Targeting Enhanced Spatial Configuration in Biodiversity Conservation Incentive Payment Programs

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Abstract

Spatial configuration, such as connectivity between conserved sites or complementarity of habitat types, is desirable in many conservation programs. However, such objectives frequently get limited consideration due to the additional complexity required in assessing alternative potential projects. We present a framework for incorporating spatial configuration into the assessment methods used in conservation incentive programs, while at the same time providing landholders with additional incentives for desired for including desired spatial characteristics into their project proposals. To achieve the best results, projects should be valued at the landscape-scale, rather than on a property-by-property basis. This can be done either by assessing the marginal contribution of individual projects to the landscape, or by assessing the total ecological value of the landscape under alternative packages of projects. If spatial configuration is valued in the bid assessment process, landholders have an incentive to offer it within their projects. Where coordination between landholders is required (for example, forming a conservation corridor across a landscape), this can be achieved by extending the bidding process, to allow landholders to modify their bids in order to better align with those of their neighbours. The complexity of landscape-focussed approaches can be readily tailored to fit a wide variety of purposes and budgets. At their most basic they can employ virtually identical input data to that employed by traditional project-focussed approaches. Taking the landscape-scale approach offers an opportunity to more directly target ecological function in incentive programs, increasing the cost effectiveness of public investment and better protecting species and ecological communities.

Introduction

Incentive payments are a policy tool to promote the conservation of biodiversity (or the provision of other ecosystem services) on private land. Payments can be fixed, offering all participants a certain rate per unit of area conserved or service provided, or market-based, with participants competing to offer cost effective projects. Market-based instruments, usually in the form of a competitive tender, have proven to be a particularly cost-effective mechanism for delivering conservation incentives (Latacz-Lohmann and Van der Hamsvoort 1997; Stoneham et al. 2003; Windle et al. 2009). In a typical competitive tender scheme, landholders submit bids to carry out conservation projects, specifying the actions they will carry out (e.g. remove livestock, fence and conserve remnant vegetation) and the price they require. Where multiple landholders are bidding to receive incentive payments, a program manager needs to discriminate between alternative bids in order to select those which offer the best value for money.

However, there is often a gap between conservation planning, which takes a broad geographical perspective, and conservation incentive programs, which typically assess bids on an individual basis. While private land is managed on a property (or smaller) scale, ecological communities function across a range of spatial and temporal scales. There is an opportunity to improve the ecological effectiveness of tenders and other incentive programs by taking a more dynamic, landscape-oriented approach to investment prioritisation. This paper considers options for targeting enhanced spatial configuration within incentive payment programs in order to deliver more resilient ecological populations and communities.

Spatial configuration is important in biodiversity conservation. Flora and fauna cannot persist in isolation, but rather must be part of viable populations and communities. Connectivity allows the movement of individuals and genes between habitat patches within fragmented landscapes. It is important at a range of spatial and temporal scales. In the short term and at the local scale, connectivity may be necessary to ensure that individuals within a population can access sufficient resources for that population to remain viable. In the medium term local populations need to be part of a viable metapopulation, with the potential for dispersal between populations and colonisation of any patches that become vacant. In the longer term species and communities will need to be able to adjust their ranges in response to climatic change and other disturbances.

Connectivity is not limited to contiguous patches or corridors. The key attribute is functional (ecological) connectivity, rather than structural (as seen on a map) connectivity. The nature of the matrix (the areas between habitat patches, typically agricultural), and the characteristics of the species or communities in question determine functional connectivity. Most species can cross the matrix, to a greater or lesser extent. Management actions to make the matrix more permeable, for example by establishing or maintaining paddock trees, can increase connectivity and hence the ecological function of a landscape. Matrix management can also enhance the condition or effective area of a habitat patch, for example by mitigating threatening processes and edge effects. Conservation programs should therefore not confine themselves to management actions within existing habitat patches.

Spatial configuration is also relevant to complementarity. Conserving complementary patches, for example patches at different altitudes, is likely to protect a greater range of biodiversity than conserving similar patches. Both connectivity and complementarity considerations mean that the marginal conservation value of a site depends on its spatial relationships to other habitat patches across the landscape. These values cannot be captured if bids are assessed on a site by site basis. Where connectivity or complementarity are important, bids should be assessed at the landscape-scale. Bids in a tender (or any other incentive program) represent management units, rather than ecological units. Ecological function needs to be assessed at the patch and landscape scale, rather than on individual properties or paddocks.

This paper outlines ecological principles and practical considerations for proactively targeting desired spatial configurations within conservation incentive programs. For this context, the most important spatial configuration is likely to be ecological connectivity, reflecting the interconnectedness of ecosystems and habitats at different scales. Achieving complementarity among species and ecosystems through adequate representation among conservation sites and protected areas is also likely to be important in some cases. A framework is presented for determining when, and how, to target spatial configuration in conservation incentive programs. The paper is framed around competitive tenders, as they are rapidly becoming the preferred model for delivering incentive payments; however, the approach could equally apply to any other incentive schemes which select projects from among a range of proposals.

Valuing landscapes

To make any informed decision it is necessary to consider the benefits and costs of alternative options. In competitive tenders for ecosystem services this process is formalised through the use of a metric. Metrics quantify the benefits offered by bids in a conservation tender into some form of biodiversity units, and are typically the most complex aspect of a competitive tender. However, they are crucially important. If the metric does not accurately quantify the environmental benefits of competing bids a program cannot cost-effectively deliver the desired conservation outcomes. A common problem is for a program to lack clear goals, resulting in a metric which attempts to be all-encompassing but may not accurately reflect ecological values. Other sources of error are double-counting some benefits or conflating costs with benefits (assuming more expensive is better). While no metric can be perfect, it is essential to have one which adequately discriminates between alternative bids, otherwise there is nothing to be gained from running a tender.

