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Increasing the impact of systematic conservation planning: recommendations, a decision support system framework, and a precursory toolbox.

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ABSTRACT

This paper aims to improve the manner that systematic conservation planning contributes to actual conservation (i.e. changes in land ownership or management that benefit biodiversity). Three recommendations are made: (1) conservation assessment should not only support design of conservation area networks, but should also provide clear and comprehensive information about every "site" in the study area; (2) conservation planning organizations should transition towards "living" decision support systems; and (3) multiple types of ownership and management should be included in the conservation planning analyses and subsequently, the results. Implementing these recommendations would allow a much broader constituency to include ecological principles in their land-use decision-making, would help conservation organizations adapt efficiently to stochasticities caused by climate change and socio-political change, and would include the "working landscape" in conservation planning. A modeling framework and precursory model were designed, in the context of an applied case study, to illustrate one approach for implementing these recommendations while also meeting the current "best-practices" of conservation planning. The framework is based on the return-on-investment philosophy and also uses contiguity and connectivity criteria to estimate, for every "site" in a study area, the benefit to biodiversity of a given type of conservation action (e.g. acquisition). The benefit is divided by the estimated "cost" of the action. The process is repeated for every conservation action under consideration. The outputs are combined to provide advice for the next conservation action at any given time, and to be an input for modeling a conservation area network. In its application, the model met the objectives of the end-users, but was slow to perform the connectivity algorithm. The resulting "code" is transparent to a wide audience of GIS analysts through use of a menu-driven GIS-programming interface. The framework may deliver important indirect benefits, such as facilitating consensus-building and coordinated actions among organizations with different goals, and among different levels of governance.

KEYWORDS

return on investment, functions of diminishing returns, conservation area design, reserve design, multicriteria decision analysis, resilience, adaptation, marginal utility, South Africa, Little Karoo

INTRODUCTION

Systematic conservation planning is a science-based process for deciding where land should be conserved and for developing strategies and plans for achieving this conservation (Margules & Pressey 2000; Knight et al. 2006). In this paper we provide a set of recommendations for improving systematic land conservation, which we define as

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changes to land ownership and/or management that benefit biodiversity (i.e. conservation actions) that are guided, at least in part, by systematic conservation planning. The recommendations are derived from our 30 years of combined experience in systematic conservation planning research and practice. We designed a precursory model to implement these recommendations. The model is now public domain and a revised version will be available soon for further use, development, evaluation and/or incorporation into other software (www.xxxxxxxx.org[1]). Although the model is not rigorously evaluated in this paper, it is described in sufficient detail so that its framework and concepts can be considered for use elsewhere.

Conservation assessment should have a dual mandate

Conservation assessment is the underpinning of systematic conservation planning; it is the scientific evaluation of the valued elements of nature to help people decide where on the landscape to allocate scarce conservation resources (Knight et al. 2006). Currently, many researchers and practitioners would define conservation assessment more narrowly, such as the process of identifying "conservation area *networks* [CANs] for the persistence of biodiversity features" (Sarkar et al. 2006). Thus, the emphasis is on identifying the overall set of areas that should eventually be conserved. We recommend that conservation assessment should not only aim to identify CANs, but also to effectively estimate and communicate the relative importance and characteristics of every "site" in a study region. Sites are defined by the resolution and goals of a study, for example "sites" could be sub-watersheds for a regional analysis, or countries for a global analysis. Decision-makers should be able to quickly and easily click on a site on a computer map and see what its relative value is to all sites in the study area and/or its sub-area, what the reasons are for the value, and how that value would change given different scenarios or increments of change. Further, it would be good to view for each site how its different measures of natural value compare to each other (e.g. habitat representation, connectivity value, habitat integrity), and to its other anthropocentric criteria (such as ecosystem services, recreational values, etc.).

This recommendation applies to all scales, but is especially directed at the regional scale, with each site being an individual property, as this is an emerging best practice for systematic conservation planning (Knight et al. 2006). A vast majority of the decisions about changing land ownership or management occur on a property-by-property basis (Theobald et al. 2000; Knight et al. 2006). This is especially true when also considering indirect conservation decisions, such as agency review of applications for development, prioritizing which land-use infractions to regulate, land-use zoning changes that are balancing all interests (such as economic growth, transportation needs, etc.), and decisions about where to site mitigation efforts. In short, top-quality ecological information about individual sites is a pervasive need. We posit that the worldwide aggregate of land conservation efforts (hereafter called the land conservation movement) is misallocating resources with the scope of conservation assessment narrowly focused on CAN design. This design is expensive: it requires the development and maintenance of a large GIS database, skilled modeling expertise, expert

[1] Note to reviewers: We will determine the web host for this model by the time this article is final.

workshops, and much revision and fine tuning. With a small additional effort the process could yield the aforementioned site-specific decision support information, thereby dramatically increasing its utility for a majority of the land conservation decisions.

