Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Biological Conservation 120 (2004) 307–313
BIOLOGICAL CONSERVATION
www.elsevier.com/locate/biocon

A gap analysis of terrestrial protected areas in England and its implications for conservation policy

Thomasina E.E. Oldfield, Robert J. Smith *, Stuart R. Harrop, Nigel Leader-Williams

Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NS, UK

Received 14 October 2003; received in revised form 11 February 2004; accepted 9 March 2004

Abstract

Many protected area (PA) systems have developed in response to socio-economic and aesthetic criteria and need to be modified to increase their conservation value. National gap analyses are an important step in describing and addressing this problem, so we sought to determine the representativeness of English PAs devoted to biodiversity conservation by using Natural Areas (NAs), elevation and PA boundary data. We found that National Nature Reserves (NNRs) and Sites of Special Scientific Interests (SSSIs) cover only 6.3% of England and are generally small, with respective median areas of 1.1 and 0.2 km^2. The English PA system under-represents lowland areas and provides a median level of 2.5% protection for the NA types, with seventy nine per cent of NA types having less than 10% protection. Therefore, we suggest that England's PA system needs to be expanded, although this would probably entail modification of existing legislation to increase involvement by landowners. We also compare our results with previous appraisals that used species distribution record data and suggest that landscape-level analyses may give a more accurate and less positive assessment.

Keywords: Gap analysis; Conservation planning; Protected areas; England; Positive incentives

1. Introduction

Protected areas (PAs) are the mainstay of most national conservation policies but many PA systems are not representative of national biodiversity as a whole (Pressey et al., 1993). This is because socio-economic and aesthetic criteria usually predominated in the choice of PA locations, often leading to the selection of unrepresentative sites of lesser conservation value (Leader-Williams et al., 1990; Pressey, 1994). The first stage in addressing this problem is to measure the extent that existing PAs represent biodiversity and identify elements that need further protection (Scott et al., 1993). This type of "gap analysis" has been undertaken in a number of countries (Hunter and Yonzon, 1993; Fearnside and Ferraz, 1995; Ramesh et al., 1997; Powell et al., 2000; Scott et al., 2001), but few European nations have followed this example. This paper attempts to partially address this by presenting the results of a gap analysis for England, one of four administratively devolved countries that make up the United Kingdom, and which has its own statutory nature conservation authority, English Nature.

One of the first steps in such a conservation planning exercise is to identify a suitable surrogate for biodiversity (Margules and Pressey, 2000). Often the choice is based on expediency, as mapping the distribution of biodiversity elements is expensive, forcing many conservation planners to use any available data. It might be expected that England would not suffer from this problem, as the distributions of many taxa, ranging from mammals to liverworts, have been recorded by a large number of volunteers (Prendergast et al., 1993). Furthermore, when compared to other national atlas datasets used in conservation planning (Rodrigues and Gaston, 2001), many of these data have been collected at the relatively fine spatial scale of 100 km^2 and have already been used to undertake preliminary assessments of the effectiveness of the English PA system (Williams

* Corresponding author.
E-mail address: r.j.smith@kent.ac.uk (R.J. Smith).

0006-3207/$ - see front matter
doi:10.1016/j.biocon.2004.03.003

et al., 1996; Hopkinson et al., 2000). However, most English PAs are far smaller than even the resolution of this fine-scale distribution data, making it difficult to know whether species recorded within a particular grid square actually occur within any corresponding PAs (Lombard, 1995), see Figs. 1–3.

An alternative in conservation planning is to use a landscape approach (Belbin, 1993; Lapin and Barnes, 1995; Awimbo et al., 1996; Duffy et al., 1999; Pressey et al., 2000), as these surrogates can be effective at representing other aspects of biodiversity, such as species distributions (Kirkpatrick and Brown, 1994; Wessels et al., 1999). English Nature has mapped these broad landscapes by dividing the mainland of England into 97 Natural Area (NA) types, each of which is a distinct biogeographical zone that is relatively homogenous in terms of the underlying geology and biodiversity (English Nature, 1999). Therefore, we decided to use the NA data in this study and to supplement these with fine-scale elevation data, which can also act as an important biodiversity surrogate (Begon et al., 1996). Using these broad-scale surrogates has particular benefits for conducting a gap analysis of a developed country such as England, where much of the land has been transformed by agriculture (Robinson and Sutherland, 2002). In these cases it is likely that most long-term conservation plans will involve elements of ecological restoration (Anon, 1994), making the present distributions of species relatively less important.

