Supplementary Material S3

Unpublished Drafts: Collaborative land-use planning and action

Contents

Introduction

In the spirit of open science I am releasing these unpublished drafts here as supplementary material. I could hold them back, awaiting the possibility that I get the time to publish them elsewhere as they stand or with changes. But this might not happen, and the challenges facing humanity are big, to say the least. We need to increase the velocity of knowledge flow towards the end goal of improving collective wisdom. People are welcome to use small portions of this material in their work and are asked to please cite it so we all benefit.

People are also welcome to take any of the below chapters past the finish line and be the lead author while I (and others in some cases) will be secondary author(s). My hope is that this will lead to exciting collaborations and cross fertilization of ideas. My expectation is less optimistic but I won't let that stop me.

Paper 1 is an essay about the importance of bringing many, many more people into the collective process of determining what we do on the land, where we do it, how we evaluate. Fortunately, if we can get beyond our mid-20th century mentality of how society works, and a few other barriers, then such an increase in magnitude is not only possible, but attainable now.

Paper 2 is an essay that recognizes that nature conservation on private land is a very important piece of the puzzle, and examines the idea of balancing the financial approaches with socio-cultural approaches in motivating people to implement this conservation.

Paper 3 is an early draft of the main manuscript before another round of SDSS development and application. This manuscript has been handed out to colleagues and also available open access from 2010-2014 on the experimental Landscape Collaborative website.

Paper 1- Why a social learning approach is needed for conservation planning and adaptive management

John Gallo,

July, 2007

Introduction

Human society is growing while life on earth is experiencing its sixth mass extinction (Leakey & Lewin 1996; Wilson 1992). Unlike the destruction of the dinosaurs and the four other events, this one is caused by one of the species themselves, namely, us (Pimm et al. 1995). Conservation science seeks to understand nature, humanity, and nature-humanity interactions; and then to advise society about this understanding in an effort to slow, and eventually reverse this destruction of life. The area-based strategy of conservation is to create reserves or special management areas in an effort to help biodiversity. Systematic conservation planning is the scientific approach to prioritizing these areas, implementing their conservation, and monitoring their contribution towards ecological goals (Margules & Pressey 2000b). But research in this field has focused primarily on the objective of prioritization, and much less effort has been given to the objectives of implementation or monitoring (Knight et al. In Prep; Newburn et al. 2005; Prendergast et al. 1999). For this and other reasons, the implementation of conservation priority areas is occurring in a piecemeal and ineffective manner (Meir et al. 2004; Pyke et al. In review). This divergence between the emphasis of research and the end goal of conservation action is being recognized as the implementation crisis of systematic conservation planning (Knight et al. 2006b; Knight et al. 2006c). It begs the question: how can systematic conservation planning be improved to better facilitate actual conservation actions?

Fortunately, there is a growing emphasis on examining and addressing implementation strategies while performing conservation planning (Angelstam et al. 2003; Davis et al. 2006b; Fagerstrom et al. 2003; Foreman et al. 2000; Knight et al. 2006c; Loucks et al. 2004; Natori et al. 2005; Newburn et al. 2006; Pierce et al. 2005; Song & M'Gonigle 2001; Younge & Fowkes 2003). Some common themes are emerging both in improvements to the conservation assessment models as well as to the conservation planning process. Some model improvements are the inclusion of socio-economic variables, opportunity cost, and land conversion threat into the model (XXX), dynamic modeling to anticipate changing conditions (XXXX), uncertainty modeling XXX, and recognition of a gradient of ecological condition (XXXX). [Insert: Bit about need for transdiciplinarity.] Emerging improvements to the process are summarized nicely by Knight et al. (2006b) and corroborated by several others (XXXX). These improvements are set out as five hallmarks: links to a conceptual framework, attention to social learning and action research, stakeholder collaboration, development of an implementation strategy, and links with local land-use planning.

This essay seconds the need for all of these improvements, but posits that there is a golden opportunity and strategy that is being overlooked for ~~regional and landscape scale~~ conservation planning. Namely, it asserts that a dramatic increase in the number of people engaged in some part of the process will lead to short and long term benefits that, when considered as a whole, merit action. This may sound similar to the common mantra of including stakeholders in the process, but in practice it is much different. In the typical stakeholder inclusion process, a small set of

representatives are included via meetings or workshops to either be briefed of progress, or in some cases, to provide some input to the process (XXXX). The dramatic increase suggested is to have an opportunity for all stakeholders not just representatives, to have the opportunity to engage in the process. (The term stakeholders is broadly defined to include interested community members that do not own land.) Further, the engagement mechanisms can be designed for every level of Arnstein's (XXXX) ladder of participation, which ranges from the public right to know to the public participation in the final decision. Example contributions from citizens can be as varied as online opinion surveys, scenario development in public workshops, and citizen science observations of plants and animals.

This essay discusses why such engagement is worthwhile and needed. Increased engagement brings with it several tensions that must be addressed in the conservation planning process if the benefits are to be realized. So, before discussing the benefits, a brief overview of these tensions is provided along with a suggested approach for resolving these tensions. ~~(The approach and strategies will be detailed further in another paper.)~~ Next, the short and long term benefits of such a strategy to conservation implementation are detailed. These arguments include X, Y, and Z. A brief discussion ensues about the way forward and the assumptions that need further testing.

The tensions of engagement and a way to address them

The obvious tension with increased engagement in conservation planning is with regards to cost. Engagement is resource intensive, requiring additional time, money and staff for a process that is already resource poor and covers large geographic areas. Allowing all interested citizens to engage is a daunting proposition. A second tension is between the need to maintain scientific rigor and credibility and the need to engage people with varying world views (i.e. mental models) and expertise. There is also a tension in balancing the need to have knowledge sharing and transparency with the need to responsibly manage sensitive data and information. (Optional: A fourth tension of note here is motivation: it is hard to build a process of engagement for conservation planning where none exists. What will motivate people to engage in this particular endeavor?) All of these tensions and more are discussed more fully in another essay which also details the following approach for resolving them.

