Toward a Framework for Conducting Ecoregional Threats Assessments

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Abstract—*Assessing threats to biodiversity is widely recognized as a critical step in conservation planning. While there have been recent advances in understanding how to assess threats at a site level, there has been relatively little consensus on how threats can be meaningfully assessed at an ecoregional scale. Drawing from numerous threat assessment studies, this paper offers a five-step framework for understanding the scope, purpose and components of a comprehensive, ecoregional-level threat assessment. The proposed framework includes the following components: 1) identifying threats within an ecoregion; 2) assessing the impact of current threats to biodiversity; 3) assessing the impact of future threats; 4) analyzing the root causes of these threats; and 5) integrating threat-related information into conservation planning.*

Introduction

An assessment of threats to biodiversity is widely recognized as a critical component of effective conservation planning (Groves 2003, Margules and Pressey 2000); six of the ten steps in site conservation planning proposed by Poiani and others (1998) are related to some aspect of conservation threats. Despite the widespread recognition of their importance, threat assessments have not been well understood or widely implemented in most parts of the world (Groves 2003). Moreover, until only recently (Salafsky and others 2004), there have been scant studies that compare different methodologies and approaches to conducting threat assessments (Rouget and others 2003). This is particularly true for threat assessments across broad geographic areas, such as an ecoregion.

This paper is an attempt to fill that void. Based on a review of threat assessments (see table 1 for a summary of a selection of these), this paper proposes a five-step framework for conducting comprehensive ecoregional threat assessments: 1) identifying ecoregional threats; 2) assessing the impact of current threats; 3) assessing the impact of future threats; 4) analyzing and interpreting underlying causes; and 5) integrating threats data into conservation planning. Selected from an initial review of over a hundred threat-related studies, the following set is intended to be a representative sample, rather than an exhaustive catalogue. Each study included the following characteristics: they assessed actual threats (versus simply developing a conceptual model); they encompassed a broad geographic scale; and they focused on assessing threats to biodiversity. Table 1 summarizes the main elements of each of these studies.

Table 1 illustrates several points. First, many threat assessments only look at a small number of threats, rather than a full range of potential threats. Second, not all threat assessments are spatially explicit about where threats occur. Third, most indicate the impact of threats on biodiversity, although with widely ranging degrees of detail. Fourth, most include some form of future threat assessment, although the method of determining future threats varies considerably. Fifth, most did not fully assess the underlying causes of threats, although many touched upon them. Finally, in only some cases the results were explicitly used, or were expected to be used, as information to improve conservation planning and practice. The rest of this paper discusses these points more fully.

Identifying Ecoregional Threats

As highlighted in table 1, some threat assessments may consider a wide variety of threats. However, many others consider only a single threat (Rouget and others 2003). Some authors suggest that a more inclusive set of threats be considered as routine practice in conducting threat assessments. Curtin and others (2002), for example, note that the driver of rangeland ecology is far more complex than simply grazing, and therefore rangeland assessments must consider such factors as invasive species, global climate change, and fire, in addition to the intensity and distribution of grazing.

There are numerous approaches to developing a comprehensive set of threats, and every shortlist candidate has

Table 1. Summary of selected broad-scale threat assessments.

