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Integrating Biological and Social Values When Prioritizing Places for Biodiversity Conservation

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Abstract: *The consideration of information on social values in conjunction with biological data is critical for achieving both socially acceptable and scientifically defensible conservation planning outcomes. However, the influence of social values on spatial conservation priorities has received limited attention and is poorly understood. We present an approach that incorporates quantitative data on social values for conservation and social preferences for development into spatial conservation planning. We undertook a public participation GIS survey to spatially represent social values and development preferences and used species distribution models for 7 threatened fauna species to represent biological values. These spatially explicit data were simultaneously included in the conservation planning software Zonation to examine how conservation priorities changed with the inclusion of social data. Integrating spatially explicit information about social values and development preferences with biological data 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, indicating that Zonation effectively combined the biological and social data to produce socially feasible conservation solutions of approximately equivalent biological value. We were able to identify areas of the landscape where synergies and conflicts between different value sets are likely to occur. Identification of these synergies and conflicts will allow decision makers to target communication strategies to specific areas and ensure effective community engagement and positive conservation outcomes.*

Keywords: biodiversity, conservation planning, development preferences, public participation GIS, social values, spatial prioritization, Zonation

Integración de Valores Biológicos y Sociales al Priorizar Sitios para la Conservación de la Biodiversidad

Resumen: *La consideración de información sobre los valores sociales en conjunto con datos biológicos es crítica para obtener resultados de planeación de la conservación aceptables social y científicamente. Sin embargo, la influencia de los valores sociales sobre las prioridades de la conservación espacial ha recibido atención limitada y se entiende muy poco. Presentamos un método que incorpora datos cuantitativos de los valores sociales para la conservación y las preferencias sociales para el desarrollo en la planeación espacial de la conservación. Realizamos una encuesta SIG de participación pública para representar espacialmente los valores sociales y las preferencias de desarrollo y usamos modelos de distribución de especies para siete especies amenazadas de fauna para representar los valores biológicos. Estos datos espacialmente explícitos se incluyeron simultáneamente en el software para la planeación de la conservación Zonation para examinar cómo las prioridades de la conservación cambiaron con la inclusión de los datos sociales. Al integrar información espacialmente explícita sobre los valores sociales y las preferencias del desarrollo con los datos biológicos produjeron priorizaciones que difirieron espacialmente de la solución basada sólo en datos biológicos. Sin embargo, las soluciones integradas protegieron una proporción similar de la distribución*

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de las especies, indicando que Zonation combinó efectivamente los datos biológicos y sociales para producir soluciones de conservación socialmente factibles de un valor biológico aproximadamente equivalente. Fuimos capaces de identificar áreas del paisaje donde probablemente ocurren las sinergias y los conflictos entre conjuntos diferentes de valores. Identificar estas sinergias y conflictos permitirá a quienes tomen las decisiones enfocarse en estrategias de comunicación para áreas específicas y asegurarse de una participación efectiva de la comunidad y resultados positivos de la conservación.

Palabras Clave: Biodiversidad, participación pública, planeación de la conservación, preferencias de desarrollo, priorización espacial, SIG, valores sociales, Zonation

Introduction

Consideration of social and ecological factors in systematic conservation planning is vital for developing effective conservation actions (Knight et al. 2006, 2010), yet few tools are available for integrating them in a quantitative and spatially explicit manner. Recent papers have argued that considering social factors can reduce conflicts between stakeholders (Redpath et al. 2013) and ensure more effective and efficient implementation of conservation programs (Knight et al. 2006). Notable progress in this area has been achieved using social–ecological systems (Ban et al. 2013), human and social capital (Knight et al. 2010), management (Polasky 2008), and behavioral (Raymond & Brown 2011) frameworks. However, no method for explicitly integrating social values and mapped biological features in a transparent, quantitative spatial prioritization framework has been presented.

Systematic spatial conservation prioritization (Moilanen et al. 2009) is a structured decision analysis approach (*sensu* Gregory et al. 2012*a*) to finding solutions to multidimensional choice problems. It focuses on the role of habitat quality and connectivity and land or opportunity costs in identifying good solutions. As a decision analysis tool, it adheres to the axioms of normative (prescriptive) decision theory (von Neumann & Morganstern 1947). Key ingredients of structured decision analysis evident in good applications of spatial conservation prioritization include clear specification of the problem, objectives, and performance measures (often biodiversity benefit measured as habitat amount and quality) and characterization of risks and uncertainties (Moilanen & Wintle 2006). Spatial conservation prioritization approaches are popular, particularly since the development of readily accessible and efficient tools such as Marxan (Ball et al. 2009) and Zonation (Moilanen et al. 2005). These are now applied to a range of problems globally, including the identification of priorities for protected areas (Kremen et al. 2008), prioritization of management actions (Lentini et al. 2013), and integration of biodiversity data with land-use planning (Gordon et al. 2009). However, most real conservation decision problems also involve some sort of trade-off between competing social objectives (Keeney 2002), and applications of conservation planning tools have to date largely avoided these issues.

