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RESEARCH ARTICLE

Modeling the impact of future development and public conservation orientation on landscape connectivity for conservation planning

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Abstract
Context Recent papers on the spatial assessment of conservation opportunity have focused on how social values for conservation may change modeled conservation outcomes. Accounting for social factors is important for regional wildlife corridor initiatives as they often emphasize the collaborative aspects of conservation planning.
Objectives We present an approach for characterizing the potential effects of public conservation orientation and projected future development land use scenarios on landscape connectivity.
Methods Using public participation GIS techniques (mail-based surveys linked to a mapping component), we classified spatially explicit conservation values and preferences into a conservation orientation index consisting of positive, negative, or neutral scores. Connectivity was then modeled using a least-cost path and graph-network approach for a range of conservation orientation and development scenarios in the Lower Hunter region, Australia. Scenarios were modelled through either adding vegetation (positive orientation) or removing vegetation (negative orientation, development).
Results Scenarios that included positive conservation orientation link the isolated eastern and western reaches of the Lower Hunter, even when negative conservation scores were included in the model. This outcome is consistent with proposed connectivity corridors identified in regional strategies. The development scenario showed connectivity patterns similar to only modelling negative conservation orientation scores, with greater fragmentation across the region.
Conclusions The modeled outcomes showed consistency between the public's conservation orientation and the ecological rationale for increasing connectivity within the region. If conservation orientation can be translated into conservation initiatives, the result will be enhanced regional landscape connectivity that is both ecologically beneficial, as well as socially acceptable.

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Keywords Public participation GIS, social research, connectivity, dispersal · Least-cost paths · Graph theory · Land use planning, conservation planning · Scenario planning · Urbanization

Introduction

Identifying, conserving or restoring vegetation in locations critical for supporting connectivity is a key focus of conservation efforts (Fischer and Lindenmayer 2006). The characterization of landscape connectivity requires a spatially explicit connectivity model combined with knowledge of species movement behavior. Connectivity can be analyzed using graph-networks in conjunction with methods for quantifying resistance to dispersal between habitat patches. Dispersal costs in areas of non-habitat are determined by land cover characteristics and represent the difficulty or mortality risk and the energetic costs of moving across these areas (Adriaensen et al. 2003; Sawyer et al. 2011). The potential for movement between patches and the optimum pathway between patches can be identified using least-cost pathways that avoid areas with high dispersal costs such as roads or residential areas for some species. These methods can be used to identify groups of patches at a regional scale that are connected and areas that are isolated due to the high dispersal cost and long distances. While these methods provide a systematic way of understanding connectivity based on existing land cover characteristics, comparatively few tools exist for systematically and spatially assessing how social factors can inform the development of regional scale connectivity networks.

Numerous calls have been made for integrating humans and their activities in landscape ecology (Wu and Hobbs 2002) and to consider the social-ecological context within which conservation priorities are situated (Cash et al. 2003; Cowling et al. 2010). Spatial prioritization studies that provide the socio-ecological context for conservation have drawn largely upon the concept of conservation opportunity (Knight et al. 2006), which suggests conservation priorities need to be assessed alongside the feasibility of implementation. A number of individual and collective factors have been proposed that may influence these opportunities including human capital, landholder attitudes and values, and land acquisition costs (Curran et al. 2012). Recent work has examined the spatial relationships between conservation priorities and self-reported conservation behavior (Raymond and Brown 2011), the social characteristics of the governance system which influence conservation actions (Ban et al. 2013; Mills et al. 2013), and the spatial relationships between conservation priorities and willingness to engage in conservation actions (Moon and Cocklin 2011).

Public participation GIS (PPGIS) methods, the process of using GIS technologies to produce local knowledge and empower local communities (Sieber 2006), have also been developed as a way to understand conservation opportunity. In this assessment context, conservation opportunities have been identified based on the spatial relationships among ecological values, social values, and public preferences for land management. Specific examples include: (i) a visual comparison of the spatial overlap between biological priorities for management and biodiversity values (Brown et al. 2004); (ii) the spatial cross-correlations between attributes of ecological value (e.g., net primary productivity) and social values (Alessa et al. 2008); (iii) the associations between aggregated indices of social value and ecological priorities (Bryan et al. 2011); iv) the relationships between social values to natural resource conditions and land cover (Sherrouse et al. 2011; van Riper et al. 2012; Brown 2013); (v) changes to biological priorities resulting from the integration of social values as species and development preferences as costs within zonation models (Whitehead et al. 2014), and (vi) an evaluation of PPGIS spatial data quality for use in conservation planning (Brown et al. 2015). These studies have enabled the spatial identification of socially acceptable and defensible areas for conservation, and in some instances, the costs associated with consideration of social values and preferences in addition to ecological values. For the purpose of simplicity, hereafter we refer to models based on social values and development preferences as the *public conservation orientation* scenario.

PPGIS methods have also been used to understand the potential for conflict between local development preferences and development zones projected by planning authorities. For example, the spatial associations between residents' social values and proposed national parks (Raymond and Brown 2006), and local development preferences and existing residential or agricultural development policies (Brown 2006; Goldberg et al.

2011). In these studies, conflict potential was derived from the spatial associations between social value or development preference point densities and projected land-uses. There was no weighting of value or preference points or consideration of the counteracting forces of acceptable and inappropriate development preferences. Brown and Raymond (2014) proposed that the highest potential for land use conflict will occur in areas where there is development preference disagreement (a large difference between areas of acceptable and inappropriate development preference) and high place importance (high landscape value intensities). Hence, the potential for development conflict was weighted according to the intensity of social values found within each grid cell.

The majority of existing studies integrating social data with ecological data have used static overlay geoprocessing methods, identifying areas of conflict and agreement (Lechner et al. 2014). More dynamic methods that integrate social data within planning tools, including feedback between the social and ecological data such as through scenario analysis, have primarily been conducted using systematic conservation planning tools [e.g. Zonation (Moilanen et al. 2013) or Marxan (Ball et al. 2009)], focusing only on biodiversity values (e.g. Whitehead et al. 2014) and have not included measures of public conservation orientation, including values of residents or communities of interest.

This study integrates social data describing the potential effects of public conservation orientation (both positive and negative) and projected development on connectivity through scenario analysis using a least-cost path and graph-based connectivity model at the regional scale, the first such study of its kind. Using the Lower Hunter region in New South Wales as a case study, we seek to answer the following research questions: (i) how would public conservation orientation, a spatially explicit measure of support or opposition to conservation, influence regional connectivity, and (ii) how would projected future development, which may or may not be consistent with public preferences for development, influence regional connectivity? We answer these research questions by modelling connectivity outcomes using graph-network software (least-cost paths) and future scenarios that add vegetation for positive conservation orientation or remove vegetation for negative conservation orientation and projected future development. We present the model results and discuss the implications for landscape connectivity and conservation planning in the Lower Hunter region.