Granted, there are by-products of CAN design that are used to infer the value of a site, such as the frequency index of the MARXAN software (Noss et al. 2002), or irreplaceability of C-Plan (Cowling et al. 2003), but we maintain that these are not as clear, explicit, or complete as necessary, especially to a land-use planner needing to balance multiple objectives. Natureserve Vista is an example of a system that satisfies some of the recommendation for site-specific information (Stein 2007). Fortunately, the developers of Vista and MARXAN have collaborated to allow the outputs of one system to be the inputs into the other. Practitioners that are creating systems that utilize both of these pieces of software are illustrating one approach for satisfying our suggested dual mandate for conservation assessment.

The conservation assessment should be part of a "living" Decision Support System

We live in a dynamic and uncertain world. As a result, conservation plans are almost never implemented as originally conceptualized. They become increasingly out-of-date and sub-optimal (Meir et al. 2004). One response to this finding has been to redouble efforts to model the future and to plan accordingly. This can manifest as trying to sequence what parts of a CAN should be implemented first (e.g. Haight et al. 2005), or as predicting climate change outcomes and planning accordingly (Heller & Zavaleta 2009). Our observations are that this strategy is important, but it is very data intensive, complex, and may face diminishing returns. We maintain that conservation efforts should not only try to anticipate the future, but should also be adaptive and resilient. One way to do this is to build the institutional capacity to react quickly and effectively to the opportunities, threats, and changes that are unforeseen (and inevitable). We need to be nimble. The creation and use of "living" decision support systems (DSS) would give us flexibility and adaptability previously lacking.

A DSS uses computers to combine human values and queries with a wealth of data and systematic analyses to provide digital and hardcopy products used as references in making decisions. The term "living" has several components in this context. It should be as up-to-date as possible. First, the system should change to reflect the changing world. As new data and information becomes available, it should be automatically integrated in to the DSS, and end-users should have the option of viewing the *current* DSS outputs, such as a CAN or the conservation valuation of a site. Further, a living DSS should be flexible, adapting to meet the needs of each end-user. It should be able to grow: allowing over time for additional criteria, new parameters, new scientific understanding, and changing social values. Meeting these objectives is not simply a logistical project left up to practitioners and data managers. The way that DSS is designed has a big influence on if all of these objectives can be met, and how much manual and computer processing are required. With a well designed DSS, we suggest that one full-time staff person could maintain the GIS database and the site valuation decision support component; this would also streamline the CAN update process.

A key nuance is that the living DSS is nested. The systematic conservation assessment can be used to support the periodic discussions and decisions about creation (and update) of the region-wide strategies and plan. The plan would then become another component of the overall land conservation DSS (LCDSS) (Fig 1). The plan would likely be the part of the LCDSS accessed by the widest range of decision-makers, and even the public at large, depending on the regional context. The sensitivity of various data and information would need to be evaluated, and access controls of the various components of the LCDSS carefully considered, but that discussion is beyond the scope of this paper. The rest of this paper focuses on the analytic models that could facilitate a living DSS that pursues a dual mandate for conservation assessment.

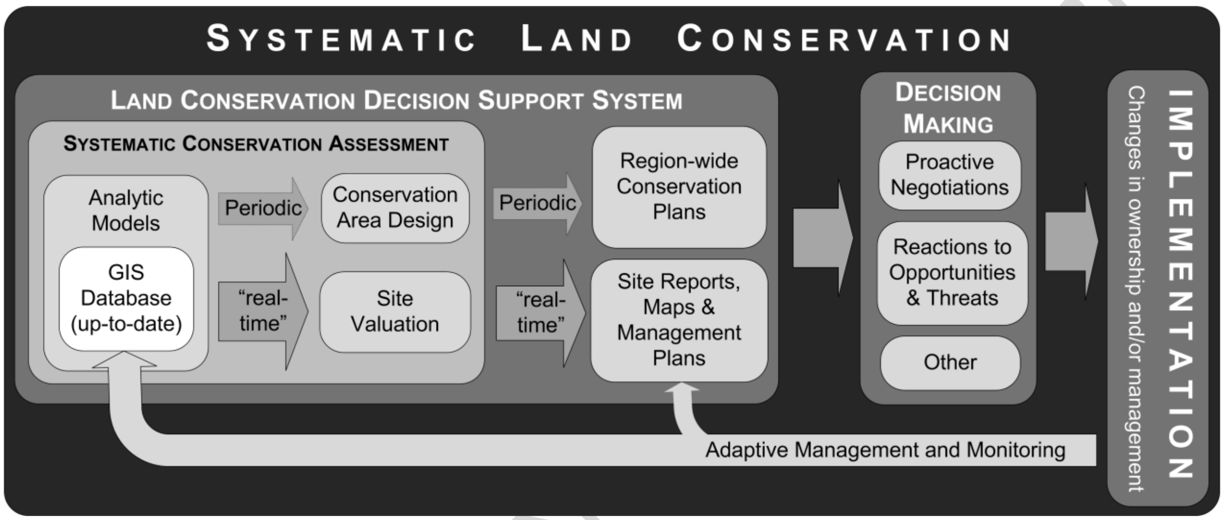

Fig 1: A conceptual framework for systematic land conservation that includes the suggested dual mandate of conservation assessment and the "living" decision support system.