A spatially explicit approach to engaging local citizens and planning stakeholders in natural resource planning, referred to as public participation GIS (PPGIS; Brown 2012), has the potential to improve the feasibility of conservation actions. In PPGIS, participants use maps to convey information about significant places or areas considered important for different uses. PPGIS has been used in over 20 applications worldwide, including national forest planning in North America (Brown & Donovan 2013) and regional conservation assessment in Australia (Raymond & Brown 2006). We used PPGIS to identify places that people value for reasons compatible with biodiversity conservation, hereafter referred to as social values for conservation. Recent studies have overlaid social and biological values for conservation (Alessa et al. 2008; Bryan et al. 2011); however, no attempts have been made to integrate social values as features of a spatial prioritization to quantify the costs and benefits associated with their inclusion.

A range of studies have considered the consistency between land-use zones and areas perceived to be socially acceptable for development, which we refer to as development preferences (Brown & Weber 2012). These studies highlight the trade-offs which need to be considered by planning authorities. However, they have examined only the degree to which social values are correlated with biological data and make no attempt to formally identify socially acceptable trade-offs (Fischer 1995; Gregory et al. 2001). The strength of overlay approaches is that they enable easy identification of potential areas of conflict and are a transparent way of communicating with conservation practitioners. However, as with other score-driven approaches, subjective overlay analyses may lead to inefficient solutions (Reid 1998) because they commonly fail to consider the complementarity of sites being prioritized (Pressey & Nicholls 1989) or lead to solutions where rare features are not adequately represented (Williams et al. 1996). Although coupling of biological and social values can increase the social acceptability (and success) of a proposed conservation plan, solutions need to be evaluated carefully against goals set by policy makers (Arponen et al. 2010) and the costs and benefits of such an approach assessed.

Finding good approaches for eliciting social preferences for land use, formalizing competing objectives, and addressing the real trade-offs involved in conservation is arguably one of the most important modern conservation challenges. Progress is being made for a subset of conservation problems (Gregory et al. 2012*b*; Mitchell et al. 2013); though we can find no examples of explicit trade-off analysis in the spatial conservation prioritization literature. We quantified the effect of social values and development preferences in a conservation prioritization analysis. Using the Lower Hunter region in New South Wales, Australia as a case study, we examined how spatially defined social values and development preferences can be incorporated into a landscape prioritization analysis to produce solutions that are ecologically defensible and socially acceptable. In doing so, we propose strategies for mapping and managing value compatibilities and conflicts.

Methods

Study Area

The Lower Hunter region is 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 region contains features that are of national environmental importance (termed Matters 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 opencut coal mining, urban residences, industry, and agriculture (Mcdonald et al. 2008). 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.

Value Mapping

We used 7 priority fauna species to represent the biological values in the Lower Hunter region: Powerful Owl (*Ninox strenua*), Masked Owl (*Tyto novaehollandiae*), Sooty Owl (*Tyto tenebricosa*), Spotted Quoll (*Dasyurus maculatus*), Koala (*Phascolarctos cinereus*), yellow-bellied glider (*Petaurus australis*), and squirrel glider (*Petaurus norfolcensis*). These species were selected due to their threat status and vulnerability to land clearance and the availability of data for modeling. Species occurrence data were obtained from 2 on-line databases and combined with biologically relevant environmental variables (Supporting Information) (Wintle et al. 2005) to produce species distribution models with MaxEnt (Phillips et al. 2006, version 3.3.3k). We used the default settings in MaxEnt, with 10,000 background points selected randomly from across the study area. For each species, MaxEnt's logistic output was used in subsequent analyses. This output equates to a probability that the species will be observed in each pixel, given the environmental conditions that exist there relative to the environmental conditions where the species is known to occur (Phillips & Dudík 2008). Species distribution modeling was undertaken with a pixel resolution of 100 m, and the output was resampled to match the 500 m resolution and extent of the social values mapping data (Fig. 1b).

We used a stratified random sampling technique to identify potential respondents for our mail-based PPGIS survey. Using lists of property owners provided under license by the NSW Government, we generated a randomized list of approximately 500 rural landholders with landholdings >10 ha in the Lower Hunter region and a list of approximately 500 urban landholders who live in urban or regional centers and owned <10 ha of land. We also invited 75 planning practitioners involved in land-use planning in the Lower Hunter to participate in the survey. We achieved a 40% response rate (395 participants) for a total of 10,206 social value points and 4,760 development preference points.

We collected data on 11 social values (Raymond & Brown 2006), but here we focused on social values for conservation (biodiversity, natural significance, and intrinsic value types) (see Supporting Information for the wording of each value statement). Participants were given sticker dots corresponding to the different social values and instructed to place their dots on map locations that they felt held the 11 values. They could place as many or as few dots on the map as they liked.

The surveyed values also included 5 types of development preferences: residential, tourism, industrial, transport, and agricultural. These development types were chosen because they emerged consistently during a preliminary community appraisal (Supporting Information). The values and preference data were digitized using a 1:1 cardinality in ArcGIS (ESRI, Redlands CA, U.S.A). Point density grids were then generated for each value and preference with a 500-m grid cell size and 2-km search radius (Fig. 1c).

