Theor Ecol
DOI 10.1007/s12080-010-0103-z

ORIGINAL PAPER

Landowners' ability to leverage in negotiations over habitat conservation

Gareth D. Lennox · Martin Dallimer · Paul R. Armsworth

Received: 7 June 2010 / Accepted: 28 October 2010

Abstract Voluntary conservation agreements are commonly used to stem the impact of habitat destruction and degradation on terrestrial biodiversity. Past studies that aim to inform how resources for conservation should be allocated across land parcels have assumed the costs of securing conservation on sites can be estimated solely on the basis of the value of alternative land uses. However, in a voluntary negotiation, a landowner could hold-out for a higher payment based on a conservation group or agency's willingness-to-pay by leveraging the value of biodiversity on the property. We examine landowners' ability to leverage and the consequences for conservation planning. To explore this, we first use an analytical approximation that simplifies the situation to one where a conservation group prioritizes one site for acquisition. Landowners' ability to hold-out for higher payments in this situation ranges from approximately 17% to 55% of the value of alternative land uses on the site. We show that landowners' ability to hold-out for higher payments is more sensitive to variance in the value of alternative land uses than variance in the biodiversity value across properties and is highest when the two factors negatively covary. Next, we consider multi-site selection decisions accounting for community complementarity across parcels. We find that leverage potential can be significantly higher in this context, with a maximum increase of 237% of the value of alternative land uses, and that community irreplaceability is correlated with landowners' ability to leverage. If one landowner holds out for a higher payment, it has implications for what other parcels should be priorities for protection.

Keywords Conservation planning · Habitat conservation · Conservation costs · Irreplaceability · Hold-outs

Electronic supplementary material The online version of this article (doi:10.1007/s12080-010-0103-z) contains supplementary material, which is available to authorized users.

G. D. Lennox (✉) · M. Dallimer · P. R. Armsworth
Department of Animal & Plant Sciences,
The University of Sheffield, Sheffield, S10 2TN, UK
e-mail: bop08gdl@shef.ac.uk

P. R. Armsworth
Department of Ecology and Evolutionary Biology,
University of Tennessee, Knoxville, TN 37996-1610, USA

Introduction

Habitat destruction, degradation, and fragmentation are the primary drivers of losses to terrestrial biodiversity (Millennium Ecosystem Assessment 2005). One of the key mechanisms used to combat this loss has been habitat protection through land acquisitions, either in full or in part. Rights over land use can be obtained in perpetuity through easements or fee simple acquisitions (Armsworth and Sanchirico 2008; Fishburn et al. 2009a; Davies et al. 2010). Land rights can also be acquired temporarily through the use of rental contracts, as used, for example, in agri-environment schemes in the EU and elsewhere (Hanley et al. 1990; Kleijn and Sutherland 2003; Dobbs and Pretty 2008). Many such agreements are reached through a negotiation process between the landowner and the conservation group. However, schemes also exist that have fixed payment levels for undertaking or refraining from predefined management practices.

Tools have been developed to assist conservation planners to prioritize the locations and sites in which to invest (Possingham et al. 1993; Costello and Polasky 2004; Meir et al. 2004; McDonald-Madden et al. 2008). In recent studies, research has focused on the relative impact of biodiversity and cost variance and on the role of their spatial covariation in determining the most effective outcome for conservation. Naidoo et al. (2006) illustrate that one can achieve the greatest coverage of biodiversity at the lowest overall cost when biodiversity and site cost are strongly negatively correlated across the candidate land parcels.

With the exception of Carwardine et al. (2010) who investigate the sensitivity of conservation priorities when sites have uncertain acquisition costs, previous studies assume conservation costs are predetermined and can be estimated using proxies for the value of alternative land uses on a site. For example, Ando et al. (1998) studied the effect of conservation costs on conservation priorities across the USA, using average county-level agricultural land values to estimate costs. Polasky et al. (2001) studied the same problem using finer grain data, which partitioned the western two-thirds of the state of Oregon into 289 individual land parcels, taking the average land value as the cost of providing conservation. On a global scale, Naidoo and Iwamura (2007) estimated conservation costs using the gross value of yields from livestock and crop production based on average prices.

There are few empirically derived estimates of actual conservation costs. In the first large-scale study of actual acquisition costs, Davies et al. (2010) found that the upfront cost of land acquisition ranged over six to eight orders of magnitude. This greatly exceeds the variation found in estimates of conservation costs relied on in previous studies, which ranged between two and four orders of magnitude (Ando et al. 1998; Naidoo et al. 2006). This begs the question as to why the disparity between variation in estimated and actual conservation costs exists and what it implies for conservation. While past studies assumed that costs can be predetermined, in a voluntary system, the cost is dependent upon two factors, the site owner's willingness-to-accept a given payment level (WTA) and the conservation group's willingness-to-pay (WTP).

The landowner's WTA is a measure of the cost to the individual of providing conservation benefits and is a measure of several components, including the value of the best alternative land use, as well as the site owner's individual preferences (Guerrero et al. 2010). Crucial to our analysis is the assumption that a landowner's WTA is private information that a conservation group cannot observe. The use of proxy data is an attempt to estimate the WTA solely through often coarse estimates of the value of the best alternative land uses. We analyze the situation where prices are not fixed a priori and the site owner can exploit the conservation group's uncertainty about their WTA to hold-out for a higher payment, thereby leveraging some of the conservation group's excess WTP.

The conservation group's WTP is the maximum value that they would be willing to pay in a negotiation on a particular site, and while the WTA is unknown to the conservation group, they base their WTP in part on the a priori estimates of the cost of securing conservation on other sites and their budget constraint, should one apply. We assume that the objective of the conservation group is simply to arrive at the highest biodiversity coverage possible. Therefore, WTP is bounded by the conservation group's overall budget and is set by the availability of substitute sites that are as important to their overall conservation strategy when accounting for the level of threat faced by the sites. For an alternative formulation in which the conservation group's WTP depends on the amount of conservation provided, see Ando and Shah (2010).

Provided WTP $>$ WTA, a negotiation that arrived at any value between these two would allow conservation to proceed. Therefore, the site owner can hold-out for higher payment so long as WTP $-$ WTA ≥ 0. The leverage potential is thus WTP $-$ WTA, which we denote as Δc_i for site i. Leverage potential, therefore, represents the worst-case scenario for the conservation group for any negotiated settlement. It exists independently of a specific negotiation structure. Differing negotiation strategies will arrive at different results, bounded between the landowner's WTA and the conservation group's WTP. Moreover, we do not contend that the landowner can know his own leverage potential. Given that the landowner can observe only his WTA and not those of other landowners, he is not in a position to demand his WTA + leverage potential. The final figure that will be arrived at in a negotiation is dependent upon the chosen negotiation structure and the information available to each party. However, leverage potential, as we measure it, bounds the set of possible outcomes.