This approach for resolving these tensions is based on the synthesis of three strategies. The first strategy is to effectively utilize information and communication technology (ICT) breakthroughs. This will involve Web 2.0 and especially its knowledge sharing and geographic components (Cite Sharl 2007). Web 2.0 is an emerging culture and set of tools that allow asynchronous, distributed, two-way interaction that is stimulating and does not require an intermediary (O'Reilly 2005; Rogers 2006). This approach will allow an exponential increase in engagement. Of course it brings up another tension, known as the digital divide between people with and without computers, which can be eased by maintaining traditional communication channels.

The second strategy is to integrate conservation planning with ecosystem-based management (and natural resource management). This strategy is really just the culmination of a trend in conservation planning (i.e. where to do conservation). The trend is the need for looking at various degrees of management (how to conserve in those areas) in assessment algorithms. Further, there is a very large overlap in the institutions responsible for the implementation of the scientific recommendations from both of these fields.

The integration occurs through the third strategy, which is the adoption of a social learning framework. Social learning is one of the hallmarks proposed by Knight et al. (2006) and is "the

collective action and reflection that occurs among different individuals and groups as they work to improve the management of human and environment relations"(Keen et al. 2005). A conservation stakeholder has their own mental models of the way the world works, and are working within different knowledge domains compared to the scientists (Roux et al. 2006). Thus it is essential to have a bi-directional knowledge flow; everyone is a learner. So there is an iterative feedback between the learner and their human-environment-technology system, with both affecting each other (Bandura 1977; Pahl-Wostl 2007; Wenger 1998). Safeguards can be instated to maintain the scientific rigor and objectivity of the process, and to responsibly address data sensitivity.

achievement of network goals.

1a.   Engagement pyramid - Time 1   1b.   Engagement pyramid - Time 2
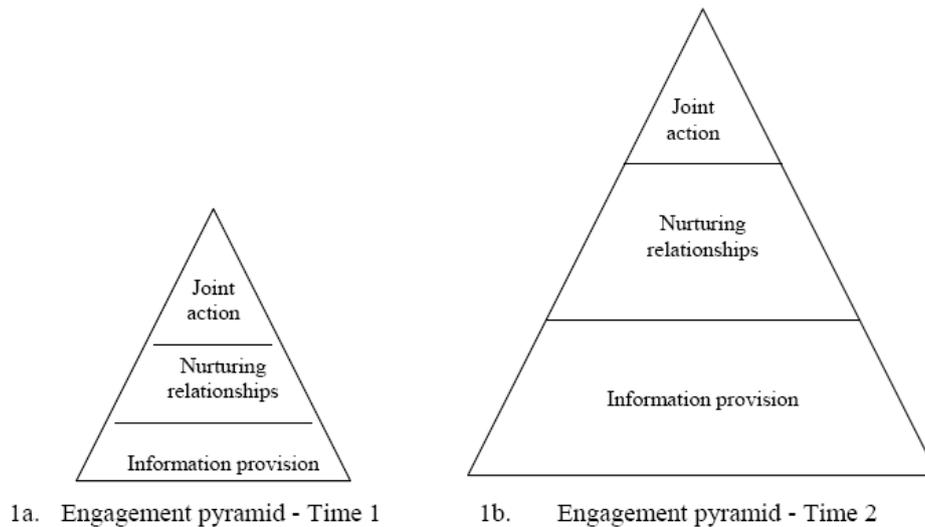
From Willard 2001 (Dating the decisionmakers)

In summary, a proposed approach for dramatically and effectively increasing the citizen engagement in conservation planning is to utilize ICT breakthroughs through a "living" knowledge network that facilitates social learning about ecosystem-based assessment, planning and management. Again, this is described in more detail in another paper. Such an approach will doubtless take a lot of effort and be controversial in its own right, so it is first very important to ask, what are the short and long term benefits of such an approach?

The short-term benefits of increased engagement

A given of this essay is that if a person is engaged in a conservation planning process, they are more likely to implement some of its findings as opposed to if they were not engaged. This given is based on several findings. If a person is involved, the product is more likely to suit their needs (Moller et al. 2004; Ostrom & Nagendra 2006). Also, public participation in decision-making processes also helps in consensus building and reducing conflicts (Couclelis & Monmonier 1995; Joerin et al. 2001). It builds the trust between and among local experts, stakeholders and the scientists that is vital for successful teamwork (Forester 1999; Jackson 2001; Stringer et al. 2006; Weber 2003). In short, there is more "buy-in" to the process, and hence, the product. Unfortunately, stakeholder involvement in conservation planning is still relatively sparse. In one review of 74 studies, only 12% involved state holders in the process (Newburn et al. 2006). (As expected, these efforts were much more successful in leading to implementation.)

Big picture and long-term behavior change

The second major argument of this essay is that increased engagement in conservation planning and ecosystem management will help change the values, beliefs and norms of society, thereby leading to behavior change towards implementation of future conservation plans, and conservation in general.

- This is very important , because societal values are moving in the other direction (cite American environmics)
- Predicted by Habermas

A paragraph talking about the drivers of values-beliefs-norms-> behavior theory (stern 2000)

- If a person is engaged in the conservation planning process, then it will build their ecological understanding to some degree.
- Cite the papers that describe this
- Engagement will also provide a sense of community, and also a purpose.

Also cite helplessness as one of the major barriers to behavior change

- Contributing to the knowledge base be it with surveys, citizen science observations or whatever provides a sense of purpose and empowerment. Removing the barrier helps repel apathy.

Being in nature builds ecological empathy.

- The citizen science component, (and "fieldtrips" opinion leader trails) gets people and scientists into nature.