Spatial Prioritization

We used the conservation prioritization software Zonation v.3.1 to conduct a spatial prioritization of biological and social values (Moilanen et al. 2005, 2012). Zonation is freely available software (http://cbig.it.helsinki.fi/software/zonation/) in which information about biodiversity features and their relative occurrences and biological needs are used to create a hierarchal ranking of the potential conservation value of sites across any given landscape. At first it is assumed that all sites (grid cells) in the landscape are protected. Cells that cause

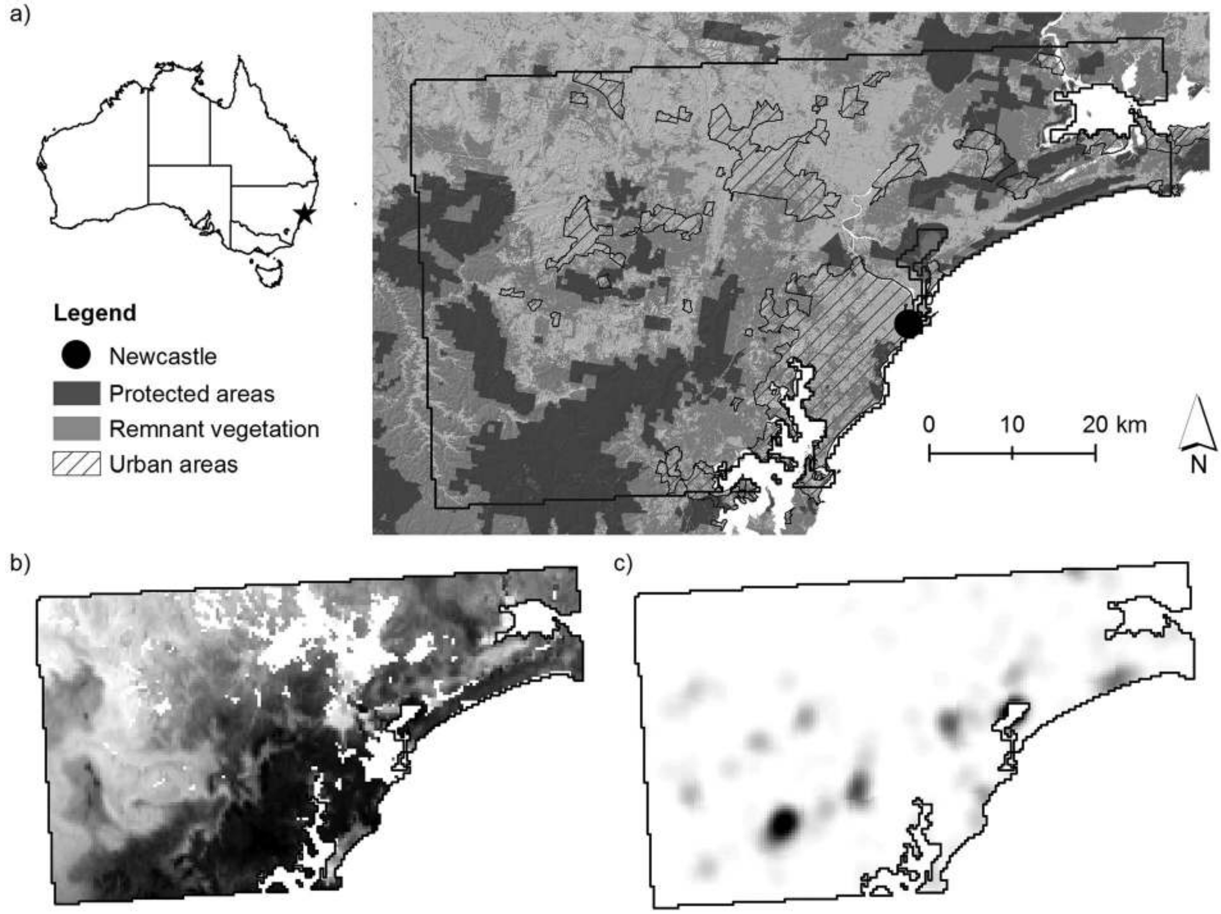

Figure 1. (a) Extent of existing protected areas, remnant native vegetation, and urban areas in Lower Hunter region in New South Wales, Australia (dark outline, boundary of study area) and examples of mapped biological and social values data included in our analyses. (b) Predicted probability of occurrence for the Powerful Owl (Ninox strenua) and (c) distribution of social data for intrinsic values (the darker the shading, either the higher the probability of occurrence or the higher the concentration of social values).

the smallest marginal loss in conservation value are then progressively removed until no cells are left. The least valuable grid cells for conservation are removed first and most valuable cells are retained until the very end. The cell removal order then produces a ranking, or conservation priority value, for each cell. Zonation uses a heuristic algorithm, which is a common approach used for complex problems where determining the global optimum across a large data set with nonlinear objectives is not possible or practical. Heuristic methods do not guarantee finding the single best solution, but they can provide good, feasible solutions that are usually close to the optimum (Moilanen & Ball 2009). The critical component of the algorithm is the definition of *marginal loss* (Moilanen 2007). We used the core-area definition of *marginal loss*, which aims to balance the solution across all features at each removal step. Mathematically, the marginal loss in core-area Zonation is defined as

$$\delta_i = \max_j \frac{w_j p_{ij}}{C_i \sum_{k \in S} p_{kj}}, \quad (1)$$

where p_{ij} is the occurrence level of feature p_j in cell i and $\sum_{k \in S} p_{kj}$ is the sum of occurrences of feature p_j in cells k that are included in the remaining set of cells S at each point of the cell removal process. Features can be weighted (e.g., by their conservation importance) with the parameter w_j. Furthermore, C_i is the cost of adding cell i to the reserve network and can be of any monetary or nonmonetary type (e.g., land acquisition cost, lost harvest yield). Thus, when costs are used, Zonation produces a cost-efficient solution in which high priority cells in the top rank have high value for each of the features but relatively low costs.