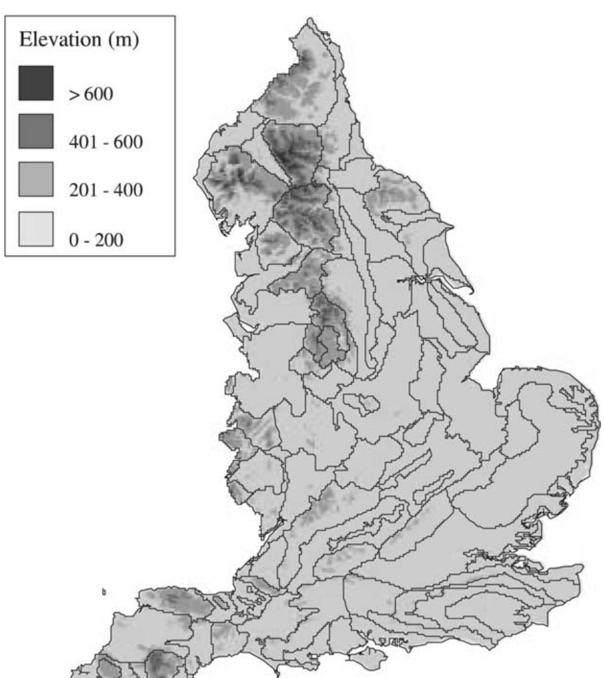

Fig. 1. Natural Area type boundaries and elevation in England.

Fig. 2. National Nature Reserves in England.

Fig. 3. Sites of Special Scientific Interest in England.

Conservation planning exercises also require data on the distribution of PAs and the situation is particularly complicated for England, where several national PA designations are in use. The best-known designation is of National Parks (NP), because this term is widely used in other countries. However, in the English context, NPs are generally areas of privately owned farmland that are established and managed by their respective national park authorities for their scenic value. Likewise, Areas of Outstanding National Beauty (AONB) were established, and are now managed by the Countryside Agency, for their scenic value. Both NPs and AONBs are not primarily gazetted for their biodiversity conservation value, and so both are classed as Category V "Protected Landscapes" by IUCN – The World Conservation Union (IUCN, 1994).

In contrast, the designations of National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSIs) form the core of national site protection measures for biodiversity in England, see Figs. 2 and 3. All NNRs must also be designated as SSSIs. Furthermore, where site protection is needed to conserve biodiversity within the scenic designations of NPs and AONBs, such sites can also be designated as NNRs and/or SSSIs. In addition, other European and international designations, such as Special Protection Areas and Special Areas of Conservation, and terrestrial Biosphere Reserves and Ramsar Sites, must also first be notified as SSSIs. Thus one site may have multiple designations, which may considerably exaggerate the apparent area of England with PA status, if the overlap between designations is not taken into account. Of the two national biodiversity designations, only NNRs are recognised by IUCN as Category IV "Habitat/Species Management Areas" (IUCN, 1994), while SSSIs are not recognised in any of the IUCN categories.

This paper, therefore, has two aims. First, we seek to map and calculate the sizes of existing terrestrial NNRs and SSSIs, the two core designations for biodiversity conservation in England. Second, we seek to determine their representativeness, based on NA types and elevation. We have excluded European and international PA designations from this analysis because they are already NNRs and/or SSSIs. In addition, we have excluded the 170 PAs managed by the Royal Society for the Protection of Birds (RSPB), because they cover an area of only 347 km^2, 63% of which is also designated as NNRs and/or SSSIs.