Methods

Study area

The Lower Hunter region is located in eastern New South Wales, Australia, and covers approximately 430,000 hectares, 60 % of which is covered in native vegetation (Fig. 1; DECCW 2009). The Lower Hunter is home to a range of native ecosystems from grasslands to wetlands. In terms of areal extent, native vegetation in the Lower Hunter is primarily found as woody dominated ecosystems, consisting of forests and woodlands. The region contains features that are of national environmental significance under Australian legislation, including a number of threatened species, both within and outside existing conservation areas (DECCW 2009). The region also supports a variety of land uses including open-cut coal mining, and residential, industrial and agricultural development. Demand for residential dwellings is a major challenge for planners; in 2006, it was estimated that an additional 115,000 dwellings will be required to house the region's growing population over the next 25 years (NSW Department of Planning 2006). These trends are placing increasing pressure on the region's natural environment.

Connectivity modelling technique

We used a regional-scale connectivity model to characterize dispersal species within the Lower Hunter region in New South Wales, Australia. The connectivity modelling focused on connecting landscape features or land-facets instead of single species (e.g. Alagador et al. 2012; Brost and Beier 2012), characterizing connectivity between patches of woody vegetation greater than 10 ha. Woody vegetation is the dominant natural vegetation cover type within the Lower Hunter. The supporting rationale for this model is that it characterizes habitat and dispersal for the majority of the native fauna species that utilize woody native vegetation and the plant species that depend on these fauna for dispersal (Lechner and Lefroy 2014).

To model connectivity between patches, we used a graph-theoretic approach with least-cost paths within the Graphab software (Foltête et al. 2012) based on a

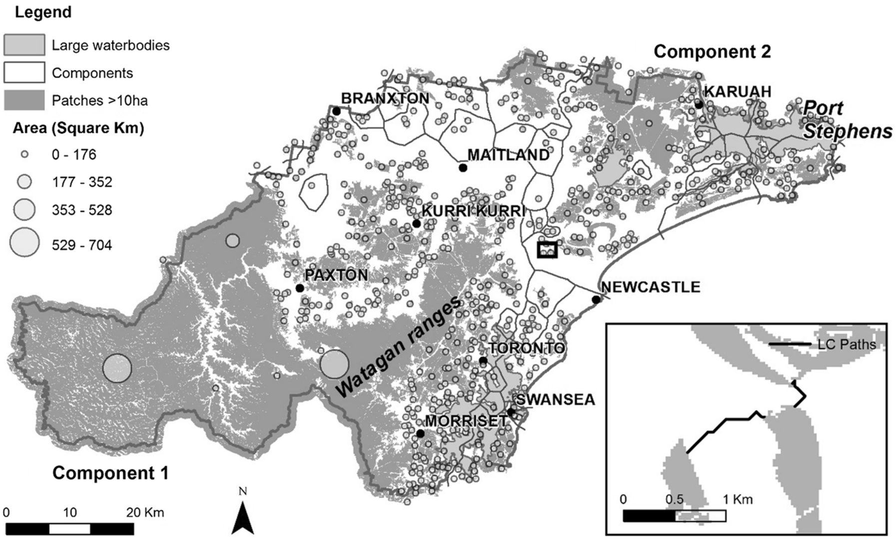

Fig. 1 Connectivity analysis using least–cost paths for patches greater than 10 ha using Graphab. *Circular graduated symbols* describing patch area are located at the center of each patch. Component boundaries are located at the midpoint between patches. Least cost (LC) paths between patches are shown in the *inset*

Table 1 Ecological parameters and input layers used in the connectivity model

Description	Value	Source
Dispersal and habitat characteristics		
Patch size	10 ha	Doerr et al. (2010)
Interpatch-crossing distance threshold with structural connectivity elements present and no dispersal costs	1.1 km	Doerr et al. (2010)
Gap-crossing distance threshold	106 m	Doerr et al. (2010)
Dispersal cost surface		
Connectivity elements absent	Infinite	Doerr et al. (2010)
Other	100 %	Eco Logical Australia (2012)
Hydrology	300 %	Eco Logical Australia (2012)
Transport	200 %	Eco Logical Australia (2012)
Infrastructure	200 %	Eco Logical Australia (2012)
Geoprocessing		
LULC layer	1:25,000 ~12.5 m	NSW LULC layer based on 1998–2000 air photo interpretation
Vegetation layer	2.5 m	SPOT satellite Greater Hunter mapping (Siggins et al. 2006)
Pixel size for connectivity model	25 m	Based on smallest pixel size that could be processed and a multiple of the input layers

the connectivity planning framework developed by Lechner and Lefroy (2014). The parameterization of dispersal distances were based on empirical evidence from a meta-analysis of Australian dispersal studies primarily in woodland and forest ecosystems by Doerr et al. (2010) (Table 1). This review synthesized all available evidence on the relationship between structural connectivity and landscape scale dispersal of Australian native fauna species. It identified three critical parameters required for our connectivity model: (i) minimum patch size of 10 ha, (ii) a gap-crossing distance threshold of 106 m, and (iii) an interpatch-crossing distance threshold of 1,100 m. The gap-crossing distance threshold describes the maximum distance in open areas (i.e., matrix/non-habitat) that individuals can cross, while the interpatch-crossing distance threshold is the maximum distance many species will cross even when structural connectivity elements are present at the gap-crossing distance. Structural connectivity elements are features that do not provide habitat in themselves (unlike the 10 ha patches), but can be used for dispersal. Connectivity elements include wildlife corridors (linear links between patches), disconnected linear elements, and stepping-stones (paddock trees, shrubs, rocky outcrops, or small clusters of these features).

The Graphab software describes connectivity based on least-cost-paths where pathways between habitat patches minimize travel distances and exposure to unsuitable habitat in a dispersal-cost surface. The dispersal-cost surface is a raster grid where each pixel's value represents dispersal cost as a percentage of interpatch-crossing distance for multiple land covers. The value assigned to each land cover type in a landscape reflects the ecological costs for species to move through it. Least-cost paths are calculated between patches based on cumulative costs. For example, a dispersal cost of 200 % in urban areas means a species can only travel 550 m rather than the maximum interpatch-crossing distance threshold of 1,100 m. Connectivity between any two patches in the landscape will be absent where cumulative costs are greater than the interpatch-crossing distance threshold of 1,100 m. Dispersal costs for each land cover were based on a report from the Port Stephens area by Eco Logical Australia (2012).