One of the key properties of Eq. (1) is that whenever part of a feature's occurrence is lost during the cell removal process, the values of the remaining grid cells that contain that feature go up. In practice, this typically means that low-quality occurrences of common features are removed first, but as the common features eventually become rare, removal of occurrences of rare and common features is balanced in a manner that minimizes

Table 1. Description of 6 spatial conservation prioritization scenarios developed through the use of biological data, social values, or development preferences, individually (scenarios A–C) or with combinations of these data, to assess the effectiveness of integrating biological and social data to produce conservation priorities (scenarios D–F).

Scenario	*Description of prioritization*
(A) Biological values	based purely on biological data of 7 species of conservation concern; considered best for conservation and forms the base scenario against which other scenarios were evaluated
(B) Social values	based on data on social values for conservation, namely biodiversity, natural significance, and intrinsic values; highlights areas that people see as important for biodiversity and treats social values as features; inverse of this priority map was also used as a cost in scenario G (Supporting Information)
(C) Development preferences	based on data on people's preferences for development as features, namely industrial, residential, agricultural, tourism, and transport development; resulting priority map highlights areas seen as most important for future development actions and was used as a cost layer in scenarios E and H (Supporting Information) and a mask layer in scenarios F and I (Supporting Information)
(D) Biological and social values	based on biological and social values, where each social value data layer (biodiversity, natural significance, and intrinsic) was treated as an additional feature; resulting high-priority sites are therefore important for both conservation and social values.
(E) Biological and social values with development cost	based on biological and social values, while accounting for development preferences as costs; cost data are the output of scenario C and hence highest priorities are given to grid cells that on average have high biological and social value but low development preference; areas of high development preferences can also be given high priority if they occur together with high biological and social values for which alternative locations do not exist (i.e., Zonation seeks to find a compromise between the contradicting values, but local conflicts can still occur if they are deemed necessary)
(F) Biological and social values excluding areas of high development preference	based on biological and social values but forcing out the 30% of the landscape most preferred for development (scenario C); assumes conflicts are not tolerated and the areas seen as highly preferable for development cannot be protected; Zonation seeks to find a solution that best compensates for the loss of areas ear-marked for development

the marginal loss. The minimum–maximum structure of Eq. (1) gives high preference to retaining locations with the highest occurrence levels of features, irrespective of the level of overlap in the distributions of features. In this way, Zonation tries to retain the high-quality core areas of all features until all the cells have been removed, and trade-offs between features are discouraged (Moilanen et al. 2005, 2012; Moilanen 2007). In addition, the cell removal order can be artificially altered to account for the fact that some areas might be ear-marked for development, whereas others are already protected by existing reserve networks. This process, called replacement cost analysis (Cabeza & Moilanen 2006), constrains Zonation to remove certain cells first (e.g., planned development areas) or to retain cells until the very end (e.g., existing protected areas) regardless of their conservation value. This produces a constrained solution for the features that can be compared with the unconstrained solution to quantify the impact of including or excluding sites from the top fraction.

We examined 9 prioritization scenarios (Table 1 & Supporting Information) to explore how social data influence the distribution of conservation priorities. We mapped areas of high biological or social value that overlapped with high development preferences (hereafter potential conflict areas) and areas of high biological and social value (hereafter potential synergistic conservation areas) in the Lower Hunter region. In the first step, we prioritized areas separately for biological values (scenario A), social values (B), and development preferences (C) to create base maps for the 3 data sets (Table 1). We then overlaid the top and bottom 30% of each priority map to identify conflict areas and synergistic conservation areas. Finally, we integrated information to prioritize for biological and social data simultaneously, where the social values were used as features (D) and then included development preferences as a cost (E) or as an exclusion mask (F) (Table 1). We also evaluated 3 additional scenarios similar to D–F that integrated the biological data with the inverse rank of the social values prioritization as a cost (G) and the development preferences as a cost (H) or as an exclusion mask (I) without the social values (Supporting Information). In all scenarios, all features were given equal weights ($w_j = 1$ in Eq. (1)). The outputs of all scenarios were evaluated against Scenario A by comparing the spatial configuration of high-priority areas and the mean level of species protection within those areas to determine the cost of integrating social values in spatial conservation prioritization to biodiversity in terms of the area of species' distributions conserved.

Results

Results of the spatial prioritizations for 6 scenarios (A–F) highlight the spatial variation in priority locations and illustrate the risks to biodiversity of using only social values or development preferences to determine conservation areas (Fig. 2). For example, using the top 30% of cells from the prioritization of social values (scenario B) as the basis for conservation planning meant that 52.5% of the highest ranking cells in the biological values solution (scenario A) were no longer protected (Fig. 2). On average,