In order to value spatial configuration it is necessary to incorporate it into a metric (as discussed below). This will inevitably add to the already complex nature of metric design. However, if it isn't valued, it isn't likely to be delivered. Biodiversity metrics may take a single species or community approach. Ideally a metric should focus on the desired outcome of enhanced ecological function. Where that is not possible (as is likely in most cases), a good proxy is required. While the focus is likely to be on structural connectivity, as this is the only form of connectivity which can be reasonably measured in most cases, consideration should be given each time as to whether this is the most appropriate measure for the particular context. For well known species or systems there may be greater potential to consider functional connectivity. Similarly for complementarity, a metric will need to consider the beta-diversity of the landscape, rather than just the alpha-diversity of the patch.

Assessing the value of a landscape for its connectivity or complementarity will require good data. Conservation tenders which assess bids on a site by site basis can rely on information provided by landholders (either within their bids or through a site inspection). To assess the contribution of a bid to the landscape, it is necessary to also have a reasonable understanding of the location and condition of other habitat patches, as well as any salient features of the surrounding matrix. While considerable data is available, its level of detail may in practice limit attempts to estimate fine-scaled landscape connectivity or complementarity values.

<u>How far to go?</u>

The ultimate metric would assemble all aspects of biodiversity conservation into a single numeric measure. Of course in many cases this is simply not possible or desirable, given the need for accurate scientific information. Conservation programs could spend their entire budgets developing a metric without fully resolving all the issues. It is therefore always necessary to consider the benefits of developing an improved metric to better allocate funds among alternative bids, against the costs, which may reduce funds available for on-ground management. In addition to the financial costs, there are also methodological concerns with increasing the complexity of metrics to account for more features of the bid in question. More complex metrics are prone to error in parameters or system representation. Complex metrics also become less transparent, which makes them harder to communicate to landholders and field officers and increases the risk of errors in implementation.

The purpose of a metric is to combine various ecological attributes into a single numeric score, so trade-offs between different attributes will always be inherent. As additional attributes are added to a metric this will inevitably dilute the weighting of existing attributes. For example, consider a very simple metric which only incorporates habitat extent (i.e. area) and condition for each bid. If an additional term is added for connectivity, extent and condition will each now carry less weight overall. A bid which offers less extent and/or condition may be ranked ahead of another by virtue of a higher connectivity score. The tender can only deliver increased connectivity (as measured by the metric) at the expense of extent and/or condition. (If connectivity is closely correlated with extent and/or condition, then they need not be traded off against each other, but there is also little to be gained from incorporating connectivity into the metric.)

We propose a parsimony principle be applied to metric design. Metrics will always be imperfect, both because the required scientific knowledge is often lacking, and because they are attempting to describe a complex ecological system with a single value. Some attributes, such as extent, can be measured with certainty, while others, such as condition, can be estimated. Connectivity or complementarity should only be included within a metric if it is considered sufficiently important to sacrifice these other attributes to some degree. It should also only be included if its relative value can be reasonably estimated and the costs of doing so (i.e. developing ecological models, obtaining spatial data, etc) are outweighed by the benefits.

The patch is the fundamental unit of landscape ecology. Even where connectivity and complementarity are of great importance, it is likely that the first priority for a metric will still be the viability of biota within an individual patch. The characteristics of the patch—such as size, shape, condition and isolation—have a direct relationship with viable populations or communities. What constitutes a viable patch, in terms of extent and connectivity, will vary between species and communities. If a program has a small budget relative to the geographical area it covers, it is unlikely to be able to contribute significantly to connectivity and so will do better to focus on protecting key environmental assets. Larger programs or those focussed on particular areas are a better placed to address spatial configuration.

Patches as ecological units, bids as management units

The patch is an ecological unit which provides a basis for assessing conservation outcomes at both the local and landscape scale. A patch is not the same as the area covered by a bid submitted in a tender. Bids in tenders (or submissions in any other conservation program) represent units of management. Bids are constrained by property boundaries, while a single patch may cover multiple properties. Therefore in any conservation metric, and particularly those considering connectivity and complementarity, it is essential to distinguish between patches (as an ecological unit) and bids (as a management unit). A patch may be impacted by more than one bid, and similarly (though less likely) a bid may cover more than one patch.

The value of a patch is likely to increase in a non-linear manner with area. Larger patches are more likely to support viable populations. The smallest patches are likely to be worth little. Beyond a certain minimum size, value increases rapidly according to the species-area relationship as a patch becomes more biodiverse. It will continue to increase in value, but at a decreasing rate, as patch size gets larger. Effective patch size is determined by the total area of vegetation and the functional connectivity within it. Edge-effects mean that the shape of a patch is also important, along with the characteristics of the surrounding matrix (Laurance et al. 2007; Prevedello and Vieira 2010). For species or communities which are negatively impacted by edge effects, the effective patch size will be smaller than the actual patch size. Such edge effects may be mitigated by creating a buffer around the patch, so as to increase the core area of the patch to some minimum viable level for a focal species. The effects of patch size will of course vary between species and taxa – what is small for a mammal may not be for an invertebrate (both because they require fewer resources and the available habitat is greater due to fractal geometry).

Patch condition may be impacted by on-site or off-site threatening processes. For example, offsite processes reducing fertiliser runoff or erosion from surrounding (or upstream) paddocks may impact on the condition of a wetland. Every bid will have an impact on a patch, either directly (by impacting extent) and/or indirectly (by increasing effective area or impacting condition). The value of these off-site management actions can be measured in terms of their marginal contribution to the condition or extent of the patch. This framework recognises off-site actions (including those on neighbouring properties) alongside on-site actions. It provides a more ecologically realistic approach to valuing and selecting among alternative bids.

While a patch is defined in landscape ecology as a relatively homogeneous area, more mobile species are not bound by patches. An area of functionally, but not structurally, connected habitat may be considered as a meta-patch. Linking patches by making the matrix more permeable may be considered to increase the effective area of a meta-patch. In other cases the contribution to a meta-patch may be counted proportionately. For example, paddock trees or small areas of remnant vegetation between habitat patches may be counted proportionately in the meta-patch area (e.g. 10% cover of scattered trees is habitat area). Exactly what constitutes a meta-patch will vary between species and communities, as some species move across open areas between small parcels of remnant vegetation, while others require contiguous understorey. Some mobile bird species utilise very small areas of remnant vegetation (Fischer and Lindenmayer 2002; Collard et al. 2009). For the birds these patches may be considered as part of a larger functionally, though not structurally, connected meta-patch. Their value will depend on being part of a linked mosaic of patches, and so can only be meaningfully valued within a landscape context.