2. Methods

GIS coverages of the boundaries of England's NNRs and SSSIs that had been digitised from 1:10,000 maps were obtained from English Nature in 2001. English Nature also provided the NA coverage, which was digitised from 1:50,000 digital maps. It was decided to exclude the Lundy Natural Area type from the analysis, as this consists of a relatively small island with a high proportion of coastline. The England political boundary and a 25 m resolution digital elevation model (DEM) data were obtained from the Landmap project.

These data were imported into the ArcView 3.2 GIS software and the PA and NA boundaries were clipped using the England political boundary coverage to remove any estuarine and marine areas. The area of each PA and NA type was then calculated in ArcView. In addition, ArcView's "Union" option was used to produce a coverage containing a separate polygon for each combination of the different NA and PA polygons and then to calculate the overlap between the two different types of PA. The percentage of each NA type with PA status was also calculated and, where a site had both NNR and SSSI status, it was considered as NNR rather than SSSI, given that the former is more internationally recognised (IUCN, 1994). The elevation coverage was produced by using the "Reclassify" option in ArcView to classify the DEM into four categories (0–200, 201–400, 401–600 and >600 m). This was converted to vector format and the "Clip" option was used to identify the PA status of each elevation class.

3. Results

3.1. Total coverage of PAs

There are currently 4297 nationally designated terrestrial PAs devoted to biodiversity conservation in England, comprising 206 NNRs and 4091 SSSIs (Table 1). The areas of the individual PAs range from 0.004 to 72 km^2 for NNRs, and from <0.001 to 160 km^2 for SSSIs, not including estuarine or marine areas. Taking into account the common designation of NNRs as SSSIs, the total area protected for biodiversity is 8238.8 km^2 or 6.3% of England's land surface (Table 1). Of this, 0.4% of England's land surface has both NNR and SSSI status, while 5.9% has SSSI status only.

3.2. Coverage by natural area and elevation

Only 21 of the 97 NA types have more than 10% of their area covered by PAs designated to conserve biodiversity, and most are found in northern England or

Table 1
Details of PA types in England

PA designation	Number	Median area (km^2)	Minimum area (km^2)	Maximum area (km^2)	Area (km^2)	% of PA coverage
NNR	206	1.1	0.004	71.7	583.3	7.1
SSSI	4091	0.2	<0.001	160.0	7655.5	92.9
Total	4297	–	–	–	8238.3	100

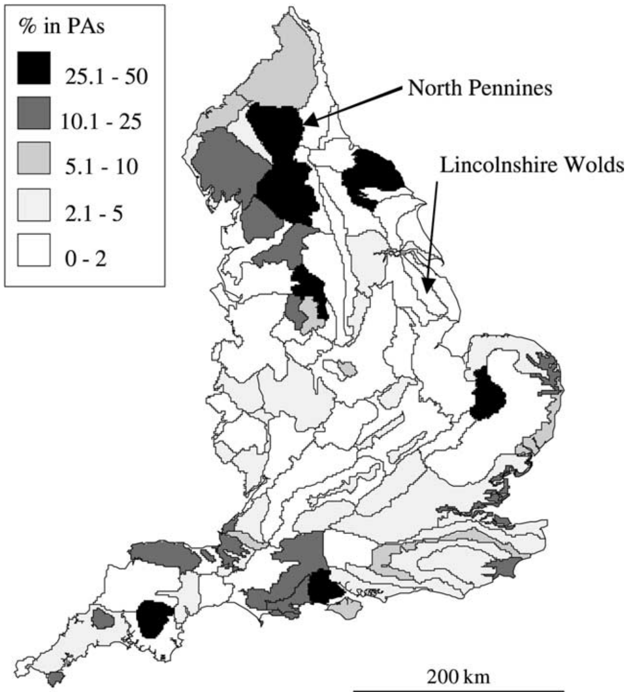

Fig. 4. Percentage of each Natural Area type with protected area status.

close to coastal areas (Fig. 4). The median level of protection across all NAs is 2.5% and the range is from 0.1% for the Lincolnshire Wolds to 47.0% for North Pennines (Table 2). In those NAs that have less than 10% protection, SSSIs made up 2085 km^2 or 89.4% of the land with PA status.