A key feature of this modelling method is the inclusion of a gap-crossing layer to identify areas in which the distance between structural connectivity elements is less than the 106 m threshold. This layer is produced by aggregating fine-scale spatial data to a coarser resolution where each course resolution pixel describes the presence or absence of structural connectivity elements at the gap-crossing distance threshold. Vegetation data at 2.5 m resolution from the Greater Hunter Mapping (Siggins et al. 2006) was used to identify vegetation that may act as structural connectivity elements. The identification of connectivity elements requires very high spatial resolution data that is not common in most satellite data (Lechner et al. 2009). The first step was to calculate the size of the coarse resolution pixel in which the average distance between two fine resolution pixels occurring in neighboring coarse resolution pixels is equal to the gap-crossing distance threshold of 106 m. This was calculated by simulating the distance between a fine resolution pixel located at random within a coarse resolution pixel and a neighboring fine resolution pixel (see Lechner and Lefroy 2014 for further details). In the next step, we aggregated the 2.5 m vegetation data to 100 m based on the above calculations (Appendix S1). Pixels at 100 m that contained at least a single 2.5 m vegetation pixel were classified as having structural connectivity elements. Dispersal is possible only within pixels identified by this layer.

Social values data collection

We used a stratified random sampling technique to identify potential respondents for our mail-based PPGIS survey. A randomized list of approximately 500 rural landholders with landholdings greater than 10 ha in the Lower Hunter region, and a list of approximately 500 urban landholders who live in urban or regional centers and own less than 10 ha of land was generated from a cadaster file provided under license by the New South Wales Government. We also invited 75 planning practitioners involved in land-use planning in the Lower Hunter to participate in the survey.

We administered the survey using a modified Tailored Design Method (Dillman 2007) which entailed: an introductory letter, first survey packet, three reminder postcards sent at weekly intervals, second survey packet to non-respondents to the first round of mailing and final reminder postcard. We achieved a 40 % response rate (395 participants) resulting in 10,206 social value points and 4,760 development preference points for our analysis. Survey respondents came from different all Local Government Areas (LGA) in the region. Of the 361 respondents, 19.9 % came from Newcastle LGA, 15.5 % from Port Stephens LGA, 23.0 % from Cessnock LGA, 26.6 % from Lake Macquarie LGA and 15.0 % from Maitland LGA (Raymond and Curtis 2013).

We collected data for 11 spatially explicit social values: (1) aesthetic; (2) recreation; (3) biodiversity; (4) natural significance; (5) cultural significance; (6) food; (7) water; (8) natural materials; (9) science; (10) health; and (11) intrinsic. Aesthetic values were most frequently assigned by all respondents, followed by recreation and then biodiversity and natural significance values. Intrinsic values were assigned significantly fewer times by all respondent groups ($p < 0.05$)

and were the seventh most frequently assigned value type (Raymond and Curtis 2013).

Values constituting the public conservation orientation index spatially aligned with conservation values identified by land-use planners. The values held by land-use planners are reflected by: (1) layers highlighting the spatial distribution of Matters of National Environmental Significance or MNES (frequency of occurrence of nationally listed rare or endangered species as defined under the Environment Protection and Biodiversity Conservation Act 1999), and (2) species distribution models of conservation priorities identified using Zonation, referred to hereafter as biological data (Whitehead et al. 2014). Proportionately more social values which support conservation (biodiversity, natural significance and intrinsic) were found in areas of medium and high MNES than low MNES areas, highlighting that respondents recognise that high and medium MNES areas are important for conservation (Raymond and Curtis 2013). Integrating social values with biological data in Zonation produced prioritizations that differed spatially from the solution based on only biological data. However, the integrated solutions protected a similar proportion of the species distributions (Whitehead et al. 2014).

Participants were given sticker dots corresponding to 11 different social values and instructed to place their dots on map locations containing the values. There were six sticker dots provided for each value and participants could place as many or as few dots on the map as they liked. Here we focus on social values related to conservation (biodiversity, natural significance, and preferences for conservation outside national park types) (Table 2). The survey also included five types of development preferences: residential, tourism, industrial, transport, and agricultural. These were chosen because they emerged consistently during a preliminary community appraisal. The values and preference data were digitized using a 1:1 cardinality into ArcGIS (ESRI, Redlands CA, USA).

Quantifying public conservation orientation

We classified the PPGIS spatial attributes (values and development preferences) into positive (supportive) and negative (constraining) influences on biological conservation. The mapped locations for biodiversity, natural significance, and conservation preferences outside national parks appear consistent with conservation objectives, while the five types of

Table 2 Social values and development preferences mapped in the study, their operational definitions, and the number of each type mapped

Value or preference type	# Points mapped	Definition
Social values for conservation		
Biodiversity	1,132	I value these places because they provide for a variety of plants, wildlife, marine life, or other living organisms
Natural significance	1,026	I value these places because of the significance of the native animals, native plants, ecosystems or geological features found there
Conservation preference	467	Use c+ dots to identify areas (excluding national parks and conservation reserves) where conservation or restoration could occur with a good plan
Development preferences		
Residential development	547	Use rd + dots to identify areas where residential development could occur with a good plan
Industrial development	468	Use id+ dots to identify areas where industrial development (e.g., shopping centers, electricity and water services) could occur with a good plan
Transport development	531	Use ti + dots to identify areas where transport infrastructure nodes (e.g. railway stations and bus interchanges) could occur with a good plan
Agricultural development	395	Use ad + dots to identify areas where agricultural development (e.g., vineyards) could occur with a good plan
Tourism development	505	Use td+ dots to identify where tourism development could occur with a good plan

development would constrain conservation outcomes. The spatial aggregation of these values and preferences provides a measure of the public conservation orientation in the study region. This aggregation method is designed to identify and emphasize areas where either positive or negative conservation orientation is clearly present. A similar type of index was employed by Brown and Raymond (2014) to spatially identify areas of positive or negative development orientation.

To identify areas of positive or negative conservation orientation, a 2 km mesh was created and the number of mapped points within each grid cell was counted. For each grid cell, the difference between the number of positive values and negative preferences was calculated and then weighted based on the total number of points to increase the level of confidence in the conservation orientation score. The score was calculated as follows:

$$\begin{aligned}\text{Positive score } = &(\text{positive values} \\ &- \text{negative preferences}) \\ &* \text{ total number of positive values}, \\ &(\text{positive values} \\ &- \text{negative preferences}) > 0\end{aligned}$$

$$\begin{aligned}\text{Neutral score} = &(\text{positive values} \\ &- \text{negative preferences}) = 0\end{aligned}$$

$$\begin{aligned}\text{Negative score} = &(\text{positive values} \\ &- \text{negative preferences}) \\ &* \text{ total number of negative values}, \\ &(\text{positive values} \\ &- \text{negative preferences}) < 0\end{aligned}$$

The result is a score that reflects the direction (positive or negative) and the intensity of conservation orientation within the spatial area defined by the grid cell.