Patches and landscapes

Landscapes are relevant to the metapopulation scale. Landscapes comprise a series of more-or-less interconnected patches, and must support viable populations or communities in the medium term (i.e. decades). The value of a landscape may be considered as the sum of the biodiversity complementarity values of its component patches along with a measure of connectivity within and among patches. Connectivity will be a function of distance and permeability between patches (either nearest neighbours or all pairs), weighted by the relative condition of patches incorporating edge-effects. Any such metric must be constructed in such a way that large, non-fragmented patches score more highly than a series of fragmented patches with similar area (Saura and Pascual-Hortal 2007). Landscapes are likely to have thresholds, below which populations of some species are unviable. Individual management actions, both within and between patches, will impact on the value of the landscape.

Incorporating landscape values into metrics

The relative importance of spatial configuration will vary between landscapes, depending on the degree of fragmentation and the dispersal attributes of the species constituting the ecological communities in question. Where it is considered desirable and feasible to include in a metric, the fundamental question is how to do so.

<u>Bid-focussed metrics</u>

To date, conservation tenders have applied metrics based around attributes of individual bids. These bid-focussed metrics typically create scores for individual bids through combining values for a number of different attributes. The score for each bid is then divided by its price in order to rank bids in terms of value for money (i.e. their environmental benefits offered per dollar requested). The most obvious way to include scores for spatial configurations such as connectivity and complementarity is through an additional attribute within a bid-focussed metric. Including a score for connectivity and/or complementarity alongside other attributes of a bid does not require any major changes to the structure of the metrics used in conservation tenders.

A key question is how much weight the connectivity score should have relative to other aspects of the metric. This is a complex issue which does not have a definitive answer, so is likely to be based on expert judgement or policy considerations linked to funding objectives and desired outcomes. For example, if the connectivity weighting is relatively small, then it will only serve to discriminate between bids with similar overall scores from other attributes of the metric. The higher the connectivity weighting, the more likely it is that bids which are well connected, but otherwise poor, will be selected. Therefore the connectivity weighting should reflect the relative importance of connectivity compared to other factors for the particular objective desired.

Similarly for complementarity, bids may be assigned a bonus score based on their relative scarcity in the region or how well they are represented among other bids and protected areas. Again, its weighting should depend on its relative importance compared to other factors. The more attributes that are considered within a metric, the less the impact of any single one is likely to be. In many cases attributes may cancel each other out, reducing their overall usefulness in the metric. Similarly if different attributes are positively correlated, including them both within a metric may result in them having undue influence.

Landscape-focussed metrics

While expert judgement and policy objectives can be used to guide the relative weights assigned to the different components of a bid-focussed metric, it is essentially an arbitrary decision. As discussed above, the units in which ecological values are best expressed (i.e. patches and landscapes) do not necessarily correspond to the units in which bids are submitted (i.e. properties or parts of properties). Bid-focussed metrics assess individual bids as though they were distinct patches. While this makes for relatively simple and tractable metrics, it does not adequately represent landscape function and is largely incapable of accommodating off-patch management actions. Ecological patches will often cross property boundaries, while bids will generally be restricted to individual properties.

Connectivity (beyond the patch scale) and complementarity are not properties of individual bids. Attempting to value them on a bid by bid basis will therefore never be fully satisfactory – this can be done far better with landscape-focussed metrics, particularly for connectivity. A key test of a metric is how it copes if individual bids are split or combined. A bid-focussed metric will value part of a patch inconsistently with the whole of the patch. A landscape-focussed metric should give consistent scores regardless of whether bids are split or lumped. By distinguishing between bids and patches it becomes possible to value conservation activities beyond the patch boundary, for example by increasing connectivity or reducing threats to habitat patches. Australian conservation programs have tended to neglect matrix management, despite its importance in a range of ecological processes (e.g. Attwood et al. 2009).

Moving from bid-focussed to landscape-focussed metrics can free conservation programs from the tyranny of the individual bid and allow a far greater range of valuable management actions to be incentivised. It recognises that management actions do not occur at the same scale as ecological outcomes and allows each to be assessed at the most appropriate scale. This also provides a better framework for evaluating and reporting the effectiveness of programs. Landscape-focussed approaches deal properly with non-additive interactions between management actions (due to complementarity and connectivity) in calculating the overall benefits, where bid-focussed approaches incorrectly assume individual scores are additive. Another advantage of this landscape approach is that remnant vegetation or other beneficial management actions on one property can be recognised for their contributions to neighbouring properties. This means that conservation actions by landholders can directly benefit their neighbours in a tender.

There are at least two methods for selecting among bids based on total landscape values. One method considers the marginal contribution of a bid to the total landscape value. An alternative method is to select the package of bids with the highest overall landscape value.

Marginal contribution to total landscape value

The most straightforward approach to implement a tender with landscape-scale values is to consider the marginal contribution of each bid to landscape ecological function. Rather than considering each bid as a distinct patch, this approach can value the contribution of a bid to the overall landscape. For example, where a bid represents part of a functional patch (e.g. because the patch extends onto neighbouring properties), it would be assessed on its contribution to that patch, and the landscape beyond, rather than being assessed as though the area covered by the bid were an island in an ocean. This approach requires the estimation of total landscape ecological values with and without the bid in question. Subtracting one from the other provides the marginal value of that bid to the landscape. This could then be divided by the asking price in order to rank bids in the same way as is done for conventional bid-focussed metrics.

Bid assessment could be done on a stepwise basis, with the best value (greatest marginal benefit to existing landscape/asking price) accepted first. This bid could then be added to the existing landscape in order to work out the marginal value of other bids. Barton et al. (2009) describe an algorithm (TARGET) for iteratively selecting conservation locations which provide the highest level of complementarity to an existing set of conserved sites. TARGET selects sites if their landscape benefits exceed the opportunity cost of conserving the site, though this requires the trade-off between cost and biodiversity complementarity (effectively a price for biodiversity outcomes) to be defined. This approach may be applied to conservation auctions if it focuses on the ratio of biodiversity to opportunity cost.

