of many thousands of hectares in the most preferred habitat of *Lepidium catapycnon* with future mining, this loss is small relative to the widespread distribution of the species and the current impacts of mining. It is unlikely the predicted further ~4% reduction in ócoreô(most likely) habitat will further threatened the species given there will still likely be many large and widespread populations throughout the Pilbara outside future disturbance footprints which will remain viable over the long-term. The predicted impacts on the species are mostly due to clearing for mining and they do not factor in the potential for successful restoration of the species in mined areas. Although more research on the seed ecology/biology of the species is warranted, it is not an unreal expectation for the species to be successfully restored in mine rehabilitation areas, especially if the species is given high priority in terms of direct seeding and/or planting of tubestock. (van Etten, E., pers. comm., 2015)

Species matter expert	MNES	Peer reviewer assessment of viability
Mike Bamford	Northern Quoll	For the Northern Quoll, the greatest risk to viability remains the Cane Toad, with feral predators and fire also of concern. Grazing and weeds may have an effect. Cumulative impacts associated with BHP operations are thought unlikely to have the landscape scale impacts that drive population viability. Identifying interactions between BHP operations and the key threatening processes is important. (Bamford, M., pers. comm., 2015)
Kyle Armstrong	Pilbara Leaf-nosed Bat	To answer this question, I feel it is informative to consider two separate things: 1. A simple compilation of known roosts with approximate colony size estimates throughout the region, with the proportion of colonies and rough estimate of specified for leases held by BHPð as a summary of the current potential for existing BHPBIO operations to impact the species. Given that information on confirmed or suspected roosts was not specified in the modelling approach, this is not explicitly and clearly identifiable in the ñexisting impactò component of the CIA modelling; 2. The CIA model as it is presented, with particular attention paid to the proportion of ironstone country that will be impacted by BHPBIO operations. Given what I currently know of the existing level of representation of the PLNB in current BHPBIO operating leases / project areas, the proportional representation of both the number of confirmed or suspected roosts and numbers, is relatively low. The largest identified colonies are either in deteriorating old gold and copper mines, or a very small number of caves in ironstone and metamorphosed sandstones outside current mining interests. However, some important occurrences are known (e.g. around Yarrie in particular), and these are relevant to consider in the context of threats to all other known or suspected roosts. If the other roosts are secure, the priority for protecting those caves around Yarrie would not be as high. With regard to the second point, there is still much potential for new roosts in ironstone country to be found, as much of it is unexplored for the PLNB. We know that most caves in the Pilbara are too shallow to support colonies of the PLNB, but there is still the possibility of additional but undiscovered large colonies in rare deeper structures. If these are within zones of mining impact, they will hopefully be identified as part of the derived proposal process. Thus, viability of the MNES attributable to the cumulative BHPBIO operations probably represents a small proportion of the overall threat allocation for this taxon in the Pilbara, but significant local losses contributing to an overall level of decline sufficient for IUCN threatened status listing could still occur without exploratory survey, mitigation and management. (Armstrong, K., pers. comm., 2015)

Species matter expert	MNES	Peer reviewer assessment of viability
Mark Fitzgerald	Pilbara Olive Python	There remains substantial and probably unavoidable uncertainty concerning the ñviabilityò of Pilbara Olive Python attributable to BHP Billiton Iron Ore operations, particularly given the time frame under consideration. Given the observed persistence of both Pilbara Olive Python and the nominate species (Olive Python *Liasis olivaceus*) in post-mining and other anthropogenically altered landscapes, e.g. quarries (pers. obs.), the circumstances of mine closure management and attributes of post-mining landscapes are considered to be important factors affecting viability of the Pilbara Olive Python, yet these matters are explicitly excluded from the CIA. Management of particular habitat features both during and post-mining are considered likely to have important implications for the survival of individual pythons, and Pilbara Olive Python populations, and thus for the viability of the Pilbara Olive Python within the Proposal area. This includes the exclusion of Cane Toads from waterbodies within mining areas, retention of large slabs of rock, and concrete (for python nest sites) and recognition of the potential importance of retaining shelter site structures likely to be used by Pilbara Olive Python in mine closure plans. These can include surface water structures, scrap metal dumps, and other mine infrastructure, where practicable. While CSIRO estimate a high probability of persistence of the Pilbara Olive Python in the region (CSIRO 2014,,p37), it is unclear whether the impact of proliferating pit lakes was considered, and the threat from Cane Toads was in my view underestimated. Without detailed information on the demographic status of the python and more reliable assessment of impacts from climate change, predictions about viability of the species are unavoidably speculative. In conclusion, while persistence of the Pilbara Olive python within the Pilbara Bioregion is considered likely, the viability of the species within the BHPBIO Proposal lands will likely depend upon timely implementation of effective threat management. (Fitzgerald, M., pers. comm., 2015)

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