The scores calculated for each grid cell were then classified into three categories to provide greater contrast in the results. Scores greater or less than the median of all positive or all negative scores were assigned to positive or negative conservation orientation categories respectively, while all other scores were assigned to the neutral conservation orientation category.

The evaluation of conservation orientation and projected development on landscape connectivity

We evaluated the potential effects of public conservation orientation and projected development on landscape connectivity using three different modelling scenarios: scenario 1—baseline connectivity that assumes no change in future land use, scenario 2—the potential effect of conservation orientation on connectivity, and scenario 3—the potential effect of projected development (Table 3). The baseline scenario represents current landscape connectivity. The other two scenarios represent possible futures based on the intensification or conversion of land use. Land use change was simulated by adding or removing vegetation and modifying the connectivity model parameters: dispersal-cost surface, patches layer and gap-crossing layer. Scenario 2 (conservation orientation) includes three sub-scenarios based on (a) consideration of only negative scores toward conservation, (b) consideration of only positive scores toward conservation, and (c) consideration of both negative and positive scores toward conservation. Negative conservation orientation is modeled by *removing* vegetation in grid cells containing negative conservation scores. Positive orientation is modeled by *adding* vegetation to grid cells with positive conservation scores that do not contain roads, water, or infrastructure. These areas are likely to be farmland. Scenario 3 considers the impact of projected development on connectivity in the Lower Hunter based on planning data obtained from local council and state government.

We evaluated the potential effects of land use change on connectivity under scenarios 2 and 3 by running the connectivity model with modified vegetation input data. We specifically focused on the potential impact of conservation orientation and projected development on patch isolation by identifying groups of patches that are linked to each other but isolated from other groups of patches. These groups of interlinked patches are known as components. Components represent sub-networks of patches that species can traverse where structural connectivity is present at the gap-crossing threshold and the distances between patches is less than the interpatch-crossing distance threshold with respect to dispersal costs. The patterns in the size and configuration of the components can be used to characterize fragmentation and locate barriers

Table 3 Landuse change scenarios

Scenario	Description	Scenario processing
1. Baseline Connectivity	The current state of connectivity in the Lower Hunter Region	N/A
2a. Negative conservation orientation	Development that results in the removal of vegetation according to negative conservation orientation locations	Removal of vegetation in negative conservation orientation cells
2b. Positive conservation orientation	Revegetation of farming areas according to positive conservation orientation	Add vegetation in positive conservation orientation cells where roads, hydrology and infrastructure do not exist
2c. Negative and positive conservation orientation	Development and revegetation according to conservation orientation locations	Combined negative and positive conservation orientation scenarios
3. Projected development	Simulate the impact of urbanization that results in the removal of all vegetation within urban areas identified from government local environmental plans (LEP) describing planning zones and future growth plans (e.g. Department of Planning, NSW). All areas zoned for development in LEPs and future plans is assumed to result in complete removal of all vegetation	Removal of vegetation and change in landuse to urban except in areas of pre-existing transport and hydrology

to connectivity and isolation. At the regional scale, large components represent areas where dispersal is possible, while smaller components characterize highly fragmented areas that act as dispersal barriers.

We calculated four landscape/network-scale graph-metrics. Three graph metrics described component characteristics: mean size of components (km^2), size of the largest component (km^2) and number of components (Minor and Urban 2008; Rayfield et al. 2011). The final graph metric used was the integral index of connectivity (IIC). It was chosen as it has been shown to have improved performance compared to other existing metrics and to be well suited for landscape conservation planning and land use change assessment (Pascual-Hortal and Saura 2006; Saura and Pascual-Hortal 2007). This metric measures the reachability of habitat across the landscape as a property of the connection between patches and the area of habitat provided by each patch. The metric can be defined more formally as the probability that two points randomly placed within a landscape fall into habitat areas that can be reached. IIC is suited to this study as it is based on a binary dispersal model where patches are either connected or not based on the interpatch-crossing distance threshold. Values for this metric increase with greater connectivity from 0 to 1. We also calculated values for the IIC as percentage change between the baseline scenario and the land use scenario.

Results

Scenario 1: baseline connectivity

The baseline connectivity model identified two large components in the west and the east (Fig. 1). The patches within the component to the west contain 80 % of the patch area in the Lower Hunter and include the three largest patches that include 65 % of the total patch area. The center of the Lower Hunter from Branxton to Morisset is highly fragmented consisting of small components made up of one or a few small, isolated patches. A total of 574 patches were identified greater than 10 ha, existing within 42 separate components (Table 4). Figure 1 inset shows the least-cost pathways used in the connectivity model to identify linkages between patches.

Spatial distribution of conservation orientation and projected development

The negative and positive conservation orientation scores were spatially clustered across the Lower Hunter (Fig. 2a) while the largest concentration of projected development is located in the currently developed region ranging from Braxton to Morriset (Fig. 2b). Areas with negative conservation orientation scores spatially overlap with areas without woody

Table 4 Connectivity characteristics of the default and four scenarios

	1. Baseline connect-ivity	2a. Neg. Cons. orientation	2b. Pos. Cons. orientation	2c. Pos. and Neg. Cons. orientation	3. Projected development
Mean size of components (km^2)	56	37	75	47	36
Size of largest component (km^2)	1,885	1,701	2,316	1,880	1,779
Largest component as percentage of total area (%)	80	79	91	80	81
Number of Components	42	59	34	50	61
Patches	574	486	520	432	541
Integral index of connectivity (IIC)	0.0217	0.0189	0.0259	0.0217	0.0190
Integral index of connectivity (IIC) % change		−13	+19	0	−13
Total area (km^2)	2,362	2,160	2,554	2,351	2,207
Total area change (km^2)		−202	+191	−11	−155