The LCDSS should value and plan for multiple types of ownership and management

We align with the ontology that while land acquisition by conservation organizations and agencies is the "cornerstone" of biodiversity conservation, it is but one of many important opportunities. In conservation planning, determining if a particular ha of habitat is "conserved" has traditionally been a binary issue (i.e. conserved or not conserved), but in our reality it is a multi-faceted issue. This needs to be built into conservation planning algorithms (Sarkar et al. 2006). For instance, open space conserved by a private landowner with a conservation easement (i.e. formal contract) is arguably better conserved than open space owned by a developer; but neither are as well conserved as state-owned wilderness. Similarly, the working landscape (areas managed both for biodiversity and natural resource production, such as sustainably harvested timberland) provides partial benefits to biodiversity. Acknowledging the partial benefits of these alternative ownership and management regimes can dramatically alter the location of conservation priorities and decrease implementation costs (Polasky et al. 2005; Gallo et al. 2009). Hence, the DSS should (1) account for many categories of land ownership and/or management in determining how well various aspects of biodiversity are conserved in a region, (2) provide CAN outputs that estimate the optimal spatial configuration of these ownership-management categories, and (3) provide a conservation value for each site for each ownership-management category. The DSS should also give the user the option of only considering reserves. Currently, Marxan with Zones (Watts et al. 2009) is a software package currently available for meeting a good portion of this recommendation.

A PRECURSORY FRAMEWORK AND MODEL FOR THE LCDSS CORE:

A precursory model was created in an effort to illustrate an LCDSS that pursues the above recommendations as well as the conventional principles of systematic conservation planning, such as complementarity, connectivity, and contiguity. Model development occurred in the context of a real-world application. The premise was that research designed to improve conservation implementation can gain direct and indirect benefits from trying to actually rather than hypothetically achieve implementation (Balmford & Cowling 2006). The precursory model, hereafter termed the prototype, was created to aid a partnership between a land trust and government agency. The land trust purchases land and then leases it to the government agency for management. Hence, the goals and principles of both agencies needed to be met in any acquisition decisions. The government agency was also pursuing other conservation strategies, such as supporting stewardship on private lands and mainstreaming conservation priorities into land-use planning. The applied study occurred in the Little Karoo region of South Africa over the course of ten months (supplementary material).

Platform

We considered piecing together two or three existing conservation planning tools in pursuing the aforementioned recommendations, with top candidates being the ones already mentioned as well as Zonation (Moilanen 2007). But we anticipated that such a chain would have a lot of redundancies among systems, and would not be as easy to learn and use as an eventual, single, integrated system. So we instead decided to start fresh to initiate movement towards such an integrated system and facilitate exploration of new ideas. We used Modelbuilder, a tool in all versions of ArcGIS 9, to construct the prototype. Modelbuilder allows the construction, documentation, and sharing of complex GIS programming, including feedback loops and iterative analyses, all in a visual, drag-and-drop, menu-driven interface (ESRI 2008). Hence, it is understandable and programmable to a wider audience than is command-line programming. This will allow all researchers and practitioners using ArcGIS to contribute to the incremental development of this LCDSS if so inclined. Further, it makes it possible for users to modify the LCDSS in applying it to their unique regional context. It may be that Modelbuilder is used for collaborative development of the LCDSS, and portions of the model eventually get ported into command-line code to create more user-friendly software. We were familiar with ArcGIS, and after following the three hour Modelbuilder tutorial that comes with the software, began constructing the prototype. We used ArcGIS 9.3 on a computer that had 3 GB of DDR2 RAM, an Intel Core-Duo 2.0 Mhz processor, and Windows Vista 32-bit OS.

Prototype Introduction

A classic approach to determining the value of a piece of land is the multi-criteria overlay (McHarg 1971). Essentially, several criteria that are spatially distributed (such as species richness, rarity, etc.) are mapped as layers of quantitative values across the landscape, and then all the values that overlay on the land unit in question are added together. There are many of merits to this approach, including its intuitive simplicity (Balasubramaniam & Voulvoulis 2005), but it fell out of favor for conservation planning because it did not identify efficient and representative reserve networks (Pressey & Nicholls 1989). Functions of diminishing returns (Davis et al. 2006; Moilanen 2007; Wilson et al. 2007; Carwardine et al. 2009) described below, allow the revival of the multicriteria overlay in conservation planning. The overlay approach has other challenges that should be addressed when applied, such as the lack of transparency that occurs when a nested hierarchy and many criteria are combined to yield a final value (Sarkar et al. 2006).

The 1,935,000 ha region was parsed into a raster grid of one-hectare cells. Each map layer of GIS data was processed to have a numerical value associated with each cell (supporting information). The numerical layers combined to become criteria layers, and these were then combined to make output criteria layers (Fig 2). These outputs were displayed “as-is” or averaged by site, defined in this study as a property [all the contiguous parcels (i.e. cadastres) with the same owner].