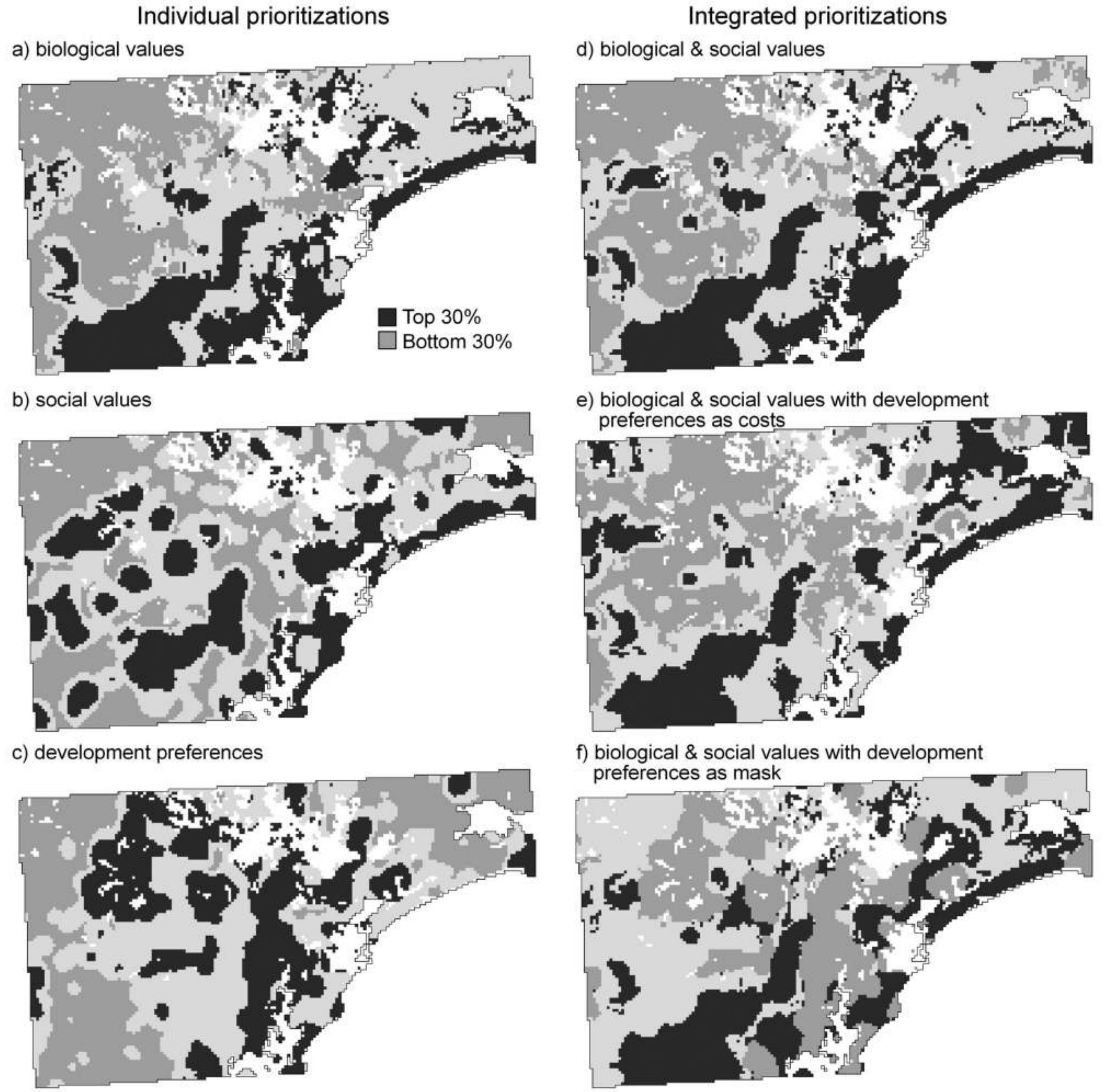

Figure 2. The upper (black) and lower (dark gray) 30% of the spatial conservation prioritization as defined by Zonation under 6 scenarios (Table 1) (light gray, intermediate rankings of the landscape; white, areas excluded from analyses): solutions for (a) biological values, (b) social values, and (c) development preferences alone and solutions for conservation when integrating biological values with (d) social values as features, (e) social values as features with development preferences as a cost layer, and (f) social values as features with development preferences as a mask.

this reduced the mean proportion of species distributions protected from 40% in scenario A to 32% in scenario B (Fig. 3). Conversely, protecting the least valuable 30% of the landscape based on development preferences (scenario C) led to a loss of 72% of the highest ranking cells compared with the biological values scenario (Fig. 2) and a reduction in the mean proportion of species distributions protected from 40% (scenario A) to 30% (scenario C) (Fig. 3).

Spatial overlays of high-priority areas (best 30%) of the landscape for biological values, social values, and development preferences highlighted synergistic conservation areas where biological and social value were high and conflict areas where high biological or social values

