LETTER

Representation of ecosystem services by tiered conservation strategies

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Abstract

In human-dominated regions, protected areas are complemented by other conservation strategies (e.g., restrictive zoning, incentive payments) to maintain biodiversity and other ecosystem services. These strategies are often not mutually exclusive, with many areas covered by multiple (tiered) management strategies. However, it is not known whether tiering increases (or decreases) representation of ecosystem services. Here, we compare the representation of four ecosystem services by areas protected by both tiered and single conservation strategies (protected areas, restrictive zoning, and incentive payments to landowners) in a human-dominated region (England). Tiering always coincided with the highest levels of stored carbon, sometimes coincided with high biodiversity and agricultural production, but never coincided with high recreational value. We also show that tiering is common in England and biased towards upland areas. Future evaluations of the effectiveness of conservation strategies should consider the degree of overlap of the different strategies fully to understand which are most effective.

Introduction

Over 12% of the Earth's land area has been set-aside in protected areas (Chape *et al.* 2005). These play a vital role in conserving biodiversity (Gaston *et al.* 2008), and based on evidence from a few case studies, can also protect other ecosystem services (e.g., Naidoo & Ricketts 2006; Eigenbrod *et al.* 2009). However, this system of protected areas is not evenly distributed and is generally located far from the human-dominated landscapes where much of the world's population lives (Loucks *et al.* 2008). This is because large, state-owned "wilderness" reserves are usually not practical in densely populated regions. Consequently, biodiversity investments in such regions rely heavily on small protected areas (e.g., Jackson & Gaston 2008) and alternative conservation strategies that aim to increase biodiversity within human-dominated portions of the landscape. Two major strategies are restrictive zoning and incentive payments to private landowners. In the former, planning legislation is used to restrict human development (Beatley 2000), while in the latter payments are provided to rural landholders in return for management actions designed to increase the abundance of native biodiversity (e.g., agri-environment or set-aside schemes). There is a considerable literature on the effectiveness of such strategies for conserving biodiversity (e.g., van Buskirk & Willi 2004; Kleijn *et al.* 2006; Maiorano *et al.* 2007; Milder *et al.* 2008), but little on the role of these alternative strategies in conserving other ecosystem services (but see Eigenbrod *et al.* 2009).

Restrictions on land availability in human-dominated regions mean that conservation strategies covering large areas are likely to have multiple management objectives (e.g., agricultural production and maintenance of biodiversity), but often also contain small areas in which biodiversity conservation is the primary objective. Such restrictions mean that the spatial overlap of conservation strategies—hereafter "tiering"—is likely. Tiering is thought to be widespread in England (Colman *et al.* 1993), and is probably also common elsewhere. For example, the Pinelands National Reserve in New Jersey, USA, is a 400,000 ha multiple-use landscape containing forests, farmland, and human settlements (www.state.nj.us/pinelands/cmp/summary/). While the whole Reserve is managed through restrictive zoning, a second level of protection for biodiversity exists in many places through protected areas (state parks and wildlife management areas). State legislation places additional restrictions where protected species occur. Thus, portions of the Reserve are covered by up to three conservation strategies—restrictive zoning, protected areas, and endangered species legislation. More generally, tiered designations for biodiversity will also occur whenever "critical" habitat for a threatened species protected under legislation (such as the US Endangered Species Act) overlaps with another conservation strategy.

It is not known how effective tiered conservation strategies are at representing biodiversity or other ecosystem services as compared to single strategies. If tiering generally occurs in the most valuable areas for biodiversity and other ecosystem services, then representation will generally be high. However, tiering could also lead to conflicting management objectives (e.g., between recreation and biodiversity conservation; Reed & Merenlender 2008), leading to decreased representation of some or all ecosystem services. Alternatively, it seems likely that the dominant management strategy of tiered areas will usually be determined by the objective that has the strongest statutory designation, leading to high amounts of one ecosystem service, but reduced amounts of others.