Landowners' leverage potential should be greater on parcels for which there are few substitutes (because they contain particularly unique species or a disproportionate amount of some conservation target). All else being equal, by definition leverage potential will also be larger on sites where landowners' WTA is lower. Since, $\Delta c_i = \text{WTP}_i - \text{WTA}_i$, a low WTA means that there is more scope for a landowner to leverage before the WTP is reached. Much of our analysis, therefore, hangs on the distribution of the biodiversity benefit to cost (meant here as landowners' WTA) ratio for a particular site.

In the section "Illustration of leveraging", we illustrate these ideas using a maximal coverage optimization, in which we simulate leveraging by individual landowners to highlight the consequences for conservation outcomes. We assume that the conservation objective is simply to maximize species coverage across properties through the acquisition of land rights on sites within a budget constraint where the site costs are the estimated purchase costs (WTA). Here, we assume that the level of threat is homogeneous (or unknown) over sites. Then in the section "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem", we examine how leverage potential on particular parcels is affected by variation in the (expected) biodiversity value of properties, variation in the value of alternative land uses (landowners' WTA) and covariation between these two factors. Using both simplified analytical and numerical approximations that do not yet account for community complementarity, we focus on the prioritization of one site. Returning to the maximization of species richness, in the section "Estimate of leverage potential for single site problem from empirical data" we use multiple conservation datasets and simulated data to explore the magnitude of leverage potential in real data. Finally, in the section "Multi-site selections", we incorporate community complementarity and determine leverage potential in the multi-site selection context as well as estimating the factors that influence an individual's ability to leverage.

Illustration of leveraging

To illustrate these ideas, we run a maximal coverage optimization (Church and ReVelle 1974) where a conservation group wishes to maximize species richness across conserved properties through the acquisition of land rights subject to its budget constraint with site costs as estimated WTA.

The optimization was run on data on the presence or absence of 81 bird species over 43 farms in the Peak District in England (Dallimer et al. 2009) and on cost data from a socioeconomic survey of the same farm businesses (Acs et al. 2010). The socioeconomic data documented estimated farm rental price per hectare. We therefore assume that the conservation objective requires that an equal area of land is conserved on each property on a temporary basis, allowing the economic cost to be reduced to the per hectare rental value. We use a budget constraint of £80 per hectare. For the purposes of this illustration, we also assume rights can only be purchased on at most three of the 43 parcels. This latter constraint is used for expository purposes in this section only given the need to limit the number of possible combinations in order to document the sequence of changes in the reserve sets brought about by the landowner leveraging (Table 2). The presented figures for leverage potential will therefore be slightly inflated. In the section "Multi-site selections", we return to multi-site selection without this additional constraint.

Table 1 shows the result of the initial optimization when assuming rights over conservation activities can be purchased for the market rental price of each property. Table 2 shows the results where we perform the same optimization but this time assume one of the landowners in the initial optimal set demands iteratively higher costs. We give the details of the conservation outcome each time the optimal set changes until the focal property itself drops out and

Table 1 Optimal reserve set for illustrative maximal coverage optimization using the peak district data

Optimal set	Richness	Costs	Total
1,5,19	58	12, 31.4, 21.1	£64.5

Table 2 Effect of leveraging on each site in the optimal set for the illustrative maximal coverage problem using the Peak District data

Δc_1	$\%\Delta c_1$	R	Sites	Costs	Total
15.5	129	57	1,5,12	27.5, 31.4, 19.5	£78.4
17.1	143	56	1,5,31	29.1, 31.4, 19.3	£79.8
17.3	144	55	1,5,9	29.3, 31.4, 8.8	£69.5
26.8	223	54	1,5,32	38.8, 31.4, 5.5	£75.7
31.1	259	53	5,7,19	31.4, 25.4, 21.1	£77.9
Δc_5	$\%\Delta c_5$	R	Sites	Costs	Total
15.5	49	57	1,5,12	12, 46.9, 19.5	£78.4
17.1	54	56	1,5,31	12, 48.5, 19.3	£79.8
17.3	55	55	1,5,9	12, 48.7, 8.8	£69.5
26.8	85	54	1,5,32	12, 58.2, 5.5	£75.7
31.1	99	51	1,2,12	12, 41.3, 19.5	£72.8
Δc_{19}	$\%\Delta c_{19}$	R	Sites	Costs	Total
15.5	73	57	1,5,12	12, 31.4, 19.5	£62.9

Costs were increased iteratively until there was a change in the optimal set and the relevant change is noted. The process was then repeated until the leveraging site was no longer included in the optimal set. At this point WTA + Δc_i = WTP. Δc_i is the leverage potential applied on site i. $\%\Delta c_i$ is the percentage increase from the landowner's WTA for site i and R denotes the richness level that can be protected

WTP − WTA = 0. We record the leverage potential Δc_i, the percentage increase from the initial value, the changes in the optimal set, changes in species richness covered by the three conservation agreements and changes in the overall cost.

When the conservation group can buy land rights at the landowners' WTA, the initial optimal set contains sites labelled 1, 5, and 19. Of the possible 81 species, 58 occur on these three properties and the overall cost of securing conservation agreements on them is £64.5 per hectare. Now suppose that the landowner of site 1 holds out for more money than that offered initially by the conservation group. Agreement can still be reached even at an increase of 129% of the initial cost for site 1. At this point the conservation group's budget constraint forces it to consider a different set of sites. Even with the increase in cost demanded by the landowner of site 1, the next best alternative still includes this site (Table 2). Instead site 19 drops out of the optimal set, and there is a decrease in the richness of species protected by the conservation agreements. This process can continue with site 1 holding out for higher payments until the cost of securing a conservation agreement on that site has increased by 259%, at which point the conservation group is forced to choose a set of sites that does not include site 1. The same processes are evident with leveraging on the other sites in the initial optimal set.

For sites 1 and 5, the initial effects of their demand for higher payment levels are felt elsewhere in the optimal set, with sites other than their own dropping out. On the other hand, site 19 is the first to drop out if the landowner on that site demands an increase that forces the conservation group to the limit of its budget. These different dynamics among sites in the optimal set suggests an important role for site irreplaceability (Pressey et al. 1994) in setting an individual landowner's leverage potential, an issue we return to in the section "Multi-site selections".

Overall, leveraging by landowners reduces the conservation group's ability to achieve its objective, with fewer species conserved for a given budget.

Methodological approach to single site problem

Before returning to multi-site selections and the effects of complementarity, we first considered simpler consequences for landowners' leverage potential based on variation in and covariation between the biodiversity value of parcels and landowners' willingness-to-accept conservation agreements upon them.

