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Management costs for small protected areas and economies of scale in habitat conservation

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ABSTRACT

Protected area management must be resourced adequately to achieve its conservation objectives. The variability in management costs across candidate sites for protection therefore should inform conservation planning. For example, when considering whether to accept a donation of a property, a conservation organisation must determine whether an adequate endowment is available to fund future management activities. We examine variation in management costs across 78 small protected areas in the UK that are managed by a conservation NGO, the Yorkshire Wildlife Trust. Management costs exceed acquisition costs when funded on an endowment basis and are not correlated with acquisition costs or with proxy measures for conservation costs commonly relied upon in conservation planning studies. A combination of geographic, ecological and socioeconomic characteristics of sites explains 50% of the variation in management costs. Site area is the most important determinant of management costs, which demonstrate economies of scale; implementing conservation management on an additional hectare adjacent to a larger protected area would incur a lower cost than doing the same adjacent to a smaller site. In evidencing this effect of site area, we avoid problems of spurious correlation that confound previous studies. Protected areas that encompass a greater richness of priority habitats for conservation also require more expensive management. Conservation organisations may have little option but to create small protected areas to conserve biodiversity in highly fragmented landscapes, but the decision to do so should take account of the greater cost burden that small protected areas incur.

1. Introduction

Protected areas play a central role in conservation efforts. Biodiversity conservation is often included among a range of management objectives for protected areas, even when it may not have been the primary motivation for originally protecting an area of land or sea (Gaston et al., 2006). Protected areas are owned and managed by public agencies and by conservation organisations such as land trusts (Bean, 2000). Protected areas listed in the World Database on Protected Areas vary in size by eight orders of magnitude. However, the majority of protected areas are small; 62% of those with polygon records in the database have an area of less than 100 ha (WDPA, 2007).

Conservation organisations and agencies face decisions over how to juggle limited financial and human resources to meet the management demands of existing protected areas when developing conservation plans. They may also face decisions over what additional sites should be prioritized for acquisition. Organisations respond to multiple factors when developing a conservation plan, including the distribution of biodiversity targets, of threats to those targets and of opportunities to improve their conservation status (Groves, 2003; TNC, 2003; Parks Canada, 2008). Conservation organisations may explicitly require a consideration of costs when evaluating alternative conservation strategies (TNC, 2003). Academic writings on conservation planning also increasingly emphasise the importance of considering the costs associated with different conservation activities (Ando et al., 1998; Polasky et al., 2001; Armsworth et al., 2006; Strange et al., 2006; Murdoch et al., 2007; Naidoo and Iwamura, 2007; Bode et al., 2008; Laycock et al., 2009; Adams et al., 2009). Greatest biodiversity gains are achieved when conservation actions can be undertaken cheaply in locations important for biodiversity; difficult trade-offs must be faced when this condition is not met (Naidoo et al., 2006).

Despite the increasing emphasis on considering costs as part of the conservation planning process, most conservation planning

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studies lack primary data on the costs of biodiversity conservation. Instead, authors have relied on more readily available data sources that are thought to proxy for conservation costs, such as the average value of agricultural land in the surrounding county (Ando et al., 1998; Strange et al., 2007) or the market value of a subset of agricultural commodities produced nearby (Naidoo and Iwamura, 2007; Cawardine et al., 2008). However, the actual costs incurred by conservation groups show much greater variability than has been suggested by available proxies (Davies et al., 2010). An alternative approach has been to fit regression surfaces to a range of parcel characteristics thought to be associated with conservation costs (Frazee et al., 2003; Naidoo and Adamowicz, 2006). The success of such regression approaches depends on our understanding of and ability to observe factors influencing variation in conservation costs.

Conservation organisations incur different types of cost when trying to protect biodiversity through the use of protected areas. Some costs can be attributed to particular sites, whereas others apply to an organisation as a whole. Many of the costs that can be attributed to particular protected areas can be grouped into upfront costs involved in acquiring new sites (e.g. acquisition or leasing costs including associated transaction costs) and running costs from managing existing protected areas (e.g. costs of onsite conservation and restoration activities, monitoring and enforcement). We focus primarily on annual running costs from managing existing protected areas, although we present some results for acquisition costs as well.