The effectiveness of tiering is also likely to depend on how well the different land management strategies complement each other. For example, layering incentive-based strategies like agri-environment schemes over land managed through regulatory strategies such as restrictive zoning or endangered species legislation can increase the effectiveness of the latter by compensating landowners for income lost through restrictions placed on their land (e.g., Langpap 2006). If, however, the prescriptions of two tiered conservation strategies are closely aligned, we assume that the more stringent criteria would subsume the other, and there would be no net benefit of tiering.

Here, we compare the spatial coincidence of biodiversity, recreation, agricultural production, and carbon storage with areas protected by up to three conservation strategies (protected areas, restrictive zoning, and incentive payments to landowners) in England. Our goal is to assess whether areas with multiple designation have higher representation of ecosystem services than those with single designation. We have few detailed a priori predictions due to the very different management objectives of the three types of strategies (Methods). However, we do predict that protected areas—in which biodiversity conservation is the overarching management objective—within areas with restrictive zoning and/or agri-environment schemes will have higher levels of biodiversity than protected areas in isolation.

Methods

We used England as our case study as this is a human-dominated region in which three different conservation investment strategies—protected areas, restrictive zoning, and incentive payments schemes—are well developed. Protected Areas—land with statutory protection specifically to conserve biodiversity (e.g., Sites of Special Scientific Interest [SSSI] and/or National Nature Reserves [NNR])—cover 6.3% of the total terrestrial area (130,439 km^2) (Figure 1; Table 1). English Protected Areas are generally small (78% cover $\leq$ 1 km^2), and over half are on private land (Jackson & Gaston 2008). Few exclude human uses altogether; indeed many Protected Areas are heavily managed to conserve a particular habitat of conservation concern (Marren 1994). These Protected Areas are largely (60%) nested within two types of Protected Landscapes—National Parks (NPs) and Areas of Outstanding Natural Beauty (AONBs)—which cover 8.0 and 15.3% of the country, respectively (Figure 1; Table 1). These Protected Landscapes are protected by law to "ensure conservation and enhancement of natural beauty (which includes wildlife)"; promotion of outdoor recreation opportunities and maintenance of the social and economic well-being of local communities are also policy objectives (Natural England 2008). English Protected Landscapes are primarily managed through restrictive zoning, but also contain most of the Environmentally Sensitive Areas Scheme (ESA), which covers 4.8% of England overall (Figure 1; Table 1). The ESA is an agri-environment scheme, where incentive payments are made to landowners to promote wildlife-friendly farming, and was set up to "safeguard and enhance parts of the country with particularly high landscape, wildlife or historical value"

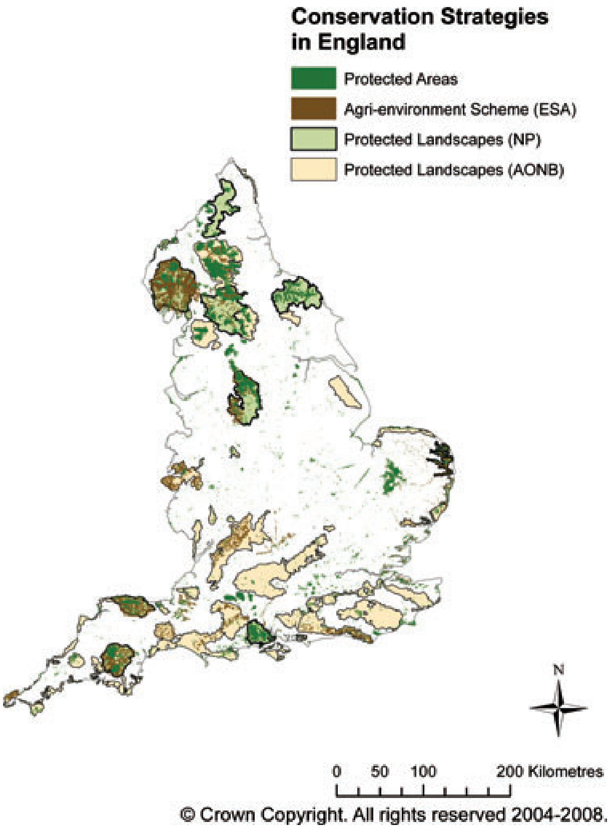

Figure 1 Distribution of contrasting conservation strategies in England.