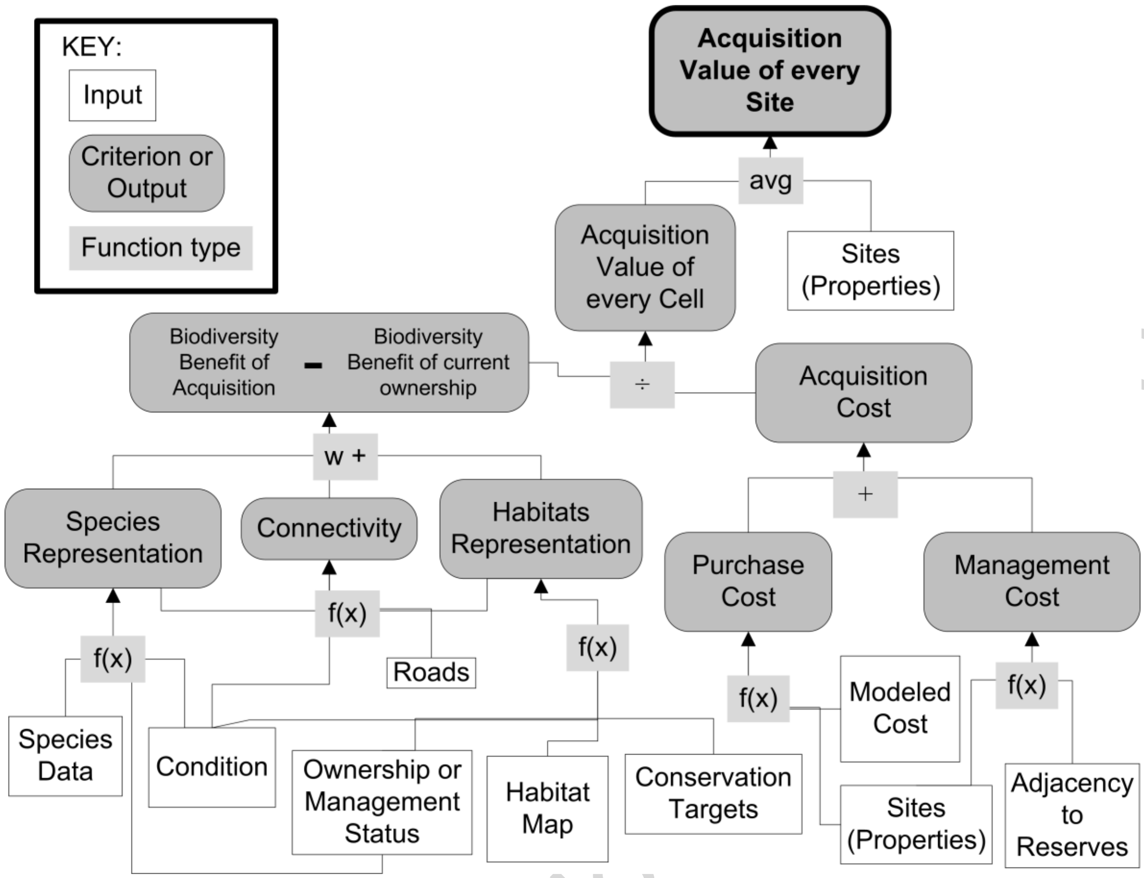

Fig 2: Data input layers combine to create criteria, which are combined to with simple or complex functions to determine the conservation value of acquiring any particular site; a similar hierarchy was used for determining the value of pursuing stewardship instead of acquisition. All the criteria can be useful spatial outputs communicated via individual maps and tables. The end-users added several context specific criteria not shown here (supporting information). Function abbreviations: f(x) = complex function; w + = weighted sum; avg = average among cells per site; ÷ = division.

Functions of diminishing returns

Functions of diminishing returns (FDR), cited earlier, were used to create the habitat and species representation criteria. FDRs implement the logic that as more of a particular habitat type is conserved; the relative benefit to biodiversity of conserving the next hectare of the habitat type diminishes. The percentage of the habitat conserved at any given moment corresponds to a point on the FDR curve, thereby giving a quantitative measure of benefit (Fig 3). The power of this approach comes from the ability to automatically define the shape of each habitat's FDR curve to reflect important conservation planning practices. The first addition we made was to account for habitat conversion (i.e. vulnerability). For example, 45.8 % of the world's historical temperate grasslands and shrublands have been converted to human uses, compared to only 2.4% of the boreal forests (Hoekstra et al. 2005). If, hypothetically, each had 9% of their original extent conserved, then it would be much more important to conserve the next 1% of grassland than forest (Hoekstra et al. 2005). We programmed the Y-intercept of each habitat's FDR to reflect this logic: the more original extent remaining, the lower the Y-intercept (Fig 4). The maximum difference between the extreme habitats was a user-defined parameter.