Empirical analyses of management costs of protected areas range in scales from global (Balmford et al., 2003) to studies that consider a handful of sites managed by a single organisation (Ausden and Hirons, 2002; Ausden, 2007). These studies reveal marked variation in management costs across protected areas and attempts to attribute this cost variation to different site characteristics suggest some common factors. For example, various studies have claimed management costs show economies of scale in which implementing conservation management on an additional hectare adjacent to a larger protected area incurs lower additional management costs than doing so adjacent to a smaller site. However, past studies testing for an effect of site area on management costs have relied on comparisons of cost per unit area with area itself (James et al., 1999; Ausden and Hirons, 2002; Frazee et al., 2003; Balmford et al., 2003, 2004; Ausden, 2007; Strange et al., 2007), an approach (relating compound variable Y/X to variable X) prone to detecting spurious negative correlations (Brett, 2004).

We analyse annual costs incurred by a medium-sized conservation Non-Governmental Organisation (NGO) in managing a portfolio of 78 small protected areas in the UK. We focus on actual investment choices made by the NGO. As such, our empirical measures of conservation costs may not equal the theoretical minimum costs of achieving a unit gain in some conservation target. Rather our results reflect the actual decisions made by the conservation group regarding resource allocation, a point we return to when discussing how our results should be interpreted. We examine what explains variation in management costs paying particular attention to the role of site area. We also relate management costs to acquisition costs where both datasets are available. Because we focus on costs faced by a conservation NGO implementing a protected area strategy, we do not account for other social costs of protected area creation.

2. Materials and methods

2.1. Case study

We examine protected areas managed by Yorkshire Wildlife Trust (YWT) as a case study. YWT is one of the 47 wildlife trusts operating within the UK. Similar to some land trusts in the USA (Merenlender et al., 2004; LTA, 2005), the wildlife trusts are regional NGOs focused on conserving the future of UK habitats and species. YWT operates across Yorkshire in the UK (Fig. 1) where it manages protected areas, as well as taking an active role in education and wider landscape conservation initiatives. YWT has an annual income of £2.5 M and total assets worth £5 M, with its funding derived from private donations and government grants.

We focus on 78 small protected areas managed by YWT (Fig. 1) that range in size from 0.08–328 ha (median = 8.24 ha). Most sites encompass multiple habitat types with a range of woodland, grassland, heathland and freshwater habitats being found in YWT reserves.

2.2. Data on management costs

YWT provided financial details through audited accounts regarding direct expenditure on each of the 78 sites. Typical expenditures covered items such as habitat management and equipment maintenance as well as administrative costs (e.g. legal fees, meeting costs, printing) where these could be attributed to the management of a particular site. Expenditure was given per year and converted to 2008 GBP£ equivalent using the Consumer Price Index. Analyses are conducted on averaged expenditure between 2004 and 2008.

An estimate of paid staff time allocated to each protected area was obtained using a face-to-face questionnaire with the 12 paid staff members involved in site management. Each of these staff members is responsible for administration and conservation work on between 3 to 27 protected areas. The percentage time allocated to each site was estimated in the questionnaires and converted into a cost equivalent based on the salaried year and relevant staff member's wage. The section of the questionnaire used to ascertain time allocation is provided in the Supplementary material: Appendix 1. We do not consider unpaid labour from volunteers in this analysis (see Section 4).

2.3. Predictor variables

We pay particular attention to the role of area in determining site management costs. We also explore what other factors influence expenditures on sites. First, as a consistency check we considered the time since YWT took management responsibility for each site to test whether management costs had stabilised or were responding to an initial pulse of investment into newly acquired sites.