(www.defra.gov.uk/erdp/schemes/esas/default.htm). See Appendix S1 for detailed methods.

We used England-wide spatial datasets to calculate the representation of biodiversity and other ecosystem services within these conservation strategies. For biodiversity we used the "species of conservation concern" prioritized by the UK government for conservation (Biodiversity Action Plan (BAP) species; Anonymous 1994) (www.ukbap.org.uk/NewPriorityList.aspx). We used the recorded presences of all terrestrial BAP species for which we had England-wide data (bryophytes, vascular plants, butterflies, herptiles, birds, and mammals) measured at the 2 × 2 km grid square resolution, with the birds modeled as per Franco *et al.* (2009). The carbon storage layer is an estimate of combined organic soil and above ground vegetation carbon (in kilogram C) calculated at the 1 × 1 km resolution. The agriculture layer is the summed gross margin of all major crops and livestock [gross margin = value of output – variable costs, with subsidy payments removed], and is spatially explicit at the scale of a ward (mean area 1,912 ha). Recreation value is based on point locations of visits to rural locations for the purpose of enjoyment of the countryside obtained from the England Leisure Visits Survey 2005 (Natural England 2006). See Appendix S1 for detailed methods.

Conservation strategies are biased towards higher elevation lands (hereafter "uplands") in England (Eigenbrod *et al.* 2009). To identify if this upland bias was more (or less) pronounced in areas with tiered designation, we calculated the mean elevation for all combinations of strategies using the GTOPO30 digital elevation model (DEM) (http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html).

We divided the percentage of each of the measures of ecosystem services contained within areas covered by a given combination of conservation strategies (e.g., protected areas and agri-environment agreements) by the percentage land area covered by that combination of

Table 1 Tiered versus single designation of three conservation strategies in England

Conservation strategy	Conservation strategy present?							
Protected Area	Yes	Yes	Yes		Yes			
Protected Landscape	Yes	Yes		Yes		Yes		
Agri-environment scheme (ESA)	Yes		Yes	Yes			Yes	
	Multiple Designation				Single Designation			None
Area (ha)	124,542	394,592	21,074	400,748	286,860	2,129,181	81,457	9,605,521
Biodiversity	2.53	3.29	**5.33**	1.78	3.53	1.54	0.66	0.73
Carbon storage	**2.29**	1.92	1.94	1.27	1.41	1.06	1.45	0.90
Agriculture	0.34	0.28	**1.25**	0.69	0.52	0.82	1.02	1.10
Recreation	0.27	0.86	0.39	0.42	**1.21**	0.94	0.53	1.05

The representation of the four ecosystem services is a ratio (amount of a service relative to England as a whole). The strategy or combination of strategies with the highest representation for each service is shown in bold. A ratio of >1 indicates that an ecosystem service is over-represented (more abundant than expected given the area of the strategy); values <1 indicate under-representation. Note that no estimates of sampling error or significance of the results are given as these values are not for samples, but rather for the entire "population" of an ecosystem services for each strategy in England. ESA refers to the Environmentally Sensitive Areas Scheme.

Table 2 Elevation, degree of tiering, and ratio of actual to predicted overlap of three conservation strategies in England

Conservation strategy	Conservation strategy present?							
Protected Area	Yes	Yes	Yes		Yes			
Protected Landscape	Yes	Yes		Yes		Yes		
Agri-environment scheme (ESA)	Yes		Yes	Yes			Yes	
	Multiple designation				Single designation			None
Mean elevation (m)	363	272	62	239	103	155	118	79
Area (ha)	124,542	394,592	21,074	400,748	286,860	2,129,181	81,457	9,605,521
Proportion of total Protected Area	0.15	0.48	0.03		0.35			
Proportion of total Protected Landscape	0.04	0.13		0.13		0.70		
Proportion of total ESA	0.20		0.03	0.64			0.13	
Ratio of actual to predicted overlap	13.39	2.99	6.45	4.28				

The ratio of actual to predicted overlap (bottom row) is based on the actual area of the tiered strategy divided by the area predicted by probability theory. A ratio of >1 indicates that tiering is over-represented (more abundant than expected given the area of the strategy); values <1 indicate under-representation. ESA refers to the Environmentally Sensitive Areas Scheme.