Author/s	Geographic area	Threats included	Threat distribution was spatially explicit	Assess impacts on specific biodiversity elements	Assess cumulative impacts of threats	Assess future threat	Assess underlying threat causes	Results clearly linked to conservation planning
Clarke & Harris, 2003	Arctic & Antarctic	Pollution, energy, climate change, fishing	no	yes	yes	yes	no	no
Curtin et al., 2002	Chihuahuan Borderlands. US SW and N. Mexico	Grazing, fragmentation, development, protected status	no	somewhat	yes	somewhat	yes	yes
Dirnböck et al., 2003	Juan Fernandez Archipelago, Chile	Invasive species	yes	yes	no	yes	no	yes
Kramer & Kramer, 2002	Mesoamerican Caribbean Reef	Coastal development, tourism, energy, port management, fishing	yes	yes	somewhat	yes	yes	yes
Laurance & Williamson, 2001	Amazon Basin	Forest fragmentation, El Niño drought, fire	no	no	yes	yes	yes	no
Maddock & Benn, 2000	North Zululand, South Africa	Protected status, agriculture, development	yes	yes	yes	somewhat	no	yes
Neke and du Plessis, 2004	South African grasslands	Mining, agriculture, afforestation, urban development	yes	yes	yes	somewhat	no	yes
Reyers, 2004	Limpollo Province, South Africa	Cultivation, afforestation	no	somewhat	somewhat	yes	no	yes
Rouget et al., 2003	Cape Floristic Region, South Africa	Agriculture, urbanization, invasive species	yes	yes	yes	yes	no	yes
Stoms, 2000	California	Urban development, roads, protected status	yes	yes	somewhat	yes	no	yes
Theobald, 2003	Colorado	Roads, housing	yes	yes	yes	yes	no	yes
Weber & Wolf, 2000	Maryland density, legal protection	Protected status, urban development, transportation	yes	somewhat	yes	yes	no	yes
Stoms, 2000	California	Urban development, roads, protected status	yes	yes	somewhat	yes	no	yes
Theobald, 2003	Colorado	Roads, housing density, legal protection	yes	yes	yes	yes	no	yes
Weber & Wolf, 2000	Maryland	Protected status, urban development, transportation	yes	somewhat	yes	yes	no	yes

its own proponents. Theobald's (2003) primary candidate is inadequate land use planning, while Zalba's (2004) are habitat loss and exotic invasions. Neke and du Plessis (2004) and Clarke and Harris (2003) favor global climate change, which they claim will trump all other threats in certain parts of the globe. In order to develop a logical framework for organizing threats, several authors have proposed a comprehensive taxonomy of threats. For example, Wilcove and others (1998) propose habitat destruction, alien species, over-harvest, pollution and disease as the five most important threats to biodiversity, and Dinerstein and others (2000) propose habitat conversion, habitat degradation and wildlife exploitation as an organizing framework for capturing threats. Salafsky and others (2004) propose one of the more comprehensive threat taxonomies, including habitat conversion, transportation infrastructure, abiotic resource use, consumptive and non-consumptive biological resource use, pollution, invasive species (including pests, pathogens and disease), and large scale modifications of natural processes (for example, global climate change, fire regime alteration). Each of these general threat categories would be translated into a specific threat, appropriate to the regional and biophysical context.

Using a consistent taxonomy would encourage researchers to consider all potential threats, rather than a select few. Bryant and others (1998), for example, assessed global threats to coral reefs, including coastal development, marine-based pollution, over-exploitation, inland pollution and erosion, but not coral bleaching associated with global climate change. In 1998, the same year the study was published, coral bleaching devastated 16 percent of the world's reefs (Wilkinson 2000). A comprehensive taxonomy of threats would also enable a better understanding of the extent, severity and spatial distribution of a wide range of threats by enabling cross-cutting analyses.

Many researchers characterize 'threat' as a future state, defined as a degree of vulnerability, risk or likelihood of change. Margules and Pressey (2000) define a threat as the risk of a conservation area being transformed to another land use, and Rouget and others (2003) as the likelihood of losing a portion of extant biodiversity. Numerous researchers have used this approach to assessing threats by developing suitability indices and then quantifying the likelihood of threat occurring from low to high (Maddock and Benn 2000, Stoms 2000, Rouget and others 2003).

Other researchers define threats as a transformation that has already occurred. Neke and du Plessis (2004), for example, describe threats in South Africa by quantifying the spatial extent of forestry, agriculture, grazing, mining and urban expansion. Similarly, Maddock and Benn (2000) describe threat as the degree of transformation of unprotected and untransformed land in South Africa. They acknowledge that it would be useful to calculate the degree of future transformation, but cite lack of available data as the major constraint in doing so.

Regardless of whether they look at the degree of vulnerability and risk in the future, or the degree of transformation in the past, most authors ultimately define threat as either an event, "extrinsic human and stochastic natural events" (Araújo and others 2002), or an activity, "any human activity or process that has caused, is causing or may cause the destruction, degradation and/or impairment of biodiversity" (Salafsky and others 2004).