- But why should conservation planners task themselves with building the ecological understanding of both their conventional targets (decision makers, donors, and apex stakeholders) AND the individual landowners and concerned citizens?

The expected indirect benefits of increased engagement

Democracy, and its effects

- Stakeholder cube. (Figure 8abc)
- Building social capital (Schwartz 2006?)
- Builds socio-ecological resilience to change

Maturation of Science

The science is more robust and multi-faceted
- 2 way knowledge flow Add (Roux et al. 2006)
    - Possibly add the last sentence from assertion 7 of the Reynolds Stafford-Smith paper that David gave me.

- - The balance of local environmental knowledge and scientific knowledge.
- Includes the socio-economic realities. Feasibility. Pragmatism
- Includes local expert knowledge of the landscape and system
- Scientists get local perspective, opportunities for field work
- Consider adding here or elsewhere Steven Holness argument from SCB conf: that SCP is a complex system, and we are treating it as complicated instead. Complex and complicated(knowable) are discussed in Kurtz and X 2003. X = Snowden, sneden Snoudu. And from Dirk Roux's talk: Kinneman and Bleich 2004 chaos, complexity, complicated.

Discussion (Retitle)

Candidate topics/directions. Keep it focused though

The way forward
- "Engaged Ecosystem Planning and Management"
  - "conservation" is a western worldview, and too binary for the reality, which is a continuum
- Good science is needed in testing some of these ideas
  - Counterfactual
  - Foundations of success (standard measures)
  - Standard measures/framework of the context
- Web-based Community of Practice can be formed around this
  - A table of the others on the web
- Framework necessary
  - Point to other paper

Gaps in the argument/things to explore

Conclusion

- Tight summary, written in a new way. Drive the point home

Draft Figures:

Figure 16: Development and maintenance of Ecological Perspectives at various scales worldwide has the potential of providing a balance to the Economic Engine.
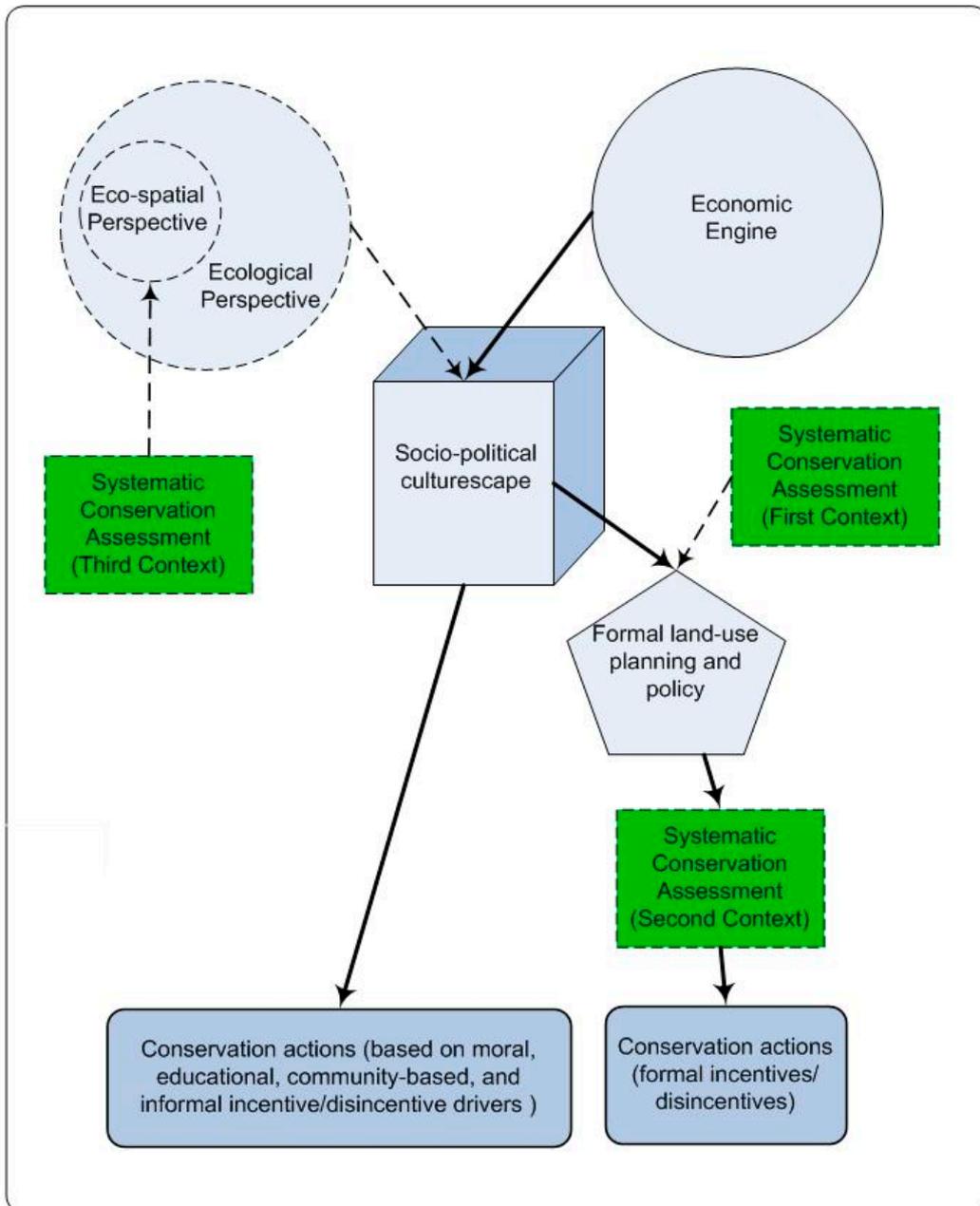
*Figure 8a: The estimated stakeholder cube for traditional conservation planning. Each grey dot represents a person that has a certain degree of power, legitimacy, and urgency regarding the sustainability of the region. The red dots represent the people participating in the conservation planning process.*
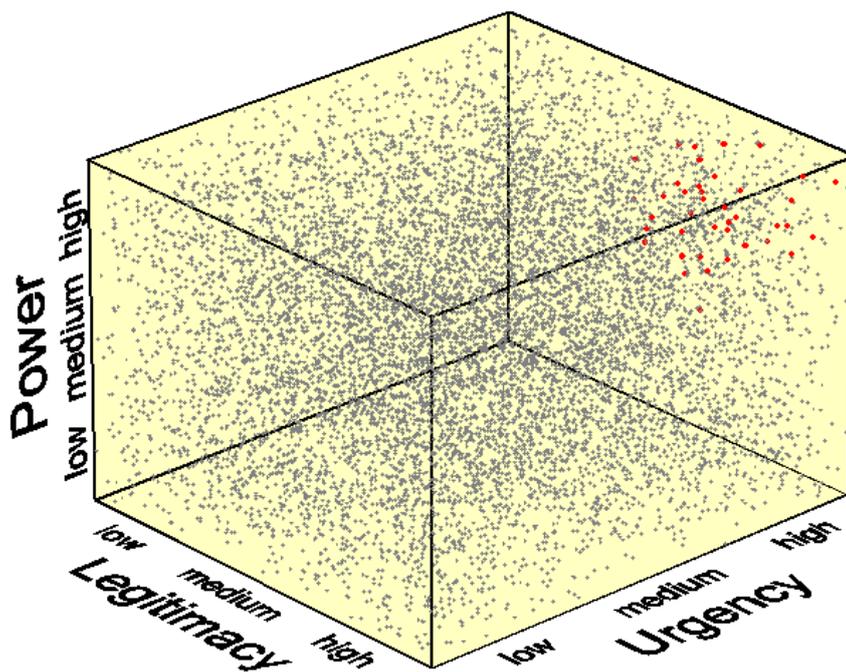
Figure 8b: The postulated stakeholder cube for initial Engaged Conservation Planning and Management
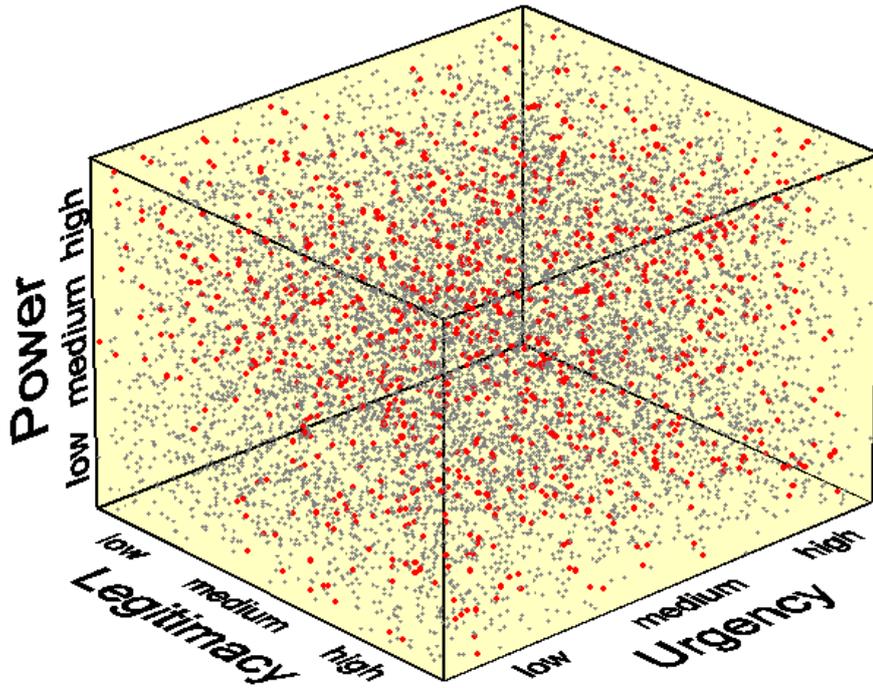
Figure 8c: The postulated shift in peoples' stakeholder status resulting from Engaged Conservation Planning and Management
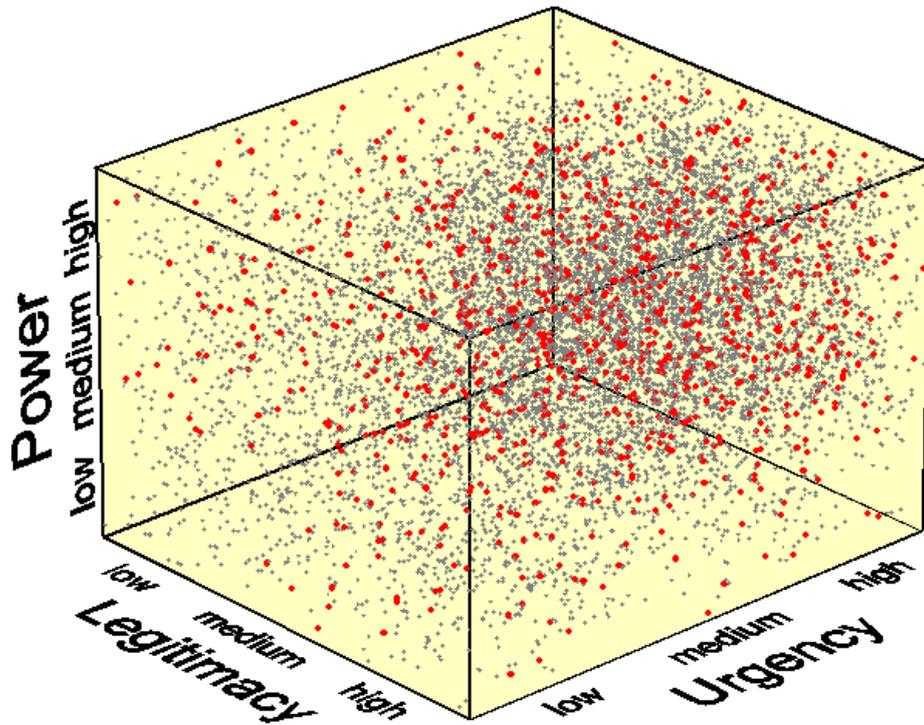
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Paper 2- Motivating people to conserve their land: balancing the financial approaches with socio-cultural approaches