strategies to quantify the extent to which ecosystem services are represented by the different possible combinations. A value greater than one in this ratio thus indicates that a particular strategy contains a disproportionately large amount of a specific ecosystem service relative to the area that it covers (Table 1) (Eigenbrod *et al.* 2009). For the ecosystem service layers other than biodiversity, we spatially delineated each layer by the exact extent of a conservation strategy. However, we were only able to delineate representation of biodiversity within conservation strategies at the 2 × 2 km grid resolution. This was because our measure of biodiversity was the summed proportion of the ranges of all BAP species, and each species was either "present" or "absent" in a 2 × 2 km grid cell. A strategy was considered as present in a grid cell (for biodiversity) if at least 40% of the cell was covered by that strategy. This threshold resulted in the best match between the actual percentage of England covered by conservation strategies and the percentage estimated based on presence/absence at the 2 × 2 km grid resolution; conclusions are not sensitive to the threshold selected (Table S3 in Appendix S1).

We also calculated whether the amount of tiering was more or less than would be predicted by chance for the area covered by each strategy. We calculated the predicted overlap of strategies by multiplying the percentage of England covered by each strategy considered. For example, given that 6.34% of England is covered by Protected Areas, 23.37% by Protected Landscapes, and 4.81% by the ESA agri-environment scheme, the predicted chance overlap of all three strategies is $0.2337 \times 0.0634 \times 0.0481 = 0.000713$; however, the actual overlap is 0.0095478. The ratio of the actual to the predicted proportion is 13.39 (Table 2), indicating that triple designation is over 13 times more common than expected by chance.

We examined regional variation in representation of ecosystem services by tiered and single conservation strategies by running the analyses we ran for England as a whole for three disparate regions—the East of England, Southwest and Northwest (Figure S1 in the Appendix S1). Both the Northwest and Southwest are hilly (mean elevation 159 and 116 m, respectively), but the former is cooler than the latter. The East of England, by contrast, is a relatively flat (mean elevation 42.5 m) region characterized by extensive agricultural activity. We did not run these regional analyses for agricultural production due to limitations of the underlying dataset (Supporting Information in the Appendix S1).

All GIS analyses were done using ArcGIS/ArcInfo 9.2 (ESRI, Redlands, CA, USA).

Results

If considered as a whole (irrespective of overlap), our results show that areas targeted primarily for biodiversity conservation—the Protected Areas—are well placed to achieve this goal, but also secondarily contain large amounts of stored carbon. In addition, the representation of recreation and agricultural production by the three conservation strategies considered here is generally low (Table 1). We discuss these results in a companion paper (Eigenbrod *et al.* 2009), but do not consider them further here, as our goal is specifically to compare tiered versus single designation.

Tiered designation always coincided with the highest amounts of stored carbon, sometimes with high biodiversity and agricultural production, but never coincided with high recreational value (Table 1). Areas with triple designation were best for carbon storage, but not for biodiversity; such areas also had the highest mean elevation (363 m) of any of the strategies considered here (Table 2). The areas with the highest biodiversity value were in Protected Areas in the lowlands, represented by dual designation as Protected Area and ESA agri-environment scheme, and Protected Areas in isolation, with additional high representation in the Protected Areas within Protected Landscapes. Agricultural production, while low overall, was highest where any combination of protected areas or protected landscapes was also covered by the ESA agri-environment scheme. Recreation was highest for Protected Areas (single designation), followed by locations with no designation at all, but under-represented in all areas that had multiple designations (Table 1).

All tiered conservation strategies are much more common in England than would be expected through chance alone, ranging from over 13 times higher than expected (triple designation) to three times higher than expected (Protected Areas within Protected Landscapes). However, in terms of absolute area, most tiering occurs within Protected Landscapes which are by far the largest of the three strategies considered here (Table 1; Figure 1). Tiered strategies (except areas designated both as Protected Areas and ESA agri-environment schemes) are also generally located at relatively high elevations (Table 2).