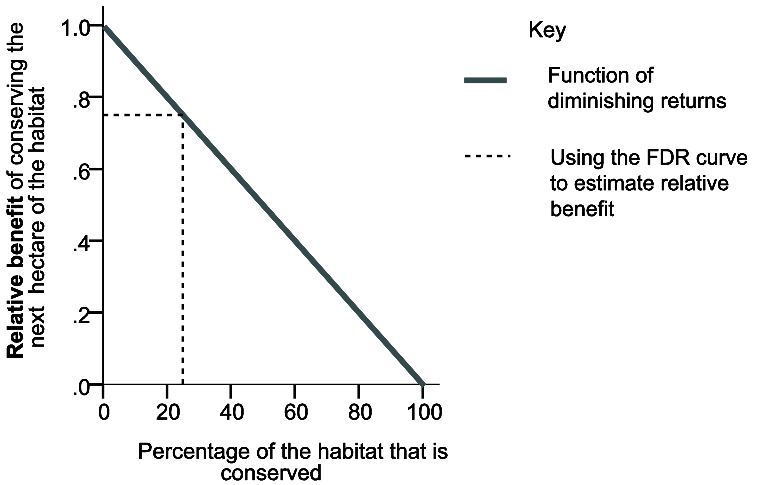

Fig 3: If an example habitat has 25% of its extent protected, and has been assigned this simple function of diminishing returns (FDR), then the relative benefit to biodiversity of conserving the next hectare of this habitat is ¾ of what it was to conserve its first ha.

Secondly, we programmed the use of conservation targets (e.g. the goal of conserving 30% of a particular habitat within a region) into the FDRs (Moilanen 2007). Targets provide a good benchmark for measuring progress, are simple to convey, and have several other socio-cultural merits (Carwardine et al. 2009). The target determined the location of the inflection point along the X axis, and the % of habitat already lost determined the Y-axis value (Fig. 5).

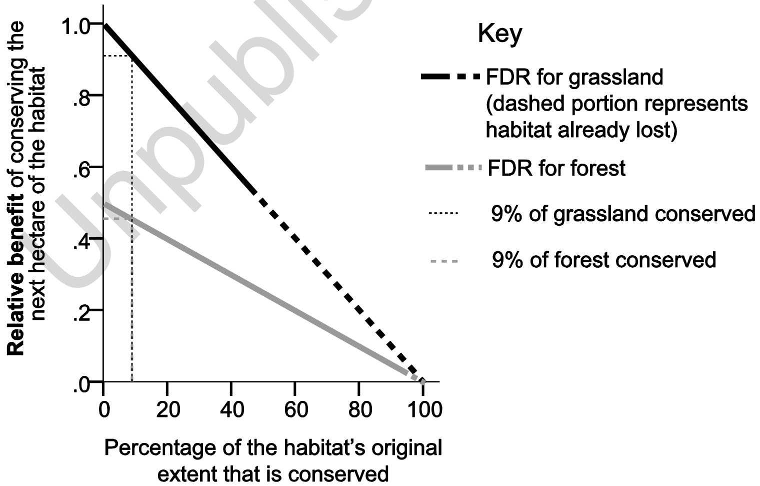

Fig 4: Given that 9% of each habitat has already been conserved, the relative benefit of conserving the next ha of grassland is 0.91 while the relative benefit of conserving the next ha of forest is 0.455. FDR = function of diminishing returns.

Fig 5:

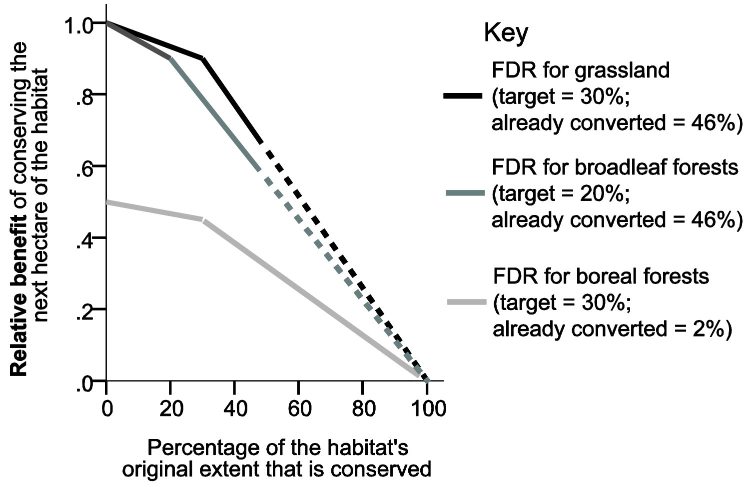

Fig 5: Three hypothetical FDR curves illustrating how different targets and different habitat conversion levels change the shapes of the curves. FDR = function of diminishing returns. [To consider: Putting in some dashed lines representing the amount protected being 25%, as per previous figures, thereby showing the three relative values. Clutter vs. clarity...]