Defining a threat at a site level can be fairly straightforward. The Nature Conservancy, for example, assesses "stresses" (processes or events with direct impacts on biodiversity, such as stream sedimentation) and "sources of stress" (the actions of entities causing the stress, such as agriculture). In this model, the relationship between a threat and its impact on a specific species is clear. However, at an ecoregional level, this relationship becomes less so. Most ecoregional threats have multiple and complex relationships with innumerable species and systems. Groves (2003) acknowledges this problem, when he states that in theory, threats should be tied to specific conservation targets, but in practice, most regional planning efforts lack the prerequisite detailed, site-based data and knowledge.

Therefore, a slightly different approach to defining threats may be needed when working at large spatial scales. One approach to large-scale threats is to assess the degree of legal protection as a surrogate for protection against many threats, particularly land use conversion (for example, Theobald 2003). However, there are several flaws with this approach. The phenomenon of 'paper parks' is widely recognized (Ervin 2003), and in some cases, legal protection can even accelerate biodiversity loss (Curtin and others 2002). While protection and management status can be a useful measure of threat, they are only weakly correlated with vulnerability (Stoms 2000), and therefore threats must be inextricably linked with their impacts on biodiversity.

Reyers (2004) notes a recent trend away from linking threats to specific species, toward linking them with higher levels of biodiversity (for example, ecosystems). Conservation International takes the opposite tack; their "Living Landscape" program links threats to a small handful of "landscape species," with the reasoning that a decline in the viability of wide-ranging species mirrors a decline in the integrity of the landscape itself (Sanderson and others 2002). Neke and du Plessis (2004) offer another alternative; their study assessed the degree of land conversion from agriculture, grazing, mining and urbanization in South Africa, and linked these with broad changes in composition, landscape structure and ecological functions.

Clearly each approach has strengths and disadvantages, and no single approach is likely to be adequate to gauge the impacts of threats on biodiversity. Therefore, a broader framework that integrates each of these approaches may be warranted, one that includes the status of coarse-filter biodiversity, a full array of threats, and the legal protection and management effectiveness of an area. In capturing both a full array of threats, as well as their multiple and diffuse impacts on biodiversity, such a framework could provide a more thorough definition of the threats to, and effective conservation of, biodiversity.

Assessing the Impacts of Current Threats

In assessing the impacts of various threats, researchers have used qualitative assessments of scope, severity and sometimes irreversibility, combined to give a score, or ranking for each threat, typically from low to very high (Poiani and others 2003, Clarke and Harris, 2003, Ervin 2003). Such qualitative assessments are simple to use, require minimal data, and are widely accepted, but are often interpreted and applied inconsistently (Todd and Burgman, 1998).

While assigning a qualitative rank to a single threat at a single site is a relatively easy, if limited, process, combining multiple threats across multiple sites within an ecoregion is far more complex. Conservation planners have generally taken two approaches: arithmetic and rule-based procedures (Salafsky and others 2004). Ervin (2003), for example, adds the rank of each threat to create a cumulative threat index, while Kramer and Kramer (2002) and Bryant and others (1998) use "rules" (for example, at least one 'high' threat results in a cumulative 'high' score, four 'low' scores equal a cumulative 'low' overall score, etc.). Both systems portray a general picture of the overall threat load of each site, but they may be misleading. Some threats may appear to have a low score individually, but in combination may have a far more pernicious effect on biodiversity. Indeed, Rouget and others (2003) argue that there is no clear understanding of how to quantitatively combine threats to arrive at a satisfactory value of threat intensity. In order to improve the utility of additive and rule-based approaches, four additional considerations are proposed below: 1) spatially-defined threatsheds; 2) target-specific analyses; 3) an assessment of synergies between threats; and 4) an integration of ecological thresholds.

The spatial configuration of threats are seldom explicit (Todd and Burgman 1998), and only recently have threat assessments begun to identify threat patterns in relation to biodiversity patterns (Rouget and others 2003). Yet spatially explicit threat assessments can be critical in understanding the impact of threats on biodiversity; they enable better predictions of the magnitude and type of biodiversity loss, better priority setting, and better conservation triage (Rouget and others 2003). Furthermore, if they capture temporal patterns (as recommended by Salafsky and others 2004), threat maps can enable better prevention and mitigation of certain threats (for example, restricting recreation during sensitive breeding times). For example, Travis (2003) argues that the distribution of forest fragmentation is at least equally as important as the extent of fragmentation in determining the impact on forest species, and Stoms (200) argues that road density indices seldom explicitly consider the spatial patterns of roads, and typically assume that all road segments have an equal effect on biodiversity.