Landscape-scale ecological benefits could be estimated using one of a number of existing theoretical frameworks which are designed to assess metapopulations. Ovaskainen and Hanski (2003) derive measures for assessing the value of an individual habitat fragment for the dynamics and persistence of a metapopulation living in a network of many fragments. The value of a fragment depends not only on the properties of the landscape but also on the properties of the species. Metapopulation capacity characterises the ability of a fragmented landscape to support long-term persistence of the species (Hanski and Ovaskainen 2000). It looks at patch size (carrying capacity, which may also refer to quality) and connectivity. Metapopulation capacity can be used to rank different landscapes in terms of their capacity to support viable metapopulations (Hanski and Ovaskainen 2000). It can also calculate how the metapopulation capacity is changed by removing habitat fragments from or adding new ones into specific spatial locations, or by changing their areas.

The probability of connectivity index (PC) (Saura and Pascual-Hortal 2007) is based on the probability that two individuals within a landscape occupy habitat patches that are interconnected. It also considers the carrying capacity of the patch (although this may be omitted). Total landscape connectivity can be calculated. Landscape elements (i.e. patches) can then be ranked according to their percentage contribution to total connectivity. This approach combines patch area (/quality) with connectivity. If permeability varies according to the nature of the intervening matrix, the full PC index may be worthwhile, otherwise a simpler binary version (Pascual-Hortal and Saura 2006) would suffice. This index measures connectivity at the landscape level rather than at the patch level, which is the more appropriate measure. It can demonstrate the marginal impact of a patch (along with the impact of the loss of some or all of a patch).

Total landscape package value

Estimating the marginal value of a bid on the landscape provides an excellent way of valuing a single bid. It may become somewhat less satisfactory where multiple bids are to be valued simultaneously, as would be the case in a conservation tender. The value of a patch and its landscape may depend on one or more bids, whose effects may not be additive. To value the patch it may be necessary to consider the various possible combinations of bids. In this case the marginal value of any one bid will depend on which other bids go ahead. Bids may therefore need to be considered as a package, with the best value package of bids selected.

Rather than valuing and selecting individual bids, a more rigorous approach is to select the package of bids which together offer the best overall outcome within a budget constraint. This allows connectivity and complementarity to be valued holistically for a package of bids within their landscape context rather than on a bid by bid basis. The package approach is also consistent with the objective in tenders of selecting the best value set of bids. However, in such a metric, individual bids are not scored or ranked against one another. Rather the tender will select the best possible package of bids which fits within a given budget. The tender is effectively selecting an overall configuration of bids, rather than a series of individual bids. It is also possible to identify the optimal packages which can fit under a range of different overall budgets, to create a cost curve for total environmental benefits against total budget. This could be used to guide policy makers in deciding how much to invest in that particular tender.

A package value approach provides a comprehensive solution to addressing spatial configuration at landscape and regional scales. It still requires appropriate levels of information and understanding in order to value alternative landscape configurations. It is also computationally challenging. Ideally it requires calculating a biodiversity value for each possible package of bids within the budget constraint. The number of combinations rises rapidly with the number of bids. For 30 bids there are one billion possible combinations; for 40 there are one trillion. As the number of bids increases, the number of calculations to value every possible package rises beyond the capability of even the most powerful computers. There are heuristics (computational short-cuts) such as genetic algorithms (e.g. Moilanen and Cabeza 2002) and simulated annealing (e.g. McDonnell et al. 2002) which can be applied to make these problems manageable. Simulated annealing, for example, has been extensively used with an objective function incorporating achievement of biodiversity targets and spatial compactness while minimising socio-economic costs to prioritise areas for conservation planning (see review by Sarkar et al. 2006). Marxan is the most commonly used software tool in this context (Ball and Possingham 2000; Watts et al. 2008).

It is feasible to develop and implement ecological metrics which assess packages of bids at the landscape scale. However, the process is inevitably more complex and costly than uncoordinated alternatives. With further research these metrics should become better understood and easier to apply. In the meantime this package approach is likely to be required only where spatial configuration is of paramount importance to environmental outcomes, or where the values of individual bids are highly interdependent. It will be particularly appropriate where there is potential for individual bids to have a major impact at the landscape or regional scale.

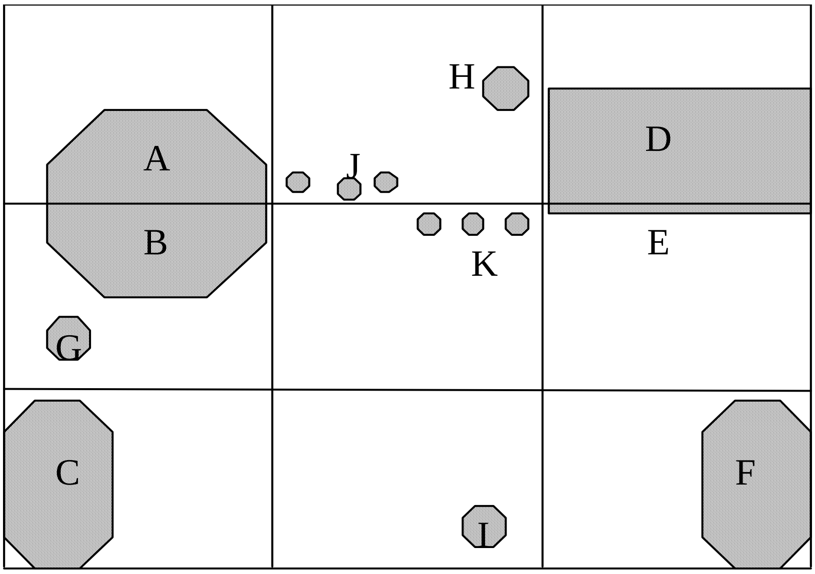
A drawback of the package approach is that the process may be compromised if one or more bids drop out of the process before contracting or implementation. If some bids in the preferred package are lost, its overall value may be significantly compromised. This would not be a problem if bids were binding, but in reality there is a very real possibility that some may be withdrawn even after the assessment process. A form of sensitivity analysis could be carried out to identify any individual bids whose loss would significantly reduce the overall value of the selected package – these landholders could be contracted first, allowing the bid selection process to be re-run if one or more drop out. Alternatively a package of bids could be identified which is more robust to the loss of any particular elements. A resilient landscape will require a series of large patches and/or metapopulations, hence dependency on individual bids should be minimised across the landscape as a whole.