% change refers to change between baseline and scenario

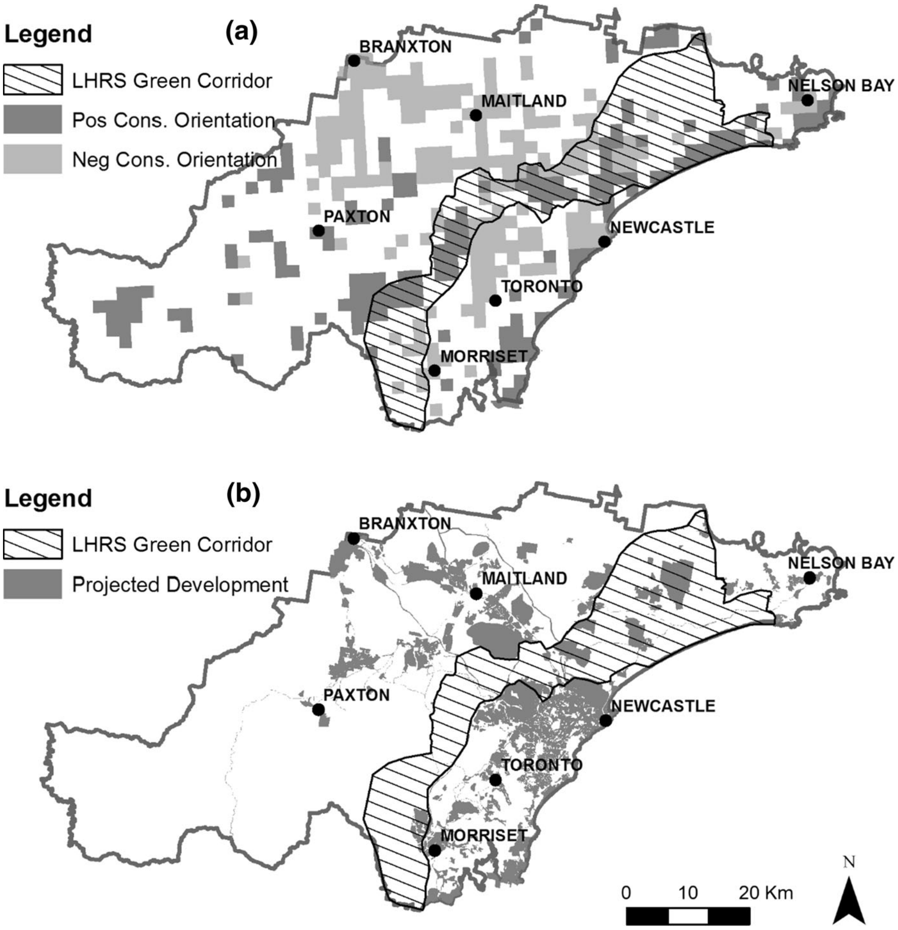

Fig. 2 Lower Hunter regional strategy green corridor, **a** positive and negative conservation orientation and **b** projected development areas

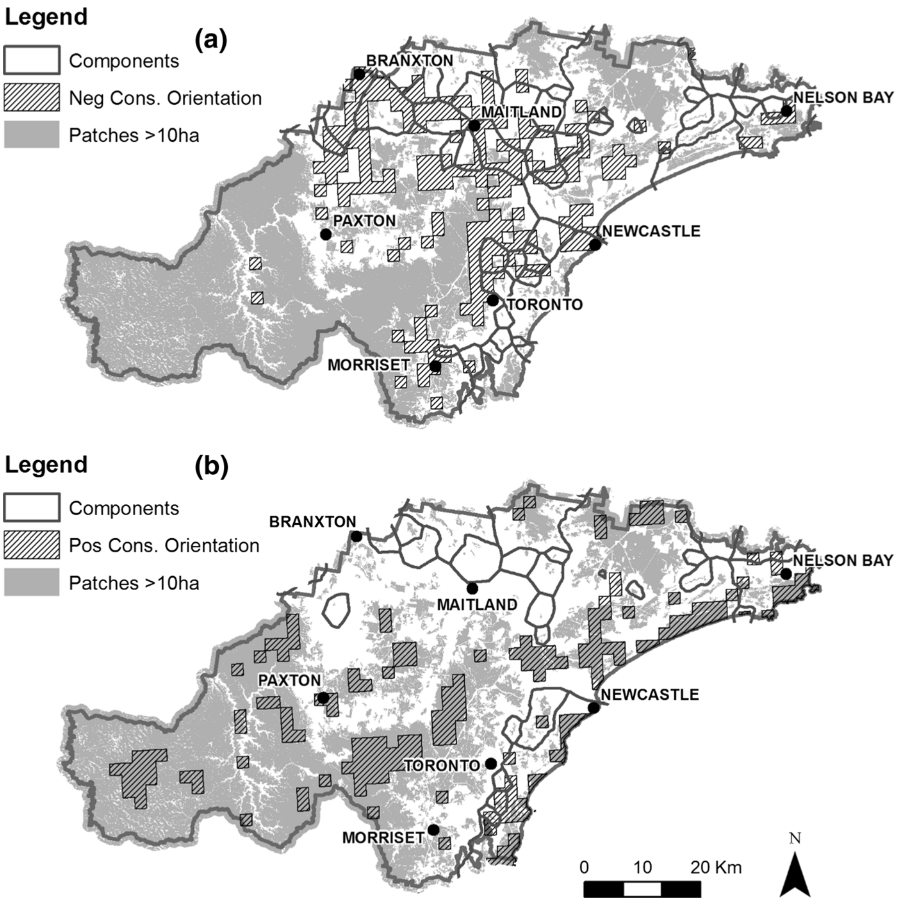

Fig. 3 Connectivity analysis for patches greater than 10 ha. **a** Negative conservation orientation scenario - vegetation is removed. **b** Positive conservation orientation scenario—vegetation added where existing water bodies are not located. Component boundaries from connectivity analysis in located at the midpoint between patches

vegetation in patches >10 ha and in areas of projected development, with the exception of an area north of Toronto. Around 45 % of the area of projected development overlaps with areas identified as having negative conservation orientation (Appendix S2). Positive conservation orientation scores are spatially coincident with locations that tend to have large areas of contiguous vegetation, except for northwest of Newcastle and south of Toronto. The area northwest of Newcastle coincides with a vegetated part of the 'green corridor' identified in the Lower Hunter Regional Strategy (NSW Department of Planning 2006) (Fig. 2) and the 'high priority corridors' identified in the Lower Hunter Conservation Strategy (DECCW 2009) (not depicted in Fig. 2, but has a similar footprint as the green corridor).

Scenario 2: conservation orientation

The negative conservation scenario (2a, Table 3) resulted in greater fragmentation in the northern parts of the Lower Hunter around Maitland as shown by the increase in the number of components in this area compared to the baseline (Fig. 3). Additionally there was greater fragmentation north of Toronto. The number of components increased from the baseline of 42 to 59 (Table 4). This occurred despite a decrease in the number of vegetation patches from 574 to 486. Some of the small vegetation patches in the central region of the Lower Hunter were removed under this scenario. Many of these patches formed components consisting of one or only a few small patches that contributed to the number of components in the baseline scenario. This scenario resulted in a decrease in connectivity measured by the IIC by 13 % compared to the baseline (Table 4). The majority of the vegetation in the west and east were unaffected by the negative conservation orientation scores.