By creating map layers of the distribution and severity of different threats (see, for example, Kramer and Kramer, 2002, Neke and du Plessis, 2004), conservation planners can identify where threats overlap spatially. When these overlays are then combined with maps of the distribution of biodiversity, the resulting analysis can be a starting point for more precisely combining the effects of multiple threats.

A second approach to combining multiple threats is to gauge the cumulative impacts of threats to a particular species or system. Travis (2003), for example, argues that different species react very differently to the same threats—specialist species with low colonization ability and poor dispersal are far more prone to extinction from global climate change than wide-ranging species, and therefore cumulative threat impacts must be assessed species by species. Similarly, Sanderson and others (2002) advocate evaluating the overall level of impact from all threats on focal landscape species. Theobald (2003) takes a slightly different approach; he evaluates the cumulative impact from roads and development by land cover type and natural communities. Whether by species or by systems, measuring the cumulative impact of different threats on specific biodiversity elements can provide an alternative approach to combining threats.

This approach may entail an additional step—a better understanding of the complex and synergistic interactions between threats. Knowledge of how different threats interact remains elusive; Dinerstein and others (2002) cite this challenge as a major handicap to conducting ecoregional threat assessments. Others, such as Clarke and Harris (2003), acknowledge that synergistic relationships exist, but decline to describe or quantify them; they simply note that the capacity of Arctic and Antarctic marine ecosystems to withstand cumulative impacts of multiple threats acting synergistically is a grave concern.

Nonetheless, some recent studies have made headway in teasing apart the complex relationships between interacting threats. Travis developed at a model that combined the impacts of global climate change and habitat loss on hypothetical species with different characteristics. He concluded that some species could survive either a certain amount of habitat loss *or* a certain rate of global climate change, but they would likely become extinct where these threats occurred in tandem. Laurance and Williamson (2001) analyzed threats from logging and El Niño drought years in the Amazon, and concluded that vulnerability to fire increased dramatically when both threats occurred. Curtin and others (2002) assessed threats to grasslands and concluded that combined grazing, invasive species and an altered fire regime often resulted in a type conversion from grassland to shrub-dominated communities, and that these conversions occurred in a dynamic, non-linear, unpredictable fashion.

Finally, a better understanding of ecological thresholds could improve threat impact assessment methods. For example, Laurance and Williamson (2001) suggests that because of feedback loops between deforestation, fragmentation, regional drying and wildfires, there are thresholds of deforestation beyond which it may become difficult or impossible to halt biodiversity loss. Ecological thresholds could be incorporated into the assignation of single or cumulative threats into a particular category (for example, a "low" score equals well below a threshold, and a "very high" score equals past a threshold, etc.).

Given the uneven distribution of threats and their range of severity across a landscape (Araújo and others 2002), ecoregional assessments should strive to capture this distribution, rather than simply seek an average threat ranking across an entire area. One way to do this is to develop threshold-based categories for each threat. For example, a threshold for fragmentation could include six categories (highly fragmented, moderately fragmented, somewhat fragmented, somewhat intact, mostly intact, fully intact), based on common fragmentation indices. Numerous authors have proposed similar types of threat categorization (Dinerstein and others 2000, Reyers 2004). Such categories, which would ideally be quantifiable, repeatable and clearly linked to biodiversity viability, would enable the consistent interpretation of threat-related data over time, and would enable threats to be compared from one region to the next.

Assessing Future Threats

Assessing the likelihood of multiple threats, and predicting the impact they will have on species and systems will likely pose major challenges. Travis (2003) claims that predicting the impact of global climate change and habitat loss is one of the most vexing challenges facing biologists. Yet an assessment of the degree and impact of future changes is critical to effective conservation planning; not only are current threats poor indicators of future threats (Groves 2003), but they do not provide the full information needed to develop strategies, prioritize conservation areas, and sequence conservation actions. Furthermore, Rouget and others (2003) argue that conservation plans that do not adequately consider future threats cannot fully plan for the persistence of biodiversity with any degree of confidence.