Most of England (87%) is covered by land with an elevation of 200 m above sea level (asl) or less, but only 3.5% of this area has PA status (Table 3), with 91.4% of this protected land having SSSI status (Fig. 5). Likewise most of the protected land between 201 and 400 m asl has SSSI status (97.6%). However, more than half of the land between 401 and 600 m asl has PA status and this increases to 65.7% for land above 600 m asl (Table 3; Fig. 5). The percentage of protected land above 600 m

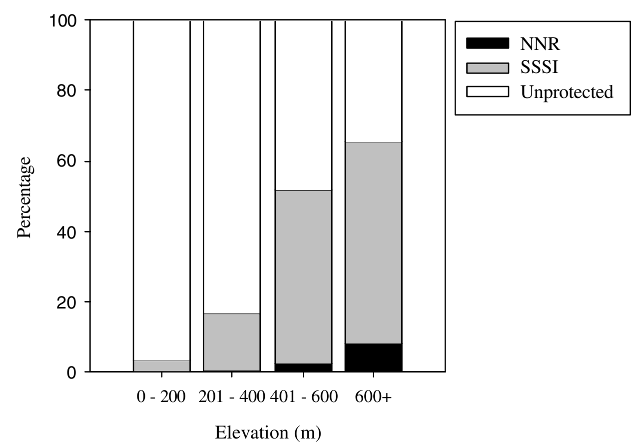

Fig. 5. Details of PA status by elevation class.

Table 2
Details of the Natural Area types with the highest and lowest percentages with PA status (from Oldfield et al., 2004)

Natural Area name	Area (km^2)	% in NNR	% in SSSI	Total %	Total % rank
Lincolnshire Wolds	844.9	0.00	0.10	0.10	97
Vale of Pickering	425.5	0.00	0.16	0.16	96
Coal Measures	2487.4	0.00	0.18	0.18	95
Midland Clay Pastures	1717.4	0.00	0.61	0.61	94
Lincolnshire and Rutland Limestone	1260.4	0.00	0.62	0.62	93
Dartmoor	874.1	0.69	29.12	29.81	5
Breckland	1019.3	0.66	38.81	39.47	4
New Forest	741.2	1.28	43.28	44.56	3
Dark Peak	866.0	0.00	46.77	46.77	2
North Pennines	2145.6	3.38	43.61	46.99	1

Table 3
PA designations by elevation class in England

	Elevation (m asl)			
	0–200	201–400	401–600	600+
Total area (km^2)	112954.97	13888.2	3285.0	353.7
Percentage of total	86.6	10.6	2.5	0.3
Percentage NNR	0.3	0.4	2.4	8.3
Percentage SSSI	3.2	16.2	49.4	57.4
Area protected (km^2)	3944.6	2299.9	1701.9	232.6
Percentage protected	3.5	16.6	51.8	65.8

with NNR status is 12.6%, which is higher than for the other elevation classes.

4. Discussion

Most PA systems tend to over-represent highland areas and other regions with low agricultural potential (Fearnside and Ferraz, 1995; Ramesh et al., 1997; Powell et al., 2000; Scott et al., 2001) and our results show a similar pattern for England. We found that only 3.5% of English lowlands ($\leqslant$ 200 m asl) have PA status, whereas 65.8% of land with an elevation of more than 600 m asl is protected. Total PA coverage was also low when compared with the commonly used target of 10% (Miller, 1984), with only 6.3% of the country having PA status. In addition, many NA types have very low levels of protection, with 77 types having less than 10% and 39 having less than 2% covered by PAs. However, using standardised targets in conservation planning exercises is problematic (Soulé and Sanjayan, 1998; Rodrigues and Gaston, 2001) and field-based projects often set specific targets for different biodiversity elements depending on their conservation value (Pressey et al., 2003). These targets are generally higher than 10% but English habitats have been greatly transformed by agriculture, so it could be argued that present levels of protection are sufficient. Moreover, English Nature has developed the PA system to contain internationally important species and ecosystems, thereby reflecting the different conservation values of each NA type (English Nature, 2003).