The positive conservation orientation scenario (2b, Table 3) showed a large increase in regional connectivity between the east and west of the Lower Hunter, and a decrease in the number of components in the

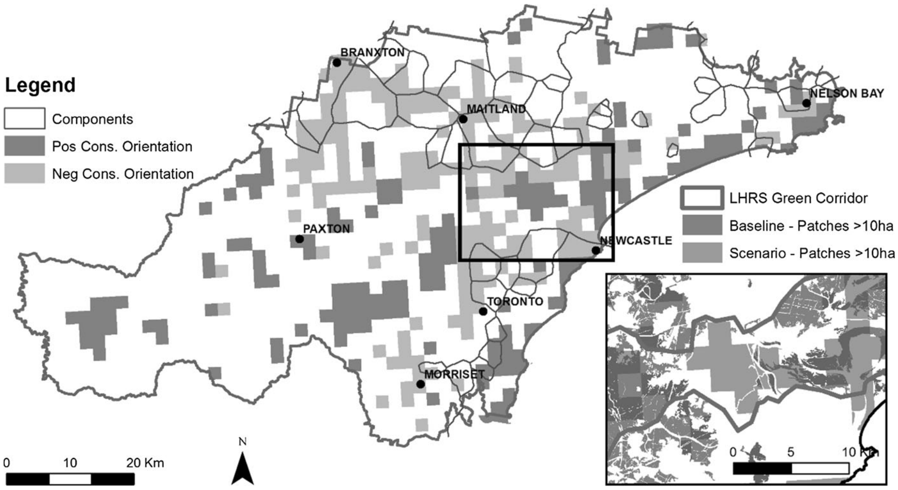

Fig. 4 Positive and negative conservation orientation scenario connectivity analysis for patches greater than 10 ha. Component boundaries from connectivity analysis in dark grey located at the midpoint between patches. Inset describes original patches baseline patches and patches generated for the scenario (original patches + positive conservation orientation patches)

region east of Morriset (Fig. 3b). The new east to west connection resulted in an increase in the largest component size from 1,885 to 2,316 km^2 with 91 % of all vegetation residing in a single large component, compared to 80 % for the default scenario (Table 4). This scenario resulted in an increase in connectivity measured by the IIC by 19 % compared to the baseline.

The combined positive and negative conservation orientation scores (2c, Table 3) resulted in the same increases and decreases in fragmentation and connectivity associated with each scenario separately (Fig. 4). However, there was greater connectivity across the Lower Hunter regionally from the creation of the east-west connection due to positive conservation orientation even with the loss of habitat due to negative conservation orientation. The largest component size was almost the same as the baseline scenario even with the connection of the two components in the east and west because the removal of vegetation with negative conservation scores affected the largest component size. The overall effect of both positive and negative conservation scenarios in parallel on connectivity resulted in no change in the IIC value from the baseline (Table 4). There were 50 components and 432 patches in the combined positive and negative conservation scenario versus 59 components and 486 patches in the negative only conservation scenario.

Scenario 3: Projected development

The projected development scenario resulted in similar patterns of fragmentation as the negative conservation orientation scenario with projected development concentrated in the already fragmented central area of the Lower Hunter (Fig. 5). However, the projected development scenario resulted in greater fragmentation with 61 components versus 59 and a greater number of patches than the negative conservation orientation scenario (Table 4). This difference was not reflected in the IIC values with both the development scenario and the negative conservation scenario resulting in the same 13 % decrease from the baseline (Table 4).

Discussion

In this paper we show how spatially explicit measures of conservation orientation (both positive and negative), and data describing projected development, can be assessed for their impacts on regional connectivity in the Lower Hunter region of New South Wales. Our analysis found that positive conservation orientation resulted in greater connectivity between the east and west regions of the Lower Hunter and this greater connectivity remained even when negative conservation scores were included in the model. These findings suggest that public conservation orientation, at least in the selected case study region, support the enhancement of connectivity and thus conservation efforts. These findings advance the understanding of scientifically defensible and socially feasible conservation priorities (e.g. Bryan et al. 2011; Raymond and Brown 2011; Whitehead et al. 2014).

Fig. 5 Projected development scenario connectivity analysis for patches greater than 10 ha. Component boundaries from connectivity analysis in dark grey located at the midpoint between patches

Overall, the differences in connectivity between all scenarios were not numerically large as the western and northeastern areas of the lower Hunter containing the majority of the woody vegetation were unaffected by fragmentation. However, the increase in connectivity resulting from the positive conservation scenario between the east and west Lower Hunter is ecologically important. This location coincides with the 'high priority corridors' identified in the Lower Hunter Conservation Strategy (DECCW 2009) or the 'green corridor' area in the Lower Hunter Regional Strategy (NSW Department of Planning 2006). In contrast, the projected development scenario showed slightly greater fragmentation both quantitatively in terms of component metrics such as mean size of components and size of largest component and visually when compared to the negative conservation orientation scenario along the north-south development area and in the region around Morriset. However, in terms of reachable habitat the projected development scenario showed the same amount of change in the IIC as the negative conservation scenario.

Implications for connectivity planning

Connectivity within the 'green corridor' area between the southern sandstone ecosystems in the Watagans Range (including Mount Sugarloaf) in the west to the coastal heaths and wetlands of Port Stephens in the east have exceptional conservation significance and is one of the few remaining vegetated links between the Great Dividing Range and the east coast (DECCW 2009). While the Lower Hunter Conservation Strategy (DECCW 2009) recognizes this area as the most significant high priority conservation area, increased fragmentation was observed within and near the 'green corridor' based on the projected development scenario. This result suggests that the projected development in regional land-use plans does not reflect the conservation and development views held by regional residents that participated in this study, as indicated by the positive and negative conservation orientation scenario that would create a green corridor and increase connectivity across the landscape.

The modelling approach presented here enables land-use planners to not only understand the consequences of projected development on habitat connectivity, but also suggests place-specific areas where development priorities could be modified to coincide with both connectivity goals and local conservation orientations. This information can be used by the Federal Environment Minister to highlight the potential for conflict between projected development and connectivity and/or social values when undertaking a Strategic Assessment in this region, as required under the Environment, Protection and Biodiversity Conservation Act 1999, and to make provisions for establishing or protecting the east-west habitat linkages from projected development, in accordance with scenarios that include positive conservation orientation.