Next we focused on ecological and physical characteristics of sites. Much conservation effort in the UK is habitat focused. Because most YWT protected areas contain a diversity of habitat types, we tested whether management costs varied with the number of priority habitats for conservation found on a site. The presence of 65 UK Biodiversity Action Plan (UKBAP) priority habitats on a site was identified by site managers (Supplementary material: Appendix 1). We document the role of dominant habitat type in determining conservation costs in the Supplementary material: Appendix 2. We also include a measure of the topographic complexity of sites, because sites that encompass a greater elevation gradient or are more rugged may be richer in biodiversity but require more time intensive management. Using a 5 m digital elevation model, we computed the maximum rate of change in elevation between adjoining cells and averaged this value across the site to give a compound measure of slope and rugosity.

We examined the role of property rights and legal status of sites in influencing management costs. Some authors have suggested that sites with more fragmented property rights involve higher management costs (Parker, 2004). YWT manage sites that the organisation

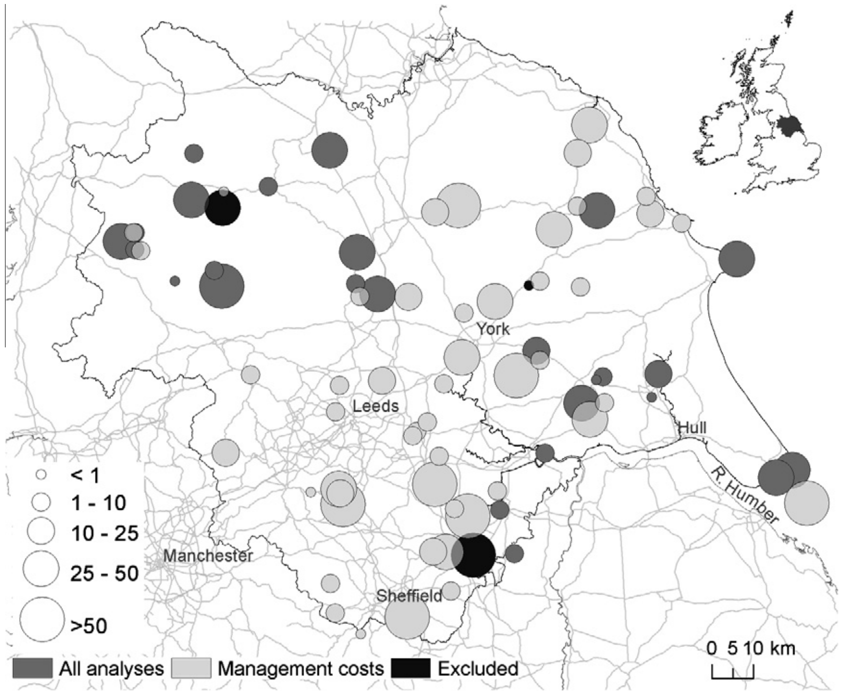

Fig. 1. Map of Yorkshire Wildlife Trust protected areas in Yorkshire, UK (inset). The size of circles provides an indication of site area on a categorical scale (<1, 1-10, 10-25, >50 ha) that is only used for illustration purposes in this figure – all analyses treat site area as a continuous variable. Management cost data were available from all sites. Data on acquisition costs were available from a subset of 27 sites owned by YWT under a freehold agreement (medium shading). Three sites (dark shading) were excluded from the model fitting exercise, because they were felt not to be representative of YWT's wider protected area management strategy.

owns as fee simple, part owns, and leases. We enter ownership status into statistical models as a categorical variable grouping sites that are fully owned, part owned and part leased (ownership covered from 21% to 97% of site area), and fully leased. Public agencies also hold a direct conservation interest in many YWT reserves either through statutory designations or voluntary conservation agreements, both of which can bring associated benefits (e.g. direct payments, or legal protections covering adjoining areas) and costs (e.g. additional administrative costs) for land managers. We entered public conservation interest in YWT sites as a categorical variable (<50% or >50% of the site covered by such agreements, see Supplementary Table S1 for details). Category boundaries for describing site ownership and public conservation agreements were chosen based on the relevant frequency distributions.