Another drawback with the package approach is that the transparency of the tender process is reduced. Once bids are assessed collectively, it is no longer so clear why some bids are in the preferred package and others are not. Some successful bids may appear to offer poorer value than some unsuccessful bids if considered on their own. This issue would need to be addressed in post tender communication with landholders (see below). A package metric can demonstrate cumulative landscape-scale outcomes from conservation investment where the whole is greater than the sum of the parts. It can do the same for the cumulative impacts of habitat degradation. Such an approach may be considered to avoid the ‘death by a thousand cuts’ which can result from incremental planning decisions.

Metric selection framework

Figure 1 shows how these different metrics would work in practice. A framework is needed to evaluate what sort of metric should be applied to any particular policy program. This depends on the policy objective, available knowledge and data, and the relative importance of connectivity in the context of species, assemblages and landscapes. As discussed above, the inclusion of spatial features such as connectivity and complementarity should only be done if it adds to the policy objective, since the more attributes that are considered in a metric the less relative weight each one will have. Table 1 compares the different approaches.

Figure 1: Metric options



Hypothetical landscape across nine properties. Assume condition and composition is the same in all remnant patches (shaded areas). Letters represent locations of potential bids.

1. **Bid-focussed, no spatial attributes**. Focus on site attributes only.
   Biodiversity value = area x condition
   Site D would have the highest ecological value as the largest site, followed by A, B, C and F; small remnants have little value; actions in the matrix are not valued.

2. **Bid-focussed, with spatial attributes** included. Connectivity represented through proxy such as % vegetation cover in surrounding area, or direct links to remnants.
   Biodiversity value = area x condition x landscape value
   Sites A, B and C likely to be favoured over the more isolated F; G and H have more value than I because they are closer to other sites.

3. **Landscape-focussed, marginal value of bid**. Total value of landscape with and without each bid estimated. Extent, condition and connectivity all considered.
   Biodiversity value = landscape with bid (area, condition, connectivity) – landscape without bid (area, condition, connectivity)
   Sites A and B would be valued higher than C as each contributes to a larger patch; paddock trees at J and K valued for their contribution to connectivity; small remnants G and H valued for proximity to larger patch; G also valued for contribution to connectivity; potential for additional matrix management actions, e.g. buffering around edges of remnant D at E, or establishing paddock trees, valued for their contribution to effective patch area and connectivity.

4. **Landscape-focussed, optimal package** selected.
   Biodiversity value = total landscape value for each possible combination of bids that fits within a budget constraint.
   Applies same ecological model as (3), but also considers interdependencies between bids. For example the value of J may be limited if K is not protected; similarly the value of G may depend on B and C both being protected. Matrix actions are still valued, but their dependencies on other bids are recognised; E is worth little without D.

Table 1: Comparison of alternative metric approaches. Metric options are outlined in box 2.

	What it does	*What it does not do*	*When to use*
1	Focuses on site attributes only. Minimises costs of designing and running tender.	No consideration of spatial configurations, complementarity, matrix management actions.	Small budget, only a few sites likely to be purchased.
2	Incorporates spatial attributes bids (e.g. proximity to other bids or protected areas).	No consideration of matrix/off-patch actions. Consideration of landscape context may lack rigour.	Will generally be inferior to alternatives.
3	Considers value of bid to landscape. Incorporates greater range of on- and off-patch management actions within metric framework.	Does not consider conditional or package values. For example, individual components of corridor each have relatively low marginal values and may not be selected, even though together they are highly valuable.	Spatial configuration and/or matrix/off-patch management actions relatively important. Ecological model and data available.
4	Selects optimal overall outcome from tender.	Computationally complex. Values are not expressed for individual bids. Bids dropping out can be problematic.	Spatial configuration and/or matrix/off-patch management actions relatively important. Ecological model and data available. Value of individual bids conditional on other bids. Impact of bids funded through the tender relatively high compared to existing managed sites.

Any of these metrics can account for expected future changes in site condition with and without the proposed management actions in each bid, at either the bid or landscape scale. A patch of remnant vegetation on private land for which no (successful) bid is submitted may be expected to decline in condition in the future. The greater the likely change in condition with versus without protection, the greater the interdependencies between bids which would favour the package value approach. That is, if sites which remain unprotected after the tender are likely to show a sharp decline in condition, this may impact the value of sites which were protected in the tender, meaning the potential value of all sites is best considered as a package.

If connectivity and complementarity are considered of relatively minor importance for conservation of a particular species or community it is likely that little will be gained from attempting to secure them within a tender. In addition to forcing trade-offs with other attributes it will also result in a more complex and administratively costly tender. Similarly, for programs with small budgets the additional costs of considering spatial configuration are more likely to outweigh the benefits. In such cases a simple approach focussing just on habitat extent and condition is likely to be preferable in order to target key conservation assets. Off-patch actions may still be incorporated to a limited extent by considering their impact on the condition or effective area of a neighbouring patch.

The greater the variability in patch quality, and the lower the dispersal ability of the species in question, the more connectivity is likely to vary between different habitat configurations, so the more there is to be gained from a landscape metric (Visconti and Elkin 2009). Landscape-scale metrics also do better when patches are aggregated rather than randomly dispersed, and where off-patch threatening processes have a greater impact. For example in the case of wetland communities, pollutant run-off from upstream agriculture is often a major conservation issue. The impact of threat mitigation actions will depend heavily on their location in the landscape and their relationship to high value patches and other mitigation activities – valuing such proposals in isolation is unlikely to be satisfactory.