Accounting for social factors that affect the success of a conservation action (Knight et al. 2006) is especially important for connectivity initiatives which emphasize the collaborative aspects of conservation planning (Parris et al. 2011; Wyborn 2013). This is especially true in regions where there are competing land uses such as urban and agricultural development impacting on native vegetation that contributes to dispersal. Connectivity and wildlife corridor initiatives commonly include more than just ecological connectivity and are used as a vehicle for a whole of landscape collaborative approach to motivate individuals, groups, and communities over large spatial scales to participate in on-the-ground delivery of conservation actions (Parris et al. 2011). "Evaluating these initiatives from a purely ecological standpoint misses the broader aims, motivations, perspectives and institutional benefits found in the connectivity space" (Wyborn et al. 2012).

The connectivity modelling approach outlined in this paper is especially useful for assessing whether there is broad community support for a particular connectivity initiative and whether this support extends to spatial awareness of important locations for connectivity. These large-scale initiatives often need local communities to provide, on a voluntary basis, labor, information, skills, and financial resources (Opdam et al. 2006). Targeting natural resource management (NRM) resources without the consideration of the socio-economic conditions under which communities value those resources can result in a significant political backlash to any NRM initiative (Parris et al. 2011). Additionally, through the inclusion of projected development data, we can assess whether the social values and preferences held by the community are in conflict or are compatible with those held by land use planners and the institutions they represent. A collaborative approach to connectivity planning would look to promote connectivity initiatives where connectivity, social values, and future development are compatible. Conservation practitioners have been reluctant to integrate local community values into conservation planning under the assumption that these values may impede, if not undermine, conservation efforts. However, the models presented here highlight how community values have the potential to leverage conservation and restoration of areas of natural significance. For example, conservation orientation scenario 2 was strongly aligned with the establishment of the east-west corridor in the Lower Hunter.

This study is useful for providing evidence to state and local government that public support exists across the region for conservation action within certain areas at a 2 km grid resolution. However, NRM groups may be required to ensure that property owners within those areas identified as having positive conservation orientation and importance for connectivity would be willing to engage in conservation activities. Ultimately, habitat connectivity efforts on private land will need to be negotiated based on the objectives of willing landholders. Additionally, at the property scale, there is the potential to address some of the impacts while allowing for development through the provision of structural connectivity elements within urban green spaces.

Further research is needed to investigate sources of uncertainty that are associated with social survey methods (Haslam and McGarty 2001; Lechner and Lefroy 2014), the ecological parameterization and ecological realism of the connectivity model (Sawyer et al. 2011), and the remote sensing data used to characterize vegetation (Lechner et al. 2012). The focus of the connectivity method used in this study was based on visualizing where connectivity was present using ecological thresholds. Future research focusing on a greater range of graph-metrics (Minor and Urban 2008) for quantifying connectivity used in conjunction with more complex methods simulating and assessing land use scenarios (Foltête et al. 2014) can provide a more comprehensive assessment of connectivity.

Conclusion

In this paper we presented an approach for assessing the potential effects of public conservation orientation and projected development on regional landscape connectivity. We found that scenarios that include positive conservation orientation result in greater landscape connectivity, particularly between the east and west regions of the Lower Hunter, a result that is spatially coincident with wildlife corridors identified in state government regional strategies. If the public's conservation orientation, as measured through the PPGIS methods described herein, can actually be translated into conservation initiatives, the result will be enhanced regional landscape connectivity that is both ecologically beneficial as well as socially acceptable. Conservation action, especially in the case of connectivity planning, is likely to be more successful with community support. The results of this study highlight the potential of public support to leverage conservation outcomes related to landscape connectivity.

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References

Adriaensen F, Chardon JP, De Blust G, Swinnen E, Villalba S, Gulinck H, Matthysen E (2003) The application of “least-cost” modelling as a functional landscape model. Landsc Urban Plan 64:233–247

Alagador D, Triviño M, Cerdeira JO, Brás R, Cabeza M, Araújo MB (2012) Linking like with like: optimising connectivity between environmentally-similar habitats. Landsc Ecol 27:291–301

Alessa L, Kliskey A, Brown G (2008) Social-ecological hotspots mapping: a spatial approach for identifying coupled social-ecological space. Landsc Urban Plan 85:27–39

Ball IR, Possingham HP, Watts M (2009) Marxan and relatives: software for spatial conservation prioritisation. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, Oxford, pp 185–195

Ban NC, Mills M, Tam J, Hicks CC, Klain S, Stoeckl N, Bottrill MC, Levine J, Pressey RL, Satterfield T, Chan KM (2013) A social–ecological approach to conservation planning: embedding social considerations. Front Ecol Environ 11:194–202. doi:10.1890/110205

Brost BM, Beier P (2012) Comparing linkage designs based on land facets to linkage designs based on focal species. PLoS One 7:e48965. doi:10.1371/journal.pone.0048965

Brown G (2006) Mapping landscape values and development preferences: a method for tourism and residential development planning. Int J Tour Res 8:101–113. doi:10.1002/jtr

Brown G (2013) The relationship between social values for ecosystem services and global land cover: an empirical analysis. Ecosyst Serv. doi:10.1016/j.ecoser.2013.06.004

Brown G, Raymond CM (2014) Methods for identifying land use conflict potential using participatory mapping. Landsc Urban Plan 122:196–208

Brown G, Smith C, Alessa L, Kliskey A (2004) A comparison of perceptions of biological value with scientific assessment of biological importance. Appl Geogr 24:161–180

Brown G, Weber D, de Bie K (2015) Is PPGIS good enough? An empirical evaluation of the quality of PPGIS crowd-sourced spatial data for conservation planning. Land Use Policy 43:228–238. doi:10.1016/j.landusepol.2014.11.014

Bryan BA, Raymond CM, Crossman ND, King D (2011) Comparing spatially explicit ecological and social values for natural areas to identify effective conservation strategies. Conserv Biol 25:172–181. doi:10.1111/j.1523-1739.2010.01560.x

Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jager J, Mitchell RB (2003) Knowledge systems for sustainable development. Proc Natl Acad Sci USA 100:8086–8091

Cowling RM, Knight AT, Privett SDJ, Sharma G (2010) Invest in opportunity, not inventory of hotspots. Conserv Biol 24:633–635. doi:10.1111/j.1523-1739.2009.01342.x

Curran P, Smedley D, Thompson P, Knight AT (2012) Mapping restoration opportunity for collaborating with land managers in a carbon credit-funded restoration program in the Makana Municipality, Eastern Cape, South Africa. Restor Ecol 20:56–64

DECCW (2009) Lower Hunter regional conservation plan. Department of Environment, Climate Change and Water, Sydney

Dillman D (2007) Mail and internet surveys: The tailored design method, 2nd edn. Wiley, New Jersey

Doerr VAJ, Doerr ED, Davies MJ (2010) Does structural connectivity facilitate dispersal of native species in Australia’s fragmented terrestrial landscapes? CEE Rev 08-007:70