By John Gallo

Fall, 2007

The global protected areas network is far from reaching its goal of conserving biodiversity (Rodrigues et al. 2004). Meanwhile habitat destruction continues at alarming levels. It is clear that the reserve strategy alone is not going to be adequate for conserving biodiversity (Morton et al. 1995); and that conservation of biodiversity should be facilitated on lands that are privately owned and will stay privately owned (Norton 2000).

The "neglected geography"(Knight 1999) of private lands are playing an increasingly important role, as many private landowners are assisting in the biodiversity conservation effort by being effective stewards of their land (Langholz & Krug 2004; Langholz & Lassoie 2001). Private protected areas are gaining notice as an important tool in the conservation toolbox, as evidenced by the Governance stream at an IUCN conference in 2003, and the private protected areas action plan (Langholz & Krug 2004). Well respected ecologists continue to urge the conservation scientists to move beyond the black-and-white view of parks being protected and all else unprotected and to instead adopt a more nuanced view in which human uses of the land are compatible with biodiversity, with the trade-offs needing to be measured and monitored (Wiens 2007). There is even a non-profit organization centered on the issue of private protected areas worldwide (www.parksnetwork.org).

Financial incentives/disincentives are the motivations commonly used by conservation strategies seeking to promote stewardship. An example is the conservation easement of the U.S., in which a landowner is given financial compensation for following an agreed upon ecologically-based management plan. There is a rich treatment in the literature of financially motivated stewardship, including a review of the role of such covenants in biodiversity conservation (Bernstein & Mitchell 2005), what motivates landowners to join them (Kabii & Horwitz 2006), and innovative mechanisms, such as cost sharing principles (Aretino et al. 2001).

By applying a conservation psychology line of reasoning (Saunders et al. 2006), it becomes apparent that there is a gap in the literature. Decades of research on environmentally significant behavior shows that while financial incentives are a strong motivator, there are many other motivating factors, such as self-interest and cultural norms (De Young 2000; Stern 2000). When this principle applies to land management, it can be termed *mutual stewardship* in that society does not have to pay a direct subsidy for the stewardship, and the landowner receives benefits from their positive relationship with society and nature.

An example of mutual stewardship as an institutional program is the Land for Wildlife program of Australia (Stoneham et al. 2000). This is a wholly volunteer program in which landowners are encouraged to conserve their land and foster wildlife protection. They receive recognition for participating and receive visits from extension officers who provide advice for

biodiversity conservation. There are over 5,000 properties involved in the state where it originated, and it has become a national program (www.dse.vic.gov.au) (Figgis et al. 2005). The rules and incentives for private protected areas in Latin America are similar, but less institutionalized and consistent (Chacon 2005). South Africa institutionalized a mutual stewardship program in the mid 1970's, designating "private nature reserves" if managed by one landowner, and "conservancies" if managed jointly by multiple landowners. The terminology changed in the post-apartheid era, and now includes options for mutual stewardship and financially-subsidized stewardship. The result has been a significant representation of biodiversity in one of the study areas (Gallo et al. 2009). The U.S. has been noticeably quiet with respect to mutual stewardship programs. Some Universities offer guidance regarding natural resource management. "Backyards for Wildlife," managed by an NGO, is another exception, but it is geared primarily for owners of small yards, not small landholdings or ranches.

For the purposes of discussion, we will call the programs that strengthen mutual stewardship the *cultural approach* to conservation, and we will call the convention of needing acquisition or at least an easement of the land the *economic approach* to conservation. We would like to encourage a discussion: what is a good balance between these two approaches in furthering conservation on private lands? (We feel that there should be more emphasis on the cultural approach in the U.S. then there is currently.) What are some best practices and theoretical frameworks for effectively implementing the cultural approach to land conservation? Specifically, what can we do to improve the persistence of private protected areas (PCA) motivated via the cultural approach?

It may be most prudent for the conservation movement to implement a strategic blend of the cultural and economic approach to conservation. Anecdotally, regions seem to be placing an uncritical reliance on the economic approach, or are rapidly trending in that direction. But this is problematic from several perspectives, including the big picture view. The human population is still increasing, and the culture of consumption is being spread to more and more of this population. Indications are that under this dominant social paradigm, society is not ready to pay the true market value of conservation. There are many indications of this (e.g. James et al. 2001), but perhaps the most telling is an article by renowned environmental economist David Pearce in special issue of Environment and Resource Economics dedicated to him (Pearce 2007). Not only is there a big deficit between what society says it is willing to pay and what it actually pays, but the current marginal economic benefits of conservation are way above the marginal economic costs, indicating that humanity is taking this natural capital stock for granted and bequeathing conservation to some future generation.

The long-term implications of relying on the economic approach to conservation are also daunting. Consider the habitat conservation plans of the U.S., which are covenants with developers to restrict their options for some lands, and to allow them to develop others, even if critically endangered species are discovered there. The wisdom of this "no-surprises" policy has been questioned, but what about when the restrictions end, which is often only 50 years? What is a developer likely going to do with their land then? Given the growth in population and the associated housing demand, the fair market value for the land at that time will likely be exponentially higher. Further, it is likely that society will have developed new technologies to replace marketable ecosystem services, like the carbon sequestration and water filtering services of intact forests and estuaries, so their relative market value will decrease. In short, if it becomes embedded in our culture to look at the land and at conservation with solely an economic lens,

then biodiversity destruction may slow at first, but there is little doubt that the long-term conservation movement will be in a sustained retreat (McCauley 2006). To be clear, we recognize that the economic approach is probably the most powerful approach at the current time, but we feel that a more even balance with the cultural approach will have strong returns on investment in the long term.