Step 1—Analytical approximation

To develop an analytical approximation that examines the consequences of the distributions of biodiversity benefits and landowners' WTA, we consider a situation where a conservation group with a limited budget seeks to identify one site from within a region in which to invest as part of its broader conservation strategy. Let the biodiversity value of candidate sites and landowner's WTA each be identically and independently distributed normal random variables that may be cross-correlated with one another. We denote by b_i the value of biodiversity on site i and by c_i the WTA on site i ($i = 1, 2, \ldots, n$). To identify priority sites for investment, one strategy would be to pick the site that offered the greatest improvement in biodiversity per pound spent, based on the ranking of sites

$$\frac{b_n}{c_n} > \frac{b_{n-1}}{c_{n-1}} > \ldots > \frac{b_1}{c_1} \tag{1}$$

where b_n/c_n denotes the highest benefit to WTA ratio offered by any site, b_{n-1}/c_{n-1} denotes the next highest, and so on. Leverage potential is then related to the difference between the highest and next highest ratios. We will refer to this as the ratio difference. Estimating this ratio difference proves easier than estimating leverage potential itself.

We rely on an approximation of the Hinkley-Fieller (HF) distribution (Fieller 1932; Hinkley 1969) to develop our analytical approach; the HF distribution is the ratio distribution of two correlated normal variables. The probability density function (pdf), $f(x)$, and cumulative density function (cdf), $F(x)$, of the approximation are

$$f(x) = \frac{b(x)d(x)}{\sqrt{2\pi}\sigma_1\sigma_2 a^3(x)} \tag{2}$$

$$F(x) = \Phi\left\{\frac{\theta_2 x - \theta_1}{\sigma_1\sigma_2 a(x)}\right\} \tag{3}$$

where θ_1 and θ_2 are the biodiversity mean and the WTA mean, respectively and σ_1^2 and σ_2^2 are the corresponding variances. Expressions for a, b, d and Φ are given in ESM: Hinkley-Fieller Distribution. We use the above approximation of the full HF distribution for two reasons. Firstly, it is significantly simpler than the full HF distribution and secondly, the approximation is such that the denominator distribution takes only non-negative values. In the context of the problem in hand, this distribution means that biodiversity is measured as the change in biodiversity from the mean improvement possible on all sites and costs are non-negative. The assumption underlying this approximation is that the variance in the denominator distribution (landowners' WTA) is smaller than the mean. Indeed, as $\theta_2/\sigma_2 \to \infty$ the approximation becomes exact. (See Hinkley 1969 for a discussion of the difference between the exact distribution and the approximation and ESM: Hinkley-Fieller Distribution for the mathematical description of the full HF distribution and the approximation).

Step 2—Distributions of b_n/c_n and b_{n-1}/c_{n-1} calculated through the order statistics of the HF distribution

To calculate the relevant expected values for the ratio distribution corresponding to the largest values in Eq. 1 we rely on the pdf for the n-th and $(n-1)$-th order statistics. Using the standard form for the pdf for the k-th order statistic from any distribution it can be shown that the pdf of the n-th and $(n-1)$-th order statistic have the following respective forms, where $f(x)$ and $F(x)$ are the parent distribution pdf and cdf respectively (Arnold et al. 2007),

$$f_{X_{(n)}}(x) = nF(x)^{n-1} f(x) \tag{4}$$

$$f_{X_{(n-1)}}(x) = n(n-1)F(x)^{n-2}(1-F(x))f(x) \tag{5}$$

Step 3—Calculation of the expected values of $\frac{b_n}{c_n} - \frac{b_{n-1}}{c_{n-1}}$

We are now in a position to combine the definition of the HF distribution from step 1 with the order statistics from step 2 to calculate the ratio difference. Using Eqs. 2–5, the ratio difference becomes

$$E(X_{(n)} - X_{(n-1)}) = n\int_{-\infty}^{\infty} xF(x)^{n-1} f(x)\ dx \\ -n(n-1)\int_{-\infty}^{\infty} xF(x)^{n-2}(1-F(x))f(x)\ dx \tag{6}$$

Equation 6 lets us determine how the ratio difference is affected by variation and covariation in biodiversity and landowners' WTA, and sheds light on how leverage potential is affected. We solve Eq. 6 using the adaptive Gauss-Kronrod quadrature method.

Simulation methods

We also conducted numerical simulations that allowed us to deal with the same issues as the analytical approximations. These simulations served two purposes. The first was to evaluate the analytical approximation. The second was that they allowed us to transform the ratio difference into the leverage potential. The analytical approximations calculate the ratio difference because it was infeasible to determine the expected value of the leverage potential itself given the complexity of Eq. 6. However, this can be approximated in the numerical simulations. The ratio difference is given by

$$\frac{b_n}{c_n} - \frac{b_{n-1}}{c_{n-1}}$$

Δc_n is the increase in WTA from the anticipated level for the site owner with highest benefit to cost ratio. Thus, the WTP is exhausted when

$$\frac{b_n}{c_n + \Delta c_n} = \frac{b_{n-1}}{c_{n-1}}$$

From which it can be easily seen that the leverage potential is

$$\Delta c_n = \frac{b_n c_{n-1}}{b_{n-1}} - c_n \tag{7}$$

This value can be extracted in the numerical simulations. While this quantity is itself informative, of greater importance is its relation to the WTA. Therefore, in the analysis, we document the maximum percentage increase in cost to the conservation group of securing a conservation agreement on a given site that could result from leveraging relative to the landowner's WTA.

Organization of the results

Our analysis in the section "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem" is comprised of two parts. In the first part, we quantify the role of the variance in biodiversity values and in landowners' WTA in influencing leverage potential. In the second part, we do the same for covariation between biodiversity and landowners' WTA. We investigate the role of variance and covariation in determining the ratio difference with the analytical approximation and both the ratio difference and leverage potential in the numerical simulations. To explore the role of variance in biodiversity values and WTA, in the analytics we changed a variance parameter for WTA while keeping that for biodiversity value across sites constant and vice versa. In the simulations, we randomly drew values from a normal distribution for the biodiversity values and values from a normal distribution that was truncated below by zero for the landowner's WTA. The parametric variance in one distribution was held constant and we determined the leverage potential and ratio difference 1000 times for iteratively higher levels of variance in the other distribution. We report the mean ratio difference and leverage potential as well as 95% confidence intervals. To examine the role of biodiversity to WTA covariance in setting the ratio difference and leverage potential, we varied the covariance parameter from -1 to 1 in the analytical approximation and in the numerics we draw values from the required distributions 1000 times for each value of correlation coefficient again reporting the mean value along with 95% confidence intervals.

Parameter values

The parameters we have chosen to use are biodiversity mean of zero and variance of 1,000. We have used biodiversity mean of zero because as we are using a normal distribution it seems more appropriate to measure biodiversity as the change in mean improvement possible on all sites, thus allowing for negative values. For WTA, we have used mean of 1,000 and variance of 5×10^4.

Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem

Sensitivity of ratio difference and leverage potential to variance in WTA and biodiversity

Figure 1 shows how the ratio difference and leverage potential are affected by increasing variance in the value of biodiversity across sites, while keeping the variance in landowners' WTA constant and vice versa. In the figure, leverage potential is represented by the percentage increase in the cost to the conservation group of securing a conservation agreement on a property over the landowner's WTA. Both the ratio difference and leverage potential respond to a greater degree to increasing WTA variance. While the ratio difference increases asymptotically for biodiversity variance, the leverage potential remains stable at around 30% of the WTA. For WTA variance, the ratio difference continues to increase over the range of variance and this is replicated in the leverage potential, which ranges from approximately 22% to over 55% of landowner's WTA. Also evident is that the ratio difference and leverage potential have the same shape for increasing WTA variance. This is not true for the biodiversity value variance but inspection of the graph highlights that there is a correspondence between the ratio difference and leverage potential in this case, with peaks and troughs at the same levels of variance.

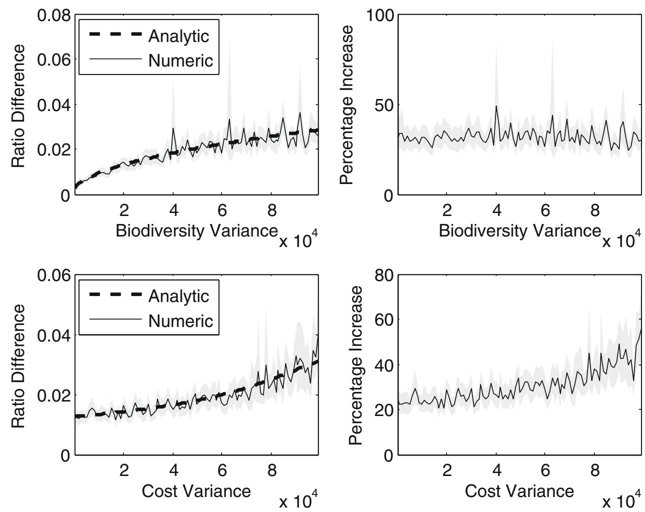

Fig. 1 Effect of variance in biodiversity value across properties and variance in landowners' WTA across properties on one landowner's ability to leverage. Leverage potential is set by the point at which the conservation group's WTP for an agreement on their top priority site is exhausted. *Left column*: Analytically and numerically derived ratio difference along with *right column*: the numerical estimate of leverage potential itself expressed as a percentage increase of the cost of securing a conservation agreement on the property over the landowner's basic WTA. *Top row*: ratio difference and leverage potential when biodiversity variance is increased and variance in WTA is held constant. *Bottom row*: ratio difference and leverage potential when variance in WTA is increased and variance in biodiversity value is held constant. Parameters are $\theta_1 = 0$, $\theta_2 = 1{,}000$ and the number of site is $n = 50$. The *grey area* is the 95% bootstrap confidence interval

Ratio difference and leverage potential for WTA and biodiversity covariance

Turning to the role of spatial covariation of biodiversity and landowners' WTA, we solve Eq. 6 for varying correlation coefficient. Figure 2 shows that the correlation coefficient of landowners' WTA and the biodiversity value across properties has a dramatic role in determining both the ratio difference and the leverage potential itself when expressed as the percentage increase in the cost of securing a conservation agreement over the landowner's WTA. Both are highest for strong negative correlation of biodiversity value and landowners' WTA across properties, the situation thought to be most favorable for conservation outcomes (Naidoo et al. 2006). Both the ratio difference and leverage potential itself are lowest at strong positive correlation of biodiversity value and landowners' WTA across properties. When biodiversity value and landowners' WTA across properties are strongly negatively correlated, the cost of securing conservation agreements on a property can be increased by approximately 50% over the landowner's

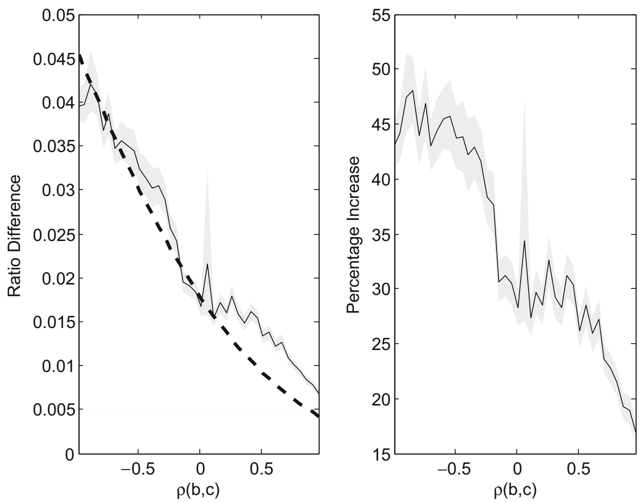

Fig. 2 Effect of covariance between the biodiversity values and landowners' WTA across properties on one landowner's ability to leverage. *Left panel*: Analytically and numerically derived ratio difference and *right panel*: numerically estimated leverage potential. The parameters are $\theta_1 = 0$, $\theta_2 = 1{,}000$, $\sigma_1^2 = 1{,}000$, $\sigma_2^2 = 5 \times 10^4$ and $n = 50$. The *grey area* is the 95% bootstrap confidence interval

Table 3 Leverage potential in empirical data

Source	Leverage	σ_1^2	σ_1^2	$\rho(b, c)$
Fishburn et al. (2009b)	30%	2.1×10^3	2.2×10^6	−0.22
Underwood et al. (2008) Aus	24%	2×10^5	4.7×10^{18}	0.14
Murdoch et al. (2007)	14%	584	7.3×10^4	0.21
Dallimer et al. (2009)	9%	48.8	1.3×10^3	−0.33
Underwood et al. (2008) Med	8%	1×10^6	6.1×10^{11}	0.08

Leverage potential is given as the percentage increase that the owner of the site having highest biodiversity value to WTA ratio can demand before the site is no longer more desirable than the second best choice. Leverage potential is calculated from five conservation datasets. Also reported is the variance in WTA, variance in biodiversity level and the covariation between them for these datasets. The Underwood et al. (2008) paper looked at different regions and we used their data from Australia and the Mediterranean separately. Also, it should be noted that the data labelled as Dallimer et al. (2009) is both the biodiversity data from that study and the Acs et al. (2010) cost data from the same set of sites

WTA. When these factors are strongly positively correlated across properties, the possible increase in cost of securing a conservation agreement is below 20%. Here we also see a strong correspondence between the shape of the ratio difference (estimated analytically and numerically) and leverage potential itself (estimated numerically only).

Estimate of leverage potential for single site problem from empirical data

Dallimer et al. (2009) and Acs et al. (2010) provide data on biodiversity and land rents on individual properties allowing an empirical estimate of leverage potential in the single site problem to be obtained (Table 3). Other published sources presenting biodiversity and cost data tend to report these data at much coarser scales (e.g., ecoregions in Murdoch et al. 2007 or states in Fishburn et al. 2009b). While these other sources are clearly not reporting data at an adequate resolution to depict the process of individual landowners leveraging the biodiversity value on their properties, we include them here for illustrative purposes and for want of published studies presenting biodiversity and cost data at the property scale.