It is also necessary to consider whether there is sufficient spatial information and ecological knowledge to measure connectivity and complementarity at scales relevant to the landscape context of the tender. The level of detail required is likely to vary depending on the objectives of the scheme. Comparing connectivity at the landscape-scale may require detailed mapping or modelling of current land-uses and vegetation cover/conditions. For other species and communities coarser scale information may suffice. Some knowledge or reliable estimates of the relationships between connectivity and biodiversity is required. If the necessary information is not available and too costly to acquire, the potential for a landscape-scale metric is limited. The level of complexity of landscape metrics can be tailored both to the requirements of the program and the available resources – in most cases they need not be considered ‘too hard’ for timely and cost-effective implementation.

Valuing bids on their marginal contributions to landscapes means that some potentially high value combinations of bids may be missed where the marginal value of individual bids is too low for any one of them to be successful. However in some cases it may prove more tractable than doing a full package optimisation (particularly for large numbers of bids as the computational issues increase rapidly). The marginal value approach is likely to work best where the new bids funded in a conservation tender constitute a relatively small part of the overall ecological function of the landscape. It will also be more attractive if only a small number of the submitted bids are likely to be accepted (e.g. due to budget constraints). The package approach will be relatively more attractive where the budget is large and there are many different options for the desired outcomes (e.g. many different ways of forming links across the landscape).

Another consideration is how existing habitat patches should be incorporated, particularly those on private land which are not covered by any formal conservation agreement. While such sites may currently be in good condition, it could be risky to assume that this will always be the case. One option is to only consider formally protected areas as habitat patches, although in some cases this will not be a good representation of landscape function. A better option would be to include all existing habitat patches, perhaps accounting for an expected level of deterioration in unprotected patches. Current and predicted condition values of both protected and unprotected sites could be based on business as usual state-transition trajectories, which would show degradation, improvement or constancy depending on the land use and management regime (e.g. Drielsma and Ferrier 2006).

Incentive design

Conservation tenders deliver financial incentives to landholders to carry out conservation works. They typically use a discriminate price mechanism, in which landholders who are successful in the tender receive the price they requested in their bid. The key design issue in a tender is to focus on revealing landholders' opportunity costs for the bids they submit. The competitive nature of tenders means that landholders are likely to offer prices which are close to, or at least reflect, their actual costs. While of course any landholder would prefer to get more money rather than less, in a competitive tender the higher their price the less their chances of success. The tender mechanism should also encourage landholders to submit bids which align with the objectives of the program as closely as possible – in some cases this may require additional incentives.

It should be noted that tenders are just one of a suite of policy options for delivering conservation policy on private land. They are not applicable to every situation, nor are they necessarily the best mechanism even where they are applicable (see Whitten et al. 2008 for a full discussion of when and how to apply tenders for environmental incentives). Where certain properties are crucial to providing biodiversity conservation in a landscape, direct negotiation may prove more effective, and administratively simpler, than a competitive tender. Tenders work best where there is variation among landholders in their cost of carrying out conservation (see table 2). The competitive tender mechanism can reveal these costs, as lower cost landholders are likely to submit lower prices. If there is limited competition, landholders are more likely to inflate their bid prices well above their true costs, and there is less benefit to be gained from running a tender.

If landholders have broadly similar costs, and these costs can be reasonably estimated by those designing an incentive program (both of which are unlikely in our experience), a fixed-price incentive will be preferable. However, if environmental benefits are likely to vary a metric should still be used to prioritise applications in a fixed-price scheme. Where costs vary but environmental benefits are relatively homogeneous across different properties (which is also unlikely), a tender may be run to reveal landholder costs without the need to develop a complex metric – bids may be ranked simply in terms of price per hectare.

Table 2: Instrument selection considerations

		Environmental benefits	
		Homogeneous	*Heterogeneous*
Landholder costs	*Homogeneous*	Fixed-price incentive, no prioritisation required	Fixed-price incentive, applications prioritised using environmental benefits metric
	Heterogeneous	Competitive tender, bids ranked on $/ha (or similar)	Competitive tender, bids ranked using environmental benefits metric

There are a number of ways in which the tender mechanism may be adjusted to increase the incentives for landholders to offer bids which match the desired spatial configuration of conservation programs. Incentives for connectivity are more likely to be necessary if landholders have a choice of bid locations to offer. If most landholders only have a limited area of remnant vegetation, or would offer the whole property, there is less to be gained from additional incentives. Rather, attention should focus on the bid selection metric, and promoting broad scale participation (see Whitten et al. 2007). As with metrics, incentives which consider spatial configurations are likely to require additional complexity. Care should be taken to minimise the transaction costs (which include the time and effort required to submit and assess bids) to landholders, as well as the administrative costs to the agencies responsible for the scheme.

In addition to the financial incentives offered through the tender, attention should also be paid to other incentives and motivations. Many landholders value biodiversity for its own sake. Conservation tenders may also foster voluntary actions, for example through providing information about how landholders can promote biodiversity on their properties, and beyond. Landscape-scale metrics may prove particularly useful for this as they can demonstrate to landholders how actions on their property impact on species and communities throughout the region. Social motivations may also be important in these tenders, as landholders are more likely to be successful if their neighbours submit competitive bids. If bids are assessed at the landscape scale, habitat patches on neighbouring properties will increase a landholder's chances of success in a tender. Even more than previously, this means that conservation-minded landholders are clearly providing a benefit to their community.

<u>One-off tender</u>

In a competitive tender with a metric which values spatial configurations, landholders have an incentive to provide them even in the absence of a formal bonus. Landholder response does however require good communication of the desired spatial configurations. Bids which can contribute to enhancing connectivity or complementarity will score highly in the metric and so have a greater chance of success in the tender. All things being equal, landholders should therefore attempt to submit bids which meet the objectives of the scheme. Where the objective is connectivity, landholders may be encouraged to coordinate their bids with their neighbours in order to offer connected bids. Alternatively they could submit group bid, although this is likely to be ruled out by contractual difficulties. There is however a danger that a tender mechanism intended to promote coordination among landholders may reduce competition and promote strategic behaviour. For example, neighbours may collude on price, or an individual near the centre of a potential corridor may be tempted to submit an offer well in excess of costs. Such strategic behaviour will erode the efficiency gains achievable in a tender, and could result in the environmental objective not being met.