The biggest counter-argument to the cultural approach is that mutual stewardship areas cannot be depended upon to be practicing stewardship at some point in the future. To discuss this persistence and durability, it is important to examine in closer detail the incentives for starting and maintaining a PCA. What drives mutual stewardship? Financial incentives can still be present in mutual stewardship even if not in the form of direct subsidies. These include ecotourism or game hunting revenues. But there are a whole host of other incentives that drive environmentally sound behavior (ESB) (De Young 2000; Stern 2000). They can be uncovered by examining self interest, which is not selfishness, but instead is taking care of yourself and getting a sense of happiness or meaning from life (De Young 2000). While this includes financial security, it also means much more. Further, happiness is not just personal-- it often manifests if an outcome that we care about is attained (Wallach & Wallach 1983 in De Young 2000). In other words, people can practice stewardship because it brings them a sense of well being, or it aligns with any number of personal factors such as values, aspirations, morals, respected social norms, or recreational and aesthetic desires. These factors are strong too; they were stronger than the financial ones for a majority of landowners surveyed in regions that did not have financial subsidy programs in place (Langholz 1996; Pasquini 2007a). In summary, there are many indications that mutual stewardship can actually be quite durable. Further, the durability can be bolstered by programs, policies, and actions that provide the key non-financial motivations. If the durability of a PCA is inextricably linked with well being, then it may be as well conserved as an area where the landowner has to receive an annual tax break in order to conserve their land.

It follows that a high priority for future research is determining effective practices for the cultural approach to expanding and strengthening mutual stewardship. Some potential research clues follow, but need to be critically evaluated.

Theory indicates that the best strategies for such behavior change utilize several of the four major motivations: moral/ethical, educational/awareness, socio-cultural, and financial (Stern 2000). Further, improving the ability and competence of a target group is essential to building receptivity (De Young 1993) (1996). The findings of surveys and follow-up interviews with over 60 landowners in the Little Karoo (Pasquini 2007b) align with these theories. The primary incentives that landowners requested for bolstering and maintaining their mutual stewardship were institutional recognition of their efforts, as well as support and dialogue with conservation organizations about ecosystem-based management (i.e. extension services). Further, the importance of building and maintaining of social capital became apparent. For this, the creation/improvement of bonds (the links between people with similar outlooks), bridges (the horizontal links between people with different outlooks, especially across communities) and links (the vertical connections established by groups with external agencies) in a community needs to be promoted (e.g. Pretty & Smith 2004, Wilcove & Lee 2004)(Pasquini 2007b). Targeting non-financial motivations has the tantalizing possibility of a positive feedback cycle, whereby change on the individual level spreads to the community of practice and the bridges to other cultural groups.

Another nuance to consider is that some landowners may prefer to avoid any sort of formal registration process, even if they can voluntarily opt-out at any time. This issue was examined as part of a detailed study in the Little Karoo study region in South Africa that included questionnaires and interviews (Pasquini 2007b). From analysis of various conservation-related attributes , it appears that registered PCAs do not outperform thee unregistered PCAs. The latter, compared to the former, "are: (i) just as likely to operate over a long timescale (20+ years) (Chi-square, $\chi^2 = 2.70$, d.f. = 1, p = 0.1); (ii) just as likely to have developed formal conservation management plans, and management goals (section 4.4.3); (iii) just as strongly driven by conservation motivations (all PCAs, whether formal or informal, attributed top scores to conservation motivations); and (iv) no different in terms of their rating of formal recognition (as a protected area) as a valuable incentive measure (Mann-Whitney test: $M_{FORMAL} = 8.42$, SD = 2.78; $M_{INFORMAL} = 8.29$, SD = 2.67; U = 245, exact p = 0.67, two-tailed)" (Pasquini 2007b). Is it possible to design conservation strategies that also bolster these unregistered PCS? If so, what measures are helpful and appropriate?

Needs conclusion and wrap up still.

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Paper 3: 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

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 (Knight et al. 2006a; Margules & Pressey 2000a). In this paper we

provide a set of recommendations for improving systematic land conservation, which we define as 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. 2006a). 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. 2006a). A vast majority of the decisions about changing land ownership or management occur on a property-by-property basis (Knight et al. 2006a; Theobald et al. 2000). 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

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

and maintenance of a large GIS database, skilled modeling expertise, expert 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.
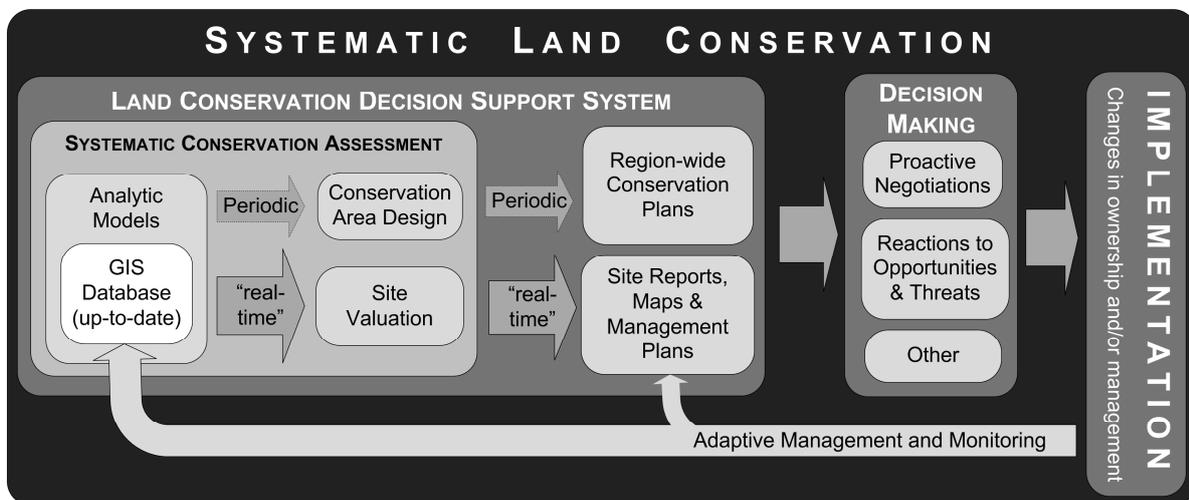