We included two factors that test the role that detrimental impacts to sites may have in determining conservation management costs. First, we computed the approximate numbers of households nearby by counting the number of postcodes (=15–20 households) within a 15 min travel-time delimited catchment around the site. Travel times were calculated from the UK Integrated Transport Network (road routing information), with the ESRI ArcGIS Network Analyst extension. Household density serves to capture the impact on sites from greater urbanisation and from more human traffic nearby (dog-walkers, vehicles, etc.). We also considered the intensity of agriculture surrounding sites to account, for example, for impacts of diffuse pollution or a decrease in the effective subsidy to onsite conservation activities provided by wildlife benefits on surrounding farmland. We used an estimate of the gross margin from agricultural production available to farms in a 1 km buffer around sites as an indicator of the intensity of neighbouring agricultural production. We used data described in Anderson et al. (2009) and Eigenbrod et al. (2009) that are available at the agricultural ward level, an administrative unit having mean area 19 km^2. The value of agricultural land surrounding protected areas has often itself been used as a proxy for the costs of conservation, something we revisit in Section 4.

2.4. Model selection

To examine possible explanations for variation in management costs across sites, we used a multiple regression approach. First, we log transformed variables to meet assumptions and then tested tolerance levels to ensure predictor variables were sufficiently independent of one another to proceed. Tolerance levels from the collinearity tests were well within acceptable bounds for all predictor variables. Next, we constructed all possible model combinations for the given predictor variables. We used AIC competition to identify a subset of models that offer parsimonious explanations for variations in the data that included all models with an AIC score within two points of the minimum (Burnham and Anderson, 2002). We calculated the multimodel average across this AIC + 2 set of models using model weights. We also tested for spatial autocorrelation in the residuals from this model average by calculating Moran's I statistics across 11 distance classes in SAM v.3.0. If present, spatial autocorrelation in residuals could indicate the presence of shared environmental characteristics across sites not accounted for by our chosen predictor variables. We used site centroids and Euclidean distances, and tested significance of Moran's I based on both analytical expectation and 199 randomisations.

We use this multiple regression framework to examine both the role of area in determining management costs as well as the role of other factors in determining these costs. To address the role of area, we compare the following two families of multiple regression models in AIC competition.

Family A: models where costs scale linearly with area, which are equivalent to analysing how cost per unit area is affected by factors other than area itself. Namely:

$$\log \text{management cost} = \alpha + \log \text{area} + \beta_1 \cdot \text{predictor}_1 + \beta_2 \cdot \text{predictor}_2 + \cdots + \text{error}$$

Family B: models where costs can vary nonlinearly with area according to a power law that can account for diminishing or increasing returns to scale.

$$\log \text{management cost} = \alpha + \beta_0 \log \text{area} + \beta_1 \cdot \text{predictor}_1 + \beta_2 \cdot \text{predictor}_2 + \cdots + \text{error}$$

where α and β_i for i = 0,1,2, ... are coefficients to be estimated. The first family of models involves one less free parameter (β_0 is constrained to equal 1) and therefore has an advantage in AIC competition. By comparing models in Family A and Family B, we are explicitly testing whether there is support for a nonlinear dependence of site management costs on site area. Within these families of models, we then examine the role that other predictor variables play in explaining variations in costs when acting in combination with area.

For model selection, we excluded three sites as being unrepresentative of the business model operated by YWT on the majority of its protected areas. With these protected areas excluded, the models conform to a multiplicative, lognormal error structure. Kirkham Wood and Newbiggin Pasture received no investment of any kind. YWT only took management responsibility for Newbiggin Pasture part-way through the final year covered by the financial accounts available to us (2008) and this site does not appear in our management cost data. Kirkham Wood is a small protected area (0.25 ha) in which YWT have made no direct investment for 5 years and which was estimated to receive no paid staff time in the questionnaire. We believe this lack of investment reflects a strategic decision by YWT not to invest in Kirkham Wood, rather than the fact that conservation benefits at that site can be obtained at zero cost. The third site, Potteric Carr, received 15 times the expenditure of any other site and 61% of overall investment. However, these much larger running costs on Potteric Carr cannot be attributed solely to habitat conservation activities and include costs resulting from YWT's decision to use Potteric Carr to deliver their broader mission objectives regarding outreach and education and to help attract subscription paying members. Potteric Carr attracts over 30,000 visitors per year and provides a variety of amenities including bird hides, classrooms, a shop and a cafe. Some of the management costs on Potteric Carr are also associated with YWT having to meet particular obligations for site maintenance around high volume rail tracks that pass through the site.