There are three closely related approaches to assessing future threats: 1) assessing the likelihood, probability and risk of a threat occurring and/or of a species becoming extinct; 2) developing predictive models for the likely spatial configuration of threats; and 3) developing multiple threat scenarios.

Researchers have taken a variety of approaches in assessing future threats. Some, (Clarke and Harris 2003), simply rank future threats from most likely to have a high impact on biodiversity to least likely. Some (Kramer and Kramer 2002, Ervin 2003) include a qualitative assessment of the future likelihood as a variable in analyzing each threat. And some (Weber and Wolf 2000, Neke and du Plessis 2004) assess future threat by combining a qualitative ranking of threat with the impact of that threat on biodiversity.

Statistical, predictive modeling is another approach that can complement these qualitative, rule-based threat analyses, as the two approaches have shown a high spatial correlation, and expert judgment may catch nuances that a statistical model may miss, particularly at small scales (Rouget and others 2003). Such models may combine recent and/or historical data, social factors, biophysical features, and species life histories. Dirnböck and others (2003), for example, used invasive species data from the 1830s onward, and combined these data with geographic features, to develop a model of the rate and distribution of future invasions. Such information can be critically important, particularly with a threat such as invasive species, where early detection and prevention are paramount (Zalba 2004). Rouget and others (2003) complicate the equation, however, by calling for models that can incorporate soil disturbance, agriculture, and changing fire and nutrient regimes—all factors that can dramatically increase the spread of invasive species. Researchers have also developed models that incorporate socio-economic factors, patterns of existing land ownership, census data, and environmental conditions, to develop predictive models of the rate and distribution of rural sprawl (Stoms 2000, Theobald 2003).

There are limitations to the accuracy and therefore utility of predictive models. Many do not account for fine-scale data (for example, town zoning ordinances, detailed environmental conditions), or such data may simply not exist (Rouget and others 2003, Zalba, 2004, Clarke and Harris, 2003). Perhaps more importantly, a single model typically shows only one potential outcome, whereas threats interact in a highly dynamic and non-linear fashion, and may have multiple potential outcomes. Theobald (2003), for example, discusses how a simple model of the threat from housing development could have complex interactions with the threat from altered fire regime; at a certain housing density, fire restoration becomes impractical or impossible.

The creation of multiple models and scenarios may be one way to show the various relationships between future threats, and may provide more insight than simple models (Groves 2003). Reyers (2004), for example, looks at future land use scenarios in South Africa, incorporating more than just land suitability, but also a range of potential scenarios based on water availability, laws governing water use, and drought resistant crops. Multiple threat models and scenarios, particularly those that show the potential impacts of land use laws, ordinances and policies, can be a powerful conservation planning tool by enabling policy makers to see the consequences of their actions.

Analyzing and Interpreting Threats

Relatively few studies have attempted to quantify or even identify the drivers of threat (Rouget and others 2003). Furthermore, these drivers, which include the socio-economic forces and circumstances that trigger threats and resulting loss of biodiversity, are generally not well understood, and where they are analyzed, are mostly limited to a few local factors (Stedman-Edwards 2000). Conservation organizations are leading the development of tools to systematically assess these drivers, including The Nature Conservancy, which conducts situation analyses as part of its site conservation planning process (Poiani and others 2003), and the World Wildlife Fund, which conducts root causes analyses as part of its policy development strategy (Stedman-Edwards 2000).

The primary tool that both organizations use for conducting these analyses is a conceptual model that shows the complex relationships, multi-directional linkages and dynamic interactions between social, economic and ecological dimensions. Understanding these complexities is important, since the causal linkages rarely provide precise predictive models (Stedman-Edwards 2000). Kramer and Kramer's (2002) study of threats in the Mesoamerican Caribbean Reef illustrates one example of a root causes analysis. The threats of over-fishing, eutrophication and habitat loss from agricultural and urban expansion are caused by a web of over a dozen root causes, ranging from human population growth and migration to poor law enforcement and inadequate legal jurisdiction over resources. Stedman-Edwards (2000) propose that the majority of root causes fall into one of five categories: 1) demographic change; 2) inequality and poverty; 3) public policies, markets and politics; 4) macroeconomic structures and policies; and 5) social change and development biases.