Fig 1: A conceptual framework for systematic land conservation that includes the suggested dual mandate of conservation assessment and the "living" decision support system.

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 (Gallo et al. 2009; Polasky et al. 2005). 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 (Carwardine et al. 2009; Davis et al. 2006a; Moilanen 2007; Wilson et al. 2007) 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].
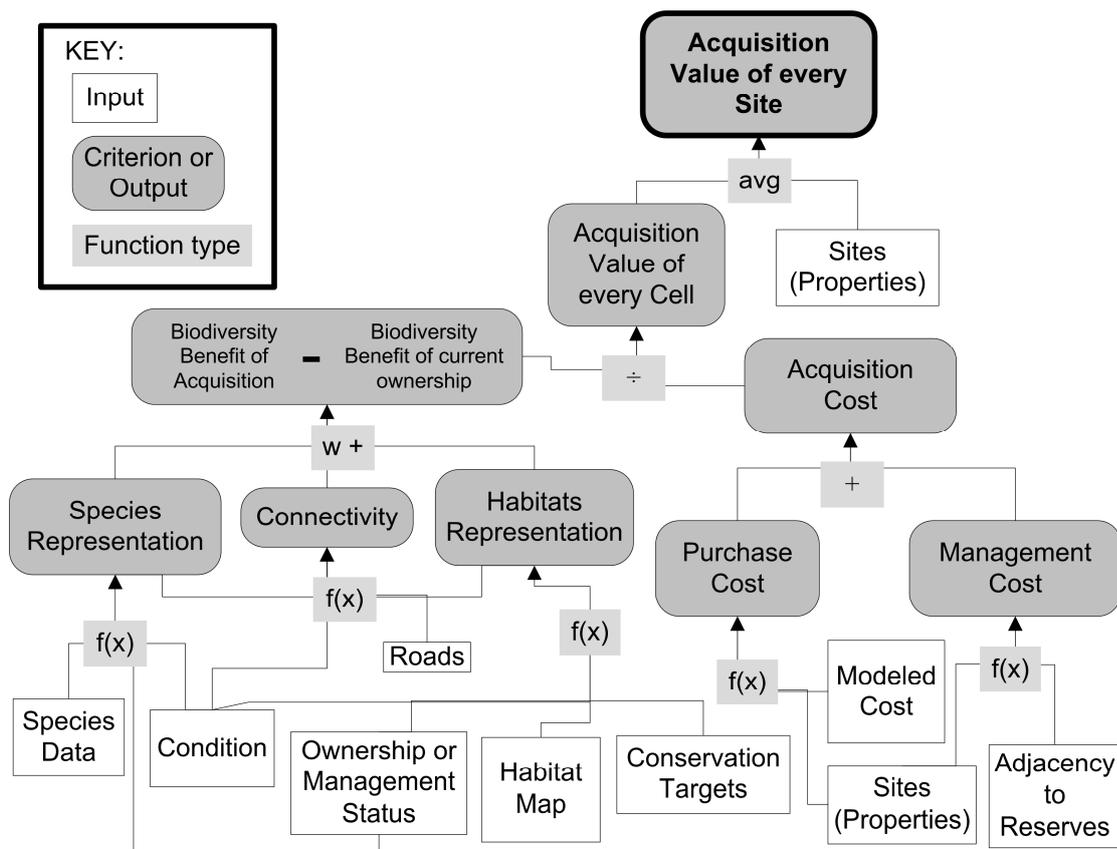
Fig 2: Data input layers combine to create criteria, which are combined to with simple or complex functions to determine the conservation value of acquiring any particular site; a similar hierarchy was used for determining the value of pursuing stewardship instead of acquisition. All the criteria can 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.
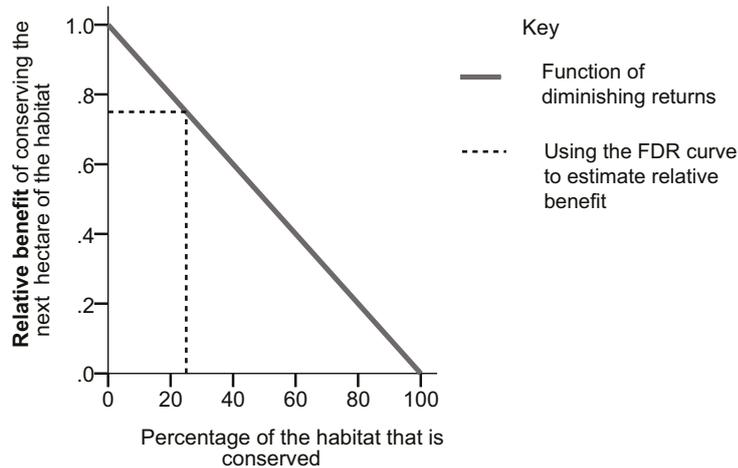

Fig 3: If an example habitat has 25% of its extent protected, and has been assigned this simple function of diminishing returns (FDR), then the relative benefit to biodiversity of conserving the next hectare of this habitat is ¾ of what it was to conserve its first ha.