2.5. Comparison with acquisition costs

YWT also provided data on acquisition costs for a subset of 27 sites held under freehold agreements to enable a comparison of annual management costs with upfront site acquisition costs. To allow this comparison, we assumed management costs on these 27 sites were funded on an endowment basis, because acquisition costs are one-off but management costs are incurred annually. We assume the endowment provides 6.1% return on the principal with 3% reinvested to offset inflation and the remainder being available for expenditure to cover management costs. These values are reasonable over the time period covered by the financial data we collected. We also comment on how the results of the comparison would be affected by reduced endowment returns in light of more recent economic conditions.

3. Results

3.1. Management costs

Direct expenditure on sites is strongly correlated with costs realised through paid staff time. If we include all sites in the correlation, the data are not normal and the rank correlation is r_s = 0.665 (n = 78, p < 0.001). Dropping sites with zeros allows a parametric correlation for those sites receiving both direct financial investment and paid staff time (r = 0.701, n = 67, p < 0.001). Management costs realised through allocating paid staff time to manage particular sites are greater than costs associated with direct expenditures (Mann Whitney U test, W = 5049.0, n_1 = 78, n_2 = 78, p = 0.0001). For the remaining analyses, we combine direct expenditure on sites and paid staff time into a single measure of overall management costs.

Sites vary in size by a factor of 4000 (Table 1). Overall management costs are strongly positively correlated with site area; a rank correlation for all sites gives r_s = 0.619 (n = 78, p < 0.001), and a parametric correlation of site area with the overall management costs for sites receiving either some paid staff time or some direct financial investment gives r = 0.670 (n = 76, p < 0.001). Table 1 summarises the variation in the datasets that combine to determine our estimate of overall management cost across the 78 sites.

3.2. Model selection

In model selection, each family (costs scale linearly with area and costs may not scale linearly with area) contains 128 models plus a null model containing only log area. We can compare the range of AIC values for each family to evaluate the role of area in determining site costs (Table 2). In AIC competition, the worst performing model in Family B that allows for a power-law relationship between management cost and site area outperforms all models from Family A in which management costs scaled linearly with site area, despite the greater number of parameters involved. The AIC + 2 set of parsimonious models contains 16 models (given in full in the Supplementary Table S2) drawn from Family B and the multimodel average across this set has an r^2 value of 0.5

Table 1
Variation in costs. Median and lower and upper quartiles for site area, direct expenditure, paid staff time, overall management costs (n = 78) and acquisition costs and management costs when funded on an endowment basis (n = 27). All financial amounts given as 2008 equivalent GBP £1000s per site.

	Q1	Median	Q3
Total area (ha)	2.96	8.24	36
Direct expenditure	0.06	0.35	1.38
Paid staff time	0.59	1.18	2.15
Overall management cost	0.77	1.73	3.72
Acquisition cost (n = 27)	0.07	21.37	65.48
Endowed management cost (n = 27)	17.92	36.68	101.44

Table 2
AIC ranges for two families of models explaining variation in overall management costs. For each approach we used seven predictors and ran 128 models with all possible combinations + a null model which only contained log area as a predictor.

	Min AIC	Max AIC
Family A: models in which coefficient β_0 on log area is constrained to equal 1	115.3	131.9
Family B: models in which coefficient β_0 on log area is unconstrained	81.9	93.5

Table 3
Parameter estimates, standard errors and partial r^2 for the model average across the AIC + 2 set of parsimonious models. This set only contains models from Family B in which β_0, the coefficient on log area, is unconstrained.