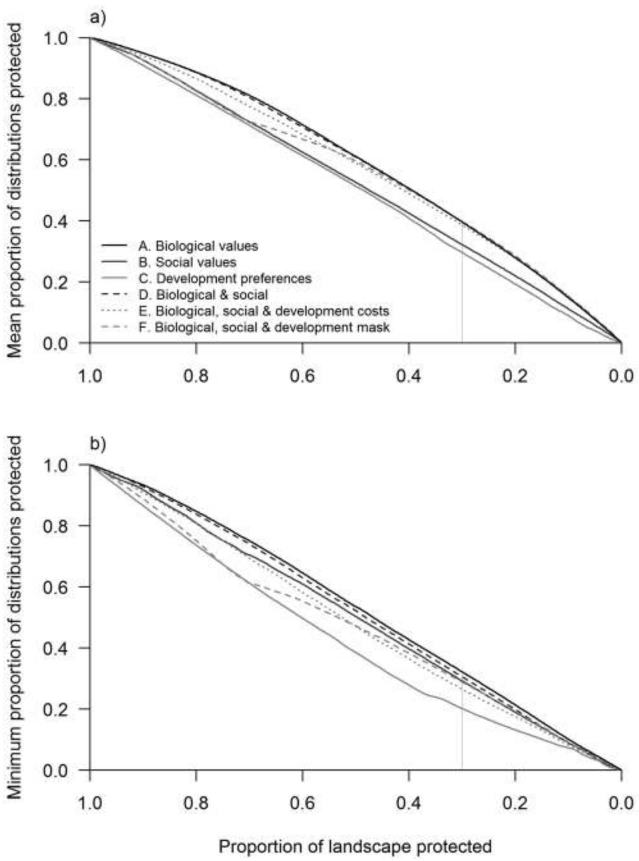

Figure 3. Relationship between the proportion of the landscape protected for conservation and the biological performance of the solution for 6 scenarios (Table 1): (a) mean proportion of species distributions and (b) minimum proportion of species distribution remaining when a given proportion of the landscape is protected.

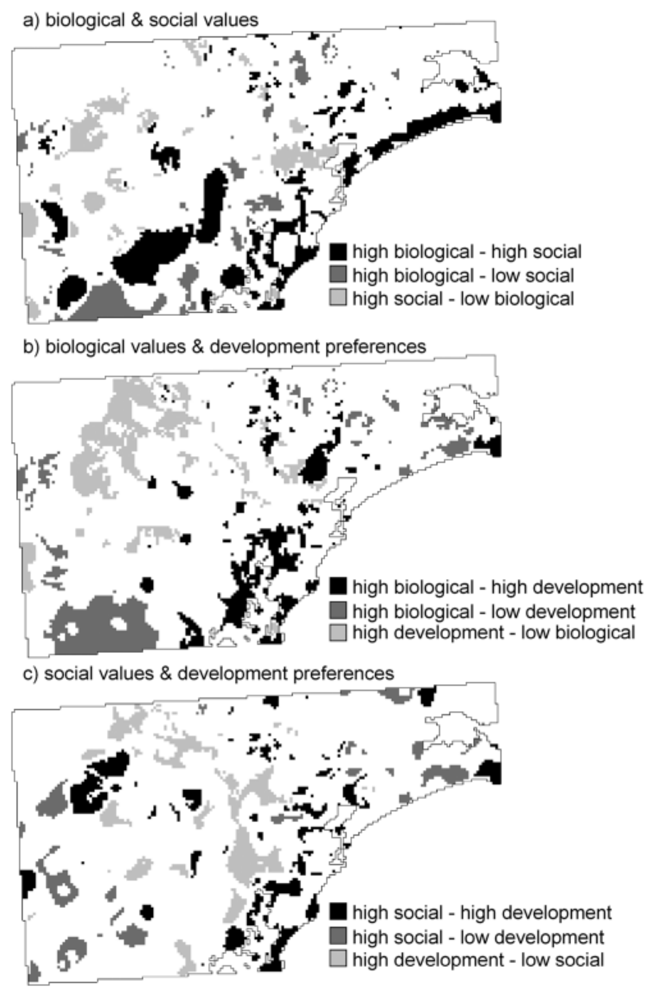

Figure 4. Pairwise overlays of the Zonation prioritizations for biological values, social values, and development preferences. High and low priority areas represent the best and worst 30% of cells in the landscape for each prioritization, respectively. Areas that have high priorities for both biological and social values (a) represent synergistic regions that are scientifically defensible and socially acceptable for conservation (A in Table 2). In contrast, high priorities for both biological and development values or social and development values (b and c) represent potential areas of conflict between the value sets (E and I in Table 2).

overlapped with high development preferences (Fig. 4). Approximately 14.2% of the landscape was identified as high priority for both biological and social values (Fig. 4a). However, high-priority areas for biological values and development preferences overlapped in 7.9% of the landscape (Fig. 4b), whereas areas of high social value overlapped with development preferences across 8.4% of the landscape (Fig. 4c). Areas of conflict were often concentrated around the coastal margins of the landscape. Comparison of biological priorities with social data allowed identification of areas that were less likely to represent conflict and that could be good places to target specific land uses. For example, 9.2% of the landscape was high priority for biological values but had a low ranking for development preferences, potentially making these areas more feasible for conservation, whereas 8.4% of the landscape had high development preferences but low biological values (Fig. 4b). Our choice of overlay threshold (the proportion of the landscape overlaid in the pairwise comparisons) did not significantly affect the ratio of overlapping cells for each comparison (Supporting Information).

Integrating biological and social values into the same Zonation analysis (scenario D; Fig. 1d) generated a very similar spatial solution to the biological values scenario (scenario A; Fig. 2a). Although there were subtle differences in the location of some of the high-priority areas of the landscape, the integrated solution performed as well as the biological values scenario when considering the proportion of species distributions that were protected (Fig. 2; lines A and D).