In addition, a study using species record data found that Britain's PAs adequately represent up to 94% of a broad range of species (Hopkinson et al., 2000). However, there are reasons to suggest that England's PA system is not adequate. Firstly, state conservation funding in England is limited (Lovelace et al., 2000; English Nature, 2003), so present protection targets are likely to be affected by financial constraints. Secondly, several measures of biodiversity have shown significant declines and this is especially the case for species associated with farmland habitats (Fuller et al., 1995; Robinson and Sutherland, 2002). This problem is exacerbated by the generally small size of PAs in England, as SSSIs have a median area of 0.2 km^2 and NNRs have a median size of 1.1 km^2. These PAs may not be large enough to support large populations of formerly common, wide-ranging species such as bumblebees (Osborne et al., 1999).

The small size of these PAs may also partly explain the discrepancy between our gap analysis results and previous studies that used species list data. These distribution data were collected for a series of 10 km $\times$ 10 km grid squares and assumed that species in a square were protected if more than 50% of the square had SSSI status (Williams et al., 1996) or if the square contained centroids of NNRs, centroids of RSPB reserves and/or a certain number of SSSIs (Hopkinson et al., 2000). Setting these protection cut-off points is necessary for analysing species list data but the small size of English PAs may increase the likelihood that species which are assumed to be protected within a grid square are not found in any of the associated PAs (Lombard, 1995). In addition, these species based analyses may be less effective when dealing with transformed areas such as England, where many species are restricted to sites that have been gazetted as PAs. Thus, even a limited PA system would contain distribution records for many of the remaining species (Cassidy et al., 2001). For example, a regional analysis showed that SSSIs effectively represented current distributions of wetland plant species in Scotland (Rodrigues et al., 1999) despite a large historical loss of associated habitats (Anon, 1994).

Therefore, our results suggest that there is need to consider ways to extend the present PA system so that it does more than protect habitat remnants, but this will rely on two major changes. First, there is a need to develop a conservation planning system that includes explicit targets for protecting landscape features to augment the present species and habitat approach (Pressey et al., 2003). These targets have been successfully used elsewhere (Mendel and Kirkpatrick, 2002; Balmford, 2003) and could be based on both biodiversity and socio-economic data (Pence et al., 2003). Such an approach is particularly relevant to England, where tourism activities are now more profitable than farming (Sutherland, 2002) so that PAs need not necessarily restrict economic development.

Second, there is a need to engage with private landowners, so that they would be willing to manage their land to increase its biodiversity value (Cassidy and Grue, 2000; Oldfield et al., 2003). This might be more easily achieved by expanding the SSSI network, as SSSIs can be established on privately owned land, avoiding the costs of establishing new state run PAs. However, the present PA system is unpopular with many landowners because of coercive legislation that leads to poor maintenance and discourages further voluntary efforts (English Nature, 2003). More stringent protection measures have been introduced recently, which include providing financial support to owners agreeing to manage their SSSI using approved techniques (JNCC, 2003). Such measures may limit the damage done to existing PAs (Royal Society, 2001) but they are unlikely to encourage the increase in PA coverage that an enhanced SSSI system could produce.

The NNR network could also be expanded, perhaps by augmenting areas of high biodiversity value with land suitable for habitat restoration. This could involve co-management agreements with private landowners and the state authority, thereby offering a more long-term land-use option for farmland. However, both these options require a system with positive incentives that encourages landowners to manage their land for biodiversity both inside and outside statutory PAs (Sutherland, 2002; Oldfield et al., 2003). Such a system would better represent English biodiversity, would be more resilient to the effects of climate change (Hill et al., 1999) and species turnover (Margules et al., 1994), and would not rely on costly enforcement measures.

Acknowledgements

We thank CHK Charities for funding this research, and English Nature for permission to use their digital data on the distributions of Natural Areas, National Nature Reserves and Sites of Special Scientific Interest. We thank Andrew Balmford, Peter Brotherton and his colleagues at English Nature, and Ian Rickards for their helpful comments on the manuscript.