Multi-round tenders, in which landholders are provided with information on the location of offers from the previous round, have the potential to promote the coordination required to achieve landscape connectivity (Rolfe et al. 2009; Reeson et al. 2011). Between rounds landholders are provided with information showing the location of offers made in the previous round. They then have the opportunity to modify their offer, or submit a new offer, in order to better coordinate with their neighbours and so increase their chances of success. Results from experimental workshops have shown that multi-round tenders can achieve better spatial configurations than a single round tender. However, using multiple rounds does increase transaction costs, and may discourage some potential participants. There are likely to be trade-offs between increased efficiency and higher transaction costs as the number of rounds increases (Rolfe et al. 2009). Minimising the costs of participation for landholders, particularly in later bidding rounds, will be important.

A multi-round tender mechanism was applied in the Desert Uplands program in Queensland, Australia (see Windle et al. 2009). The program objective was to form an east-west biodiversity corridor across the landscape. It applied a bid-focussed metric which assessed the structure and condition of habitat offered in each bid and their connections to protected areas and other bids in the tender. Given the relative importance of connectivity in this program, it made up 55% of individual bid scores. Bids were selected in terms of their relative value (metric score/asking price). The tender was run over two bidding rounds, with some landholders working together to offer coordinated bids. The tender succeeded in establishing spatially linked conservation sites in a cost effective manner.

A critical problem in corridor formation is individuals not participating, or holding out for excessively high prices. In multi-round tenders with opportunity for bid modification, and clear information on preferred spatial outcomes, there will be greater opportunity for participants to identify and work around such hold-outs. Where there are many different ways of forming a desired configuration such as a corridor across a landscape, they can evolve over multiple rounds according to the bidding behaviour of individual landholders. In this way a multi-round tender may deliver a coordinated outcome across a number of landholders without the need for complex negotiation. A confidential discriminate price mechanism would ensure that different landholders can be paid different amounts based on their opportunity costs, whereas in collective negotiations it is likely that all would seek the same payment, which would have to be at least as much as the highest individual opportunity cost.

Minor details in the design of auctions can have a major impact on market performance (e.g. Klemperer 2002). Multi-round tenders have been put through a series of laboratory economic experiments in order to refine the details of their design (Reeson et al. 2011); results show that these tenders can deliver coordinated outcomes. They work most efficiently where the number of rounds is unknown to participants in advance, and bidders are prevented from raising their prices between rounds. These rules serve to limit the potential for bidders to act strategically. If participants are uncertain as to whether the current round will be the last they are less likely to inflate their price for fear of missing out – the laboratory results indicate that they in fact put in very competitive bids. By reducing strategic behaviour, connectivity could be secured in the laboratory scenario within 2-3 rounds of bidding. These simple rules can enable complex landscape-scale objectives to be achieved through competitive tenders in a relatively straightforward and cost effective manner.

Repeated tenders

A one-off or multi-round tender can be used to make a single large investment in conservation, either across a localised or broad area. In practice budget limitations or capacity constraints may mean funds have to be invested over a number of years. Running repeated tenders in the same area over a number of years raises some additional issues. In theory it may be possible to make a series of coordinated purchases over a number of years – an agency could effectively come back and 'fill in the gaps' in the landscape until the desired spatial configuration is reached. In practice, such a mechanism may promote strategic behaviour by landholders, with some holding out in the hope of higher prices in future years, particularly if they perceive their property to be in a key location.

There are questions over the repeated application of tenders with the same group of landholders. An experimental study by Schilizzi and Latacz-Lohmann (2007) showed that, while initially tenders can be more efficient than fixed-price programs, if the tender is repeated this advantage declines. By the third repetition the tender was no more efficient than a fixed-price scheme, due to participants learning and adapting their bidding strategies. While this study was based on a simple experimental scenario, it does suggest that caution should be applied when considering repeated tenders in the field. In practice the exact focus would also change between repeats due to prior purchases which would make gaming the tender more difficult. There is a need here for further experiments to explore repeated auctions in a spatial context.

An alternative policy approach may be to use an initial tender to establish landholders' opportunity costs, and then use this as a basis for offering set payments in future programs. If the level of variability in bid prices in the initial tender is particularly high, the benefits of ongoing tenders may be relatively greater. If not then fixed payments may subsequently be offered. Another possibility to consider is the purchase of 'options' in an initial tender in which a landholder would agree to enter a contract at a particular price at some point in the future, should funds become available. This could avoid the need for future tenders, though would clearly involve some additional complexity.

Conclusion

Conservation on private land needs to move beyond locking up individual paddocks or properties to consider functional communities and landscapes. A weakness of many existing conservation programs is that they consider projects on a site by site basis. They fail to distinguish between habitat patches, which are an ecological unit, and bids, which are unit of management. This immediately narrows their focus to preserving pockets of remnant vegetation and foregoes opportunities to enhance their condition through managing off-site processes. Valuing projects on their contributions to the overall landscape, or even just on neighbouring habitat patches, can significantly enhance the scope and effectiveness of conservation tenders.

Connectivity is important ecologically. However, its relative importance varies between species and communities. Seeking connectivity through a conservation incentive program will inevitably come at the expense of other aspects such as total habitat area and condition. Therefore it should only be considered when connectivity is judged to be relatively important compared to other ecological attributes. It should also be noted that connectivity is absolutely not restricted to contiguous habitat such as corridors. Most species can navigate gaps between habitat patches, to a greater or lesser degree. In practice connectivity is determined by the distance between habitat patches and the characteristics of the intervening matrix. Managing the matrix to increase connectivity can make a significant contribution to ecological function, and should be promoted where possible within conservation incentive programs.

Connectivity is not a general property, but rather varies depending on the attributes of the species or communities in question. There can therefore be no single formula for managing for connectivity. The relative importance of connectivity, and how it should be measured and managed, will vary according to the objectives of each conservation program. However, it is possible to develop a framework for conservation tenders which accounts for connectivity and complementarity. Methods exist for valuing connectivity and other ecological functions at the landscape scale. Application of these methods may be limited by available knowledge regarding the ecology of species and communities, and by the availability of detailed data on the distribution and condition of habitat patches and the nature of the intervening matrix.