Usage of FDRs allowed accounting of different ownership-management categories in determining habitat representation. A user-defined *management quality value*, ranging from 0 (worst) to 1 (best), needed to be assigned to every cell on the landscape. This was done by assigning each ownership-management category a default value (determined at the end-user workshop). In the future, these standard values could then be adjusted for individual properties as information became available. A user-defined *habitat integrity value* from 0 (worst) to 1 (best) needed to be assigned to every cell.

This was simply the inverse of habitat conversion, so pristine habitat was a 1, and moderately degraded habitat was a user-defined fraction. To get the total *quality-weighted area* conserved for a particular ha, the management quality value of that particular ha was multiplied by the habitat integrity value. The quality weighted areas of every ha of a habitat were summed to get the habitat's total quality weighted area conserved (the x-axis value of Fig 6). This was then entered into the FDR to determine the relative value of conserving the next ha (y-axis value).

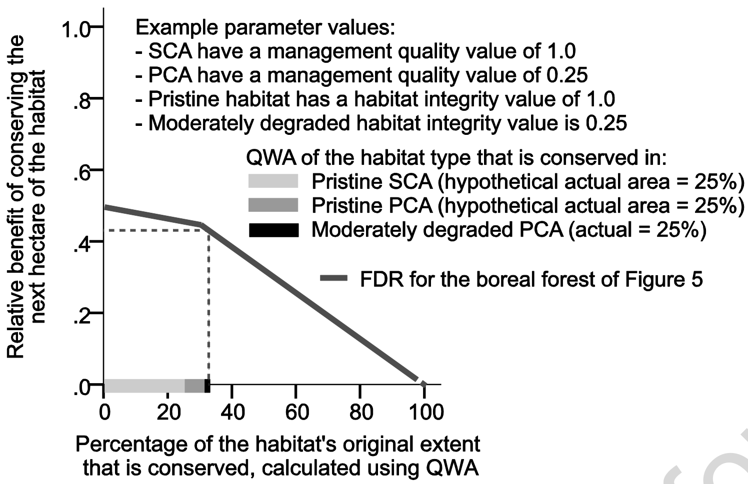

Fig 6: The quality weighted area (QWA) conserved is 32.8125% for this example habitat and scenario even though 75% of the actual area (i.e. un-weighted) is conserved in some form, thereby leading to a marginal relative benefit of 0.432. The original extent is always assumed to be pristine. FDR = function of diminishing returns.

Given any land-use scenario, the prototype combined the above concepts to automatically calculate the FDR for every habitat, its quality weighted area remaining and conserved, and the corresponding relative value of conserving the next ha of the habitat.

FDRs can be used for species representation as well. If each species has a high-resolution range map, then the same or similar approach as habitat representation can be applied. Such data were not available in our case study, only species observations. Also, the species did not have conservation targets. The model was programmed to allow the end-user to parameterize the relative benefit (i.e. FDR y-intercept) of conserving each class of listed species (i.e. endangered versus threatened species). Further, the user could define the rate of diminishing returns for the most endangered classification, and all the other rates were relative. The spatial precision (certainty) of any observation was a third factor in determining the quality weighted area (supporting information).

Connectivity and Contiguity

The principle of landscape connectivity is that large core reserves should be connected by linkages of decent habitat to allow gene flow and population movements (Soule & Terborgh 1999). To estimate the connectivity value of every cell on the landscape, we used a "gated" least-cost-path analysis (Lombard & Church 1993; Gallo 2007). Each path from one reserve to another was assigned a numerical value based on how easy it is for organisms to use. The value of each cell was assigned the value of the best path that went through that cell and linked one reserve to the other (supplementary material). Rather than using the ecology of one or several focal species to estimate the ease of use of a path, we used a synthesis of criteria (Rouget et al. 2006). In this case the synthesis was the weighted sum between the habitat and species representation analyses. We also included the road network in defining ease of use. This analysis was the one part of the prototype not programmed solely with the Modelbuilder interface; a Python script was written and embedded within Modelbuilder.

Conserving large, contiguous areas decreases habitat fragmentation and the problems it brings, such as edge-effects, and not being able to support the regulatory level of the food web, large predators (Soule & Terborgh 1999). For the prototype, a precursory contiguity heuristic was used: all the cells within a site that was adjacent to an existing conservation area were automatically coded with a contiguity value of 1 and all other cells were zero. This criterion was used in determining cost of implementation, and arguably should have been used in determining biodiversity benefit, but was not in concern of double-counting the criterion.

Modeling the value of each ownership-management category for each site

For each category of conservation action under consideration in the analysis (e.g. acquisition, stewardship, etc.) a unique multicriteria hierarchy was created, and a unique set of parameter values assigned. For instance, the cost of stewardship did not include an acquisition cost sub-criterion. Further, a narrative could exist that stewardship is much worse than acquisition at protecting endangered species, but nearly as good at maintaining habitat connectivity. So the weights would be adjusted accordingly. Because the multicriteria outputs were always transformed to range from 0-1, the biodiversity value needed to also be multiplied by a fraction that corresponded with the general benefit of the management strategy to biodiversity. The default fraction was the management quality value used to determine the functions of diminishing returns. The biodiversity-management value was the result. For each cell, the biodiversity-management value of the current status was subtracted from that of the proposed action to get the expected improvement. This was then divided by the modeled cost of changing a cell's current management to the management in question . This resulted in the conservation action value, and all the cells of a property were averaged to create a map showing the estimated return-on-investment (Murdoch et al. 2007) for that strategy for every property. This was done for each strategy under consideration, and the outputs were all in the same units: total biodiversity benefits per Rand (~0.133 Dollar). All the strategy output maps were overlaid, and for each site, the strategy that yielded the highest return-on-investment was displayed on the multi-strategy conservation value map.