References

Anon, 1994. Biodiversity: the UK action plan. HMSO, London.

Awimbo, J.A., Norton, D.A., Overmars, F.B., 1996. An evaluation of representativeness for nature conservation, Hokitika Ecological District, New Zealand. Biological Conservation 75, 177–186.

Balmford, A., 2003. Conservation planning in the real world: South Africa shows the way. Trends in Ecology and Evolution 18, 435–438.

Begon, M., Harper, J., Townsend, C., 1996. Ecology: individuals, populations and communities. Blackwell Science Ltd., Oxford.

Belbin, L., 1993. Environmental representativeness – regional partitioning and reserve selection. Biological Conservation 66, 223–230.

Cassidy, K.M., Grue, C.E., 2000. The role of private and public lands in conservation of at-risk vertebrates in Washington State. Wildlife Society Bulletin 28, 1060–1076.

Cassidy, K.M., Grue, C.E., Smith, M.R., Johnson, R.E., Dvornich, K.M., McAllister, K.R., Mattocks, P.W., Cassady, J.E., Aubry, K.B, 2001. Using current protection status to assess conservation priorities. Biological Conservation 97, 1–20.

Duffy, D.C., Boggs, K., Hagenstein, R.H., Lipkin, R., Michaelson, J.A., 1999. Landscape assessment of the degree of protection of Alaska's terrestrial biodiversity. Conservation Biology 13, 1332–1343.

English Nature, 1999. Natural areas, Peterborough, UK.

English Nature, 2003. Annual Report 2002/2003, Peterborough, UK.

Fearnside, P.M., Ferraz, J., 1995. A conservation gap analysis of Brazil Amazonian vegetation. Conservation Biology 9, 1134–1147.

Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R., Carter, N., 1995. Population declines and range contractions among lowland farmland birds in Britain. Conservation Biology 9, 1425–1441.

Hill, J.K., Thomas, C.D., Huntley, B., 1999. Climate and habitat availability determine 20th century changes in a butterfly's range margin. Proceedings of the Royal Society of London Series B – Biological Sciences 266, 1197–1206.

Hopkinson, P., Travis, J.M.J., Prendergast, J.R., Evans, J., Gregory, R.D., Telfer, M.G., Williams, P.H., 2000. A preliminary assessment of the contribution of nature reserves to biodiversity conservation in Great Britain. Animal Conservation 3, 311–320.

Hunter, M.L., Yonzon, P., 1993. Altitudinal distributions of birds, mammals, people, forests, and parks in Nepal. Conservation Biology 7, 420–423.

IUCN 1994. Guidelines for protected areas management categories. IUCN, Cambridge, UK and Gland, Switzerland.

JNCC 2003. Partnership approach to nature and countryside conservation. Available from <http://www.jncc.gov.uk/communications/natcons/partnership.htm>.

Kirkpatrick, J.B., Brown, M.J., 1994. A comparison of direct and environmental domain approaches to planning reservation of forest higher-plant communities and species in Tasmania. Conservation Biology 8, 217–224.

Lapin, M., Barnes, B.V., 1995. Using the landscape ecosystem approach to assess species and ecosystem diversity. Conservation Biology 9, 1148–1158.

Leader-Williams, N., Harrison, J., Green, M.J.B., 1990. Designing protected areas to conserve natural-resources. Science Progress 74, 189–204.

Lombard, A.T., 1995. The problems with multi-species conservation: do hotspots, ideal reserves and existing reserves coincide. South African Journal of Zoology 30, 145–163.

Lovelace, D., May, R., Perkins, R., 2000. Money Makes the Countryside Go Round. WWF, Godalming, UK.

Margules, C.R., Nicholls, A.O., Usher, M.B., 1994. Apparent species turnover, probability of extinction and the selection of nature reserves – a case study of the Ingleborough Limestone pavements. Conservation Biology 8, 398–409.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

Mendel, L.C., Kirkpatrick, J.B., 2002. Historical progress of biodiversity conservation in the protected-area system of Tasmania, Australia. Conservation Biology 16, 1520–1529.