For each dataset listed in Table 3, we solved Eq. 7. First, we ranked locations by their biodiversity to WTA ratio. Then, we determined the extent to which a "landowner" (likely a regional government for the coarser datasets) representing the location attributed the highest priority in this ranking could leverage in negotiations with a conservation group looking to secure a conservation agreement. Leverage potential was again determined by the point at which the biodiversity benefit to WTA ratio becomes equal to that of the second most beneficial location. The values for the leverage potential in Table 3 are in a similar range (8–30% of the landowner's WTA) as those found in the section "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem".

Multi-site selections

In the sections "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem" and "Estimate of leverage potential for single site problem from empirical data", we calculated leverage potential for the simplified case where a conservation group is seeking to secure a conservation agreement on a single site in a given area. Now we return to the multi-site case illustrated in the section "Illustration of leveraging". As we did in that illustration, we still focus on estimating leverage potential when a single landowner holds-out for a higher payment. However, now we examine the situation where the relevant land parcel is part of a network of several sites on which the conservation group are seeking to secure habitat conservation agreements.

The leverage potential we found in the example in the section "Illustration of leveraging" (73–259% of WTA) was much larger than that found in the sections "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem" and "Estimate of leverage potential for single site problem from empirical data" (approximately 8–55% of WTA) that focused on securing a conservation agreement on a single site. Several reasons might account for this disparity. (1) The increased leverage potential in the section "Illustration of leveraging" is an artifact derived from us only allowing a single landowner to hold-out for a higher payment. This individual is then able to capture the overall leverage potential across the set of sites prioritized for conservation that would likely be shared across different landowners. (2) If we were to rank possible reserve networks instead of individual sites in the way that we did in Eq. 1, the distributions of biodiversity value and landowners' summed WTA across reserve networks might look very different to those for individual sites, which could contribute to the observed increase in leverage potential. (3) The result may have been influenced by the constraint that a maximum of three sites could be selected. (4) Finally, the disparity may arise because the substitutability of sites diminishes when we recognize community complementarity and landowner's leverage potential is increased as a result.

Leverage potential in multi-site problem for summed occurrences/without community complementarity

We first set out to explore the simpler role of factors 1 and 2 in setting leverage potential and then incorporate community complementarity, which allows us to test the role of factors 3 and 4. To achieve this we first consider prioritizing sets of sites based simply on the sum of species richness found on each site. This is equivalent to setting the conservation objective to maximizing the occurrences of species. We then test the effect of a complementarity analysis in influencing the landowner's leverage potential.

When maximizing the sum of species' occurrences we value rare and common species equally or assume that all species are endemic to all sites. With the incorporation of community complementarity the value of rare species increases dramatically given that we seek to include as many species as possible in our network (Rodrigues et al. 2000). Thus, sites that contain rare species are more desirable when considering complementarity as opposed to simply the sum of species' occurrences. In the single site selection context the two metrics are equivalent. However, in the multi-site selection situation the change in conservation objective could affect leverage potential. When first seeking to consider only factors 1 (one landowner is capturing everyone's leverage potential) and 2 (changed benefit-cost distributions) in setting leverage potential through identifying a reserve network that will maximize the total number of occurrences of species across sites, we used both simulated data and the datasets used in the section "Estimate of leverage potential for single site problem from empirical data".

As noted earlier, we have one data source representing the true spatial scale of our problem, the Dallimer et al. (2009) biodiversity data and the Acs et al. (2010) cost data. Thus, in generating the simulated data throughout the section "Multi-site selections", we produced random binary matrices for species representation with the same dimensions as the Dallimer et al. (2009) data and bootstrapped the Acs et al. (2010) cost data. In the summed occurrences analyses, the rows of the binary matrix were summed to give us the occurrences of species on each site.

To identify our optimal reserve network we have used a simple greedy heuristic. This algorithm selects the best site to be added to our network iteratively until the budget is exhausted. After having determined our reserve set we calculate the leverage potential as in the section "Illustration of leveraging". For each of the sites in the reserve set, we iteratively increased its WTA until it was no longer a member of the set. We used a budget constraint of five times the mean initial cost over all sites. The use of the heuristic algorithm as opposed to the exhaustive search algorithm used in the section "Illustration of leveraging" allowed us to remove the three-site constraint included there for illustrative purposes.

The top section of Table 4 illustrates that even when not yet accounting for community complementarity in the multi-site case, leverage potential can be significantly higher than in the single site case and can lead to large increases in the cost of securing a conservation agreement on a given site/location. The mean value for the leverage potential in the simulated data was 70.2% of WTA. The conservation datasets gave similar values. Although for some sites there was little scope for leveraging, large increases were also possible, with some sites having leverage potential above 150% of the WTA.

Table 4 Leverage potential on one site when selecting multiple sites for protection

Source	Opt	Mean	Interval
Simulated data	SO	70.2	[61.9 79.1]
Fishburn et al. (2009b)	SO	97.7	[17.8 172.7]
Underwood et al. (2008) Aus	SO	119.4	[0.1 208.1]
Murdoch et al. (2007)	SO	19.6	[2.9 93.6]
Dallimer et al. (2009)	SO	104.2	[0 233]
Underwood et al. (2008) Med	SO	90.7	[25.6 180.2]
Simulated data	SR	122.9	[103.7 142.6]
Dallimer et al. (2009)	SR	132.6	[52 237.3]

In the top section of the table we optimize the sum of species' occurrences (SO) and in the lower section we optimize species richness (SR). For the simulated data we record the mean leverage potential that the individual landowner can demand until his site is no longer in the reserve network, along with 95% confidence intervals. For the datasets we also record the mean increase possible but the interval here is the range of leverage on all the sites in the optimal reserve network. Again it should be noted that the data labelled as Dallimer et al. (2009) is both the biodiversity data from that study and the Acs et al. (2010) cost data from the same set of sites

Leverage potential in multi-site problem with community complementarity

Finally, we account for the role community complementarity when the objective is to cover as many species as possible in the reserve set and redundancy in species' occurrences across sites is not rewarded. Because we value rare species much more highly in this context, the value of sites has the potential to be higher than when we simply wish to find the maximum of summed occurrences. This greater desirability of particular sites may allow landowners to hold-out for higher payments. Evidence of this can be seen both in Table 4 and the initial illustration of leverage potential in the section "Illustration of leveraging". Comparing the leverage potential results for the simulated data for summed occurrences and species richness shows that focusing on community complementarity significantly increases the leverage potential of the individual landowner. The Dallimer et al. (2009) and Acs et al. (2010) data also allows for a direct comparison between the two and again we see that leverage potential when valuing community complementarity can be higher.

We can also conclude that the three-site constraint artificially inflated leverage potential. Comparison between the Dallimer et al. (2009) leverage potential for the community complementarity analysis and that calculated in the section "Illustration of leveraging" shows that the ability to hold-out is around 20% lower when this constraint is removed.