Conservation Area Network Design

To provide the draft conservation area network design that could then be refined by a stakeholder process into a conservation plan, the prototype implemented an iterative “maximize short term gains” heuristic (Davis et al. 2006; Wilson et al. 2007). This is usually not as accurate as simulated annealing for estimating optimality, but is much faster (McDonnell et al. 2002). The output was a CAN with each site’s suggested management type designated. To do this, the multi-strategy conservation value map was created as above, and the model assumed that the site with the highest biodiversity benefit per dollar gets conserved in the manner suggested. If this change truly occurred, it would change the conservation value of many or all of the other sites in the region. The prototype recalculated the values of all the sites in the region and identified the next best site. This process repeated until either the user-defined total conservation budget, or targeted number of properties, was met.

CURSORY OBSERVATIONS:

The prototype took the form of a Modelbuilder model that could be exported to any ArcGIS user and added to their toolbox as an icon. Upon clicking the icon, a window popped up with a short description of each parameter and an associated entry field that was blank or filled with a default value. Running the model created a 1 ha grid (raster) output file for every criterion in the model (Fig 2). A shapefile (vector file) was also automatically generated. This file had a table with each row being one of the properties on the map, and the columns were the average value of each criterion grid (for that property). The shapefile and grids could be used to make maps on demand.

A two-day workshop was held to introduce the two organizations to the prototype and to come to consensus on the key parameter values. Both sides were satisfied with the outputs and the land trust boardmember stated that he would approve acquisition of any of the top ranked properties. A final report, maps, and GIS files were provided a month later in time for an important board meeting deciding on which lands to purchase. These outputs aided their decision-making process (supporting information).

Conservation Area Network Design

The CAN design algorithm was too slow to be useful for standard use, but fortunately, the problem can be rectified. The primary cause was the excessive processing time required by the experimental connectivity algorithm. The end-users wanted connectivity to and from small reserves as well as large reserves. Consequently, there were 31 reserves in the region, which required 465 pairwise analyses with the gated least-cost-path algorithm. This required about 12 hours of computer processing time. The maximize-short-term-gains algorithm for CAN design needed to reiterate all of this after each property was selected. We considered this unacceptable. Fortunately, the end-users did not need a CAN for their initial set of decisions, so this objective was postponed. The species representation analysis was also cumbersome, requiring about 1.5 hrs. This version of the framework required potentially overlapping distributions to be calculated separately. So each species distribution layer (N = 353) required a sequence of commands. The habitat representation analysis by comparison used a single layer which mapped all habitats, thereby requiring just one sequence of commands which took only 5 minutes.

Site assessment

The precursory model addressed several of the challenges facing the use of multicriteria overlay models in site assessment. The functions of diminishing returns were successfully programmed into Modelbuilder and executed in the grid (raster GIS) environment. This allowed for complementarity to be incorporated into site valuation. The contiguity and connectivity criteria allowed for spatial context to be incorporated. The multiple grid outputs, and the multi-field shapefiles allowed for an end-user to see why a particular cell or site got its final conservation value.

Updateability

The updateability of the model was put to the test when the end-users notified us near the end of the project that some of the sites known to be important candidates had new boundaries not reflected in our data. We made the changes to the cadastre layer, plugged the new layer into the data directory in place of the old layer, and then ran the model again. It updated seamlessly.

Flexibility

The flexibility of the prototype was put to the test by two scenarios typical of end-user engagement. The parameterization workshop entailed viewing the results of the model after the consensus-based parameter values had been entered. At this point the end-users decided that they wanted to also see the results summarized by cadastre (i.e. parcel) not property (which could have many cadastres). During lunchtime we copied the site summary model, pasted it, changed the site boundary input file to be the cadastre layer instead of the property layer, and had the summary ready by early afternoon.

Secondly, a concern was expressed by a staff member two days before the final presentation of results to the Board of Directors of the land-trust. The concern was that the average value of all the hectares in a site might not be the most accurate way of summarizing value. The ecologist felt that a site with some of the best habitat in the region, counter-balanced by completely degraded habitat, had a higher ecological importance than a site with the same average value but with a more even coverage of average habitat. Within a few hours we were able to program an alternate site summary shapefile that had an indication of variance added to the mean value (supporting information). This acted as additional decision support, not as the “final answer.”