The metric is the single most important feature of a conservation tender. A poor metric guarantees a poor outcome. Even with a good tender mechanism it will still achieve a poor outcome, albeit cost effectively. Figure 2 summarises the steps to consider in order to determine the most appropriate form of metric for a particular program. Where connectivity or complementarity are important, projects should be assessed at the landscape scale, rather than on a site by site basis, in order to better reflect ecological outcomes. This is only feasible for programs which have sufficient resources to make an impact at the landscape scale (and the greater the geographical scope of the program, the more money is likely to be required to have a significant impact), and where ecological models and data are available (or can be obtained at reasonable cost). Where these conditions are not met, a metric should focus on individual projects. Such metrics should be parsimonious, focussing on key attributes rather than attempting to incorporate everything. However, they may be extended to consider the impact of off-patch management actions on the extent or condition of neighbouring patches where these effects are important.

In order to address connectivity or complementarity adequately in a conservation tender it will be necessary for metrics to consider landscape values, rather than just individual bids or patches. While this is a more complex approach, it is necessary to consider values at the most appropriate scale. Landscape-scale metrics can far better describe ecological function, and so can enhance the capacity of tenders to deliver the best possible conservation outcomes. These metrics can consider either the marginal value of each potential project to the landscape, or they can select the best possible package of projects from those on offer. The marginal value approach is computationally simpler, but may fail to reflect values where there are strong interdependencies between projects. The package approach is likely to be required where the total values of combinations of projects are likely to be significantly different to the sum of their individual marginal values. This is most likely where spatial requirements are particularly exacting. For example, if it is essential to have contiguous habitat, a single gap could make the difference between a viable and an unviable population.

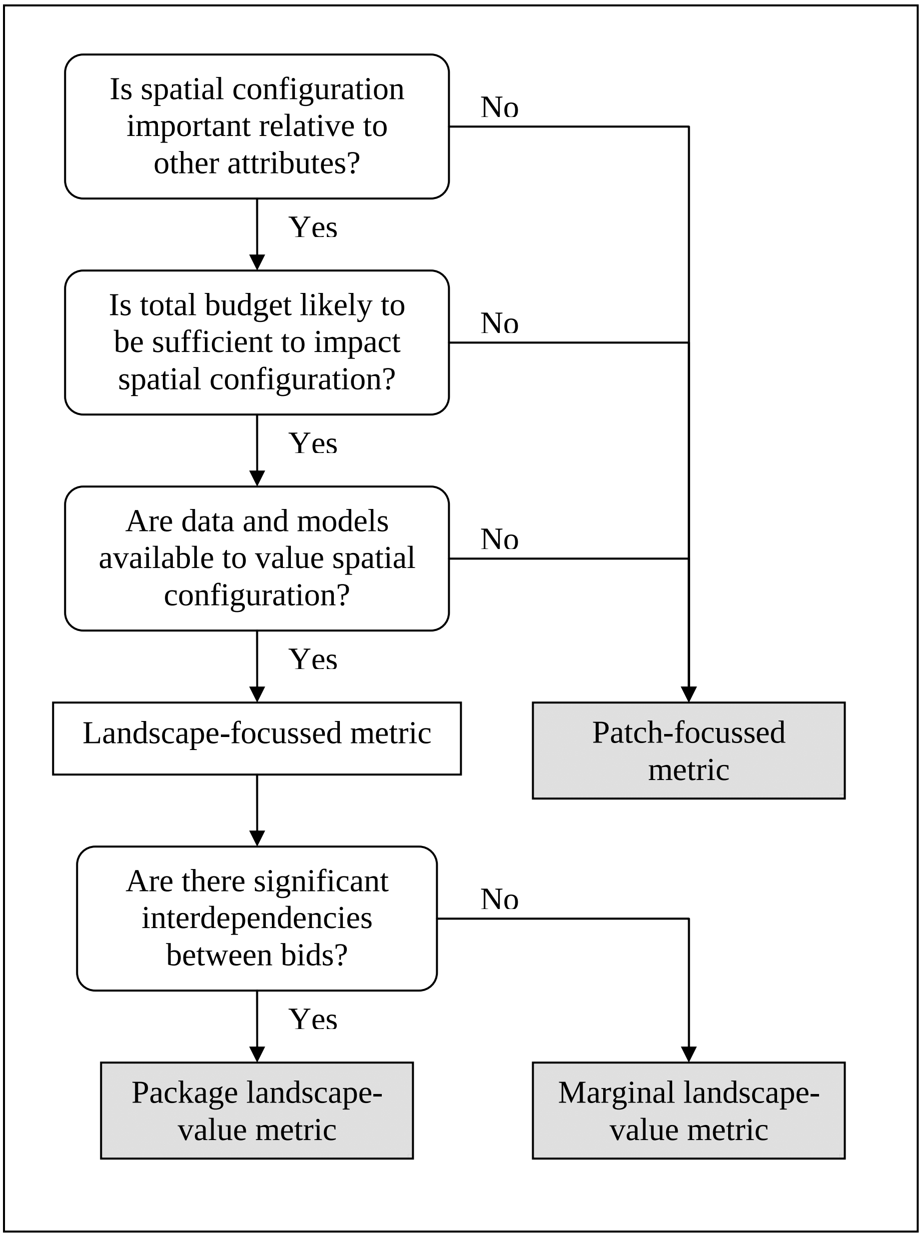


Figure 2: Metric selection process

The research reviewed in this paper shows that landscape-scale metrics are feasible and tractable, and so are ready to be applied in conservation tenders. While this represents a change from existing metrics, the landscape-scale approach does not have to be more complex. In many cases the ecological data required and the on-ground site assessment process would be very similar. By valuing a project's contribution to the overall landscape landholders have a financial incentive to submit bids which contribute to desired spatial configurations. In most cases a single tender round should be sufficient. However, where the details of individual bids relate to others in the landscape (such aligning habitat corridors across properties), multi-round tenders may be applied to promote coordination among landholders. Such tenders are empirically tested, and offer a relatively straightforward way to achieve potentially complex landscape configurations.

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