Miller, K., 1984. The Bali Action Plan: a framework for the future of protected areas. Washington, DC.

Oldfield, T.E.E., Smith, R.J., Harrop, S.R., Leader-Williams, N., 2003. Field sports and conservation in the United Kingdom. Nature 423, 531–533.

Oldfield, T.E.E., Smith, R.J., Harrop, S.R., Leader-Williams, N. (2004). The protected area status of England's terrestrial Natural Area types. Durrell Institute of Conservation and Ecology, United Kingdom. Available from <http://www.kent.ac.uk/anthropology/dice/resources/england_coverage.pdf>.

Osborne, J.L., Clark, S.J., Morris, R.J., Williams, I.H., Riley, J.R., Smith, A.D., Reynolds, D.R., Edwards, A.S., 1999. A landscape-scale study of bumble bee foraging range and constancy, using harmonic radar. Journal of Applied Ecology 36, 519–533.

Pence, G.Q.K., Botha, M.A., Turpie, J.K., 2003. Evaluating combinations of on-and off-reserve conservation strategies for the Agulhas Plain, South Africa: a financial perspective. Biological Conservation 112, 253–273.

Powell, G.V.N., Barborak, J., Rodriguez, M., 2000. Assessing representativeness of protected natural areas in Costa Rica for conserving biodiversity: a preliminary gap analysis. Biological Conservation 93, 35–41.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., Eversham, B.C., Gibbons, D.W., 1993. Rare species, the coincidence of diversity hotspots and conservation strategies. Nature 365, 335–337.

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H., 1993. Beyond opportunism – key principles for systematic reserve selection. Trends in Ecology and Evolution 8, 124–128.

Pressey, R.L., 1994. Ad hoc reservations – forward or backward steps in developing representative reserve systems. Conservation Biology 8, 662–668.

Pressey, R.L., Hager, T.C., Ryan, K.M., Schwarz, J., Wall, S., Ferrier, S., Creaser, P.M., 2000. Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. Biological Conservation 96, 55–82.

Pressey, R.L., Cowling, R.M., Rouget, M., 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation 112, 99–127.

Ramesh, B.R., Menon, S., Bawa, K.S., 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. Ambio 26, 529–536.

Robinson, R.A., Sutherland, W.J., 2002. Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology 39, 157–176.

Rodrigues, A.S.L., Tratt, R., Wheeler, B.D., Gaston, K.J., 1999. The performance of existing networks of conservation areas in representing biodiversity. Proceedings of the Royal Society of London Series B – Biological Sciences 266, 1453–1460.

Rodrigues, A.S.L., Gaston, K.J., 2001. How large do reserve networks need to be? Ecology Letters 4, 602–609.

Royal Society, 2001. The future of sites of special scientific interest (SSSIs). The Royal Society, London.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., Derchia, F., Edwards, T.C., Ulliman, J., Wright, R.G., 1993. Gap analysis – a geographic approach to protection of biological diversity. Wildlife Monographs, 1–41.

Scott, J.M., Davis, F.W., McGhie, R.G., Wright, R.G., Groves, C., Estes, J., 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecological Applications 11, 999–1007.

Soulé, M.E., Sanjayan, M.A., 1998. Ecology – Conservation targets: do they help? Science 279, 2060–2061.

Sutherland, W.J., 2002. Restoring a sustainable countryside. Trends in Ecology and Evolution 17, 148–150.

Wessels, K.J., Freitag, S., van Jaarsveld, A.S., 1999. The use of land facets as biodiversity surrogates during reserve selection at a local scale. Biological Conservation 89, 21–38.

Williams, P., Gibbons, D., Margules, C., Rebelo, A., Humphries, C., Pressey, R., 1996. A comparison of richness hotspots, rarity hotspots, and complementary areas for conserving diversity of British birds. Conservation Biology 10, 155–174.