Model average	Intercept	Log area	Start date	Ownership fully owned[a]	Ownership partly owned[a]	Public conservation interest >50% of site[a]	Log postcode 15	Log avg. agricultural production	UKBAP richness	Log slope range
Coefficient ± 1 s.e.	2.26 ± 3.22	0.47 ± 0.08	0.00 ± 0.00	−0.04 ± 0.07	0.05 ± 0.10	−0.16 ± 0.14	0.00 ± 0.02	0.00 ± 0.02	0.12 ± 0.05	−0.08 ± 0.10
Partial r^2		0.29	0.00	0.007		0.02	0.00	0.00	0.05	0.01

[a] For categorical variables, the estimates are differences between means relative to the omitted baseline values described by the intercept.

(Supplementary Table S3). Residuals from this multimodel average show no evidence of spatial autocorrelation. A comparison of the partial r^2 values for different predictor variables makes clear that area determines much of the variation in the management costs that can be explained (Table 3). The coefficient of log area in the model average (0.47 ± 0.08 for 1 s.e., Table 3) reveals that management costs show economies of scale with area ($\beta_0 < 1$).

Of the other factors that could influence management costs, the richness of BAP habitats on a site offers the next highest partial r^2 value (Table 3). BAP habitat richness appears in all sixteen models in the AIC + 2 set with sites that contain more priority habitats for conservation receiving more investment from YWT (Supplementary Table S2). The remaining predictor variables explain relatively little of the variation in overall management costs (Table 3).

Had we failed to account for the nonlinear relationship between area and management costs and instead examined the AIC + 2 set one would obtain if only considering models in Family A, we would arrive at different predictions about what determines variation in management costs (Supplementary Table S4). Specifically, our measure of topographic complexity would have appeared to be more important.

3.3. Comparison with acquisition costs

We compared our estimates of overall management costs with acquisition costs on a subset of 27 sites owned by YWT under freehold agreements (again converted to 2008 GBP£ using the CPI, Table 1). The variation in acquisition costs across sites is not correlated with the variation in overall management costs when controlling for area (Spearman partial correlation = 0.070, $n = 27$, $p = 0.73$). Management costs when funded on an endowment basis are greater than acquisition costs (Mann Whitney U test, $W = 1067.0$, $n_1 = 27$, $n_2 = 27$, $p < 0.001$), exceeding acquisition costs on all but two of the sites. If we were to assume endowments will offer lower returns in the future in light of recent economic conditions, then management costs when funded on an endowment basis would become even larger relative to acquisition costs.

4. Discussion

Conservation organisations need to project costs involved in managing protected areas to inform conservation planning. For example, if offered a donation of a property, a conservation organisation must examine whether the donation is accompanied by an adequate endowment to support required management. Site management costs include both direct expenditures and an allocation of time from salaried staff. We examined variation in management costs across 78 small protected areas managed by YWT, a regionally focused conservation NGO in the UK. Management costs were not correlated with acquisition costs on sites where both datasets were available. We were able to explain 50% of the variation in management costs across sites. The relationship between cost and area accounted for much of this variation and was nonlinear; protecting an additional hectare adjacent to a larger protected area cost less than doing the same adjacent to a smaller protected area.