DISCUSSION:

The ability of the prototype to update the conservation value of every site on the landscape after any change, and to be able to do this without having to perform a laborious CAN analysis, should facilitate “real-time” decision-making at the site level. There is much room for improvement, and the analytic framework needs to be evaluated before it can reach its full potential.

One of the initial improvements needed is to decrease the CAN processing time.

- The connectivity model can be improved or replaced by an alternate such as Circuitscape (McRae & Shah 2009).
- An option could be added to only recalculate the connectivity criterion after a user-defined N iterations of the maximize-short-term-gains heuristic. A similar option could be employed for the species representation.
- The species representation analysis could be sped up by an option for having the species FDR be flat until a target is met, and then have value drop to zero (Stein 2007).
- Processing time can also be greatly reduced through affordable and remote access to supercomputers via the "cloud."

Reduced processing time would also improve the speed of sensitivity analyses, a best-practice of responsible multicriteria modeling (Sarkar et al. 2006) that needs to be programmed into the LCDSS.

An incremental and very useful improvement to FDR creation would be to have the curve drop vertically by some user-defined percentage where it intersects with the target (Fig 7). This would allow a more robust and flexible treatment of target achievement in using the LCDSS.

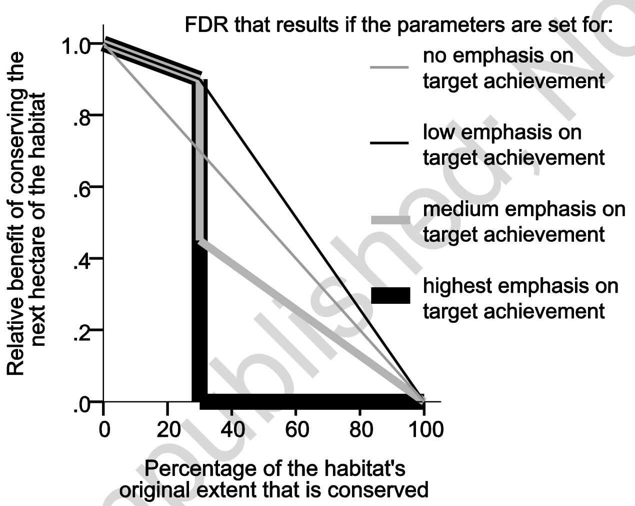

Fig 7: Four possibilities of the FDR for the grassland example (which had a target of 30%) if a user-defined "target emphasis" parameter is programmed into the LCDSS prototype. FDR = function of diminishing returns.

The most important factor that still needs to be programmed into the prototype is the treatment of spatially explicit future threat. These data could arguably be (1) part of the FDR calculation (Davis et al. 2006), (2) made into a high-level criteria to be combined with cost and biodiversity value, and/or (3) a criteria influencing the "persistence" factor of management quality value. The contiguity model needs programming for different types of conservation areas and for sites adjacent to the adjacent site.

Further research is needed to provide ecological guidelines for the different parameters of the FDR curves, and to explore the benefits and costs of integrating so many conservation principles into FDR creation and use. A related line of research is in communicating and reducing the uncertainties that arise when criteria with different non-normal distributions are transformed and combined.

Some of the exciting implications of the LCDSS framework might not be immediately obvious.

- The multicriteria framework lends itself to model flexibility, easily allowing for the additional sub-criteria, such as opportunity cost, or major criteria that can be balanced with biodiversity value, such as ecosystem services or even working landscape criteria, such as agricultural production.
- Because of the emphasis on overlay analysis rather than targets and networks, the framework can be programmed to have automatic information feedbacks between nested spatial scales. For instance, the results of a state-wide analysis can be inputs to a regional LCDSS as a "coarse-scale priorities" criterion and/or influence parameter values, and vice-versa.
- Monitoring and adaptive management, the oft-overlooked Stage 6 of Margules and Pressey's (2000) seminal paper on systematic conservation planning, would be greatly facilitated by the living, multi-scale and site-specific aspects of the LCDSS, as well as by the ongoing measurement and modeling of management quality value and habitat integrity value.
- Multicriteria frameworks are conducive to consensus-building (Feick & Hall 1999; Theobald et al. 2000; Balasubramaniam & Voulvoulis 2005). Automating some of the negotiations for defining parameter values (e.g. Regan et al. 2006) could decrease the amount of time needed for consensus building and/or increase the number of organizations that can be involved. A consensus among organizations on a set of parameters, and the associated outputs, should streamline the creation and implementation of region-wide plans. This "consensus LCDSS" could also increase the conservation movement's resilience to climate change or one of the many other drivers of unanticipated opportunities, threats, and impacts; it would facilitate the rapid and similar assessment of any major stochasticity and allow a coalition to mobilize quickly and accordingly.
- If the multi-scale and consensus-buildingefforts engage the emerging culture of the internet and are widely participatory (Gallo 2007), this framework could facilitate the interplay between and among the hierarchical levels and parallel domains of our society: jurisdiction, management, institution, time, area, and knowledge (Cash et al. 2006).

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SUPPORTING INFORMATION

XXX (Appendix S1) is available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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