The inclusion of both social values for conservation and development preferences (scenarios E and F) in the prioritization markedly changed the spatial configuration of the solutions and hence the relative ranking of areas originally identified as high priority when considering biological features alone (Fig. 2e). For example, areas in the northeast and northwest of the landscape which were ranked in the bottom 30% in the biological values scenario, shifted into the top 30% when development preferences were included as a cost layer. These areas represented parts of the landscape that had low values for biodiversity but also a low cost with respect to community development preferences. Although the spatial configuration of the solution differed from the biological values scenario, Zonation produced a solution that did not greatly reduce the average proportion of species distributions protected (Fig. 3). When we considered the top 30% threshold, the average protected distribution of all species declined from 39.5% under the biological values scenario to 38.5%, whereas the proportion retained for the worst-off species dropped from 32.1% to 26.4%.

Excluding the best 30% development preference areas (scenario C) from the integrated biological and social values solution (scenario F) again led to more subtle spatial changes in the prioritization (Fig. 2f) than those generated by integrating biological and social values with development preferences as cost. Using development preferences as a mask produced a solution with minimal impact on the average conservation returns when considering the top 30% of the landscape but a smaller proportion of protected area for the worst-off species (28.8% compared to 32.1%).

Discussion

Using Zonation and data from the Lower Hunter region of NSW, we have shown how spatial priorities based on biological data can be integrated with social values and development preferences. In this case study, there were multiple options for locations that achieved similar biodiversity conservation outcomes, irrespective of how social values and development preferences were incorporated into the analysis (Fig. 3, lines A, D, E, and F), implying spatial flexibility in how conservation targets may be met in the region.

Incorporating development preferences produced the greatest changes to priority areas for conservation, yet the only scenarios that had significantly reduced performance in terms of biodiversity protection were those that did not contain any biological data at all (Fig. 3, lines B and C). However, we considered only 7 charismatic species dependent on trees for reproduction, roosting, or foraging. The public may have consciously or subconsciously considered these species when assigning values or may consider areas of high biodiversity value to be those that embody the wooded, rugged characteristics typical of existing protected areas (Pressey et al. 2000). Incorporating species with different habitats could result in a greater disparity between social values for conservation and biological values. We did not consider economic costs, such as acquiring high-priority land for conservation purposes. Incorporating spatially explicit cost data and the restriction of a fixed budget into the analyses may change the distribution of spatial priorities (Naidoo et al. 2006).

A number of issues need to be considered carefully when integrating biological values, social values, and development preferences. We acknowledge limitations in the PPGIS approach, including uncertainties in spatial resolution of data (resulting from survey participants placing stickers on maps), effects of existing familiarity with the study area, and survey response rates (Brown 2012). The PPGIS-based quantification of social data do not compensate for the need to understand the interactions between scientific and local knowledge (Fazey et al. 2012) or the importance of interviews and workshops with local community and stakeholders when negotiating land-use conflicts (Reed 2008).

Another key consideration is whether social data should be integrated into the analysis as a feature or as a cost. Using the social values layer as a feature means the software treats it in the same way as biological data (i.e., as a species p_j in Eq. (1)). This means areas of high social value could be assigned high priority even if they do not overlap with areas of biological value, so their protection could come at the expense of biologically valuable areas. Furthermore, trade-offs between features can be influenced by their spatial distribution in the landscape: when there is little or no overlap between features, trade-offs are difficult to avoid. In such cases, large differences in the relative number of different types of features, such as social and biological values, could influence how these values as a group are prioritized relative to each other. The general overlap of features we used (Figs. 1a-b & 4) means that the different number of biological and social features had negligible effect to the prioritization process. The alternative approach of using the inverse of social values as a cost (C_i in Eq. (1)) means that the social values are used only to recalculate the relative contribution of biological weighting assigned to the biodiversity values of cell i. Thus, social data would not cause areas in the landscape to be prioritized when they have no biological value, though they may result in areas of high biodiversity value being assigned lesser priority due to the relatively high social cost of dedicating those areas as conservation reserves. The choice of which approach to use depends on the objectives of the decision maker. Consequently, because the social values had significant overlap with areas of biological importance (Figs. 1a-b & 4), whether we used the social data as a feature (Figs. 2 & 4) or a cost (Fig. S2g) made little difference in the spatial conservation priorities identified by our analysis.

There are currently limitations in available conservation planning tools for integrating social and biodiversity values. Commonly used software such as Marxan and Zonation are primarily designed for use with data representing biological features and costs. Other tools that support multicriteria analysis exist (e.g., ConsNet, Ciarleglio et al. 2009), but they lack the capacity for sophisticated spatial ecological analysis. There is an opportunity to integrate the realistic decision analysis context captured by multicriteria approaches with advanced ecological characterization of spatial conservation. We see some relatively simple approaches emerging whereby features (e.g., biological and social values maps) included in a Zonation analysis could be weighted according to the results of a social preference elicitation method (Fischer 1995). We opted to keep the analysis simple and weight all the features in the prioritizations equally. The decision to do so was somewhat arbitrary, but we believe differentiation of the relative importance of biological and social values without a formal multicriteria weighting process would be highly subjective. The exploration of different weighting schemes within and between the biological and social features would be a straightforward extension of our analysis, and we recommend that this be undertaken in situations where stakeholders can articulate multiple weighting schemes. Implicit weighting of features (i.e., how features are treated when they have equal weights) in Eq. (1) is primarily driven by their distribution size. In the medium term, there is a need to better reconcile the role of decision analysis tools, such as Zonation, with normative decision theory (Clemen & Reilly 2001) so that well-understood pitfalls are avoided and opportunities to build on existing tools for dealing with uncertainty and risk are maximized (Raïffa 1968).