Eco Logical Australia (2012) Port Stephens biodiversity connectivity mapping. Prepared for Port Stephens Council

Fischer J, Lindenmayer DB (2006) Habitat fragmentation and landscape change: an ecological and conservation synthesis. Glob Ecol Biogeogr 16:478

Foltête JC, Clauzel C, Vuidel G (2012) A software tool dedicated to the modelling of landscape networks. Environ Model Softw 38:316–327

Foltête J-C, Girardet X, Clauzel C (2014) A methodological framework for the use of landscape graphs in land-use planning. Landsc Urban Plan. doi:10.1016/j.landurbplan.2013.12.012

Goldberg CS, Pocewicz A, Nielsen-Pincus M, Waits LP, Morgan P, Force JE, Vierling LA (2011) Predictions of ecological and social impacts of alternative residential development policies to inform decision making in a rural landscape. Conserv Lett 4:423–432. doi:10.1111/j.1755-263X.2011.00194.x

Haslam SA, McGarty C (2001) A 100 years of certitude? Social psychology, the experimental method and the management of scientific uncertainty. Br J Soc Psychol 40:1–21. doi:10.1348/014466601164669

Knight AT, Cowling RM, Campbell BM (2006) An operational model for implementing conservation action. Conserv Biol 20:408–419

Lechner AM, Lefroy EC (2014) General approach to planning connectivity from local scales to regional (GAP CLoSR): combining multi-criteria analysis and connectivity science to enhance conservation outcomes at regional scale. Centre for Environment, University of Tasmania. www.nerplandscapes.edu.au/publication/GAP_CLoSR. Accessed Jan 2015

Lechner AM, Stein A, Jones SD, Ferwerda JG (2009) Remote sensing of small and linear features: quantifying the effects of patch size and length, grid position and detectability on land cover mapping. Remote Sens Environ 113:2194–2204

Lechner AM, Langford WT, Bekessy SA, Jones SD (2012) Are landscape ecologists addressing uncertainty in their remote sensing data? Landscape Ecol 27:1249–1261. doi:10.1007/s10980-012-9791-7

Lechner AM, Raymond CM, Adams VM, Polyakov M, Gordon A, Rhodes JR, Mills M, Stein A, Ives CD, Lefroy EC

(2014) Characterizing spatial uncertainty when integrating social data in conservation planning. Conserv Biol 28:1497–1511. doi:10.1111/cobi.12409

Mills M, Pressey RL, Ban NC, Foale S, Aswani S, Knight AT (2013) Understanding characteristics that define the feasibility of conservation actions in a common pool marine resource governance system. Conserv Lett 6:418–429. doi:10.1111/conl.12025

Minor ES, Urban DL (2008) A graph-theory framework for evaluating landscape connectivity and conservation planning. Conserv Biol 22:297–307

Moilanen A, Meller L, Leppänen J, Pouzols FM, Arponen A, Kujala H (2013) Spatial conservation planning framework and software Zonation v.3.1 User manual. University of Helsinki, Helsinki

Moon K, Cocklin C (2011) Participation in biodiversity conservation: motivations and barriers of Australian landholders. J Rural Stud 27:331–342. doi: 10.1016/j.jrurstud.2011.04.001

NSW Department of Planning (2006) The Lower Hunter regional strategy 2006. Government of New South Wales, Sydney

Opdam P, Steingröver E, van Rooij S (2006) Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landsc Urban Plan 75:322–332. doi:10.1016/j.landurbplan.2005.02.015

Parris H, Whitten S, Wyborn C, Hill R, Freudenberger D (2011) An overview of key socio-economic factors, principles and guidelines in wildlife "corridor" planning and implementation. A report for the Australian Government Department of Sustainability, Environment, Water, Population and Communities, CSIRO Ecosystem Sciences, June 2011

Pascual-Hortal L, Saura S (2006) Comparison and development of new graph-based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. Landscape Ecol 21:959–967. doi:10.1007/s10980-006-0013-z

Rayfield B, Fortin MJ, Fall A (2011) Connectivity for conservation: a framework to classify network measures. Ecology 92:847–858. doi:10.1890/09-2190.1

Raymond C, Brown G (2006) A method for assessing protected area allocations using a typology of landscape values. J Environ Plan Manag 49:797–812. doi:10.1080/09640560600945331

Raymond CM, Brown G (2011) Assessing conservation opportunity on private land: socio-economic, behavioral, and spatial dimensions. J Environ Manag 92:2513–2523

Raymond C, Curtis A (2013) Mapping community values for regional sustainability in the Lower Hunter Region. University of Tasmania, Hobart, Tasmania

Saura S, Pascual-Hortal L (2007) A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. Landsc Urban Plan 83:91–103. doi:10.1016/j.landurbplan.2007.03.005

Sawyer SC, Epps CW, Brashares JS (2011) Placing linkages among fragmented habitats: do least-cost models reflect how animals use landscapes? J Appl Ecol 48:668–678

Sherrouse BC, Clement JM, Semmens DJ (2011) A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. Appl Geogr 31:748–760. doi:10.1016/j.apgeog.2010.08.002

Sieber R (2006) Public participation geographic information systems: a literature review and framework. Ann Assoc Am Geogr 96:491–507. doi:10.1111/j.1467-8306.2006.00702.x

Siggins A, Opie K, Culvenor D, Newnham G (2006) Mapping vegetation cover and vegetation formation from SPOT5 satellite imagery. In: McCauley A (ed) Vegetation survey and mapping—hunter, central and lower North Coast Region of NSW. HCCREMS, Tocal, NSW, Australia, pp 39–46

Van Riper CJ, Kyle GT, Sutton SG, Barnes M, Sherrouse BC (2012) Mapping outdoor recreationists' perceived social values for ecosystem services at Hinchinbrook Island National Park, Australia. Appl Geogr 35:164–173. doi:10.1016/j.apgeog.2012.06.008

Whitehead AL, Kujala H, Ives CD, Gordon A, Lentini P, Wintle B, Nicholson E, Raymond CM (2014) Integrating biological and social values when prioritising for biodiversity conservation. Conserv Biol 28:992–1003

Wu JG, Hobbs R (2002) Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. Landscape Ecol 17:355–365

Wyborn C (2013) A collaborative future for Conservation: lessons from connectivity conservation. Innovation 21st Century Conservation Publishing, CSIRO, Campbell, pp 44–49

Wyborn C, Jellinek S, Cooke B (2012) Negotiating multiple motivations in the science and practice of ecological restoration. Ecol Manag Restor 13:249–253. doi:10.1111/j.1442-8903.2012.00667.x