In the absence of primary data on conservation costs, conservation planning studies have commonly used other measures to proxy for the costs of acquiring and managing protected areas. Early conservation planning studies simply used area as a measure of cost and sought strategies that would protect as much biodiversity as possible in the smallest area (Kirkpatrick, 1983; Margules et al., 1988). In our study, area showed a strong correlation with management costs. However, using area itself as a cost measure would fail to account for the nonlinear relationship we found between area and management costs. Other commonly used proxies for primary data on conservation costs rely on representations of the agricultural value of land in the vicinity of sites to be protected. In considering the threat to sites from intensive agriculture, we used a relatively resolved version of such a proxy, the gross margin from agricultural commodities available to farms surrounding YWT sites. The multiple regressions did not suggest that this factor was important in explaining variation in site management costs, and a direct correlation of management cost per unit area with our measure of agricultural rents indicates the same (log transformed, $r = 0.036$, $n = 78$, $p = 0.75$). This lack of correlation suggests that agricultural rents may serve as a poor proxy for protected area management costs in conservation planning at this scale. However, while our measure of agricultural rents fails to predict spatial variation in management costs across sites, it does not systematically under- or over-estimate protected area management costs per hectare (log transformed, $t = 0.34$, df = 102, $p = 0.732$). Therefore, such measures could still be useful for informing larger scale conservation planning exercises that examine what regions should be priorities for conservation investment, rather than what sites within regions should be prioritised. Finally, we were able to compare management costs to acquisition costs on a subset of 27 of the sites. We found that the two types of conservation costs are not correlated and that management costs would typically be much larger than acquisition costs if funded on an endowment basis. This suggests that fully costed conservation plans need to project both acquisition and management costs and cannot rely on one to serve as an adequate surrogate for the other. The lack of correlation of management costs and acquisition costs should perhaps be expected. Acquisition costs reflect the market value of alternative land uses, whereas management costs reflect the needs of the biodiversity on the site and will often respond to factors that are outside the market economy.

The set of possible drivers of cost variation considered in this study allowed us to explain around half of the observed variation in management costs. Much of this variation is accounted for by a nonlinear relationship between management cost and site area; management costs increase approximately as the square root of site area. This confirms a suggestion from previous studies that adding a hectare to a larger protected area would increase management costs by less than adding a hectare to a smaller one. However, past studies based claims regarding economies of scale in management costs on comparisons of cost per unit area with area itself

(James et al., 1999; Ausden and Hirons, 2002; Frazee et al., 2003; Balmford et al., 2003, 2004; Ausden, 2007; Strange et al., 2007). In our analysis, this comparison would give a Spearman correlation coefficient of −0.51. However, a negative correlation should be the null expectation, because of the dependence between cost per unit area and area. To illustrate, we conducted a bootstrap by randomly assigning management costs to sites first, thereby destroying any association between management costs and area. We obtained a distribution of Spearman correlation coefficients with 5th, 50th and 95th percentiles [−0.79, −0.71, −0.63], which indicates that for YWT reserves cost per unit area are less negatively associated with area than would be expected by chance alone, because larger sites receive more investment. As the bootstrap illustrates, simply documenting a negative relationship between cost per unit area and area is not sufficient evidence to conclude that management costs show economies of scale with site area.

We use an alternative approach to test for economies of scale in costs that examines whole site management costs and meets assumptions of statistical independence. Models in which management costs show economies of scale with site area consistently outperformed models that assumed a linear relationship. Arguments for conservation groups to focus on large reserves have long emphasised ecological benefits derived from reserve size (Simberloff, 1988; Caughley, 1994). Here we have shown that larger reserves also offer cost savings over a set of small reserves of equal area. Despite these advantages offered by larger reserves, many protected areas are extremely small. In England, 78% of sites subject to statutory protection primarily for biodiversity conservation have an area of less than 100 ha (Jackson and Gaston, 2008); the mean size of the 2256 protected areas managed by the UK's 47 wildlife trusts, including YWT, is only 40 ha.

In addition to the influence of site area, sites that contain a greater number of priority habitats for conservation under the UK's Biodiversity Action Plan cost more to manage. The situation offering the greatest efficiency savings in conservation, where sites assigned the greatest ecological priority are also those where conservation costs are lowest (Naidoo et al., 2006), is therefore not achieved for this set of protected areas. An alternative approach to emphasising the richness of priority habitats for conservation would have been to focus on the dominant habitat type found on each site (Frazee et al., 2003). In the Supplementary material, we provide additional results showing that dominant habitat type explains little of the variation across sites in either overall management costs or management costs per hectare (Supplementary material: Appendix 2: Dominant habitat type).

Other factors considered in the models also explain very little of the variation in conservation costs. For example, there is no evidence from this set of sites that protected areas situated near denser human populations require more expensive management, after controlling for the effect of the other variables. It would be interesting to test whether the same is true for protected area management in other regions that contain a larger gradient in population density, because creating protected areas near human populations offers other benefits (e.g. for recreation and the provision of other ecosystem services, Eigenbrod et al., 2009).