The social acceptability of a conservation policy can be assessed via consideration of both social values and development preferences (Table 2). Where biological values coincide with high social values for conservation (A in Table 2), there is likely to be a high level of acceptability of conservation actions. Conversely, where they intersect with low concentrations of social values (B in Table 2) or strong preferences for development, it is likely that conservation actions (e.g., establishing a new reserve) will have less community support, necessitating engagement with local groups to identify the nature of their concerns and steps toward managing them.

Policy makers and conservation planners can also use integrated outputs of social values, land-use preferences, and biological data to help predict and resolve land-use conflict and assist in making transparent trade-offs between antagonistic land uses. Identifying areas of low development preference and high biological or social value (B and F in Table 2) may assist in decisions on where to purchase or lobby for the establishment of protected areas with minimal community backlash. Where areas identified by the community as suitable for development coincide with areas of conservation importance based on biological data (E in Table 2), potential for conservation conflicts is likely to be high and careful planning will be needed to avert the high risk of biodiversity loss. Land-use planners may be able to minimize land-use conflict by prioritizing development in areas of high development preference and low social and biological values (J in Table 2) (Bekessy et al. 2012). However, protecting areas of low development potential can result in opportunity costs; such areas are unlikely to be developed and are therefore at low risk of loss (Pressey & Tully 1994).

Although maps of spatial priorities based on social and biological data do not contain all the necessary information for land-use decision making, they may add a valuable level of sophistication and transparency to this process. Depending on the specific decision making context (e.g., identifying new conservation reserves, protecting social values, or prioritizing new urban development), full integration of these data, as opposed to the spatial overlay approach (Figs. 2d–f), can identify potentially robust solutions to complex socioecological spatial planning problems. However, we stress that these fully integrated solutions must be performed in conjunction with decision makers. Aspects to consider include weighting of social and biological features, the flexibility in defining development areas, the minimum target level of protected habitat for different species (Supporting Information), and uncertainties associated with areas of no social value and development preference data.

Ours is one of the first studies to fully integrate social values and species distribution data into a quantitative spatial prioritization analysis. Thus, there is scope for modifying the typology of values and preferences, including marine planning and fine-scale urban conservation contexts. Other spatial metrics (e.g., diversity indices) could be used to account for the degree of variance and divergence of development preferences. Such research could build upon recent work on the compatibility of different social values (Brown & Reed 2012) and specifically target conservation outcomes. For example, important questions relate to which landscape features are associated with social values for conservation (e.g., high levels of canopy cover); how preferred features might relate to requirements of species of conservation concern; and whether the protected status of a reserve increases the strength of social value of an area. There is also a need for researchers to work closely with decision makers and conservation practitioners to promote new techniques in land-use planning, particularly with respect to how social and biological values can be integrated at different geographic scales of management and how to account for different types of spatial uncertainty when integrating social values and biological data.

Table 2. Policy implications generated from pairwise comparison of areas prioritized for conservation based on biological values and the overlap with social values for biodiversity and development preferences, with possible strategies for dealing with synergies and conflicts between different values.

	Social value		*Development preference*	
	high	*low*	*high*	*low*
Biodiversity value				
high	(A) conservation areas: biologically important and good community support for conservation	(B) high biodiversity areas with low community support: biologically important but poor community support for conservation; community engagement, education, and awareness-raising needed to increase social acceptability of conservation actions	(E) high conflict areas: conservation actions justifiable scientifically yet conflict with community development preferences; communications and conflict resolution to be directed to these areas	(F) conservation areas: high conservation priority biologically and little conflict resolution required
low	(C) high community support but low biodiversity value; conservation actions well supported by the community but not a biological priority; opportunistic action may take place; further community engagement recommended to determine why these areas are highly valued by the community	(D) discount areas: neither acceptable nor of high biological priority to conserve	(G) development areas: support development in these areas	(H) low conflict areas: maintain under current land use
Development preference				
high	(I) high conflict areas: community preference for development might compromise their conservation values; further community consultation needed.	(J) areas feasible for development: support development in these areas		
low	(K) areas feasible for conservation: social acceptability of conservation actions do not conflict with development preference	(L) low conflict areas: maintain under current land use		

While creating an extra level of complexity for conservation planners, this approach offers the potential to improve conservation outcomes in contested landscapes. In addition to considering the economic costs of conservation actions (Naidoo et al. 2006), this approach could be used to maximize the compatibility of conservation plans with development preferences (either perceived or real), thereby maximizing conservation gains while increasing the social acceptability of land-use changes. The approach also enables conservation planners to evaluate how social values conflict or intersect with the distributions of species and to quantify the potential costs of integrating social data to spatial conservation prioritization.

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Supporting Information

A table of environmental variables used in the MaxEnt models (Appendix S1), results of the MaxEnt models for each species (Appendix S2), operational definitions of the social values and development preferences used in the PPGIS study (Appendix S3), description of 3 additional prioritization scenarios analyzed (Appendix S4), plot showing proportion of overlapping cells in pairwise comparisons of Zonation solutions at different landscape thresholds (Appendix S5), spatial prioritizations for 3 additional scenarios (Appendix S6), and replacement cost curves for 3 additional scenarios (Appendix S7) are available on-line. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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