The national trends in the representation of ecosystem services were generally also true at the regional level (Table S5 in the Appendix S1). As in England as a whole, areas with tiered designation always had the highest carbon storage in the East of England, Southwest and Northwest, sometimes had the highest levels of biodiversity (East of England and Southwest), but never had the highest representation of recreation. However, recreation was higher than expected in areas with double designation in the East of England, and there was considerable variation in which combinations of strategies had the highest levels of carbon storage and biodiversity between the three regions.

Discussion

Conserving both biodiversity and ecosystem services in human-dominated landscapes will require a range of policy instruments in addition to the traditional protected areas to succeed (Daily & Matson 2008). The crucial step of evaluating the effectiveness of this multitude of investment strategies (Ferraro & Pattanayak 2006) will best be accomplished not by considering each strategy in isolation, but rather by examining the portfolio of strategies across an entire landscape. Our results here show that considering the degree of overlap of different strategies within such an assessment will help to understand which strategy, or combination of strategies, best protect ecosystem services.

Overall, the level of coverage of ecosystem services in tiered conservation strategies depended on the services considered. For two services—carbon storage and recreational use—the reasons for their respective over- and under-representation by tiered strategies are likely fairly straightforward. For carbon storage, high representation is probably a reflection of the strong upland bias of areas with multiple designation; English uplands are dominated by grassland and moorland habitats that have large amounts of soil carbon stocks (Milne & Brown 1997). Proximity to urban centres is a major driver of recreational use of natural areas (Hörnsten & Fredman 2000), and English conservation strategies are generally located in lightly populated parts of the country (Eigenbrod *et al.* 2009). Areas with tiered designation are particularly biased towards the north and west of England (Figure 1), and thus well away from the major urban conglomerations of the southeast (Greater London) and Midlands (Birmingham), so the most likely explanation for the poor representation of recreation by areas with tiered designation is their geographic isolation from centers of population.

The performance of areas with tiered designation was less clear for biodiversity (species of conservation concern) and agricultural production. Protected Areas and ESA agri-environment schemes in isolation have higher representation for biodiversity and agricultural production, respectively, than most multiple designations, probably due to their being largely situated in the more low-lying and productive portions of the country. However, if species groups are considered separately (plants, animals, bryophytes) (Table S4 in the Appendix S1), then areas with tiered designation always have the highest representation for biodiversity. Bryophytes and plants are best represented in Protected Areas also covered by the ESA agri-environment schemes, while areas with triple designation have the highest representation for animals (birds, butterflies, mammals, and herptiles). In addition, representation of biodiversity in Protected Landscapes was highest where tiering occurred. This suggests that tiered designation within these multiple-use landscapes occurs in the portions of the landscape that "protect" the highest number of species. However, representation of biodiversity was lower in areas of triple designation than in areas of double designation within Protected Landscapes, except when animals were considered separately (Table S4 in the Appendix S1). Triply designated areas occur on agricultural land (hence their designation under the ESA agri-environment schemes) in high elevation areas, and consequently provide habitat for a narrow range of species.

A surprising finding was that the highest representation of both biodiversity and agricultural production was within areas designated as both Protected Areas and ESA agri-environment schemes. Biodiversity conservation is generally not considered to be compatible with intensive agriculture (e.g., Norris 2008), so this might indicate that "ecoagriculture" (Scherr & McNeeley 2008)—where high levels of production, biodiversity, and other ecosystem services co-exist—is occurring in these areas. However, this result may also be an artifact of the combination of the highly fragmented nature of this combination of management strategies (mean area of land patches with this dual designation is 14.2 ha) and limitations of the underlying datasets (Supporting Information in Appendix S1). In other words, most of the biodiversity might be packed into small natural areas within agriculturally productive regions, rather than species occurring on the farmed land. In addition, only 0.16% of the English land surface falls into this dual designation, so even if this result is not an artifact, the scope for reconciling biodiversity conservation within highly productive agriculture might be limited.