In our illustrative example of the section "Illustration of leveraging", Table 2 highlights the fact that even when the sites labelled 1 and 5 demand higher payment levels, their inclusion remains necessary to meet the conservation objective through several changes in the optimal reserve set. In contrast, site 19 drops out of the optimal reserve when leveraging causes the budget constraint to be met for the first time. This difference among sites in the initial optimal reserve network may reflect site "irreplaceability," a metric that has been commonly used in the literature to capture site uniqueness, and which has been defined as the likelihood that a site will be required to meet a given set of targets (Pressey et al. 1994; Ferrier et al. 2000). To investigate the possibility that irreplaceability was an important factor in determining variation in leverage potential across sites in the multi-site selection scenario, we calculated the irreplaceability value of each of the three sites in our initial optimal set from the section "Illustration of leveraging". To do so, we determined all the combinations of sites that would lead us to within five species of the maximum possible species richness. We measured site i's irreplaceability to the conservation strategy as the proportion of all possible solutions within this near optimal set that contained site i. The results in Table 5 suggest there may be a relationship between leverage potential and irreplaceability: the sites with higher leverage potential have a higher irreplaceability value.

In order to explore the possible relationship between site irreplaceability and leverage potential further we calculated leverage potential and irreplaceability in 1,000 similar situations. To test the null hypothesis that there was no significant relationship between irreplaceability and leverage potential, we constructed a quasi-Poisson generalized linear model. The full model had as explanatory variables: irreplaceability, biodiversity to cost correlation and site cost.

The model rejected the null hypothesis of no relationship between irreplaceability (coefficient = 1.82,

Table 5 Leverage potential and irreplaceability for each of the sites in the initial optimal reserve using the Dallimer et al. (2009) and Acs et al. (2010) data

Site	Leverage potential	Irreplaceability value
1	31.1	0.30
5	31.1	0.57
19	15.5	0.09

p-value < 0.001) and the biodiversity to cost correlation (coefficient $= -0.39$, p-value < 0.01). However, the model showed no evidence against the null hypothesis with respect to site cost (p-value $= 0.46$). Thus, we can conclude that irreplaceability and biodiversity to cost correlation are important variables in determining leverage potential in the multi-site selection scenario.

These regression coefficients should be interpreted with caution because the response variable (leverage potential) does not satisfy the assumption of independence from the latter two explanatory variables (biodiversity to cost correlation and site cost). That being said, the issue of potential non-independence is more obvious when dealing with site cost, which offered little explanatory power anyway.

Discussion

Conservation planning studies increasingly emphasize the importance of accounting for the costs of securing conservation benefits. To estimate conservation costs, these studies rely on estimates of the market value of alternative land uses, which, at best, provide partial estimates of landowners' WTA conservation agreements (Dutton et al. 2008; Guerrero et al. 2010; Knight et al. 2010). In principle, a voluntary transaction between a conservation group and landowner could go ahead as long as the conservation group's WTP for conservation on the site exceeds the landowner's WTA. However, due to the fact that conservation groups cannot observe a landowner's true WTA, the possibility exists in a negotiation that landowners may be able to hold-out for higher payments and capture some of the conservation group's excess WTP. The maximum amount landowners could capture is WTP-WTA, a quantity that we have termed the leverage potential for the site. We examined how ecological and economic factors combine to determine this leverage potential across sites and the possible consequences of landowners leveraging for conservation strategies and their effectiveness.

Leverage potential is a function of landowners' WTA conservation agreements, the conservation group's overall budget and the potential substitutability of different sites when trying to achieve particular conservation objectives. While specific to our context, leverage potential is therefore related to ideas such as irreplaceability (Pressey et al. 1994; Ferrier et al. 2000), asset specificity (Huusom and Strange 2008) and fungibility (Salzman and Ruhl 2000) that arise elsewhere in the conservation planning literature.

Leveraging by landowners has the potential to dramatically increase the cost of securing conservation on a site. When prioritizing one site for protection, we found that the upper bound on the increase in cost that the conservation group could face due to leveraging was approximately 55% of the WTA. When moving to the multi-site selection situation, leverage potential had the capacity to be higher still. For simulated data and a range of conservation datasets, the upper bounds on the cost of securing conservation agreements was often over 100% and in several cases over 200% of the landowner's WTA. Leveraging by landowners will reduce the overall effectiveness of conservation investments by increasing the costs of securing conservation agreements on a site. Interestingly, the illustrative example in the section "Illustration of leveraging" indicated that leveraging also determines the particular properties that should be priorities for investment and that leveraging by one landowner can change a conservation group's prioritization of other available sites.

Evidence for this type of phenomenon was found in the recent study by Carwardine et al. (2010). In scenarios that sought to expand the protected area network in Queensland, Australia, they investigated the effect of uncertain costs on conservation priorities. Specifically, they estimated cost through a valuation of the unimproved land and this then allowed them to determine the priority of different land parcels. They then varied the cost of those land parcels and calculated how their priority was affected. One of the most striking results was that sites that were essential remained so throughout the range of cost change. Our result, thus, complements theirs and highlights that sites of high priority have the scope to demand much higher than anticipated costs. This is something that needs to be accounted for in conservation plans.

To unpick how different factors combine to influence leverage potential, we first considered the implications of trying to secure a conservation agreement on a single site. In these analyses, we examined the role of variance in the biodiversity value and in landowners' WTA conservation agreements across sites. We found that WTA variance is more important in determining leverage potential than the variation in biodiversity values. Leverage potential was stable at around 30% of the landowner's WTA for increasing biodiversity variance. However, for increasing WTA variance, the increase that the landowner could demand became substantially higher. At the lowest level of variance the leverage potential was around 20% of the WTA. At the highest level of variance considered, the leverage potential rose to approximately 55% of the WTA. This result complements other work showing that socioeconomic factors can be more important in determining conservation priorities than variation in biodiversity levels (Ando et al. 1998; Naidoo and Iwamura 2007; Bode et al. 2008).

The role of covariation between biodiversity values and landowners' WTA over sites was shown to have significant influence on the landowners' ability to leverage. Leverage potential was highest when there was a strong negative correlation between these distributions and lowest when this correlation was strongly positive. The change in leverage potential when moving from a strong positive to strong negative correlation was approximately 30% of the landowner's WTA. In the context of fixed predetermined costs, Naidoo et al. (2006) argue that conservation will achieve most when there is a strong negative correlation between biodiversity value and costs across sites. However, it is in this situation that the ability for the site owner to hold-out for a higher payment level is greatest, potentially dissipating some of this advantage. More generally, this finding suggests that regional prioritizations for conservation investments that one might arrive at based on a priori estimates of WTA may ultimately prove less efficient than anticipated. Moreover, the disparity between the estimates of WTA and the actual cost arrived at through a negotiation process could produce an unrealistic picture of what conservation investments can achieve.