In interpreting our results, it is important to bear in mind that we focused on actual costs incurred by YWT. For an alternative approach, see Frazee et al. (2003) who asked managers to estimate the ideal amount of resources needed to manage protected areas effectively. There are few published estimates of actual management costs that include staff time to compare to our results. In their study of habitat management costs on nine lowland wet grassland sites in the UK managed by a second NGO, the Royal Society for the Protection of Birds (RSPB), Ausden and Hirons (2002) report a mean cost per hectare of GBP £270 (±£40 ha^{-1}) where we have updated these figures to 2008 equivalent value. These per hectare management costs are somewhat lower than those we observed on YWT sites, as would be expected because the RSPB protected areas involved were larger (most were over 200 ha). In contrast, the acquisition costs reported by Ausden and Hirons for 14 grassland (mean cost per hectare 2008 GBP£5870 ± £640 ha^{-1} for 1 s.e.) and five arable sites (mean cost per hectare 2008 GBP£8060 ± £390 ha^{-1} for 1 s.e.) are somewhat larger than the acquisition costs for the 27 YWT reserves where these data are available, perhaps reflecting higher land values for agriculture on the relevant sites.

Typically site managers choose among various management options that each incur different costs. For example, when seeking to restore a peat bog that is overgrown with trees, helicopters can be used to lift trees out while minimising surface habitat disturbance, potentially allowing conservation objectives to be met within a few years. The management cost of such an operation in our study area would be in the region of £4000 per hectare (based on inflation corrected costs from the restoration of Langlands Moss documented in Brooks and Stoneman, 1997). Alternatively, a commercial timber license could be issued where the sale of the timber would approximately cover the cost of extraction. While this would be cost-free for a conservation group, the resulting disturbance to the site would be such that conservation goals might only be met over 10–20 years. Different business models followed by conservation NGOs also lend themselves to different management costs at the site scale. YWT tend to manage smaller protected areas than some other UK NGOs and to rely more on unpaid volunteer labour to augment their investment into sites. In the questionnaire with site managers, we asked them to approximate the amount of volunteer labour (in days per year) invested in sites that they manage. A rank correlation reveals a positive association between the amount of volunteer labour invested in site management and overall site management costs ($r_s = 0.614$, $n = 78$, $p < 0.001$), suggesting that investment in sites and volunteer labour are complements not substitutes, but this relationship warrants a more detailed examination.

Our results only consider expenditures on protected area management incurred by YWT. It would be interesting to go further and integrate these cost estimates with some measure of the ecological effectiveness of the conservation activities undertaken to develop an overall return on investment measure (Ferraro and Pattanayak, 2006; Murdoch et al., 2007). Available data on the ecological condition of our study sites are limited, and do not reveal a relationship between ecological condition and overall management costs or management costs per hectare (Supplementary material: Appendix 3: Ecological condition). In general, evidencing the impact that a particular management intervention has had on the ecological condition of a protected area is known to be challenging (Parrish et al., 2003; Gaston et al., 2006).

5. Conclusion

Given the growing interest in accounting for costs in conservation planning (TNC, 2003; Naidoo et al., 2006), more case studies that examine the actual costs faced by conservation organisations when managing protected areas are needed. We examined site management costs incurred by a regionally focused conservation NGO that manages a set of small protected areas. Site management costs were not well-approximated by commonly used proxies in conservation planning studies and would exceed site acquisition costs on most sites if funded on an endowment basis. Management costs demonstrated economies of scale with site area such that protecting a 40 ha site would be expected to incur only double the management cost involved in managing a 10 ha site. When trying to conserve remnant biodiversity in highly fragmented landscapes, conservation organisations may have no choice but invest in small protected areas. Nonetheless, the decision to take on management of small protected areas should be made in light of the greater cost burden to an organisation that small reserves bring.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.09.026.

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