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).
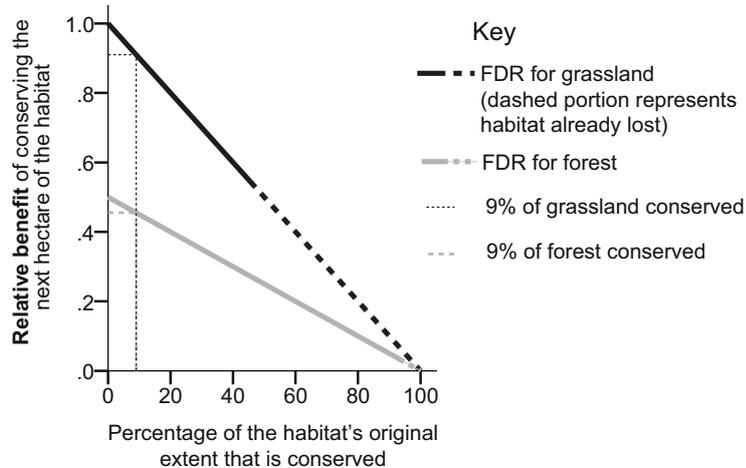

Fig 4: Given that 9% of each habitat has already been conserved, the relative benefit of conserving the next ha of grassland is 0.91 while the relative benefit of conserving the next ha of forest is 0.455. FDR = function of diminishing returns.

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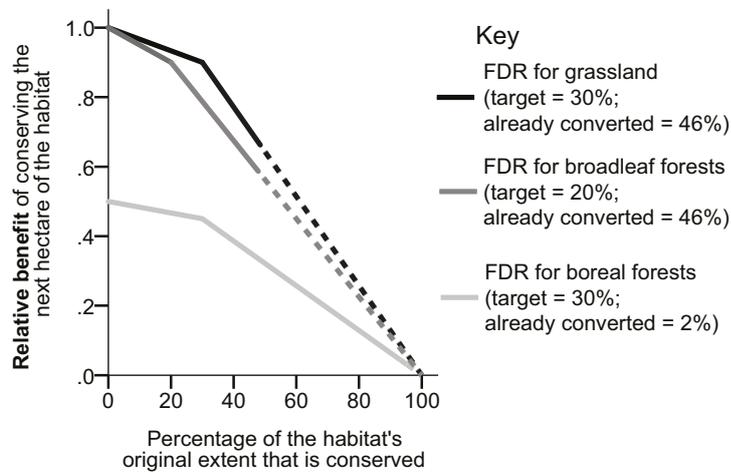
Fig 5: Three hypothetical FDR curves illustrating how different targets and different habitat conversion levels change the shapes of the curves. FDR = function of diminishing returns. [To consider: Putting in some dashed lines representing the amount protected being 25%, as per previous figures, thereby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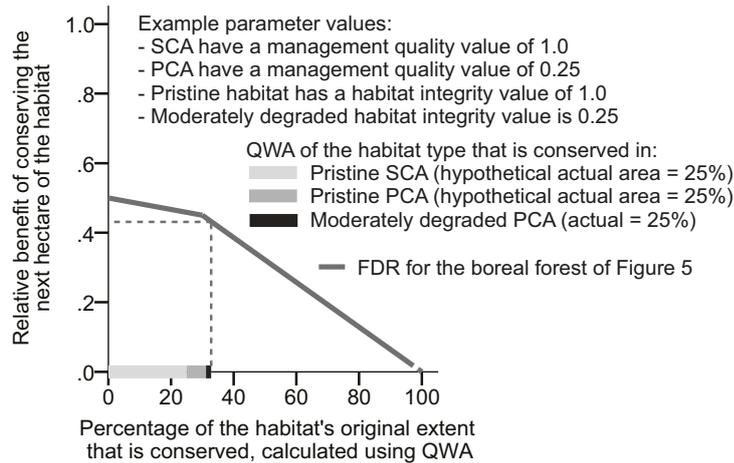

Fig 6: The quality weighted area (QWA) conserved is 32.8125% for this example habitat and scenario even though 75% of the actual area (i.e. un-weighted) is conserved in some form, thereby leading to a marginal relative benefit of 0.432. The original extent is always assumed to be pristine. FDR = function 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 (Gallo 2007; Lombard & Church 1993). 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. 2006a; 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.
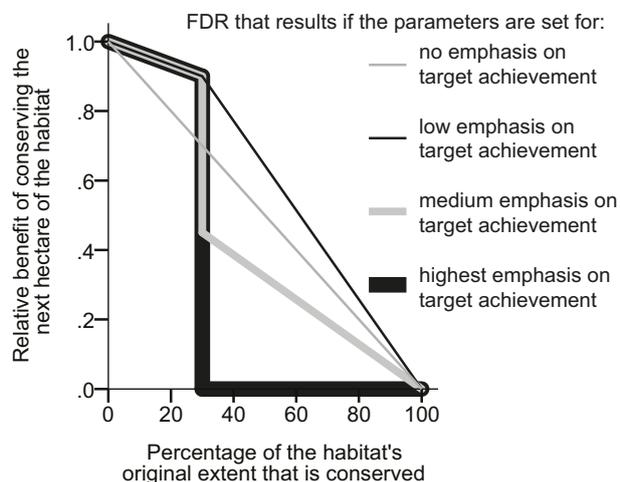

Fig 7: Four possibilities of the FDR for the grassland example (which had a target of 30%) if a user-defined "target emphasis" parameter is programmed into the LCDSS prototype. FDR = function of diminishing returns.

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. 2006a), (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 (Balasubramaniam & Voulvoulis 2005; Feick & Hall 1999; Theobald et al. 2000). 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-building efforts 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).

Acknowledgements

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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