Our results might also indicate that tiered conservation strategies are more effective for conserving biodiversity than single strategies, though also that different combinations of strategies are needed for different species groups. Representation of species richness (both for all species of conservation concern combined and when species groups are considered separately) within Protected Landscapes is much higher where these are also covered by Protected Areas; this might indicate that the extra statutory protection afforded by Protected Area status is beneficial. Representation of biodiversity was also higher in Protected Areas and Protected Landscapes also covered by the ESA agri-environment schemes than areas covered by these two regulatory strategies alone, providing some support for layering incentive-based conservation strategies onto regulatory strategies. More research is needed to test if these patterns are indeed indicative of management success, or simply due to tiering generally occurring in areas with high pre-existing biodiversity value which would have been equally (or better) maintained with single (or no) conservation strategy(ies) in place. Time series data would be required to determine the effectiveness of tiered strategies in *protecting* ecosystem services; such data are unfortunately unavailable at the scale of this analysis.

The upland bias of areas with tiered designation as compared with single designation is also interesting, as it suggests that the global bias of protected areas to upland regions (Loucks *et al.* 2008) is even more pronounced in areas with tiered designations. This could result from the increasing restrictions on use imposed by multiple levels of designation being easier to achieve in less economically valuable upland areas ("residual reserves" cf. Pressey & Bottrill 2008).

Finally, our study—the first to quantify the extent of tiering of conservation strategies—raises a number of questions for future research. Our results support the suggestion of Colman *et al.* (1993) that tiering of conservation strategies in England is common; more work is needed to quantify if this is true globally and to what extent the patterns we identify for England can be generalized. The 553 UNESCO Man and Biosphere Reserves that exist globally could form the basis of such an analysis, as these are characterized by core Protected Areas nested within multiple-use Protected Landscapes. More work is also needed to understand why tiering occurs. Colman *et al.* (1993) suggest that for England, tiering occurs after designation by one level of policy arouses conservation interest in an area, leading to subsequent policies that aim to address shortcomings of that initial policy. We show that areas with triple designation are particularly over-represented, but were unable to test directly whether initial designation in one category attracts additional conservation strategies beyond the level that the habitats in these areas would have warranted anyway. Additional studies are also needed to identify which combinations of conservation investments are best suited to conserving particular ecosystem services, and to what extent layering multiple strategies with different management objectives (e.g., recreation and biodiversity) can actually deliver multi-service objectives. Finally, practitioners should explicitly consider the degree to which new conservation strategies will overlap with existing strategies when planning for ecosystem services (Cowling et al. 2008; Tallis et al. 2008), and the potential impact (both positive and negative) that such tiering is likely to have on different ecosystem services.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Supporting information on methods.

Figure A1 Locations of regions used in analyses of regional variation of ecosystem services by tiered and single conservation strategies

Table A1 The cutoff value used to convert modelled bird distribution values (Supporting Methods) to binary presences (> cutoff) and absences (< cutoff).

Table A2 Summary of values used in calculating the gross margin of agriculture production (Supporting Methods). Gross margins per unit area in £/ha unless otherwise indicated. The decoupled single payment subsidy is removed in all cases; the removal of additional subsidies is indicated in the notes where applicable.

Table A3 Changes in the Biodiversity ratios depending on the minimum area of a conservation strategy required for it to be 'present' in a 2 km grid square. 'Area (%) of Conservation Strategy' is the percent of England that the strategy covers using a particular cutoff. We use 0.40 for the main results, as this best corresponds to the actual area covered by all strategies.

Table A4. Biodiversity results (BAP species) by species group for three conservation strategies – Statutory Protected Areas (StPA), Protected Landscapes (PL) and the ESA agri-environment scheme (ESA) – both in isolation and in combination. A ratio of >1 indicates that an ecosystem service is over-represented (more abundant than expected given the area of the strategy); values <1 indicate under-representation (Methods). The highest representation for each species group is shown in bold. Species were considered present in a strategy if >40% of a 2 × 2 km grid cell was within the given strategy or combination of strategies.

Table A5. 2 Representation of ecosystem services within three conservation strategies (in isolation and in combination) in three regions of England – the Northwest (NW), Southwest (SW) and East of England (EE). A ratio of >1 indicates that an ecosystem service is over-represented (more abundant than expected given the area of the strategy); values <1 indicate under-representation (Methods). The highest ratio for each service for each region is shown in bold.

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