Our study also demonstrates that leverage potential is determined in part by the conservation objectives one is trying to achieve. When moving beyond the special case of securing a conservation agreement on a single site to looking at networks of sites, we contrasted leverage potential when the conservation objective was to maximize species' occurrences and when it was to maximize species richness. In general, flexibility on how conservation outcomes can be achieved reduces the potential for landowners to hold-out and leverage. Leverage potential was highest when we sought to maximize species richness across a reserve network. When seeking to protect as many species as possible, the maximum increase available to landowners from the conservation datasets was 237% of WTA and for the simulated data the mean leverage potential was 123% of WTA. This value is in the region of 50% greater than the corresponding figure when seeking to maximize species' occurrences. Evidence that this effect is due to the reduced substitutability of sites when seeking to maximize richness as opposed to occurrences was seen in the fact that site irreplaceability was positively correlated with leverage potential.

Past studies that have focused only on landowners' WTA to estimate the costs of delivering a conservation strategy present the most optimistic outcome for conservation groups. Our estimates of the leverage potential for sites illustrate the most pessimistic situation for conservation. The actual cost of securing a conservation agreement on a property could in principle fall anywhere in between. The negotiated settlement that will be agreed in a willing-buyer, willing-seller transaction depends in part on the negotiation process that is followed. The nature of the negotiation process will depend on the particular conservation program, which can range from governments contracting on large numbers of sites at one time to a conservation group seeking to purchase rights on a particular property in a fee simple or easement transaction.

Studies in mechanism design focus on efficient means to allocate contracts when there exists informational asymmetries between the negotiating parties. Many government funded conservation programs have fixed payment levels for undertaking or refraining from predefined management practices (Schilizzi and Latacz-Lohmann 2007). However, recently much research has focused on the use of discriminatory-price auctions for the allocation of contracts. These have been shown to offer many theoretical advantages given that their competitive nature creates a price revelatory mechanism that can compensate for the informational advantage that the landowner holds, leading to lowered informational rents and higher cost-efficiency (Latacz-Lohmann and Van der Hamsvoort 1997). In one of the first adequately controlled comparisons, Schilizzi and Latacz-Lohmann (2007) find that the advantages of such auctions over fixed price schemes are small in some cases and nonexistent in others. Jack et al. (2008) argue that designing tendering programs in conservation instruments that seek to resolve property-scale variation in landowners' WTA, such as discriminatory-price auctions, may not always be helpful, because they open the possibility for leveraging and hold-outs.

Alongside the design of mechanisms for the allocation of conservation contracts, other factors will determine the figure in the range of WTA to WTP at which a negotiated settlement arrives. For instance, the role of timing will be influential in setting the negotiating power of either party. If a conservation group must act quickly to secure biodiversity on a site then the bargaining power of the landowner will be higher. Furthermore, as evidenced in the section "Leverage potential in multi-site problem for summed occurrences/without community complementarity", the substitutability of the sellers influences negotiation power. However, this is true also of the buyers, in this case the conservation groups. If the landowner has multiple conservation groups vying for his land then his negotiating power is strengthened and his ability to hold-out is increased.

Assumptions

Throughout the analyses, we made a number of assumptions. For example in the sections "Methodological approach to single site problem" and "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem", we used the Hinkley-Fieller distribution. This distribution is the ratio of two correlated normal random variables. We used a simplified approximation of this distribution that led to the appealing consequence of non-negative costs. The approximation becomes exact when the ratio of WTA mean to variance tends to infinity. Therefore, it would appear that a necessary assumption for the use of the approximate distribution was that WTA mean be significantly higher than its variance. However, throughout our analyses this assumption was violated. The smallest ratio of WTA mean to variance used in the investigations was $1/100$. Yet comparison between the theoretical and numerical results in Figs. 1 and 2 shows that they are in almost exact correspondence. Therefore, we can conclude that violation of the assumption that WTA mean should be much higher than the variance had no bearing on the results and further that the use of the HF distribution to questions that require a ratio distribution need not be limited to the rather specialized cases where the mean of the denominator distribution is significantly larger than the associated variance.

In a second example, we focused on the leverage potential that one site owner could demand when analyzing leverage potential in the multi-site prioritization problem, assuming that the other sites could be protected at the anticipated market value. This gave us the upper bound for the increase that an individual landowner could demand. Presumably, if more than one landowner demanded increased payment levels, the ability of other landowners to place leverage on the conservation group would be influenced. This relationship between the actions of landowners is one that needs to be explored in order to fully understand leverage potential in the multi-site selection situation.

Thirdly, we have also not taken into account several factors that would affect the range of WTP-WTA. There are costs that would be met by the conservation group, such as assessments of biodiversity levels, transaction costs and recurring site management and monitoring costs. Thus, the range of leverage potential would be reduced when these costs were taken into account.

Finally, the assumed level of the budget constraint needs to be carefully considered in the formulation that maximizes species richness within a budget constraint (the section "Multi-site selections"). In the absence of a valuation function that sets WTP for different levels of biodiversity coverage there exists the possibility that leverage potential could scale with the budget. Should a global optimal solution be found for a site selection problem within a particular budget, raising the budget from this level will increase the leverage potential by the same amount. We have attempted to avoided this particular pitfall by removing the artificial three-site constraint used for illustrative purposes only in the section "Illustration of leveraging" and by assuming that budgets are always relatively small (five times the mean site cost). Nonetheless, unrealistic and inflated values for leverage potential could in principle be arrived at with this formulation should the budget be made arbitrarily large (i.e. large enough that all species are protected). This factor though does not affect the analyses of leverage potential based solely on site substitutability (the section "Effect on leverage potential of variance and covariance in biodiversity and landowners' WTA for single site problem").

Conclusions

We have revealed that there is potentially a large gap between landowners' WTA conservation agreements and a conservation group's WTP that bounds the actual cost at which a willing-buyer, willing-seller negotiation over a conservation contract could arrive. Moreover, we have begun to analyze factors that cause variation in just how large this gap will be in different situations. Taken together, these results suggest that the current practice in conservation planning studies of estimating the cost of securing conservation agreements based on partial estimates of landowners' WTA an agreement will over-estimate just how much a conservation initiative can achieve and may lead to inefficient distortions in funding priorities. In light of this, further studies that focus on the actual costs of securing conservation agreements (see for example, Stoneham et al. 2003; Latacz-Lohmann and Schilizzi 2005; Davies et al. 2010) may offer the most promise for obtaining a more accurate empirical picture of what conservation can achieve. Moreover, greater attention is needed in conservation planning studies to how the negotiation process governing the allocation of conservation contracts can be designed to minimize landowner leveraging and drive the actual cost of securing conservation agreements as close to landowners' WTA as possible.