Incorporating Threats Into Conservation Planning

As discussed earlier, threat assessments are an integral and critical component of both site conservation planning and broad-scale, systematic conservation planning processes. At an ecoregional level, threat assessments can be integrated into conservation planning processes and used for a variety of purposes, including: 1) to develop ecoregion-wide strategies; 2) to set geographic priorities; 3) to sequence and prioritize conservation areas and strategies; and 4) to measure changes in threat status over time. An assessment of existing threats can be used to identify where and how severely multiple threats occur across the landscape, and help in formulating appropriate ecoregion-wide strategies, such as land protection, management strategies, restoration and monitoring (Groves 2003, Poiani and others 2003).

A number of studies have integrated threats into geographic priority-setting processes (Theobald 2003, Reyers 2004). These studies primarily focus on a measure of future threat, usually expressed in terms of vulnerability, as well as a measure of conservation value, expressed in terms of conservation value, focusing on rarity, endemism, species richness, protected status and/or ecological integrity (Stoms 2000, Groves 2003). The resulting information enables planners to prioritize areas most at risk. Maddock and Benn (2000), for example, describes how species, vegetation types, ecological processes, legal protection and threats from land transformation were combined to identify "conservation worthy areas" in Zululand, South Africa.

A third and related use of threat assessments is to determine the timing of conservation actions; an assessment of urgency can help determine the relative sequence of geographic priorities and conservation actions (Araújo and others 2002). Groves (2003) describes this as a process of conservation triage, asserting that threat assessments are vital in identifying which areas will clearly benefit from immediate conservation actions, which ones are likely to persist if nothing is done, and which areas could, with sustained efforts, be feasibly restored over the long term. While such sequencing and prioritization efforts help to ensure efficient use of resources (Theobald 2003), this process also requires an understanding of the potential tradeoffs between restoring land versus preventing threats, high and low cost, effort and feasibility, and between differing conservation values (for example, high endemism versus high species richness).

Threat assessments can also be used to measure threat status over time. A measure of threat status can be taken at any given time by capturing the distribution and severity of current and future threats. Although few studies have done so, tracking the status of threats over time can be useful in several ways. Governments and conservation organizations can use threat status measures to assess the broad effectiveness of their threat abatement actions. Conservation planners can use threat status measures to reassess their programmatic and geographic priorities, as the conservation landscape shifts and new threats emerge. Conservation advocates can use threat status measures to communicate complex information about biodiversity in clear and compelling ways.

Conclusion

Many threat assessments cover some or most of the elements proposed in this paper; few cover all of them. A comprehensive threat assessment framework, such as the one proposed in table 2, could serve several purposes. It could enable conservation planners to be more explicit about which steps are not included in their assessments and why. It could serve to identify information and data

Table 2. Elements of a comprehensive, broad-scale threat assessment.

Identify threats	Assess impact of threats	Assess future threats	Analyze and interpret threats	Incorporate threats into conservation planning
Consider the broad array of potential threats, rather than a small subset of threats	Be spatially explicit about the distribution of each threat, creating multiple threat layers	Assess the likelihood of existing threats to continue and new threats to occur	Develop conceptual models that incorporate both socio-economic drivers and biological factors	Incorporate threats into broad-scale strategy development
The following is proposed as a minimum set of threats to consider:	Be explicit about how each threat affects specific elements of biodiversity	Assess the risk of biodiversity elements to threats, using suitability indices and statistical predictors	Explicitly show multi-directional linkages of relationships between drivers and threats	Use threats to determine geographic priorities
-Habitat conversion -Transportation infrastructure -Energy development -Use and management of biological resources -Tourism and other non-consumptive uses -Invasive species, pests and pathogens -Pollution -Global climate-related events and processe	Assess the synergies and interrelationships between different threats and their impacts on species and systems	Develop predictive spatial models for patterns of threat development in the future	Explicitly link causal factors and drivers of threats to conservation strategies and actions	Use threat information to sequence and prioritize actions and geographies
	Incorporate ecological thresholds into impact assessments	Develop multiple threat predictions that incorporate different scenarios and pathways, including socio-economic factors		Track threat status over time to measure change and enable adaptive management

gaps. Perhaps most importantly, it could encourage a more systematic and thorough approach to threat assessments, one that considers the multiple social, economic and ecological factors and the complex spatial and temporal dimensions of threats to biodiversity.

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