Acknowledgements G.D.L. was funded by a Natural Environment Research Council (NERC) Studentship. M.D. was funded as part of the UK Research Councils' Rural Economy and Land Use Programme (RELU). RELU is a collaboration between the Economic and Social Research Council, NERC and the Biotechnology and Biological Sciences Research Council, with additional funding from Defra and the Scottish Government. Thanks also go to the authors of several studies whose data was used in the sections "Estimate of leverage potential for single site problem from empirical data" and "Multi-site selections" as well as to the two anonymous reviewers who provided valuable insights and suggestions. Finally, G.D.L would like to thank Ana Aguilar Ojeda for her helpful discussions and support throughout.

References

Acs S, Hanley N, Dallimer M, Robertson P, Wilson P, Gaston KJ, Armsworth PR (2010) The effect of decoupling on marginal agricultural systems. Land Use Policy 27:550–563

Ando A, Camm J, Polasky S, Solow A (1998) Species distributions, land values, and efficient conservation. Science 278:2126–2128

Ando AW, Shah P (2010) Demand-side factors in optimal land conservation choice. Resour Energy Econ 32:203–221

Armsworth PR, Sanchirico JN (2008) The effectiveness of buying easements as a conservation strategy. Conservation Letters 1:182–189

Arnold B, Balakrishnan N, Nagaraja H (2007) A first course in order statistics. SIAM, Philadelphia

Bode M, Wilson KA, Brooks T, Turner W, Mittermeier R et al (2008) Cost-effective global conservation spending is robust to taxonomic group. Proc Natl Acad Sci USA 105:6498–6501

Carwardine J, Wilson KA, Hajkowicz SA, Smith RJ, Klein CJ, Watts M, Possingham HP (2010) Conservation planning when costs are uncertain. Conserv Biol. doi:10.1111/j.1523-1739.2010.01535.x

Church RL, ReVelle CS (1974) The maximal covering location problem. Pap Reg Sci Assoc 32:101–118

Costello C, Polasky S (2004) Dynamic reserve site selection. Resource Energy Economics 26:157–174

Dallimer M, Acs S, Hanley N, Wilson P, Gaston KJ, Armsworth PR (2009) What explains property-level variation in avian diversity? an inter-disciplinary approach. J Appl Ecol 46:647–656

Davies ZG, Kareiva P, Armsworth PR (2010) Temporal patterns in the size of conservation land transactions. Conservation Letters 3:765–775

Dobbs TL, Pretty J (2008) Case study of agri-environmental payments: the United Kingdom. Ecol Econ 65:765–775

Dutton A, Edwards-Jones G, Strachan R, Macdonald DW (2008) Ecological and social challenges to biodiversity conservation on farmland: reconnecting habitats on a landscape scale. Mamm Rev 38:205–219

Ferrier S, Pressey R, Barrett T (2000) A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biol Conserv 93:303–325

Fieller EC (1932) The distribution of the index in a normal bivariate population. Biometrika 24:428–440

Fishburn I, Kareiva P, Gaston KJ, Armsworth PR (2009a) The growth of easements as a conservation tool. PLoS ONE 4:e4996

Fishburn IS, Kareiva P, Gaston KJ, Armsworth PR (2009b) State level variation in conservation investment by a major non-governmental organisation. Conservation Letters 2:74–81

Guerrero AM, Knight AT, Grantham HS, Cowling RM, Wilson KA (2010) Predicting willingness-to-sell and its utility for assessing conservation opportunity for expanding protected area networks. Conservation Letters. doi:10.1111/j.1755-263X.2010.00116.x

Hanley N, Whitby M, Simpson I (1990) Assessing the success of agri-environmental policy in the UK. Land Use Policy 162:267–280

Hinkley DV (1969) On the ratio of two correlated random variables. Biometrika 56:635–639

Huusom H, Strange N (2008) Transaction costs economics of irreplaceability: ex ante and ex post evaluation of conservation networks vulnerability to environmental shocks. Environ Manage 41:551–565

Jack BK, Leimona B, Ferraro PJ (2008) A revealed preference approach to estimating supply curves for ecosystem services: use of auctions to set payments for soil erosion control in indonesia. Conserv Biol 23:359–367

Kleijn D, Sutherland W (2003) How effective are european agri-environment schemes in conserving and promoting biodiversity? J Appl Ecol 60:947–969

Knight AT, Cowling RM, Difford M, Campbell BM (2010) Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. Conservation Letters. doi:10.1111/j.1523-1739.2010.01494.x

Latacz-Lohmann U, Schilizzi S (2005) Auctions for conservation contracts: a review of the theoretical and empirical literature. Scottish Executive Environment and Rural Affairs Department, Edinburgh

Latacz-Lohmann U, Van der Hamsvoort C (1997) Conservation contracts: a theoretical analysis and an application. Am J Agric Econ 79:407–418

McDonald-Madden E, Bode M, Game ET, Grantham H, Possingham HP (2008) The need for speed: informed land acquisitions for conservation in a dynamic property market. Ecol Lett 11:1169–1177

Meir E, Andelman S, Possingham HP (2004) Does conservation planning matter in a dynamic and uncertain world? Ecol Lett 7:615–622

Millennium Ecosystem Assessment (2005) Biodiversity and human well being. Ecological Management and Restoration 9:226–227

Murdoch W, Polasky S, Wilson K, Possingham HP, Kareiva P et al. (2007) Maximizing return on investment in conservation. Biol Conserv 39:375–388

Naidoo R, Iwamura T (2007) Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. Biol Conserv 40:40–49

Naidoo R, Balmford A, Ferraro PJ, Polasky S, Ricketts TH, Rouget M (2006) Integrating economic costs into conservation planning. Trends Ecol Evol 21:681–687

Polasky S, Camm JD, Garber-Yonts B (2001) Selecting biological reserves cost-effectively: an application to terrestrial vertebrate conservation in oregon. Land Econ 77:68–78

Possingham H, Day J, Goldfinch M, Salzborn F (1993) The mathematics of designing a network of protected areas for conservation. In: Decision sciences: tools for today. Proceedings of the 12th National Australian Society for Operations Research Conference, Australian Society for Operations Research, Canberra, pp 536–545

Pressey RL, Johnson IR, Wilson PD (1994) Shades of irreplaceability—towards a measure of the contribution of sites to a reservation goal. Biodivers Conserv 3:242–262

Rodrigues AS, Cerdeira JO, Gaston KJ (2000) Flexibility, efficiency, and accountability: adapting reserve selectionalgorithms to more complex conservation problems. Ecography 23:565–574

Salzman J, Ruhl JB (2000) Currencies and the commodification of environmental law. Stanford Law Rev 53:607–694

Schilizzi S, Latacz-Lohmann U (2007) Assessing the performance of conservation auctions: an experimental study. Land Econ 83:497–515

Stoneham G, Chaudhri V, Ha A, Strappazzon L (2003) Auctions for conservation contracts: an empirical examination of Victoria's bushtender trial. Aust J Agric Resour Econ 47:477–500

Underwood EC, Shaw MR, Wilson KA, Kareiva P, Klausmeyer KR (2008) Protecting biodiversity when money matters: maximizing return on investment. PloS ONE 3:e1515